GEORGIA DOT RESEARCH PROJECT 09-03
FINAL REPORT

BEST PRACTICES IN SELECTING PERFORMANCE MEASURES AND STANDARDS FOR EFFECTIVE ASSET MANAGEMENT

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16. Abstract:

This report assesses and provides guidance on best practices in performance measurement, management and standards setting for effective Transportation Asset Management (TAM). The study is conducted through a literature review, a survey of the 50 state DOTs, an internal assessment of Georgia Department of Transportation's TAM capabilities and performance measurement and management procedures, and a review of risk applications in TAM with a case study demonstrating the impacts of uncertainty on project prioritization. The study isolates three generations of agencies as far as performance management is concerned. The study recommends conducting a review of GDOT's performance measurement and management process and procedures using current standards; benchmarking against similar and more mature state agencies; developing metrics for evaluating progress toward strategic goals; linking performance metrics with resource allocation decisions; developing analytical and data capabilities for evaluating tradeoffs in resource allocation decision making; refining measures for use in broad agency functions; refining performance communication tools; addressing uncertainties in performance metrics and management in TAM, and upgrading existing performance procedures and capabilities to meet state audit requirements.

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Best Practices in Selecting Performance Measures and Standards for Effective Asset Management

FINAL REPORT

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EXECUTIVE SUMMARY

This report reports the results of a study that assesses and provides guidance on performance measures and standards for effective Transportation Asset Management (TAM). Performance measures are defined as indicators of system effectiveness and efficiency. Asset Management is the combination of management, financial, economic, engineering and other practices applied to physical assets with the objective of providing the required level of service in the most cost effective manner. Thus, performance measurement and management are critical components of an effective TAM system. TAM and performance management are both evolving practices, meaning that applications and best practices in these fields continue to expand and improve systematically over time.

The study was conducted through a literature review, a survey of the 50 states for current and best practices in performance measurement and management in TAM, an internal review of GDOT's present TAM capabilities and performance measurement and management procedures; and a review of risk applications in TAM followed by a case study demonstrating how uncertainty can be incorporated in project prioritization to enhance prioritization outcomes.

The study findings show that performance measurement alone is incomplete for effective TAM but, in addition, performance metrics must be applied in resource allocation decision making to manage agencies toward achieving their strategic goals consistently. Agencies with effective TAMs will have fewer, clearer strategic goals that are linked with performance measures (including outcome measures) for which metrics are developed and utilized in resource allocation decisions.

As performance management is an evolving practice, various agencies are at different levels in measuring and managing performance. First-Generation or "Traditional" agencies (with large number of measures, not strategically aligned), Second-Generation or "Hierarchy of Measurement" agencies (with many measures tracking system performance and organizational process improvement for their specific program and project decision-making purposes; but not usually linked meaningfully to other agency processes) and Third-Generation or "Catalyst-Driven" agencies (that use lessons learned to refine practices and have developed the flexibility to retool and adapt an established system in response to changing agency priorities and external pressures). Communicating performance effectively to external stakeholders (i.e., the general public, the legislature and media) is critical. Effective performance communication within the agency is also critical for achieving strategic objectives.

The Georgia Department of Transportation (GDOT) has developed four strategic goals and is in the process of developing performance measures to evaluate and manage progress toward strategic objectives. GDOT has multiple infrastructure management tools (such as pavement management, bridge information management, and maintenance management, etc.) with supporting data that will be helpful for generating performance metrics. The study recommends the following: (i) performance benchmarking against other state DOTs; (ii) developing metrics to evaluate progress toward strategic objectives; (iii) linking performance metrics with resource allocation decision making and developing data and analytical capabilities for evaluating tradeoffs; (iv) refining metrics for use in broader agency functions (e.g., planning and management, operations and design/management); (v) refining performance reports to be more effective communication tools; (v) addressing uncertainties in performance management to improve the quality of performance outcomes data; and (vii) understanding the requirements of state performance audits in order to proactively address gaps in current performance procedures.

1. OBJECTIVES

> *"The real value of performance measurement is in the development of an improved decision-making and investment process, not the achievement of many arbitrary short-term targets."*
> - *USDOT International Scan on Performance, 2004*

This report presents the results for the research study "Best Practices in Selecting Performance Measures and Standards for Effective Asset Management," sponsored by the Georgia Department of Transportation (GDOT) and conducted from January 2009 to June 2011. The objectives of this study were to assess and provide guidance on factors influencing the selection of performance measures and standards for effective Transportation Asset Management (TAM). The report summarizes the key messages and findings of the study. Companion appendices include supporting deliverables that can be referenced for additional detail.

Performance measures are defined as indicators of system effectiveness and efficiency. State Departments of Transportation (DOTs), including GDOT, have long used performance measurement for analyzing system processes, outputs and outcomes as part of engineering and planning disciplines. However, the focus on *performance measurement* has largely grown and shifted to *performance management* during the period of this study. According to NCHRP Report 666, performance management is the regular ongoing process of selecting measures, setting targets and using measures in decision making; and reporting achievement, leading to the development of a culture of performance throughout the agency (CS and HS Consulting, 2010). Performance management thus goes beyond performance measurement to link metrics to resource allocation decision making in order to enable agencies achieve their strategic objectives. This report adopts the broader perspective of performance management, which is necessary for effective Asset Management.

Asset Management is the combination of management, financial, economic, engineering and other practices applied to physical assets with the objective of providing the required level of service in the most cost effective manner (NCHRP/AASHTO 2010). Similarly, the AASHTO TAM Strategic Plan defines TAM as a "strategic and systematic process of operating, maintaining, upgrading and expanding physical assets effectively throughout their life cycle" (AASHTO Asset Management Strategic Plan). Asset Management, like performance management, is an evolving practice, meaning that the current status and best practices of Asset Management (and performance measurement and management) expand and improve systematically over time. The current standard for Transportation Asset Management is contained in such documents as the AASHTO[1] Transportation Asset Management Guide Vols. 1 and 2, and the International

[1] American Association of State Highway and Transportation Officials

Infrastructure Management Manual, and the best practices at any point in time can be identified through studies. Figures 1 and 2 depict the key roles of performance in TAM. Figure 1 highlights the importance of performance measures in condition assessment, performance modeling and prediction, and project prioritization. Figure 2 depicts TAM showing the importance of performance in setting policy goals and objectives, allocating resources for planning and programming, and program delivery, evaluating tradeoffs, and monitoring the system (NCHRP 2002).

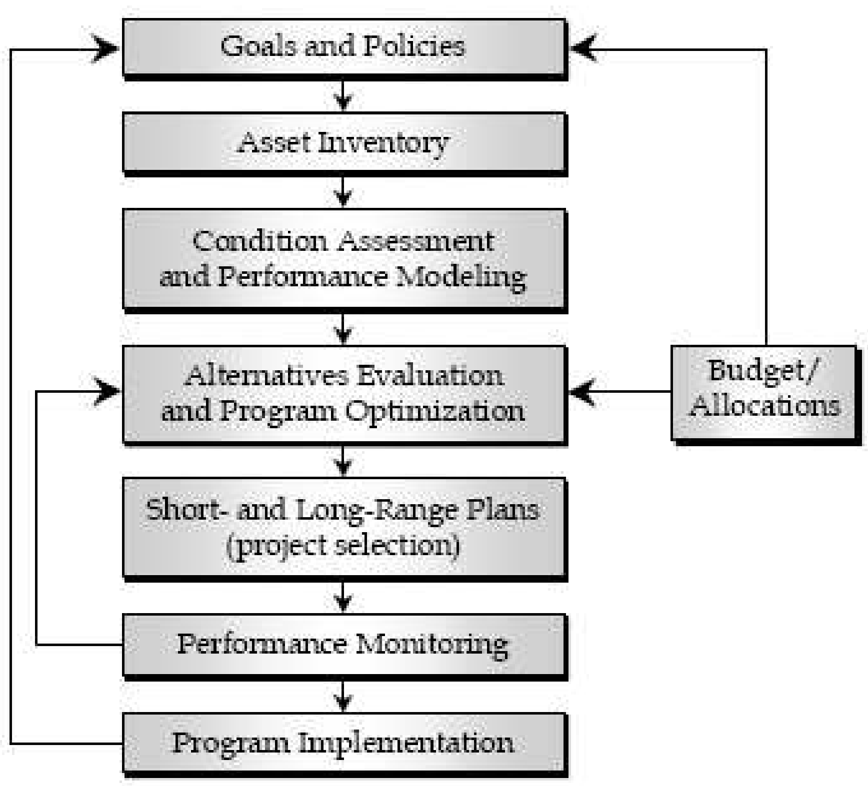

FIGURE 1: Overview of Transportation Asset Management (FHWA[2])
Source: Transportation Asset Management Guide, Vol. 1 (NCHRP/AASHTO 2002)

[2] Federal Highway Administration

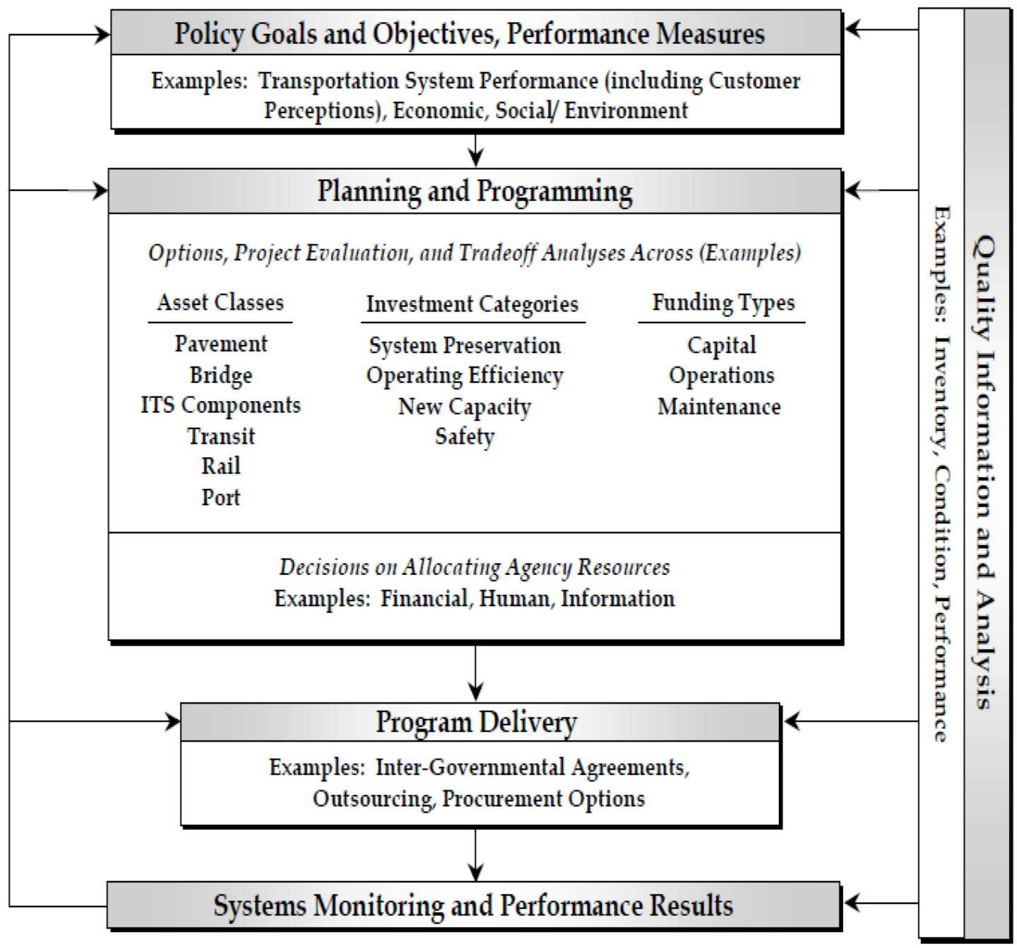

FIGURE 2: Transportation Asset Management: Resource Allocation and Utilization
Source: Transportation Asset Management Guide, Vol. 1 (NCHRP/AASHTO 2002)

2. METHODOLOGY

The study was conducted by reviewing the transportation and management performance measurement literature and surveying state DOTs to determine current and best practices in the development of performance measures and targets/standards, and for performance management. The researchers also undertook an internal review of GDOT's asset management tools and data, and facilitated and reported on an asset management peer exchange that included the Utah, Georgia and Indiana DOTs. Additionally, a literature review was conducted on risk applications in TAM, data obtained from the National Bridge Inventory, and multiple attribute decision making (MADM) methodology was applied to demonstrate the impact of including uncertainty in project prioritization, and how normalization of attributes and data disaggregation in project ranking can affect the final prioritization outcomes. Finally, a catalogue of performance management resources was developed to facilitate access to available resources supporting the development of performance management programs in agencies.

3. KEY MESSAGES AND FINDINGS

Performance management involves the successful application of performance data to manage agency performance toward achieving strategic goals consistently. NCHRP Report 666 (Transportation Performance Management: Insight from Practitioners) identifies three basic considerations that shape performance management implementation: customer needs and desires; engineering requirements and limitations; and fiscal limitations. Performance management is viewed as closely linked with strategic planning and reporting where strategic planning involves identifying what an agency hopes to achieve. Strategic planning is based on developing an agency vision or mission, identifying supporting goals and objectives, and developing initiatives and implementation strategies to achieve these objectives in agreed upon time frames. Performance management is the regular on-going process of selecting measures; setting targets and using measures in decision making; and reporting achievement, leading to the development of a culture of performance throughout the agency (CS/HS Consulting 2010).

3.1 Guidelines for Selecting Performance Measures and Targets

The literature review indicates that many states have committed to using performance measures, but that the degrees to which performance measurement systems are developed varies widely among them. The literature highlighted the following guidelines for selecting performance measurers and targets:

1. Performance measures should flow directly out of an agency's mission and objectives.
2. Performance measures should provide a balanced picture of an agency's business and utilize input, output, outcome and productivity or efficiency measures in an appropriate manner.

3. An effective performance measurement system will have a few, well-defined measures tied to a handful of clear goals to be achieved within specific time frames.
4. Performance measurement systems should be periodically evaluated in an iterative process.
5. Performance measures should use reliable and available data that the agency can collect without straining its resources.
6. Performance measurement reporting and communication should be clear and easy to understand.
7. Comparative performance measurement, also known as benchmarking, has been recognized as important among state DOTs.
8. Customer satisfaction, environmental quality and sustainability are increasingly important outcome measures.
9. Performance targets should be set in relation to achieving the agency's strategic goals, considering policy guidance and public input, funding availability, benefits, costs, risks and tradeoffs (or opportunity costs of setting various targets). Scenario analysis is a useful analytic tool when setting targets.
10. A growing number of agencies are using formal performance frameworks to select performance measures. Performance frameworks are structured processes that provide guidance for selecting performance measures, e.g., the Balanced Scorecard Framework.

Internationally, various transportation agencies are using performance measurement for a range of functions. A 2004 international scan tour of performance measurement systems in Australia, Canada, New Zealand and Japan showed that performance measures were used more extensively in those countries than in the U.S (FHWA 2004). These systems often emphasized safety, included output and outcome measures including environmental and customer satisfaction indicators, integrated data collection, used before and after studies and benchmarks, and considered multimodal investment tradeoffs. Successful programs directly used performance measurement to influence programming discussions and budget allocation. The scan recommended in particular that safety and benchmarking should be emphasized more by the FHWA. Furthermore, the scan suggested that the U.S. generate research, training, conference meetings, technical guidance and sustainability actions, using these international examples.

The scan sheds light on some important points about performance measurement and target setting in other countries (FHWA 2004):

1. "A limited number of high-level national transportation policy goals linked to a clear set of measures and targets are used;
2. Intergovernmental agreements on how state, regions and local agencies will achieve the national goals are negotiated while translating them into local context and priorities; and
3. The real value of performance measurement is in the development of an improved decision-making and investment process, not in the achievement of many arbitrary short-term targets."

3.2 Best Practices: Performance Measurement in State DOTs

3.2-1 Survey Results

A survey conducted from September 2009 to February 2010 explored the use of performance measures in the 50 state DOTs. Approximately 75% (39) of the 50 state DOTs responded to the survey. A majority of state DOTs reported that they have linked performance measurement with strategic planning, and are using performance measures and targets in planning and management. The key findings of the survey are given below (Pei et al., 2010a):

1. Over 90% (36 out of 39 respondents) of the responding state DOTs reported having a strategic plan in place. Most of the responding agencies reported that they update their plans annually or bi-annually.
2. DOTs reported that strategic objectives are largely related to transportation system safety, system preservation and mobility. Agencies also reported to a lesser extent that employee and organizational development, customer satisfaction, economic growth and vitality and environmental quality are included in strategic objectives.
3. More than half of the responding DOTs (23) reported having performance measures tied to strategic goals and objectives.
4. About 33% (12) of the responding DOTs reported that they review their measures annually.
5. About 70% (28) of the agencies reported that performance measures are mostly used in management and planning, and not in all DOT functions. About half (21) reported using performance measures in operations and slightly less than half (18) in design/engineering.
6. Over 75% (30) of the responding DOTs reported that they use performance measures to engage stakeholders.
7. About 80% (31) of the responding DOTs reported that they set performance targets, developed largely by upper management and program managers, and also by benchmarking and consensus, considering funding levels and stakeholder input.
8. About 80% (31) of the responding agencies reported that top management reviews performance information.
9. About 70% (27) of the responding agencies reported that they have an asset management program in place with most programs used to monitor the condition of highways and bridges.

3.2-2 A Generational Model for Performance Management

> *"Performance measurement is an evolving practice. All state DOTs have used some aspect of performance measurement for analyzing system uses and conditions as part of the engineering and planning disciplines. Yet, the business process improvement and accountability aspects of the performance measurement field have only emerged in the transportation industry in the past decade."*
> *-Baird and Stammer 2000 as quoted in Bremmer et al. 2000*

Performance measurement, like asset management, is an evolving practice. Bremmer et al. (2004) present a Generational Model of Performance Management to depict this evolving practice of performance management. Citing Baird and Stammer (2000), and Poister (2004), Bremmer et al. emphasize that while all state DOTs have used some aspect of performance measurement for analyzing system uses and conditions as part of engineering and planning, the business process improvement and accountability aspects of the performance measurement field are more recent in the transportation industry having emerged in the 90s. They recognize that DOTs can be vastly different from one state to another, managing transportation systems that vary in complexity and scope in distinctive political and economic environments. As the concept of measurement has expanded, states have tried to follow suit, some making the leap to track organizational performance in order to improve business processes or to demonstrate accountability. Some have taken the step to integrate measures into strategic frameworks aimed at focusing the organization on a few key outcomes. Such agencies are often focusing on the newer generation of performance measures described as more outcome-oriented, more integrated with strategic goals and objectives, and on quality and customer service than the input and output measures of the past. Table 1 summarizes the three types or generations of agencies when it comes to performance measurement and management.

Various pressures drive change that can influence how agencies organize their performance measures and management procedures. These include leadership changes at the top of the state DOT or the state (e.g., PennDOT, Caltrans); new funding or a legislature's view that a state DOT requires more oversight (e.g., MoDOT, MnDOT, VADOT, WSDOT); external mandates for benchmarks and performance reporting (Maryland State DOT, Oregon DOT, WSDOT); and performance audits and reviews of state DOTs (over 30 states) (Bremmer et al. 2004).

TABLE 1: Generational Model of Performance Management

Generation of Agencies	Characteristics	Examples in 2004
First-Generation Agency: *Traditional Infrastructure and Organizational Measurement*	• Develops measures in response to internal Total Quality Management initiatives or specific legislative requirements. • At the same time, may already have robust established measurements in traditional system planning and program areas, such as preservation. • "Standard measures" track basic system performance and organizational process improvement; useful for specific program and project decision making purposes but not meaningfully liked to other agency processes • Usually lack a strategic measurement framework; only starting to use performance measures to define progress in meeting long-range plans or shorter-range plan goals.	Alaska DOT Arizona DOT Delaware DOT
Second-Generation Agency: *Hierarchy of Measurement*	• Generally has proliferation of measures as part of a framework or hierarchy for measuring the agency's performance. • Measures are usually based on a traditional planning framework and are often long range measurements that link to mid-range strategic and/or short range business plans. • Agency ties measurement areas together in a strategic orientation used by leadership and managers to track business functions and planning goals. • Measurement areas eventually expand to include difficult-to-measure higher-level outcomes, societal goals and customer expectations. • As practices evolve, measurement systems can grow increasingly complex, making results difficult to communicate. • There could be a well developed public reporting tool that communicates the results of the measurement scheme to meet legislative, public or agency needs.	Florida DOT Missouri DOT Maryland DOT
Third Generation *Agency: Catalyst-Driven Adaptation*	• Agency can respond to change catalysts, e.g., new agency administrations, governmental changes such as a new governor, funding crises or increases, new state or federal requirements, etc., and retool and adapt an established system in response to changing agency priorities and external pressures • Agency has the ability to proactively use performance measures to set its agenda and more effectively communicate its needs. • Agency is at the forefront of using dynamic	Minnesota DOT Ohio DOT Washington State DOT

	approaches that provide real-time information responsive to the needs of agency leadership and the state's political context and places high value on public accountability. • Agency recognizes the complexity created within the traditional planning framework and explores alternative ways to measure and communicate performance. • Agency's performance measurement system is of a narrow focus compared to earlier, less strategic outcomes: agency tends to focus on building effective measurement systems and communication tools centered on agency responsibilities and investment decision needs. • While continuing to seek viable indicators for broader societal planning goals and outcomes, the agency tends to focus on building effective measurement systems and communication tools centered on agency responsibilities and investment decision needs.	

Source: Bremmer, Cotton and Hamilton (2004)

3.2-3 Performance Communication to Multiple Stakeholders

Performance measurement and reporting occurs for multiple functions and at multiple levels for an agency's internal and external stakeholders. Figure 3 depicts VicRoads' (in Victoria, Australia) information reporting hierarchy. Agencies that evaluate the comprehensiveness of their performance measurement activities and the quality and effectiveness of the performance reports for their internal and external stakeholders continue to refine their reports to be more effective communication tools for their various stakeholders.

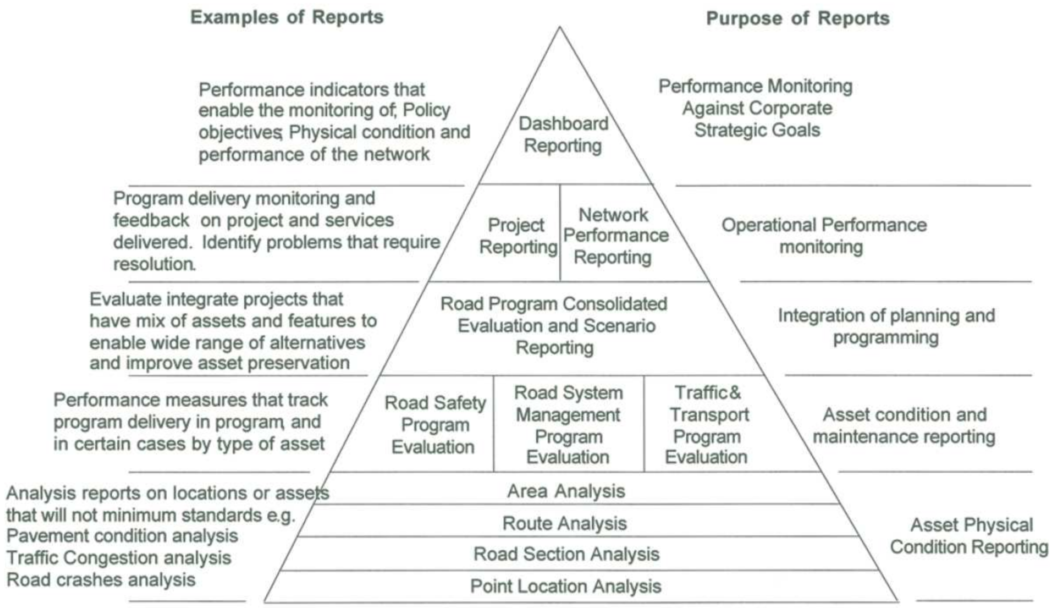

FIGURE 3: Information Reporting Hierarchy at VicRoads, Victoria, Australia
Source: Transportation Asset Management in Australia, Canada, England and New Zealand (FHWA 2005)

3.3 Evolution of Asset Management at Georgia Department of Transportation (From September 2009 to the Present)

We get lots of projects done. We spend a lot of money. But we are not sure we are getting the best value on the dollar.”
-State DOT Upper-level Manager, Utah/Indiana/Georgia TAM Peer Exchange, August 2009

Asset management is a business process that can be used to improve the value of assets per dollars expended. In the course of this study, the Transportation Asset Management (TAM) program at GDOT evolved significantly from its initiation in 2009. At the onset of the project, an internal review was conducted of the status of TAM in the agency; the Project Investigators provided documentation support for a TAM Peer Exchange organized for GDOT, Utah DOT and Indiana DOT in September 2009, and developed an inventory of TAM tools and data at GDOT. The following sections summarize key messages and findings from these activities.

3.3.1 TAM Internal Review

Participating in an internal review conducted on the status of asset management at GDOT, several GDOT officials felt that the agency has a very good asset management program; however, most of the asset management activities were considered office-specific in the sense that each office has good data and uses the data to prioritize needs. For example the GDOT pavement management system (PMS) was used to prioritize pavement projects that were part of the economic stimulus package. Crash statistics were used together with PMS and bridge management system (BMS) information to prioritize projects. GDOT officials emphasized the importance of taking a ROW-to-ROW (i.e., right of way to right of way) line asset management perspective and were interested in obtaining a 100% database (rather than a sample database) for all assets being managed. There was interest in knowing what other states were doing in asset management but a feeling that what works in one state would not necessarily work in another.

3.3.2 TAM Peer Exchange

In September 2009, FHWA organized a scan/peer-exchange on TAM for Utah, Indiana and Georgia DOTs. The report, *Asset Management Peer Exchange: Utah/Indiana/Georgia* summarized the key findings and recommendations of the peer exchange (Amekudzi, 2009). The recommendations of the report with respect to important program steps for asset management were:

1. Conduct a self-assessment exercise; and
2. Develop an Asset Management Implementation Plan. The Implementation Plan would involve: (a) streamlining strategic goals; (b) developing performance measures that align strategic goals with work at all levels of the agency; (c) developing analytical procedures for the bridge database; (d) integrating data, and (e) integrating analysis tools.

Additional details can be found in the Peer Exchange report included in Appendix 5(b).

3.3.3 Development of TAM Program at GDOT

Following the internal review and peer exchange, GDOT took definitive steps to advance asset management as a core business process in the agency. GDOT formally adopted Transportation Asset Management in 2009 to optimize infrastructure investment by applying program resource allocation and asset preservation techniques. Subsequently, TAM has been adopted as a core business process intended to serve as the basis for decision making throughout the agency (GDOT, 2010).

Formal strategic planning in GDOT, begun in 1994, is now used as a management tool in setting agency direction, identifying specific initiatives and facilitating employee teamwork to implement initiatives and projects that are necessary to achieve organizational improvements toward strategic agency goals. The Department implemented a strategic management process in 2003. Four strategic goals were identified (GDOT, 2010):

1. PEOPLE: Making GDOT a better place will make GDOT a place that works better
2. SAFETY: Making safety investments and improvements where the public is most at risk
3. MAINTENANCE: Taking care of what we have in the most efficient way possible
4. CAPACITY: Planning and constructing the best set of mobility-focused projects we can, on schedule.

On-going work on performance management includes formally tightening the linkage between performance measurement and decision making to achieve strategic objectives.

3.3.4 GDOT TAM Inventory of Tools and Data

A review was conducted of the TAM analysis tools and data being used in GDOT. Table 2 summarizes some of the main TAM tools and data used in the agency (O'Har, Amekudzi and Meyer, 2009). Other tools and data can be found in Appendix 4.

TABLE 2: Summary of GDOT TAM Tools and Data

Tool (#1):	**Highway Maintenance Management System (HMMS)**
Objective:	Allows GDOT to track the daily work of maintenance crews throughout the state; assimilate outstanding work on roads from inspections; develop a work program for tracking equipment costs, labor costs and material costs (input measures)
Data:	Biannual drainage reports, condition assessment of pipe, location of signs and pipes (coordinate info), and data from inspections (guardrail, pavement, vegetation, etc.; no coordinate info)
Units using Tool:	Maintenance managers throughout the area and district maintenance offices
Use of Results:	To develop an annual needs-based budget and an annual work program; determine the condition of pipe systems; compare actual and estimated costs with budget office costs
Tool (#2):	**Pavement Condition Evaluation System (PACES)**
Objective:	A pavement condition assessment survey that rates every mile of every road each year
Data:	Condition evaluations of roadway (asphalt and concrete)
Units using Tool:	Area and district maintenance offices; Office of Materials and Research; data output from this tool feeds into the Georgia Pavement

	Management System (GPAMS)
Use of Results:	To determine overall condition of roadway; determine what work needs to be done (e.g., crack sealing, resurfacing); predict the future condition of roadway (i.e., LOS of roadway) with available funds; determine the cost of work that needs to be done
Tool (#3):	**Pipe Inventory**
Objective:	A module of the HMMS, provides a condition assessment of pipe
Data:	Data from physical inspections of pipe tracked with a coordinate system
Units using Tool:	Area and district maintenance offices
Use of Results:	To determine what work needs to be done on each line of pipe
Tool (#4)	**Bridge Information Management System (BIMS)**
Objective:	Collects input data from bridge inspections; allows the Department to retrieve certain information without going through paper work; separate from the Federally-required National Bridge Inventory (NBI); collects more data than the Federal government requires.
Units using Tool	Bridge Maintenance unit, Office of Transportation Data, upper management (for planning)
Use of Results	Federal reporting requirements for the NBI; generating deficiency reports; input data for HMMS; determining necessary repairs; routing (vertical clearance and load requirements for oversize/overweight loads); budgeting and funding decisions
Tool (#5):	**Life Cycle Cost Analysis (LCCA) Tool**
Objective:	Gives comparison of lifecycle costs for different pavement types
Data:	Quantities of materials, length of a project, unit costs, maintenance costs, time frames
Units using Tool	Pavement Management
Use of Results	Making decisions on pavement type; deciding between construction and rehabilitation
Tool (#6)	**Highway Performance Monitoring System (HPMS)**
Objective:	Mandated by the FHWA to provide the Department’s road inventory data; sample-based system consisting of 98 data items; provides a variety of data (roughness, AADT, etc.)
Data:	
Units using Tool:	Not used much within GDOT; the Department has its own road

Use of Results:	inventory database Used by the Federal Government in allocating funds; other data items from this tool are used within the Department
Tool (#7)	**Benefit/Cost Tool (B/C)**
Objective:	Used in the project prioritization process; contributes to a project score
Data:	Overall cost of a project (design, construction, etc.); benefits (times savings through a corridor, fuel cost); safety benefits; dollar values based on national average values (commercial versus non-commercial)
Units using Tool:	Planning office; Design office; and Traffic Operations
Use of Results	A piece of the decision-making process; everything is not based on the B/C ratio

4. UNCERTAINTY AND RISK IN TRANSPORTATION ASSET MANAGEMENT

4.1 Risk and Transportation Asset Management

All of the agencies examined in the FHWA/AASHTO international scan tour on Asset Management in 2005 practiced some degree of risk assessment in selected areas of their TAM programs. Furthermore, all the agencies used the concept of risk to establish investment priorities (FHWA 2005). As TAM systems are already in place in many state transportation agencies, particularly in larger agencies, they can be used as appropriate platforms to incorporate uncertainty and risk in decision making. In a 2006 scan on TAM conducted in the U.S., there was little evidence of risk being used in asset management (CS and Meyer 2007). A number of the agencies that have applied risk assessment methods have done so by conducting scenario analysis. Typically, different scenarios are defined based on different levels of funding. These scenarios then predict pavement, bridge and other asset condition ratings at various levels of funding.

4.2 Uncertainty and Risk

One of the most common uses of the term "risk" when applied to transportation infrastructure refers to the risk of catastrophic or non-catastrophic failure. Non-catastrophic failure can also be referred to as performance failure, i.e., the failure of a facility or system to perform as intended. This requires the selection of minimum levels of service (LOS). Risk in this context generally refers to the chance that a negative event occurs (e.g., bridge failure) and the severity of the consequences of this negative event, also known as technical risk (Haimes 2004 and Piyatrapoomi et al. 2004).

Uncertainty is an inherent part of the decision-making process when choices are made based on incomplete knowledge, when there are sources of error, or when there is inherent randomness in the system or facility under consideration. (Piyatrapoomi et al. 2004; Helton and Burmaster 1996). Decision makers often do not have complete knowledge of every facet of a decision. Some level of uncertainty is present in nearly all decision making. This type of uncertainty is generally termed subjective uncertainty and is reducible. This is in contrast with objective uncertainty arising from the randomness of systems, which is irreducible (Winkler 1996).

While it is impossible to eliminate uncertainty from infrastructure asset management (Haimes 2004), uncertainty can be modeled to improve the quality of decision making. Sources of error for infrastructure assets include data errors, forecasting errors, and modeling errors. Data errors are due to measurement error and simple human error or forecasting errors. These types of errors can be measured through the use of statistical techniques and can be reduced by collecting more complete historical data. Model errors are a result of the difference between observed or real-world values and model values. Forecasting errors relate to the uncertainty associated with future events. Various studies have shown that forecasting errors are much more significant than model and data errors (Amekudzi and McNeil, 2000; AbouRizk and Siu, 2008). There are limitations on the ability to decrease forecasting errors since it is not easy to predict future events accurately. However, simulations can be applied to incorporate forecasting uncertainties in models (Amekudzi and McNeil, 2000).

4.3 Risk Assessment and Risk Management

Risks are often dealt with through risk assessment and risk management activities. The risk assessment and management process is aimed at answering specific questions in order to make better decisions under uncertain conditions. Risk assessment refers to the scientific process of measuring risks in a quantitative and empirical manner and usually precedes risk management. Risk management is a qualitative process that involves judging the acceptability of risks within any applicable legal, political, social, economic, environmental and engineering norms and implementing measures to reduce them to acceptable levels (Haimes 2004; Piyatrapoomi et al. 2004).

In the management of technological systems, the failure of a system can be caused by the failure of the hardware, the software, the organization, or the humans involved. The initiating events may also be natural occurrences, acts of terrorism or other incidents. In risk assessment, the analyst often attempts to answer the following set of questions (Kaplan and Garrick 1981; Haimes 2009):

- What can go wrong?
- What is the likelihood that it will go wrong?
- What are the consequences (and what is the time domain)?

Answers to these questions help risk analysts identify, measure, quantify and evaluate risks and their consequences and impacts.

Risk management builds on risk assessment by seeking answers to a second set of questions (Haimes 1991):

- What can be done and what options are available?

- What are the associated tradeoffs in terms of all costs, benefits and risks?
- What are the impacts of current management decisions on future options?

4.4 Risk Attitudes

The last question (in the risk management trio above) is the most critical one for any managerial decision making. It involves defining the agency's risk tolerance (i.e., the level of exposure and nature of risks that are acceptable). Decision makers must determine acceptable levels of risk. This acceptable level of risk is often influenced by public perceptions of risk. Society perceives various risks at different levels. For example, the risk of a traffic accident is far greater than the risk of bridge failures (judging from actual statistics), but in general, communities are more willing to tolerate the risk of a traffic accident than that of a bridge failure (Atkan and Moon 2009). In other words, communities will generally be willing to pay more to reduce the risk of catastrophic bridge failure than they would to improve roadway traffic safety in order to reduce roadway fatalities -- even though the risk for roadway fatalities is much higher than that of bridge fatalities. Risk attitudes influence how an agency determines investment priorities.

4.5 Examples of Risk Applications in TAM

To date, risk applications in TAM can be found in the prediction of facility performance and prioritization of projects, programs or plans for investment. A number of risk examples and applications are presented below to illustrate the nature of risk applications in TAM.

4.5.1 U.S. Federal Highway Administration - Risks Identification for Coastal Roadways

A FHWA hydraulic engineering circular highlights the fact that 60,000 miles of highways nationwide lie within the Federal Emergency Management Agency's (FEMA) 100-year floodplain (FHWA, 2008). This Circular also points out that more than 1,000 bridges may be vulnerable to failure modes that have been associated with recent coastal storms, such as Hurricane Katrina. Potential risks such as water level change, storm surge, shoreline erosion, shoreline recession, tsunamis, and upland runoff are presented in the guidance for analysis of planning, design and operations of highways in the coastal environment. Identifying such risks is the first step in risk assessment and management. Subsequent steps will involve quantifying the risks and developing actions to reduce the risks to acceptable levels. The failure of roadways and bridges in the Gulf Coast area during Hurricane Katrina would be considered catastrophic by most. In anticipation of future storms and sea level rise, several bridges in the Gulf Coast area have already been reconstructed at higher elevations (Meyer, 2008).

4.5.2 Department for Transport (England) – Risk Matrix for Projects

For the Department for Transport (DfT), England's transportation agency, project prioritization includes identifying and managing risks associated with the road network.

The DfT has developed a risk matrix that assigns project values a score that relates to the probability of failure associated with a specific component. The higher the likelihood of failure, the greater the attention received in the investment program. The likelihood of a risk event is calculated as follows:

L(Risk Event) = L(Cause) * L(Defect)* L(Exposure) * L(Effect)
where L stands for likelihood.
(Equation 1)

Table 3 shows the agency's values for calculating the likelihood of risk events.

TABLE 3: Values for Calculating Likelihood of Risk Events (England DfT)

Likelihood Rating	Description	Range of Likelihood Values	Midpoint Values
Certain	Certainty	1.0	-
High	Highly likely	0.7-0.99	0.85
Medium	Likely	0.3-0.69	0.50
Low	Possible, but not Likely	0.0-0.29	0.15

As an example, suppose that for a particular project, agency officials have determined that the likelihood of the cause of failure occurring is high (0.85), there is medium likelihood of the defect occurring (0.50), a low likelihood of exposure (0.15) and a high likelihood of the effect occurring (0.85). The risk associated with the project is estimated as follows:

L(Risk Event) = 0.85*0.50*0.15*0.85 = 0.054 or 5.4%

Similar assessments are made of all projects being considered and ranked according to the level or risk associated with each. This type of analysis can be conducted to identify the projects that pose the highest risk and allocate funds to solve the most serious problems (FHWA 2005).

4.5.3 Risk Analysis for Bridge Prioritization – Queensland, Australia

Queensland has developed a program called Whichbridge that assigns a numerical score to each bridge based on the risks attached to the condition of the bridge. Factors considered in this assessment include the condition of the bridge components, environmental impacts, component materials, currency of inspection data; obsolete design standards and traffic volumes. System reports use a relative (rather than absolute) ranking to rank structures based on risk exposure and safety considerations. The risk is determined as a product of the probability of failure and the consequence of failure. Consequence is used as a surrogate for the costs of failure, which relate to such things as human factors, environmental factors, traffic access, economic significance and industry access consequences (FHWA 2005).

4.5.4 Risk Analysis for Asset Prioritization – Edmonton, Canada

The City of Edmonton, Canada, has developed a risk-based approach for bridging their infrastructure gap (AbouRizk and Siu 2008; FHWA 2005). Their approach uses the traditional technical definition of risk as previously defined. Data such as the asset replacement value, age, dimensions, quantity and condition are collected. The condition rating system used is the ordinal scale for the ASCE Infrastructure Report card where A is very good, B is good, C is fair, D is poor and F is very poor. The alphabetical grades are converted to a numerical ordinal rating from 1 (F) to 5 (A), with 5 being the best. Using this system, estimates for expected failure of the assets are determined by multiplying the probability of failure of an asset in a particular condition by the elements of an asset in that condition by and summing the expected failure for each condition state as shown in Equation (1) below:

$$\mathbf{E(L) = E(L_A) + E(L_B) + E(L_C) + E(L_D) + E(L_F)} \text{ - } (\textit{Equation 2})$$

where:
$E(L_j)$ = Probability(asset failing while in condition j) x (# of elements in condition j)

Determining the impact of asset failure will vary depending on what risk factors an agency considers to have more impact. The City of Edmonton uses five areas to measure impact of failure and assigns the following weights (in parenthesis) to each area: safety and public health (33%), growth (11%), environment (20%), monetary value required to replace an infrastructure element (20%), and services to people (16%). The level of importance assigned to various types of impacts relates to the values of the communities that an agency serves.

Once the expected failure of an asset and the impact of failure are determined, the risk severity can be calculated as the product of the two values. The City of Edmonton defines risk severity zones as shown in Table 4. Classification of the assets into various risk severity zones provides information for allocating resources to manage the prevailing risks most cost effectively.

TABLE 4: Sample Risk Severity Zones (Edmonton, Canada)

Zone	Description
Acute	An *acute* level of severity is one in which both the expected failure and the impact of each unit of failure are intolerably high. At this level, there is the potential for loss of life if an asset fails combined with a high likelihood that an element asset will fail.
Critical	If the asset is deemed to be at a *critical* level of risk, then either the expected failure will be high and the impact substantial or the impact of an asset's failure will be devastating and the probability of failure still moderate.
Serious	Assets with a *serious* level of risk may have severe or substantial levels of impact; however, these tend to be combined with a low level of expected failure. As such, assets at this level of risk will require attention, yet their needs do not necessarily require immediate rehabilitation or repair.
Important	An asset considered to be at an *important* level of risk corresponds to a situation where the levels of expected failure and impact can be addressed in keeping with a municipality's strategic approach. An important level of risk has been anticipated for most elements.
Acceptable	The *acceptable* level of risk represents a situation in which the combined expected failure and level of impact are manageable.

The City of Edmonton has also applied **risk analysis to develop a risk severity/replacement value chart** that shows the relative risks and costs of different assets. The risk analysis segments the infrastructure assets into logical groupings based on common characteristics. For each segment (e.g., 1 km of road), data are collected describing the inventory, state and conditon of the 0-year rehabilitation estimates for the asset. The asset condition is categirzed using Emondton's standardized rating system and conditions assessed by reviewing the assets within a given department through a combination of workshops and independent analysis. Failure is assumed to occur in two ways, either suddenly and unexpectedly (i.e., catastrophic failure) or gradually and expectedly (i.e., performance faliure). The approach uses 155 deterioration curves and probabilities to determine expected failure. Risk severity values are plotted againset relacement values (Figure 3). Assets found in the upper right quadrant (i.e., high risk severity, high replacement value) are considered to be greater priority.

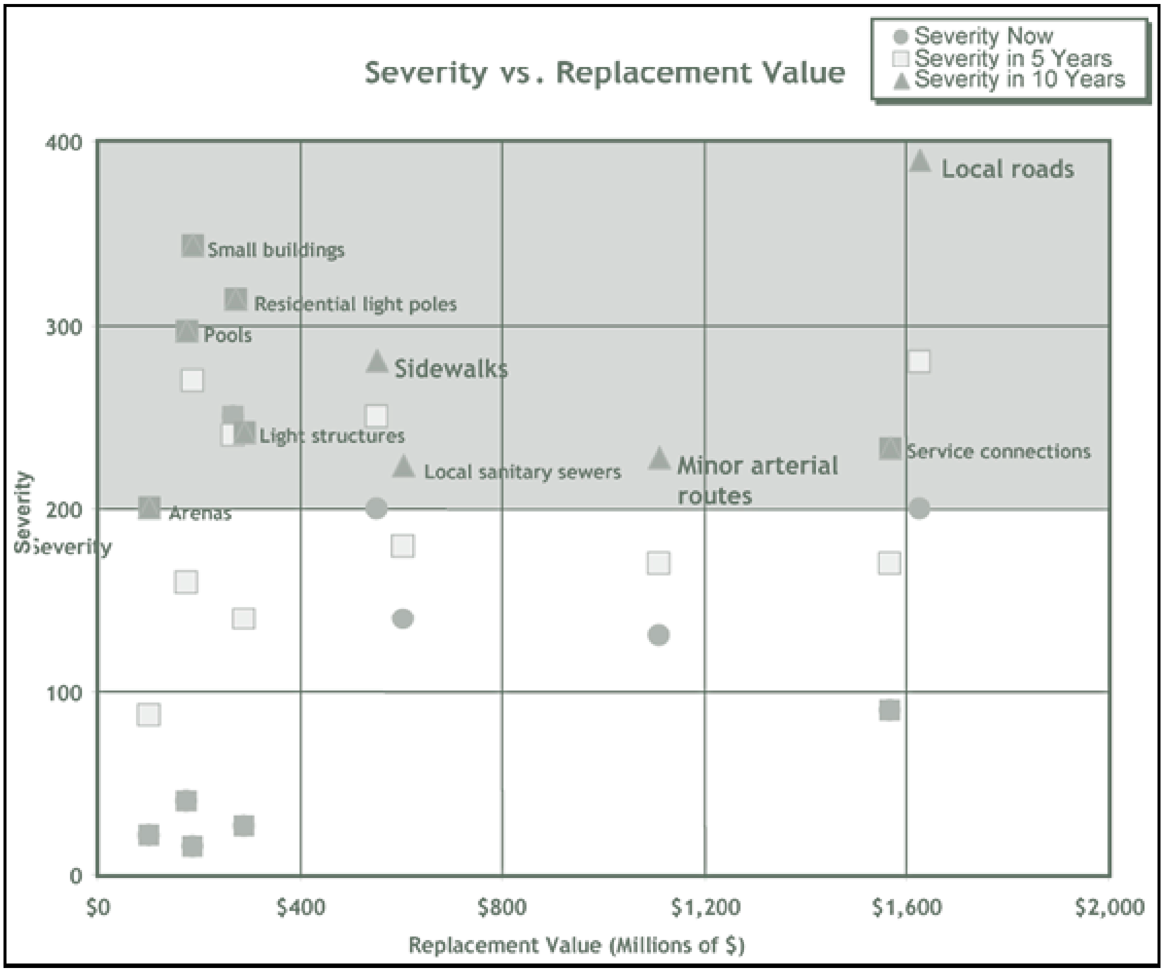

FIGURE 4: Risk Severity vs. Replacement Value Chart – Edmonton, Canada
Suurce: (FHWA 2005)

4.5.5 Risk Analysis for Bridges – Prioritizing Bridge Investments and Inspections

In light of the collapse of the I-35W Bridge in Minneapolis, Minnesota, there has been growing interest in incorporating risk into transportation asset management as these systems relate to bridge management. Cambridge Systematics, in collaboration with Lloyd's Register, a firm that specializes in risk management in the marine, oil, gas, and transportation sectors, have developed a highway bridge risk model for 472,350 U.S. highway bridges, based on NBI data. The model developed uses Lloyd's Register's Knowledge Based Asset Integrity (KBAI™) methodology, which was implemented on Lloyd's Register's asset management platform, Arivu™ (19). This application defines risk as the product of the chance of failure and consequence of failure. However, failure is not defined as catastrophic failure, but rather as performance failure. Failure is defined as bridge service interruption, which may be caused by emergency maintenance or repair, or some form of bridge use restriction. The model predicts the mean time until a service interruption. A so-called, highway bridge risk universe, as shown in Figure 5, can be visualized using the Arivu™ platform (Maconochie et al. 2010).

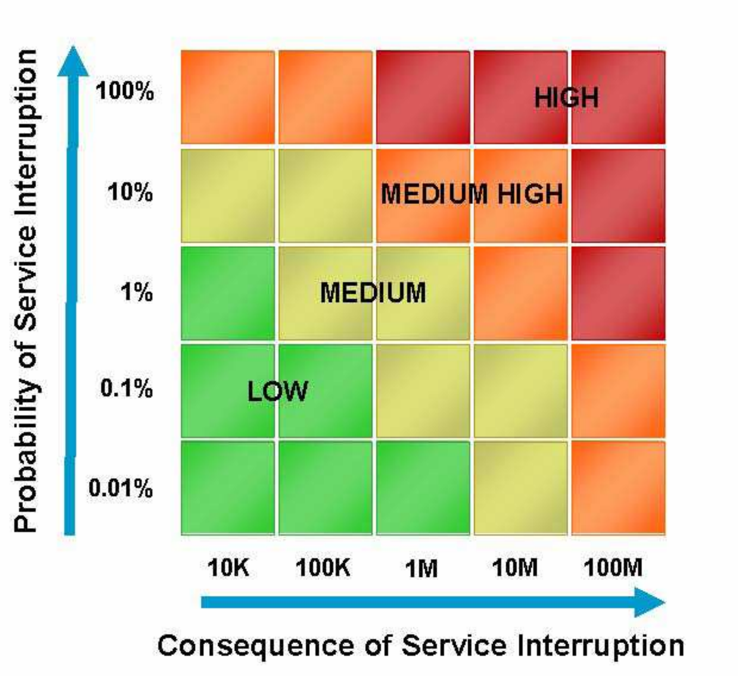

FIGURE 5: Highway Bridge Risk Universe
Source: (Maconochie 2010)

Probability of service interruption is calculated based on three risk units: deck, superstructure, and substructure. The probability that each one of these units would cause a service interruption is calculated. These probabilities are then added together to determine the overall probability that a bridge will experience a service interruption in the next year. Consequences of service interruption are determined using a number of bridge characteristics, such as ADT, percentage of trucks, detour distance, public perception, and facility served, that indicate the relative importance of the bridge to the network and users of the system. The consequence of service interruption is dimensionless, which allows the user to define the characteristics used to determine the relative importance of the bridge (Maconochie et al., 2010).

This model has a variety of potential applications. It can be used to prioritize bridge investments to minimize risk, and to prioritize bridge inspections.

4.6 Scenario/Risk Analysis: Applying MADM Methods to Prioritize Georgia Bridges

Using NBI data and the GDOT bridge prioritization formula, Multiple Attribute Decision Making (MADM) methods were applied to demonstrate the following:

(1) The importance of normalizing bridge (or other asset) attribute scores before summing and ranking;

(2) The potential impact of disaggregated data on bridge (or other asset) prioritization outcomes; and

(3) The potential impact of performance risk on bridge (or other asset) prioritization outcomes.

GDOT has a working bridge prioritization formula to allocate investment dollars. The formula has multiple criteria taking into consideration a range of factors of bridge condition and performance (Table 2). Each bridge is assigned an overall score based on the formula. GDOT's Bridge Information Management System (BIMS) contains data elements for each state or locally owned bridge in Georgia. The data elements used in the bridge prioritization formula are identical to (or based on) data elements from the NBI. The general form of GDOT's bridge prioritization formula is:

$$Score = \{(HS + ADT + BYPASS + BRCOND) \times Factor\} + TimbSUB + TimbSUP + TimbDECK + POST + TEMP + UND + FC + SC + HMOD + Narrow$$

(*Equation 3*)

Table 5 describes the decision criteria in the bridge prioritization equation. Each variable in the formula is assigned a number of points based upon predetermined criteria set by the Department. For example, the point values for ADT range from 0 to 35; bridges with ADT greater than 24,999 receive 35 points, those with ADT greater than 14,999 receive 27 points, etc. The extreme values of points for any factor indicate the best and worst values for that particular factor. The point values for each bridge are inserted into the prioritization formula to calculate an overall score.

TABLE 5: GDOT Bridge Prioritization Formula -- Parameter Descriptions/Values

Variable	Description	Point Values
HS	Inventory Rating	0, 13, 25, 35
ADT	Average Daily Traffic	1, 3, 6, 10, 15, 21, 27, 35
BYPASS	Bypass/detour length (Also accounts for posting, ADT, and % trucks)	0, 10, 18, 25
BRCOND	Bridge Condition – based on condition of deck, superstructure, and substructure	0, 10, 15, 20, 25, 30, 35, 40
Factor	Weighting Factor – based upon functional classification, i.e., interstate, defense, NHS	1.0, 1.3, 1.5, 1.8
TimbSUB	Timber Substructure	0, 2, 5 (state owned)
TimSUP	Timber Superstructure	0 or 2
TimbDECK	Timber Deck	0 or 2
POST	Bridge Posting	0 to 5
TEMP	Temporary Structure Designation	0 or 2
UND	Underclearance	0, 1, 2, 3, 4, 5, 6
FC	Fracture Critical	0 or 15
SC	Scour Critical	0, 1, 2, 3, 4, 5, 6
HMOD	Inventory Rating less than 15 tons for HMOD truck	0 or 5
Narrow	Based on number of travel lanes, shoulder width, length, and ADT	0 or 30

(Source: GDOT Bridge Prioritization Formula, January 13, 2010)

Using data for seven selected bridges in Georgia, three scenarios were developed to examine the impacts of (a) normalization, (b) data disaggregation and (c) performance risk on the bridge prioritization outcomes.

The results of the study demonstrate that in bridge (or other asset) prioritization (ranking), it is important to normalize the values of the different decision criteria (e.g., ADT, bridge condition, bypass/detour length, etc.) prior to finding the aggregate value of the prioritization function in order to indicate the relative utilities of each decision criterion to the decision maker. Not normalizing these values can result in misleading information in the bridge prioritization outcomes.

Secondly, the results show that disaggregating the bridge condition data into substructure, deck and superstructure data can result in a different ranking than when they are aggregated, indicating the value of using more disaggregate data when it is available. In aggregated data, for example, poor substructure condition can be averaged out by very good superstructure condition, and the result of the ranking can fail to reflect the poor substructure condition.

Thirdly, the results demonstrate that including historic bridge data in the bridge prioritization formula can capture the performance risk of bridges and result in a change in bridge prioritization outcomes. The analysis results also show that performance risks will influence minimum standards for TAM.

This study recommends that bridge prioritization decision making will be enhanced if the bridge data is normalized before it is aggregated into an overall score; better prioritization outcomes will be obtained if the bridge condition data is disaggregated as far as the data makes it possible, and bridge performance risk should be captured in the prioritization by using historic bridge condition data when this is available. The results also show that a failure to address performance risk in bridge (and other asset) prioritization may result in undetected performance reduction in the overall system. A full-scale analysis is available in the Appendix 6.

5. THE PERFORMANCE RESOURCE CATALOGUE

A catalogue on performance management resources was developed to facilitate GDOT's access to performance management resources. The Transportation Performance Management Resource Catalogue organizes performance management resources under seven main headings and makes them readily available to agencies for use as they develop their performance management programs:

1. Strategic Planning
2. Performance Measures
3. Performance Targets
4. Funds Allocation and Programming
5. Organizational Structure

6. Data
7. Communicating with Stakeholders.

The full catalogue is included in the Appendix 7.

6. PIPELINE OF TRANSPORTATION PROFESSIONALS

This project supported three students in obtaining masters degrees in Civil Engineering (Transportation): Ms. Yi Lin Pei (currently employed at Cambridge Systematics, Atlanta); Mr. J. P. O'Har (currently in the Ph.D. Program in Transportation Systems at the Georgia Institute of Technology); and Ms. Jamie Fischer (currently in the Ph.D. Program in Transportation Systems at the Georgia Institute of Technology). Developing and presenting peer-reviewed research is a critical part of the graduate education of students supported by research through the Georgia Transportation Institute/University Transportation Center. Listed below are additional related conference presentations and peer-reviewed journal publications developed and delivered by these students during their masters programs.

1. Pei, Y. L., A. A. Amekudzi, M. D. Meyer, E. M. Barrella and C. L. Ross. Performance Measurement Frameworks and Development of Effective Sustainable Transport Strategies and Indictors. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2136, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 73-80.

2. Meyer, M., Amekudzi, A. and J.P. O'Har. *Transportation Asset Management Systems and Climate Change: An Adaptive Systems Management Approach*, Paper accepted for publication in the Journal of the Transportation Research Board, Washington D.C: National Academy Press, 2010.

3. O'Har, J. P. Risk-Oriented Decision Making Approaches in Transportation Asset Management. *Sixth Annual Interuniversity Symposium on Infrastructure* Management, University of Delaware, June 2010.

4. Fischer, J. M., A. A. Amekudzi, M. D. Meyer and A. Ingles. The Transportation Performance Management Resource Catalogue, *Fourth International Transportation Systems Performance Measurement Conference*, May 2011, Irvine CA. (Poster Presentation)

5. O'Har, J. P., and A. A. Amekudzi. Effect of Uncertainty on Project Prioritization, *Fourth International Transportation Systems Performance Measurement Conference*, May 2011, Irvine CA. (Poster Presentation)

7. CONCLUSIONS AND RECOMMENDATIONS

This study identifies factors and guidance for developing performance measures and targets for effective asset management. The study was conducted through a review of the transportation, performance management and performance measurement literature, a statewide survey to determine the status of performance management, an evaluation of risk applications in TAM and a scenario/risk analysis to contribute to the enhancement of GDOT bridge prioritization procedures.

The study finds that performance measurement is an evolving practice and occurring widely among state DOTs, with different agencies at different levels of maturity in the process, As performance measurement has evolved, there has been a shift in focus from performance measurement to performance management which entails using the data collected to make budget allocation decisions that result in the achievement of strategic goals. The study identifies three generational models of performance management moving from the traditional model with several measures not necessarily integrated with any overarching strategic goals (Generation 1) to streamlined outcome measures strategically selected to evaluate progress toward agency strategic goals (Generation 2) to increased adaptability to respond quickly to political and other external pressures to create responsive performance measurement and management (Generation 3).

Over the period of this study, GDOT has moved to refine agency strategic goals to four clear goals and taken steps to develop performance measures and metrics for evaluating progress toward the goals, assigning ownership of various measures to different agency officials, all characteristics of a second generation agency. The following recommendations are made based on the study findings.

1. **Conduct a review of GDOT's performance measurement and management process against current standards:** Using the performance standards identified in this study, conduct a review of GDOT's performance measurement and management process and procedures.

2. **Benchmark against selected DOTs**: Given that performance measurement and management in TAM is an evolving practice, benchmarking has been found to be a worthwhile activity in progressively refining agency performance measurement and management in TAM. Other second-generation agencies identified in 2004 (such as Florida DOT, Missouri DOT, Maryland DOT) are good candidates for benchmarking: GDOT can compare notes on what such agencies are considering as their next steps. Third-generation agencies (such as Minnesota DOT, Ohio DOT and Washington State DOT) are good candidates for benchmarking: GDOT can compare notes on longer range options particularly to add flexibility to enable the agency to quickly adapt or fold in new requirements. This capability will allow the agency to respond quickly to leadership, legislature, funding and other changes -- anticipated and unanticipated. Utah DOT and Indiana DOT are also good candidates for

benchmarking: having participated in a peer exchange with GDOT in 2009, these agencies can be considered to compare progress made within the last two years.

3. **Develop Metrics for Evaluating Progress toward Strategic Goals**: Demonstrated progress toward strategic objectives is a critical element of a well functioning performance measurement and management program in TAM.. Appropriate metrics are importance for measuring performance progress, and appropriate targets for managing progress in reasonable timeframes.

4. **Link Performance Metrics with Resource Allocation Decision Making/Develop Capabilities for Evaluating Tradeoffs:** These two actions are internationally linked because developing appropriate performance reports for resource allocation decision making will entail having the appropriate capabilities for evaluating investment tradeoffs across different business units and asset classes to achieve agency strategic objectives more effectively. Using performance metrics to actually manage agency progress toward strategic objectives will involve linking metrics with decision making to allocate resources across different business units and assets. Doing this successfully will involve having adequate capabilities for evaluating tradeoffs for investments in different asset categories with respect to how these investments achieve various agency strategic objectives and goals.

5. **Refine Metrics for Use in Broader Agency Functions:** The survey shows that about 70% (28) of the responding agencies in the survey reported that performance measures are mostly used in management and planning, and not in all DOT functions. About half of the responding agencies (21) reported using performance measures in operations and slightly less than half (18) in design/engineering. Evaluating the use of performance metrics in agency functions and developing appropriate reports for resource allocation decisions is a critical step to link performance metrics with decision making. In addition, an internal survey to understand the performance data needs and opportunities for planning, management, operations and design/management, can assist in refining performance data for such needs. In addition, identifying performance data needed to manage to achieve goals for the "people" objective will help the agency make progress in these areas. This will involve the development of near-term and longer-term targets, aligned with agency objectives, financial constraints, customer satisfaction data, etc.

6. **Refine Performance Communication Tools**: This recommendation speaks to the importance of improving public and internal communication. At least one third-generation agency (i.e., WSDOT) has reported that surveying external and internal stakeholders about transportation performance (including the general public, legislature and media) was critical in helping them improve performance communication with their stakeholders. Quarterly reporting emerged in response to a credibility crisis with the legislature and media and the need to demonstrate accountability. Through quarterly reporting, WSDOT has demonstrated accountability and improved credibility with the legislature and media. This credibility gain led to the 2003 Transportation Funding Package which raised the gas

tax and several fees to support an expanded highway and rail construction program as well as transit and demand management programs. A number of agencies have adopted project delivery performance reporting systems, e.g. Missouri DOT and Virginia DOT, including project dashboards, quarterly report cards, etc. Bremmer et al. (2004) recommend proactive performance communication to prepare stakeholders for various future initiatives in the horizon.

7. **Address Uncertainties in Performance Management**: Identify and assess uncertainties in existing TAM procedures and data and develop appropriate procedures to incorporate the uncertainties in performance reporting. Unaddressed uncertainties in TAM procedures, e.g., performance modeling and project prioritization, can affect the quality of decision support information from TAMS as demonstrated in this study (Appendix 6). The study demonstrated that incorporating uncertainties in prioritization procedures can lead to notably different results in prioritization outcomes.

8. **Performance Audits:** Evaluate performance audits for states to determine the requirements of state audits for DOTs and address gaps in existing performance management procedures to ensure readiness. State DOTs that use and publish performance measures are increasingly being subjected to performance audits. Information supplied by the National Association of State Auditors, Comptrollers and Treasurers (NASACT) suggests that programs for efficiency and economy audits were being conducted in at least 30 states as reported in Bremmer et al. (2004) and Raaum and Campbell (2006). In the state of Georgia, the Georgia State Department of Audits and Accounts (DOAA) conducts evaluations of state funded programs and activities to answer such questions as: (i) Is this program achieving its goals and objectives? (Are there other ways to achieve this goal?) (Is this goal still relevant?) (How do other states achieve this goal or fulfill this need?) (ii) How well does this program do what it is intended to do? (How many are served?) (What does it cost per unit?) (How does Georgia compare with other states in this regard?) (iii) Is this program complying with all applicable laws and regulations? (Does this program meet all federal grant requirements?) (Is the program fulfilling its obligations as mandated by state law?) (Georgia DOAA Website)

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Best Practices in Selecting Performance Measures and Standards for Effective Asset Management

APPENDICES

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Best Practices in Selecting Performance Measures and Standards for Effective Asset Management

APPENDIX 1

Best Practices in Selecting Performance Measures and Standards

A LITERATURE REVIEW

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1. INTRODUCTION

This literature review was conducted to highlight current and best practices for selecting performance measures and targets in transportation asset management in particular, and transportation planning in general, both domestically and internationally. The review is part of the deliverables for the project: "Best Practices in Selecting Performance Measures and Targets in Transportation Asset Management," funded by the Georgia Department of Transportation. The transportation planning, transportation asset management and business management literature were reviewed to identify current and best practices. What follows is a summary of key considerations for selecting performance measures and targets. In addition, the review touches upon frameworks for developing performance measures and best practices in transportation agencies. The Appendix includes an annotated bibliography of the documents that provided major content for this report.

2. SELECTING PERFORMANCE MEASURES

Performance measures are specific numerical measurements to track progress toward particular goals and objectives of an agency. The central function of any performance measurement process is to provide regular, valid data on indicators of performance. The current planning and management literature identifies some basic principles of good performance measurement presented below.

1. **Performance measures should flow directly out of an agency's mission and objectives.**

Establishing a performance measurement process begins with identifying a program's or agency's mission and its basic objectives. Setting clear, concise and achievable goals and objectives is critical to the success of any planning effort (CS, 2000). What is the agency intended to accomplish? Performance information should flow from, and be based upon, the answer to this fundamental question. A mission/objectives statement should identify the major results an agency or program seeks to achieve. It should also identify who the agency's or program's customers are, unless it is already obvious. Who benefits from the program? Who are direct recipients? Who are indirect recipients? What other people not directly targeted by the program can be significantly affected? (Hatry and Wholey, 2007)

This best practice not only includes the need to create an integrated framework that aligns agency objectives across different levels vertically (i.e., one that is vertically integrated), but also ensures that such a framework is horizontally integrated across the agency's functional units. While top-to-bottom consistency is essential for providing a strong linkage between policy objectives and decision making, horizontal consistency allows for tradeoffs to be made across different functional areas. Ohio DOT and New York State DOT have a vertical alignment of performance measures while Michigan DOT conducts regular meetings across different functional units horizontally to improve communication (CS, 2006). Virginia DOT's strategic process emphasizes the use of performance measures in achieving each goal that is ultimately tied to improving organization accountability (Poister, 2004).

2. Performance measures should provide a "balanced" picture of the agency's business.

The populated framework of performance measures should provide a concise overview of the organization's performance (Kennerly and Neely, 2002). They should reflect financial and non-financial measures, internal and external measures, and efficiency and effectiveness measures (Kaplan and Norton, 1992; Keegan et al., 1989). General categories of information used in performance measurement systems are given below. Effective performance measurement systems tend be results oriented, incorporating output and outcome measures.

Inputs relate to the resources (i.e., expenditures or labor) dedicated to the program to produce output and outcomes.

Outputs relate to the products and services delivered by the program, such as the amount of work done by the organization or its contractors (e.g., the number of miles of road repaired).

Outcomes relate to conditions that are outside the activity of a program itself and that are of direct importance to customers and the general public. While outputs are the work that the organization does, outcomes are what these outputs accomplish for the customer. Outcomes are not what the program itself did but the consequences of what the program did.

Efficiency or productivity relates to the relationship between the amount of input and the amount of output or outcome of an activity or program (Hatry and Wholey, 2007).

Input and output measures have been more common in the past two decades. However, there has been a general movement toward managing for results or outcomes, driven by increased demands for accountability (Poister, 2007). Results-based measures not only reflect an agency's success in meeting stated goals and objectives, they also focus on the beneficiaries of the agency's service, i.e., the customers. However, an over-focus on outcome measures has been criticized recently owing to difficulties in measurement, higher cost, and their technical nature that makes them harder to understand (CS, 2006). As a result, many agencies are reverting to including output measures, as a blend of output and outcome measures is believed to be preferable to using either type alone (CS, 2006). At the state level, MnDOT has already started to re-emphasize output measures at lower levels and Montana DOT has recognized the difficulty in coordinating pavement and bridge preservation strategies using outcome indicators (CS, 2006). Internationally, officials also have a good understanding of the importance of using both output and outcome indicators. In

Canada for instance, a chain that divides outcomes into immediate, intermediate and ultimate outcomes, is used in each functional area to support the ultimate objective of developing a more sustainable transportation system (FHWA, 2004).

The use of input and efficiency measures can help with tracking how efficiently agencies are using their resources to generate outputs and outcomes.

3. An effective performance measurement system will have few and well-defined measures that are tied to a handful of clear goals to be achieved within a specific timeframe.

Conventional practice has it that what gets measured gets managed, and that a short and more targeted list of performance measures is likely to be applied more effectively than a long and unfocused one. An effective performance measurement framework will contain a handful of clear objectives that are linked with the organization's goals. More goals are not necessarily better than fewer goals as the latter can provide a clearer picture of the agency's priorities and have a higher likelihood of being used effectively. Along the same lines, the performance measures used under each goal should be kept to a meaningful few that help to measure progress in reaching that goal. Numerical targets are also better than obscure or 'aspirational' targets to track progress toward goals. Also, specifying a timeframe for achieving strategic goals is highly recommended to ensure accountability.

As performance measures are increasingly used to report to external audiences, such as the governor and the general public, creating more performance measures simply to comply with external mandates sometimes becomes attractive. However, performance measures appear to be more useful when they are created out of a genuine commitment on the part of agency officials to measure performance and use the data meaningfully toward achieving agency goals. Among DOTs, decision rules in developing performance measurement systems, such as tracking only performance that the agency seeks to influence and believes it can feasibly impact, are used to keep the number of measures both meaningful and manageable.

In addition, formal performance measurement frameworks may be used to develop meaningful measures. Such structures tend to be useful when the accompanying performance measures are well thought out to link with broader agency goals and objectives. For instance, Montana DOT uses a balanced scorecard model for performance measurement. After implementation, the agency realized that too many action items were used, some of which were rather general with no indication of tasks to be undertaken, while some had unpredictable effectiveness. As a result, the plan became too cumbersome and the DOT worked to reduce action items down to about 150 from 200 (Poister, 2004).

An international scanning tour on performance measurement found that the most important measures are those needed to influence budget allocation and investment decisions, and that long lists of measures that lack focus tend to exert little influence on decision making. For example, Japan uses a core set of 17 performance measures, which not only reflect issues considered really important but also simplify data collection and reporting and lessen the burden on staff (FHWA, 2004).

Lastly, a harder task lies in how to select performance measures that are collectively unbiased and lead to improved performance in the right direction. Potential biases need to be thought through as measures are selected for tracking progress toward broader agency goals.

4. Customer satisfaction is a key performance measure.

Customer satisfaction should be a key factor in setting up performance measurement for a transportation system, as the end purpose of transportation infrastructure is to provide service to its users, the customers. A good performance measurement system must therefore have systemic customer feedback.

Several state DOTs have a customer focus that is reflected in their performance measurement systems. In the early 1990s, for example, Minnesota DOT begun to survey motorists in the state to assess the percentage that are satisfied with travel times. PennDOT uses surveys to determine the condition of roads used by motorists. Montana DOT conducts public opinion surveys and meets with stakeholder groups regarding the outcomes of its Performance Programming Process. The process provides feedback to the agency and assists in future policy formulation. New Mexico DOT's Compass incorporates 16 customer-focused measures (Bremmer et. al., 2005).

Internationally, measures of customer satisfaction are common. For example, New Zealand's approach to customer satisfaction focuses on identifying customer dissatisfaction. By asking more focused questions in customer surveys, agencies are more successful in getting feedback to determine organizational performance.

Balancing the satisfaction of the public/media, legislature and management are all important within a political environment. Sate DOTs such as New Mexico, Minnesota and Washington have demonstrated real time success with balancing the three factors (Bremmer et. al., 2005).

A framework such as the Balanced Scorecard used in Business Management and to a limited extent in Transportation can be effective in balancing customer, financial, internal business and growth perspectives (Poister, 2007) across vertical and horizontal levels.

5. Performance measurement systems should be periodically evaluated in an iterative process.

A performance measurement system should evolve in response to evolving goals and changing priorities of an agency, and data availability, among other factors. A performance measurement system therefore needs to be periodically refined through evaluation and feedback.

There are several ways to structure the feedback process to support policy and resource allocation decisions in asset management. For example, Florida DOT uses a Continuous Cycle approach where policy is developed and implemented, performance is measured and the results affect the long and short range plans through the adjustment of policies (CS, 2006). Frequent performance reviews, such as the quarterly management review adopted by Colorado DOT can also be used, where problems, e.g., under performance, can be recognized quickly and corrected. In addition, performance evaluation can also be achieved through public feedback. Such performance measurement systems are viewed as customer focused. Montana DOT, for example, conducts public opinion surveys that provide critical feedback to their performance programming process and help with future policy formulation (CS, 2006).

In addition to helping with policy formulation, the performance measures can also be revised and improved. In this regard, DOTs can experiment to develop and revise approaches to performance measurement in an attempt to resolve issues with quality, methodology, reliability, cost and usefulness. For example, before and after studies are important elements of performance measurement in Japan and Australia (FHWA, 2004). The impact of adopted actions on selected performance measures serve as feedback to the decision making process helping officials to determine the likely results of similar actions. The relative usefulness of performance measures should be periodically evaluated to help refine the measures as needed.

6. Performance measures should use good and available data that the agency can reasonably collect without straining their capacity.

As outlined in the AASHTO Transportation Asset Management Guide, good data are critical to performance measurement (2002). However, balancing data availability and affordability with quality and analytical rigor is often a difficult task. While having too little data makes it difficult to track performance effectively, having too much data is not only expensive, but less cost-effective, and potentially confusing and lacking in cohesiveness to the general public and other external stakeholders.

An integrated data collection strategy can be used to address this issue. Centralizing the data collection function at the highest level possible can also lessen the effort needed for data collection and allow for greater consistency. For example, the small size of Maryland gives the DOT an advantage of having only one inspecting team to conduct statewide data gathering, saving costs and providing greater data consistency (CS, 2006).

Internationally, some of the more successful performance measurement programs have occurred in data-rich environments with a history of strong data collection and analysis. Sophisticated measures can be used in areas where there is a need and the institutional capacity allows for the collection of supporting data.

7. Performance measures increasingly include measures of environmental quality and sustainability.

A recent survey of the 50 state DOTs indicates that various state DOTs appreciate the importance of sustainability in their internal and external activities, and can point to specific initiatives that demonstrate their interest in or commitment to sustainability (Barrella et al., Forthcoming).

In Transportation, sustainability is a term used to capture the balance between transportation mobility and accessibility, and the economy, environment and social quality of life including equity. The concept of sustainability is increasingly important as energy and climate change, and other related issues have become a national and global priority.

A number of DOTs have performance measurement systems that include sustainability factors, particularly environmental factors, e.g., Washington State DOT, Missouri DOT and Iowa DOT. CalTrans and Texas DOT have adopted a range of sustainability indicators. A number of DOTs have also developed green rating systems that use sustainability principles and measures to prioritize projects for development, e.g., GreenLITES, i.e., Green Leadership in Transportation Environmental Sustainability (NYSDOT); Green Roads (WashDOT), and STARS, i.e., Sustainable Transportation Access Rating System (Oregon). Sustainability measures in Transportation are increasingly being used internationally as well, e.g., in the U.K. and New Zealand. In addition, while dollar valuations of environmental measures such as air pollution have long existed, the monetization other sustainability measures is gaining more traction (Weisbrod et. al., 2007).

All of these activities reflect a growing interest in incorporating environmental quality and sustainability concepts and measures in Transportation planning.

8. Performance measurement reporting and communication should be clear and easy to understand.

Increasing demands for accountability make performance measurement communication a critical issue in transportation agencies today. Effective reporting to external stakeholders, i.e., reporting on budget and demonstrating on-time performance, are critical to obtaining funding. Various approaches are used by DOTs to communicate key issues to political decision makers and the general public.

One approach is the scorecard where key indicators are presented as measures of success in achieving objectives. Actual values are presented against target values for designated time periods. For example, Missouri DOT tracks the implementation of various strategies using scorecards in key areas; these scorecards are reviewed by top management on a quarterly basis (Poister, 2004). While scorecards may be used largely for internal communication, report cards and reports are developed by various DOTs, e.g., Florida DOT, Washington State DOT and Virginia DOT, to report performance to external stakeholders. Posting these reports on the Internet not only increases readership but also improves transparency and accountability.

The dashboard has been designed to report progress at a glance, often employing symbols and colors to display results. Virginia DOT has a dashboard online that can be easily updated to track progress, and can also allow different units within the Department to easily crosscheck each others' progress (Bremmer et. al., 2005). Minnesota DOT has developed dashboard reports that clearly show performance versus targets for each department (Bremmer et. al., 2005).

Visualization of critical information is important to effectively communicate performance to stakeholders. Ineffective presentation can result in the loss of funding and public support, and impede progress.

3. SELECTING PERFORMANCE TARGETS

One of the important gaps in managing transportation performance is how to set performance targets, or standards, for performance measurement. While there is extensive and growing literature on performance measures, relatively little attention has been given to how to set performance targets and the role of targets in transportation planning (Schmitt, 2007). A research proposal was generated for setting effective performance targets (Schmitt, 2007). NCHRP Project 8-70 is developing a comprehensive set of methods for establishing performance targets for all aspects of transportation. The final report is anticipated this year. *NCHRP Report 551 on Performance Measures and Targets for Transportation Asset Management* (CS, 2006) provides some guidance on setting performance targets. Despite its focus on asset management, the steps it outlines can be extended to other DOT functional divisions as well. The report recommends that consideration should be given to financial, policy, technical and economic factors when setting performance targets. In addition, it suggests that the establishment of long term and short term targets should follow seven logical steps as follows (CS, 2006):

1. Define contexts and time horizons
2. Select scope of measures for targets
3. Develop long-term goals

4. Consider funding availability
5. Analyze resource allocation scenarios and tradeoffs
6. Consider policy and public input
7. Establish targets and track progress

A piece of the literature that examines performance targets in the UK provides additional information on different methods of establishing performance targets, and the tradeoffs among the methods (Marsden and Bonsall, 2006). It first summarizes the motivations for developing targets: legal and contractual obligations, resource constraints, consumer orientation and political aspirations. Based on these motivations, three ways to set targets are discussed. Model-based methods rely on computer models to examine how a given indicator varies under a range of scenarios. It is the most realistic method and can allow for different scenarios to be examined. Where variables cannot be modeled, extrapolation and evidence-led judgment can be used in a second method that is based on historical data. The most subjective method is aspirational, where targets are set because they *should* be set. While each method has positive and negative aspects, the best method is perhaps one that can establish targets that can be tied back to the most fundamental goals (Marsden and Bonsall, 2006). The target setting procedure presented in NCHRP Report 551 appears to be a combination of the three methods.

A case study on performance measures and target setting in Detroit's planning process provides a good example of performance target setting in the US. The Southeast Michigan Council of Governments (SEMCOG) uses the *AssetManagerNT* program to explore different scenarios in program funding and the expected future performance of different program areas, such as bridge preservation. The target setting process not only involves running different scenarios, but involves the engagement of stakeholders to determine which scenarios are most positively received (Guerre and Evans, 2008). Such a process that considers different constraints and involves stakeholder input can generate realistic and effective performance targets.

4. PERFORMANCE FRAMEWORKS

Performance frameworks are structured processes that provide guidance for selecting performance measures. They explain the rationale used in selecting adopted measures. While various agencies may have informal and undocumented processes for selecting performance measures, there is usually a rationale behind the adoption of performance measures. Some examples of formal frameworks are given below to highlight documented procedures for selecting performance measures. Documented processes can help agencies re-evaluate measures periodically to keep them current with agency goals and objectives, customer expectations and other internal and external factors.

Balanced Scorecard Framework

Performance frameworks in the Management and Accounting fields are being used in a limited but growing extent in Transportation field. Perhaps, the most popular example is the Balanced Scorecard framework for performance measurement.

The Balanced Scorecard model was conceived in 1992 by Kaplan and Norton (12manage, 2009). It provides a strategic and balanced approach to measuring corporate performance from four perspectives: 1) finance, 2) the customer, 3) business process and 4) learning and growth. This framework has helped companies to achieve success by focusing the organization on a few strategic efforts, integrating various programs and vertically integrating measures at all levels in an organization to improve performance (12manage, 2009).

Because of the success of this model, various government organizations, including some state DOTs, have adopted the Balanced Scorecard framework. The City of Charlotte DOT (North Carolina) was the first agency to adopt the model. Illinois DOT and TxDOT have also customized the model (Poister, 2007; Wholey et al., 2004). Figure 1 shows the modified model for TxDOT that still keeps four quadrants of measurement, but with modified contents.

The Balanced Scorecard Framework identifies goals that relate directly to the internal operations of the agencies and external stakeholders such as the customers, political decision makers, who are important elements of the agency's operations and success. It is important that the Balanced Scorecard Framework also identifies "process" and "results" elements, which can help the agency fine tune its efficiencies in meeting outcomes while tracking its progress in achieving these outcomes. The Balanced Scorecard Framework reflects that the structure used in developing performance measures can influence the overall effectiveness as well as efficiency of the agency.

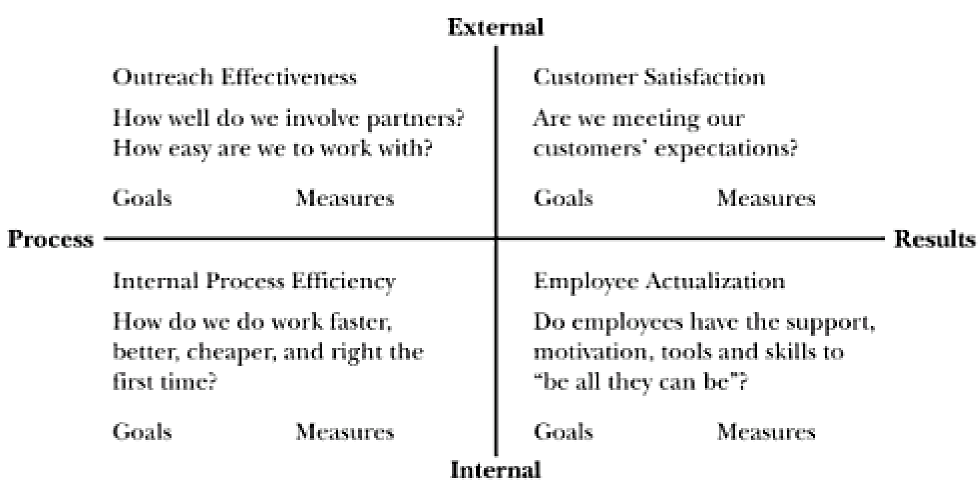

Figure 1: The Balanced Scorecard Framework (Doyle, 1998)

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Best Practices in Selecting Performance Measures and Standards for Effective Asset Management

APPENDIX 2(a)

Performance Measurement in State Departments of Transportation: A Literature Review and Survey of Current Practice

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ABSTRACT

Performance measurement, when properly implemented, can ensure efficiency, accountability and transparency for transportation agencies. This principle is to be highlighted in the next federal legislation for surface transportation, which will call for the explicit use of performance based measures as part of a strategic planning process. Clearly, understanding the current state of performance measurement practice in the United States is important for identifying and filling in existing gaps. As a result, the objective of the paper is twofold: 1) to explore the use of performance measurement in state DOTs through review of the literature, and 2) to explore the use of performance measurement in general, in setting targets and in asset management through a comprehensive survey. Results from the literature review show that performance measurement systems in transportation agencies are increasingly more strategically focused, and tied to the long term goals of the organization. Performance measurement is also used in different program areas, such as asset management, and is being used in other ways, such as benchmarking for comparative performance. While gaps exist in understanding performance target setting, recent efforts to learn from peer countries foretell of a promising future of development in the area of performance measurement. Results from the survey show that there is increased integration between performance measurement systems and strategic planning. Second, benchmarking is observed to be an important method to measure performance. Third, target setting, while it exists for most DOTs, can be a more formal process. Fourth, asset management is being viewed as an important area by most DOTs and more integrated systems are needed. The implication of the results on transportation in the US is direct and significant in several ways: 1) on a strategic level, the developments noted in performance measurement can aid transportation agencies to be better prepared for the reauthorizing of the federal surface transportation legislation; 2) the identification of a performance measurement system can help agencies stabilize their financial situation; 3) a comprehensive strategic planning framework can lead to better integration and accountability through the local, state, and regional levels; and 4) such a system will eventually lead to long term system effectiveness, transparency and longevity. Such a system would also be dynamic and readily responsive to changes in DOTs.

INTRODUCTION

Performance measures, defined as indicators of system effectiveness and efficiency, are increasingly becoming a central focus in transportation planning in the United States. A performance-based transportation planning system is important because as the saying goes, "what gets measured gets done." A proper performance-based measurement system can help ensure effectiveness, efficiency, accountability and transparency. The next federal legislation for surface transportation will call for the explicit use of performance-based measures as a central tenet, acknowledging the importance of using performance measurement as part of a strategic planning process. The current US Department of Transportation (DOT) Strategic Plan is already performance based, where under each strategic goal, outcomes, strategies, performance measures and external factors are clearly laid out *(1)*. It is a results-oriented strategic plan. DOTs at the state level adopt more concrete and context-specific strategic plans that can be used to execute, track and monitor progress to ensure accountability especially in light of the recent economic climate.

Clearly, understanding the current state of performance measurement practice in the United States is important for identifying areas of improvement and addressing them. The purpose of this paper is to illuminate the state of performance measurement practice in state transportation agencies. The paper does the following: 1) explores the use of performance measurement in state DOTs through review of the literature, and 2) explores the use of performance measurement in general, in setting targets and in asset management through a comprehensive survey. The results of the explorations should aid DOTs in preparing for the reauthorizing of the federal surface transportation legislation and lead to long term agency effectiveness, efficiency, accountability and transparency.

LITERATURE REVIEW OF PERFORMANCE MEASUREMENT IN STATE DOTS

Review of Performance Measurement

State DOTs have long used performance measurement for analyzing system processes, outputs and outcomes as part of the engineering and planning disciplines. Outputs are "products and services delivered" by the agency (e.g., miles of roadway repaired), whereas outcomes are the "the consequences of what the program did," (e.g. percent reduction in crashes) *(2)*. Yet, using performance measurement to manage, especially for accountability is a relatively new concept *(3)*. Privatization or management reforms have affected performance management in state DOTs. For instance the balanced scorecard model, which is by far the most used business performance model, has also been widely adopted by transportation agencies. In addition to privatization and a need to be competitive, other important factors have triggered interest in DOT performance measurement. These include: 1) the need to support strategic planning processes with information on DOT performance; 2) demands for increasing accountability from the public, legislators, and governors; 3) government-wide mandates; 4) growing commitment to customers; 5) leadership changes; and 6) funding and politics *(3-5)*.

As far back as 1993, NCHRP Report 357 *(6)* intended to isolate and define the key program performance measures and indicators of state highway and transportation departments for effective and efficient administration. This report provided information on the value of goal setting, the necessity of tailoring performance measurement systems to the special characteristics and transportation needs of each state, and the need for public accountability. However, the report also noted that while several states had initiated programs to develop and use performance measurement tools, no state had comprehensive experience *(6)*.

NCHRP Report 357 *(6)* reflects a model of the first generation transportation agency, where measures were typically developed in response to internal initiatives or to specific legislative requirements. Performance measures were often robust and well-developed, but they were usually not meaningfully linked to other agency processes. Second generation frameworks on the other hand, which emerged in the late 1990s, usually tied measurement to strategies for tracking business functions and planning goals *(4)*. During this period, many states took significant steps to measure the performance of their programs and services, moving beyond traditional operation-level, system-oriented measures to monitoring inputs and immediate outputs. This generation of performance measurement also put greater emphasis the customer's perspective. However, second generation performance measures were often too complex, making results difficult to communicate, and agencies struggled to develop tools for reporting to stakeholders *(3, 4)*.

In 2000, a guidebook was published linking performance measurement to transportation planning. It was intended to provide transportation organizations, planning practitioners, and decision makers with practical tools for considering system performance in the multimodal transportation planning and decision-making process. It is also aimed to support the investment decisions needed in major transportation systems *(7)*.

Subsequent publications have furthered these concepts and moved towards a third generation of performance measurement that uses dynamic approaches providing real time information. Third generation frameworks respond to the needs of agency leadership and the political context while placing high value on accountability *(3)*. Performance measurement is also increasingly tied with strategic planning, asset management and other program areas. For instance, a handbook for CEOs and executives was developed on strategic planning that combined performance measurement and strategic management into a strategic performance measurement system. The report included detailed information about setting up and maintaining a strategic performance measurement system that can energize strategic management efforts, maintain focus, and enable organizational change, in addition to being able to track progress *(8)*.

NCHRP Synthesis 326 examines the experience of state and provincial DOTs' with strategic planning in 2004. It synthesizes the existing approaches to strategic planning and decision making, including performance measurement. Although many DOTs still struggled with defining "meaningful, reliable, accessible and cost effective," *(9)* performance measures in 2004, they were placing a greater focus on customer satisfaction and feedback. Also, DOTs began using time-sensitive numerical targets around this time, and they began developing asset management programs within the frameworks of their strategic plans *(9)*.

The importance of performance measurement and asset management is further explored in NCHRP Report 551 of 2006, which describes several principles to support asset management. The report determines that performance measures should be policy driven, strategic in perspective, considerate of tradeoffs and options, and should be implemented across organizational units and levels. In addition, performance decisions should be based on good information and should be evaluated and monitored through a feedback process *(10)*.

Comparative performance measurement, also known as benchmarking, was recognized as important in the 2006 report *Measuring Performance Among State DOTs (11)*. It was found that many DOTs were still skeptical about benchmarking but were willing to try it. The report summarized the basic elements for developing a comparative framework, including a multistate working group, adequate staff, identification of common strategic focuses, identification of templates for measures, data collection and analysis systems, and the sharing of information. A peer group study of several states tracked two performance measures, on-time performance and on-budget performance, and found that there is great variation between different states *(11)*.

Learning from other countries can prove valuable. A 2004 scan of performance measurement systems in Australia, Canada, New Zealand and Japan showed that performance measures were used more extensively in those countries than in the US *(12)*. These systems often emphasized safety; included output, outcome, customer satisfaction, and environmental indicators; integrated data collection; used before and after studies and benchmarks; and considered multimodal investment tradeoffs. Successful programs directly used performance measurement to influence programming decisions and budget allocation. The scan recommended, in particular, that safety and benchmarking should be emphasized more by the FHWA. Furthermore, the scan suggested that the US generate research, training, conference meetings, technical guidance and sustainability actions, using these international examples.

This review of the literature indicates that many states have committed to using performance measures, but the degrees to which performance measurement systems are developed may differ widely among states. A list of attributes of good performance measurement are generated below, synthesized from the best practices found in the literature.

Review of Performance Targets

Little attention has been given to setting performance targets and what role targets may play in transportation planning *(13)*. NCHRP Report 551 *(10)* provides some guidance on setting performance targets. The report recommends that the setting of targets should consider financial, policy, technical and economic factors. In addition, it suggests that the establishment of long term and short term targets should follow seven logical steps as follows *(10)*:

1. "Define contexts and time horizons,"
2. "Select scope of measures for targets,"
3. "Develop long-term goals,"
4. "Consider funding availability,"
5. "Analyze resource allocation scenarios and tradeoffs,"
6. "Consider policy and public input," and
7. "Establish targets and track progress."

A 2006 examination of performance targets in the UK provides additional information on different methods for establishing performance targets, and the tradeoffs between them *(14)*. It summarizes the motivations for developing targets as legal and contractual obligations, resource constraints, consumer orientation and political aspirations. Based on these motivations, three ways to set targets are discussed. Computer-based models examine how a given indicator varies under a range of scenarios. These are the most realistic methods and can allow for different scenarios to be examined. Where variables cannot be modeled, extrapolation and evidence-led judgment based on historical data can be used. The most subjective method is aspirational, based on the desires of agency decision makers. While each method has positive and negative aspects, the best method is perhaps one that can establish targets that are tied back to the most fundamental goals *(14)*. The target setting procedure presented in NCHRP Report 551 appears to be a combination of the three methods.

The overseas literature on performance targets points to the need for the US to learn from its peers. A 2010 international scan, *Linking Transportation Performance and Accountability (15)*, carried out in Australia, Great Britain, New Zealand and Sweden, studied how the transportation agencies of different countries use target setting to demonstrate accountability to elected officials and the public. This timely scan shed light on some important points about performance measurement and target setting in other countries:

1. "A limited number of high-level national transportation policy goals that are linked to a clear set of measures and targets are used,"

2. "Intergovernmental agreements on how state, regional, and local agencies will achieve the national goals" are negotiated "while translating them into local context and priorities," and

3. "The real value of performance management is the development of an improved decision making and investment process, not the achievement of many arbitrary short-term targets." *(15)*

The scan is a step in the right direction to help the US develop better performance measurement systems for accountability. Further, a web tool called *State Measures* has been created that synthesizes documents such as state transportation statistical, annual, and performance reports *(16)*. These recent developments show that challenges in the area of performance measurement are being actively addressed, perhaps in anticipation of the performance measurement requirements expected with the pending reauthorization of the surface transportation bill.

SURVEY ON PERFORMANCE MEASUREMENT AND TARGETS SETTING IN STATE DOTS

Introduction

The goal of this comprehensive survey was to identify common approaches to selecting performance measures and targets in state transportation agencies. While other surveys have been carried out to understand performance measurement, no survey was found that looks at performance measures holistically from an agency's strategic planning perspective, and whether agencies have systematic procedures for setting targets. This survey tries to fill in the knowledge gaps within the literature review above, in addition to providing information on state of the practice in asset management at DOTs.

Survey Methodology

The survey took place from September 2009 to February 2010, and was conducted through telephone interviews and online questionnaires, consisting of eight survey questions. Mainly planning and performance measurement departments or divisions within the DOTs were contacted. Respondents were given a choice between being asked the questions on the phone, or filling out the responses online. For the latter, respondents were further contacted to clarify responses if needed.

Survey Results

The overall response rate of the survey was quite good, as 39 State DOTs (or equivalents) responded to the survey out of the 50 states plus the District of Columbia. This corresponds to a response rate of 78%. Figure 1 below shows the geographic spread of the states that responded. The following sections present the survey results.

1. Organizational Strategic Goals and Objectives

The purpose of this question is to find out whether an agency has a functional strategic plan on which performance measurement can be based. It also seeks to find how often the strategic plans are updated, how these plans are organized, and which specific goals are set.

Out of the 39 responses, 36 agencies responded "yes" indicating they have a strategic planning process, while 3 agencies responded "no", reflecting a high positive response rate of 92%. However, it should be noted that while most DOTs understood that strategic plans are different from Long Range Transportation Plans (LRTP), certain DOTs gave objectives from their LRTPs.

The survey results show that most DOTs have a strategic plan that is updated annually, with some DOTs updating them biennially or in three- and four-year intervals. Plans updated less frequently than every five years are very rare. These results imply that most DOTs are proactive in responding to new planning imperatives. Short review intervals also provide feedback loops that can allow for faster improvements in performance.

There are different ways in which agency goals are organized. The most common organization is a one tier arrangement. For instance, Virginia DOT lists six broadly defined goals addressing transportation issues such as safety, systems preservation, and mobility; outcomes such as economic vitality and quality of life; and organizational issues such as financial accountability and inter-agency collaboration.

The second way that goals can be presented is through a multi-tiered arrangement, where goals are broadly defined, and more specific objectives are defined to clarify the broader goals. More intricate structures that are tied to a specific performance measurement framework, such as the balanced scorecard are also used. For instance, New Hampshire DOT's goals are arranged according to a multi-tiered balanced scorecard structure, with four big-picture areas of performance, each with two to four specific goals.

The third way strategic goals can be arranged is in an area-specific manner, where different goals are listed for each division, and some agency-wide goals may overlap across divisions. The NYSDOT's strategic goals are organized according to seven specific program areas: highway and bridge infrastructure, public transportation system, statewide rail system, aviation system, multimodal transportation mobility, environmental sustainability, and multimodal transportation safety. Goals are described within each area, and in some cases organized into multiple subareas; for instance, different statewide rail system goals are specified for passenger and freight rail.

Naturally, there is no best way to arrange an agency's goals. So long as they are comprehensive and reflect agency and stakeholder priorities, they are potentially effective goals. Agencies range from having as few as four goals to having as many as hundreds of goals arranged in several categories. However, most agencies have fewer than 10 goals. Also, the survey has shown that most DOT goals fall into few major categories. Table 1 below lists 29 categories which capture all of the goals used by survey respondents, sorted from the highest to the lowest number of occurrences. Although some of these categories are closely related, they have been formulated based on the wording of the various survey responses.

It can be seen from Table 1 that goals related to safety, systems preservation, and mobility are the most common of all strategic goals. The "transportation system safety and security" category relates to safe roadway designs and is represented in 67% of all survey responses. It is considered separately from the similarly worded "system preparedness, security" category, which relates to responsiveness in emergency situations; however if the two were considered together, they would be represented in 76% of responses. The "asset management and systems preservation" category is especially important to note, in light of the recent and upcoming legislative focus on better infrastructure management. Its broad representation (56%), is in stark contrast with that of "public and alternative transportation expansion and improvement" (10%), and "highway expansion and capacity increase" (5%) goals. "Transportation system mobility" seems to be similar to "transportation system effectiveness and efficiency," which relate to such performance measures as travel time delay. Together these mobility and efficiency goals are represented in 53% of the responses.

Compared with the goals mentioned above, which relate to the direct physical and functional aspects of the transportation system, outcome goals related to the economy, the environment, and society are less widely adopted. "Economic growth and vitality," which is a community-oriented outcome, is a goal area for 28% of respondents. Organization-oriented goals related to the economy are also represented in 12% of responses: "agency conservation and business efficiency," along with "cost effective products." "Environmental quality and sensitivity" is specifically mentioned by 10 of the 39 respondents (25%), with others mentioning related ideas such as "stewardship" and "sustainability."

"Customer satisfaction," is the most popular socially-oriented goal area, appearing in 28% of responses. However, this relates more to agency image than community outcomes. Other agency-oriented social goals are related to "employee innovation" and "agency leadership." Relatively few agencies set goals related to quality of life and accessibility, however, which are more community-oriented. Social equity was not mentioned explicitly by any of the respondents.

The concept of "sustainability," which was mentioned explicitly by two survey respondents, implies a commitment to improving the economic, environmental, and social outcomes. Although the concept has become more widespread in recent years, the results of this survey show that sustainability is of less frequent concern to transportation agencies than are measures of effectiveness and efficiency. If agencies wish to improve their relative sustainability, they will need to incorporate human outcomes, related to the economy, the environment, and social equity, more explicitly into their strategic goals.

2. Strategic Planning and Performance Measures

This question seeks to find out the extent to which DOTs are using performance measures to monitor the progress of their strategic plan, and to find out how the performance measures are structured. It is not to find out exactly what performance measurements are used, but how they are tied to the overall strategic planning process. From the survey results, 23 out of the 39 DOTs indicated they do have performance measures that are used to gauge success in achieving their strategic goals and objectives. While the rest do not have performance measures linked to the strategic plan, several DOTs are in the process of adopting such a system.

Most of the measures are organized in a multi-level structure where the highest level usually consists of goals identified in the first question (also called Key Performance Indicators) and shape the overall priority of the organization. The second level contains more detailed objectives, and underneath that specific strategies (action-level measures) are identified. This indicates that most DOTs align their measures to strategies to help achieve their objectives in an organized manner.

The number of measures also varies greatly between different DOTs. While some DOTs have only a few measures (e.g. Oklahoma DOT has 12 measures in 5 goal areas), others, for instance Maryland, have over 400 measures in its different divisions. Several DOTs also follow a performance measurement framework that aids in measurement formulation and better feedback. For instance, Florida DOT has always used a well developed pyramid framework that sets the goals and objectives from the policy level down to the project level. Interesting to note, Florida DOT also has developed measures in a kind of multi-perspective structure, in order to answer three separate questions *(17)*:

- How we report on what we are accomplishing
- How we are being measured by others
- How we measure ourselves on an ongoing basis

These three questions are important because they distinguish performance measurement from benchmarking, where the latter can sometimes be more effective in improving the organizations.

While measures are important in and of themselves, how well measures are tied to the overall planning process is perhaps more important. For instance, Caltrans provides a good framework in which the performance measurement system is directly linked to the operational plan, and informs both strategic planning through program evaluation *(18)*. Another good example comes from Louisiana DOTD *(19)*, which adopted a Performance Indicator Matrix that vertically integrates performance measures with objectives set at the program level. In this framework, each objective is clearly stated, and measures are divided into input, output, outcome, efficiency and quality categories. Also, Missouri DOT has a tracker system that is built around 18 tangible results that corresponds to over 100 performance measures. This system allows for easy updates to be made and easy tracking.

3. Performance Measurement Review

To carry the previous question further, this question attempts to find out how often the performance measures are reviewed. Out of the 23 DOTs that have a performance measurement system for strategic planning, 13 reported that they review their measures annually, four quarterly, three biennially and two semi-annually. The remaining one agency reported that they review their measures when their plans are updated. The results indicate that most agencies that have performance measures in their existing strategic plan review them frequently, usually coinciding with how often the plans are updated.

4. Role of Performance Measures in Functional Divisions

This question seeks to find out the extent to which performance measurement is used in each division of the DOT. For the 39 DOTs that responded, Table 2 lists the twelve most common functional divisions in which performance measurement is used. As can be seen from the results, performance measurement in planning and program development is considered important by most DOTs, followed by operations and engineering. In order for performance measurement in these areas to be effective, agencies will need clear and comprehensive strategic plans that can guide operations, engineering and other action areas. Other divisions, which were listed by very few DOTs and are not listed in the table, include environmental divisions, multimodal divisions and public private partnership initiatives. Also worth noting is that several DOTs report performance management within an operations division, but not within maintenance, although these two activities ("O&M") are often thought of as closely linked. Certainly, some agencies may deal with maintenance within operations. Nonetheless, more research could uncover whether performance management practices in maintenance might facilitate the shift to a system preservation focus.

According to the survey, there are two ways in which DOT functions are organized. The first consists of a one-tier structure, where the DOT functions are broken down into distinct divisions (usually above 10) and each manages their functions independently. The second is a two-tier system, where the DOT is broken down into broad functional areas, such as engineering, headed by a director, and each area is further broken down into several divisions, such as maintenance, civil rights, and planning. Regardless of the organizational structure, functional divisions should reflect a comprehensive picture of the priorities the agencies represent.

Regarding the role of performance measures in each division, DOTs generally responded that performance measures are used for overall management and planning to advance projects and make business decisions. While several DOTs use performance measurement in each of their units, most DOTs only use it in certain business units for internal tracking. For certain DOTs, different performance measurement models are used by different divisions to track progress. Or, as in the case of NYSDOT, the same division may use a combination of multiple models. NYSDOT's Engineering Division utilizes a Performance Improvement Model (PIM), but the Office of Design, within the Engineering Division, has also incorporated a balanced scorecard approach and publishes its performance metrics and an overall index on the Department's internal website. A few other respondents also stated their use of a balanced scorecard system, and several DOTs have spearheaded such a process. However, the majority of DOTs could better use performance measurement in a manner that is both horizontally integrated across divisions and vertically integrated within a division, linking performance measurement more clearly to division and agency goals.

5. Performance Measures and External Stakeholders

The extent to which performance measures are used to engage external stakeholders is looked at in this question. Out of the 30 DOTs that do engage with external stakeholders, they reported that primary stakeholders are the public, legislature, governor and industries. Engaging with external stakeholders is important to ensure customer satisfaction, transparency, accountability and improve the organization through useful and unbiased feedback. The most common ways DOTs use to engage with external stakeholders include customer satisfaction surveys, focus groups, public meetings and public hearings. Websites also contain information available to stakeholders, such as dashboard information. Simulation and trend analysis are used in public meetings to explain capital needs and budget impacts. Annual and quarterly reports are used to report progress to key stakeholders. Customer feedback can be used to improve performance. For instance, Missouri DOT's Tracker program includes measures tracking the number and satisfaction of customers involved in public planning processes.

6. Setting Performance Targets

One of the observable gaps in the transportation performance management literature is the lack of guidance for setting performance targets, or standards for performance measurement. To fill this gap, the sixth question asks DOTs if they set target performance levels and how they go about setting their targets. Thirty-one out of the 39 DOTs responded that they do set targets. This response rate is higher than for performance measures because many DOTs do not directly tie targets to the strategic planning process or performance measurement. Based on the survey, Table 3 shows the most common ways performance targets are set. Some agencies use multiple methods, or multiple inputs, for setting targets.

It is clear from the results that the majority of DOTs do not follow a scientific process in setting targets. Rather, funding opportunities and constraints play significant roles in determining how ambitious targets will be. The results from this question also reveal that methods for setting targets vary depending on the type of targets being set. For instance, Maryland DOT's overall outcome targets are established by senior leadership while output targets are determined by program managers based on funding levels. Furthermore, benchmarks have been used as a target setting tool for several DOTs. Missouri DOT, for instance, prefers benchmarking between to traditional performance measurement because it has improved their performance relative to other region. This preference is also shared by Texas DOT, which focuses on continuous improvement towards a goal such as 'zero fatality" rather than setting an absolute standard.

7. Top Management and Performance Information

The review of performance data by top management is important to help keep an organization on track with respect to strategic goals and to reflect necessary policy and strategic changes in a timely manner. For instance, Missouri DOT indicated that strategies and actions to improve performance are worked on and implemented continually to show improved results in the next period. Thirty two DOTs responded that top management does review performance data. With the overwhelming majority of these, data is reviewed on a quarterly basis in meetings. However, these meetings might merely include informal reviews of any performance information, regardless of whether they are tied to a strategic framework.

Annual, semi-annual and continuous reviews are also carried out in several DOTs. For instance, in Minnesota DOT, top staff convenes once a year (during the first quarter) to review performance data across the functional areas and make decisions about results. To manage the capital budget, DOT and District top staff meet once a year (3rd Quarter) to review the actual and predicted results of their four- and 10-year program against statewide performance targets for safety, smooth pavements, bridge preservation, and travel speeds. Each prepares a performance-based scenario that identifies total resource needs to meet performance targets, and a fiscally constrained scenario that identifies projects to be built with available revenues. In addition, managers at the division level receive updates of the performance data quarterly.

8. Asset Management

Asset Management is seen as an important program area for state DOTs, as demonstrated by their objectives. This may be due to the increasingly constrained funding situation in transportation, which requires better management of assets to reduce costs in the long run. Twenty-seven state DOTs responded that they have an asset management program in place, while the rest are in the process of developing one or did not respond. Most state DOTs use their asset management programs for monitoring and determining the conditions of highways and bridges. Other areas where it can be used are maintenance, traffic Level of Service and safety. While many DOTs have asset management programs, almost all of these indicate that their asset management programs are not integrated across divisions. For instance, Colorado DOT employs different programs for the three different assets (pavement, bridges, and maintenance) and uses different software for managing each. Top managers allocate resources among the three areas based on their needs relative to performance targets.

It is important to note that most DOTs have realized that an integrated and unified asset management program is beneficial and many have started developing such a program. Vermont Agency of Transportation (VTrans) is one example of an agency that has a well developed asset management and performance based program that really shifts the agency's focus to preservation and maintenance by emphasizing preservation of existing assets rather than the construction of new highways *(20)*. In addition, New Hampshire DOT, together with Vermont and Maine, has a tri-state, collaborative asset management program, demonstrating mature inter-jurisdictional cooperation.

SUMMARY AND CONCLUSIONS

This paper has explored current practices in performance measurement through 1) review of the literature on performance measurement in state DOTs and abroad, and 2) a survey on the current use of performance measurement, on setting targets and on asset management in DOTs.

From the literature review, it can be seen that performance measurement has had a long history of being used in state DOTs. In the last two decades, however, significant development has occurred with movement through a first, second and third generation of performance measurement systems. Today, performance measurement systems in transportation agencies are increasingly more strategically focused, and tied to the long term goals of the organization. Performance measurement is also used in various program areas, such as asset management, and it is being used in other ways such as benchmarking.

Articulation of the relationship between strategic plans, transportation system plans, and performance measurement systems in general is needed *(5)*. Recent efforts to better understand performance targets, however, suggest a promising future of development in the area of performance measurement.

Current DOT practices largely coincide with what would be expected based on the literature review. The survey results show that performance measurement is widely used among DOTs, and many agencies have successfully integrated their performance measurement practice with strategic planning. Several methods of organizing the performance measurement program are used in the US, but the study does not suggest that any one of these methods is best. Furthermore benchmarking is observed to be an important method for setting performance targets, although target setting is still an informal process for some DOTs. Finally, the survey has shown that asset management is being viewed as an important area by most DOTs, although more integrated systems are needed.

These results signify that progress has been made in performance measurement for transportation in the US. However, some significant challenges remain. For instance, target setting practices are less mature in the US than in other countries such as the UK. The NCHRP scan of international practices provides some useful guidelines in this area *(10)*. As agencies seek continued improvement, they can develop more systematic, data-driven targets which also account for stakeholder and public priorities. They can ensure that targets and performance measures are closely linked to their strategic planning processes, and that they are integrated horizontally and vertically throughout the organization. On a strategic level, these developments can aid transportation agencies to be better prepared for the reauthorizing of the federal surface transportation legislation, and agencies will experience benefits such as increased public transparency and accountability as they improve performance measurement practices.

In the future, studies will be needed to follow up on the progress of strategic planning, performance measurement, target setting, and asset management in state DOTs. As methods vary, specific future research could include surveys and case studies to identify best practices that maximize the benefits of performance measurement relative to strategic goals.

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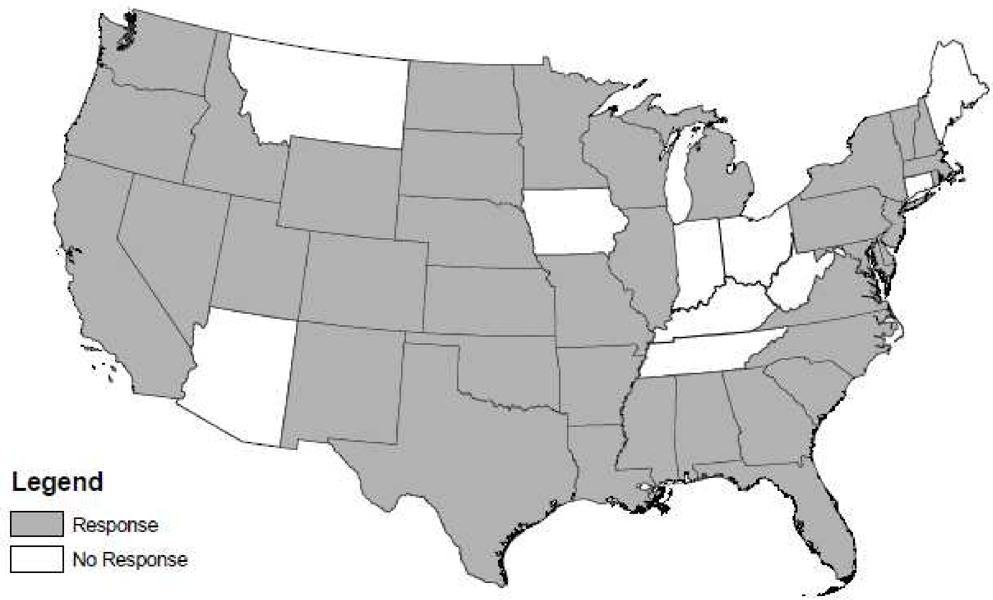

FIGURE 1: State DOTs that responded to survey (Alaska and Hawaii did not respond to the survey).

TABLE 1: DOT Goals and Objectives

Goals	Tally
Transportation System Safety and Security	26
Asset Management and Systems Preservation	22
Transportation System Mobility	14
Employee and Organizational Development	11
Customer Satisfaction	11
Economic Growth and Vitality	11
Environmental Quality and Sensitivity	10
Transportation System Effectiveness and Efficiency	7
Integrated and Multimodal Transportation System	7
Agency Program Service Delivery	7
Better Freight Movement	6
Stewardship	4
Public and Alternative Transportation Expansion and Improvement	4
System Preparedness, Security	4
Quality of life	4
Agency Accountability and Transparency	4
Stakeholder Communication and Cooperation	4
Modal Shift and Auto Trip Reduction	3
Agency Conservation and Business Efficiency	3
Highway Expansion and Capacity Increase	2
Agency Program Funding	2
Employee Innovation	2
Land Use and/or Economic Development Connection	2
Congestion Reduction	2
Accessibility	2
Sustainability	2
Cost Effective Products	2
Agency Leadership	1
Needs vs. Community Wants	1

TABLE 2: Major Functional Divisions within state DOTs

Functional Division	**Tally**
Planning/Programming/Development	28
Operations	21
Design/Engineering	18
Administration	17
Maintenance	14
Finance	11
Construction	10
Public Transportation	10
Aeronautics	7
Safety	5
Motor Vehicles	5
Program Delivery	4

Table 3: How Performance Targets are Developed in DOTs.

How Targets are Development	**Tally**
Upper Management	7
Program Manager	6
Funding Levels	5
Benchmarking	3
Stakeholder Input	3
Consensus	3
Historic Data and/or Past Experience	2
Customer or Public Input	2
Internal Discussion	2
Engineering Judgment	2
Expert Panel	2
Resource Management	1
Alignment with National Goals	1
Engineering Analysis	1
General Accepted Standards	1

Best Practices in Selecting Performance Measures and Standards for Effective Asset Management

APPENDIX 2(b)

Best Practices: Selecting Performance Measures and Targets for Effective Asset Management

Survey Results (State DOTs)

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April 28, 2010
(Revised)

Survey Purpose

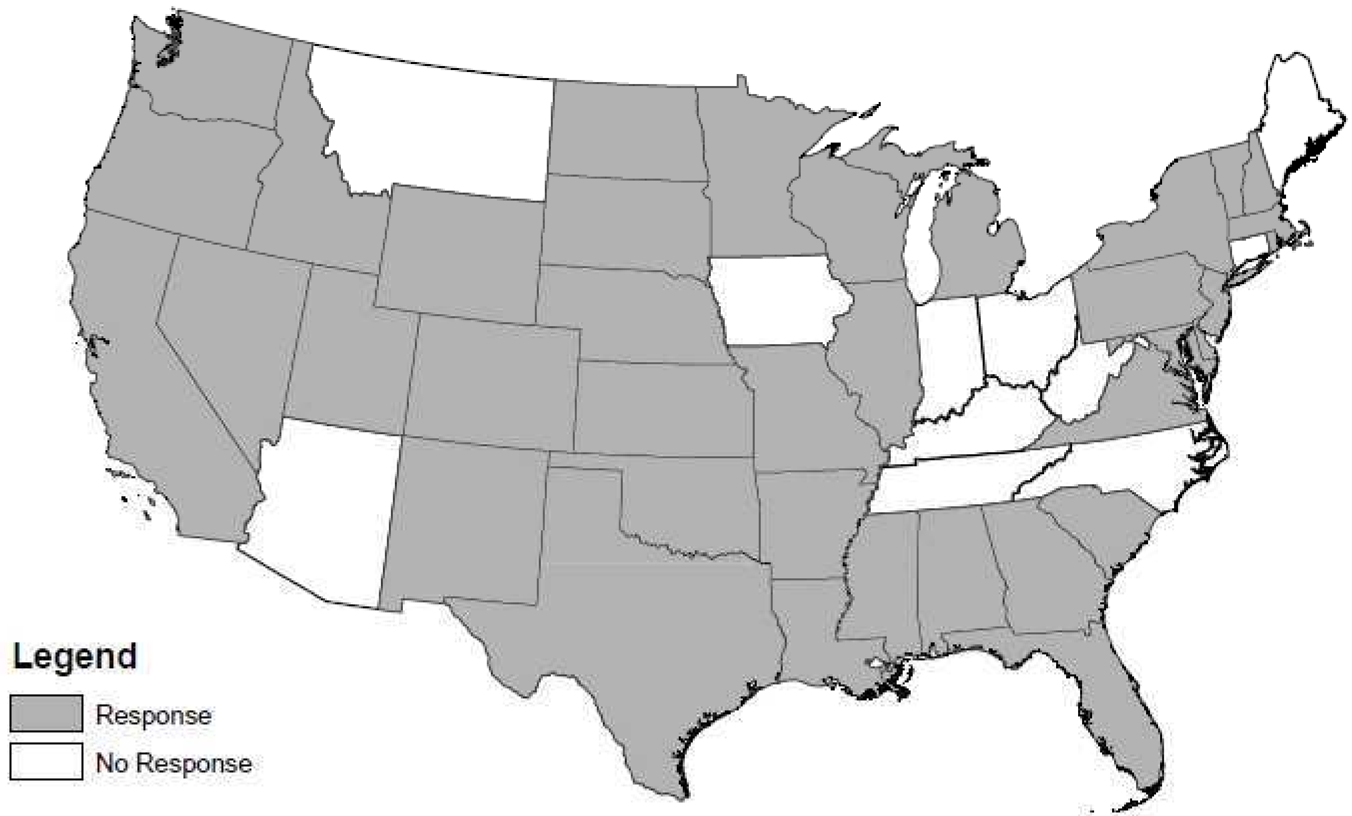
- To identify common approaches for selecting performance measures and targets in state transportation agencies.

Survey Methodology

- Survey was conducted by telephone interviews and online questionnaire.
- Survey took place from September 2009 to February 2010.
- Planning and performance measurement departments were contacted.

Survey Response Rate

39 out of 50 DOTs + Washington DC (76%) responded.



*No responses from Alaska and Hawaii

Survey Results

Organizational Strategic Goals/Objectives

- This question sought to find out whether an agency has a functional strategic plan upon which performance measurement can be based.
- 36 agencies have a strategic plan in place.
- These plans are usually updated annually, bi-annually.
- Several ways agency goals are organized:
  - One tier arrangement
  - Multi tier arrangement (sometimes employing specific models, such as the balanced scorecard)
  - Program area specific (sometimes overlapping)

Examples of PM Models (1)

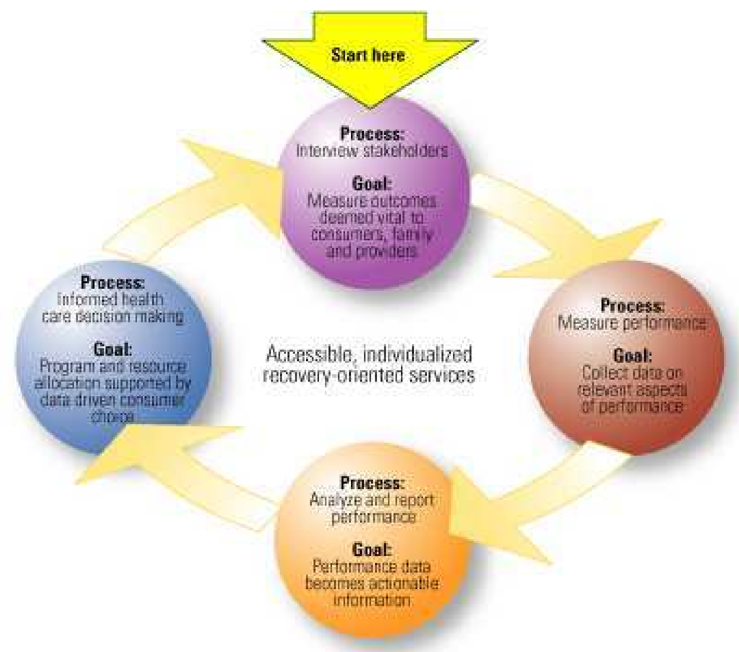
One tier (Virginia DOT)

- Provide a safe, secure and integrated transportation system that reflects the needs throughout the Commonwealth.
- Preserve and manage the existing transportation system through technology and more efficient operations.
- Facilitate the efficient movement of people and goods, expand travel choices, and improve interconnectivity of all transportation modes.
- Improve Virginia's economic vitality, environmental quality, quality of life, and facilitate the coordination of transportation, land use and economic development planning activities.
- Ensure that VDOT is continuously improving its financial accountability, business practices and workforce.
- Strengthen the culture of preparedness across state agencies, their employees and customers.

Examples of PM Models (2)

Multi-tier – Balanced Scorecard (NH DOT)

- Area 1: Employee development
- 1. To hire efficiently.
- 2. To optimize employee health and safety.
- 3. To develop and retain employees.
- Area 2: Performance
- 1. To identify, collaborate and communicate with partners.
- 2. To optimize transportation strategies.
- Area 3: Resource management
- 1. To effectively manage financial resources.
- 2. To effectively manage workforce.
- 3. To protect and enhance the environment.
- Area 4: Customer satisfaction
- 1. To increase customer satisfaction.
- 2. To improve asset conditions.
- 3. To increase mobility.
- 4. To improve system safety and security.



Examples of PM Models (3)

Program Area Specific (NYSDOT)

Area 1: Highway and Bridge Infrastructure

Extend the service life of all highway and bridge-related assets, with priority given to the facilities that are the most critical links in the transportation system serving economic and community needs, through the application of both maintenance and capital investments.

Area 2: Public Transportation System

Ensure the efficient, safe and reliable movement of public transportation users through investments in core public transportation infrastructure, equipment and services which improve connectivity, accessibility, livability, sustainability and modal choice.

Area 3: Statewide Rail System

Subarea 1: High-Speed Intercity Passenger Rail Service

Maintain and improve safe, efficient and reliable intercity passenger rail service through strategic investments in core system infrastructure, including track, train control signals and passenger stations. Facilitate increased service, frequency, reliability and expanded High-Speed Passenger Rail Service.

Subarea 2: Freight Rail and Upstate Ports System

Extend the service life of essential rail and port facilities through public investments that promote asset preservation and the attainment of a State Of Good Repair infrastructure condition. Promote intermodalism, accessibility and mobility and support initiatives to improve service reliability. Improve rail and ports systems' energy efficiency, environmental sustainability and economic competitiveness.

Area 4: Aviation System

Extend the service life of essential aviation facilities through public investments that promote asset preservation and the attainment of State Of Good Repair infrastructure condition and ensure secure facilities. Promote economic development of commercial and general aviation airports and improve the connectivity of the overall transportation network.

Area 5: Multimodal Transportation Mobility

Enhance the movement of people and goods through improvements in system reliability, cost-effective congestion mitigation, network connectivity, accessibility and modal choice.

Area 6: Environmental Sustainability

Support a sustainable environment through improved energy efficiency in the transportation system and the protection and improvement of air and water quality.

Area 7: Multimodal Transportation Safety

Improve safety in all transportation modes, regardless of jurisdiction, to save lives, to reduce the number and severity of personal injuries and to prevent crashes.

DOT Goals and Objectives (1)

Goals	**Tally**
Transportation System Safety and Security	26
Asset Management and Systems Preservation	22
Transportation System Mobility	14
Employee and Organizational Development	11
Customer Satisfaction	11
Economic Growth and Vitality	11
Environmental Quality and Sensitivity	10
Transportation System Effectiveness and Efficiency	7
Integrated and Multimodal Transportation System	7
Agency Program Service Delivery	7
Better Freight Movement	6
Stewardship	4
Public and Alternative Transportation Expansion and Improvement	4
System Preparedness, Security	4

DOT Goals and Objectives (2)

Quality of life	4
Agency Accountability and Transparency	4
Stakeholder Communication and Cooperation	4
Modal Shift and Auto Trip Reduction	3
Agency Conservation and Business Efficiency	3
Highway Expansion and Capacity Increase	2
Agency Program Funding	2
Employee Innovation	2
Land Use and/or Economic Development Connection	2
Congestion Reduction	2
Accessibility	2
Sustainability	2
Cost Effective Products	2
Agency Leadership	1
Agency Needs vs. Community Wants	1

Strategic Planning and Performance Measures

- This question sought to find out the extent to which DOTs are using performance measures to monitor the progress of their strategic plan, and how the performance measures are structured.

- 23 DOTs reported having performance measures tied to strategic goals and objectives.

- Most measures are organized by a multi -level structure.

- Measures can vary from a few to a few hundreds.
  - Oklahoma DOT has 12 measures in 5 goal areas.
  - Maryland DOT has over 400 measures that reflect about 75 objectives.

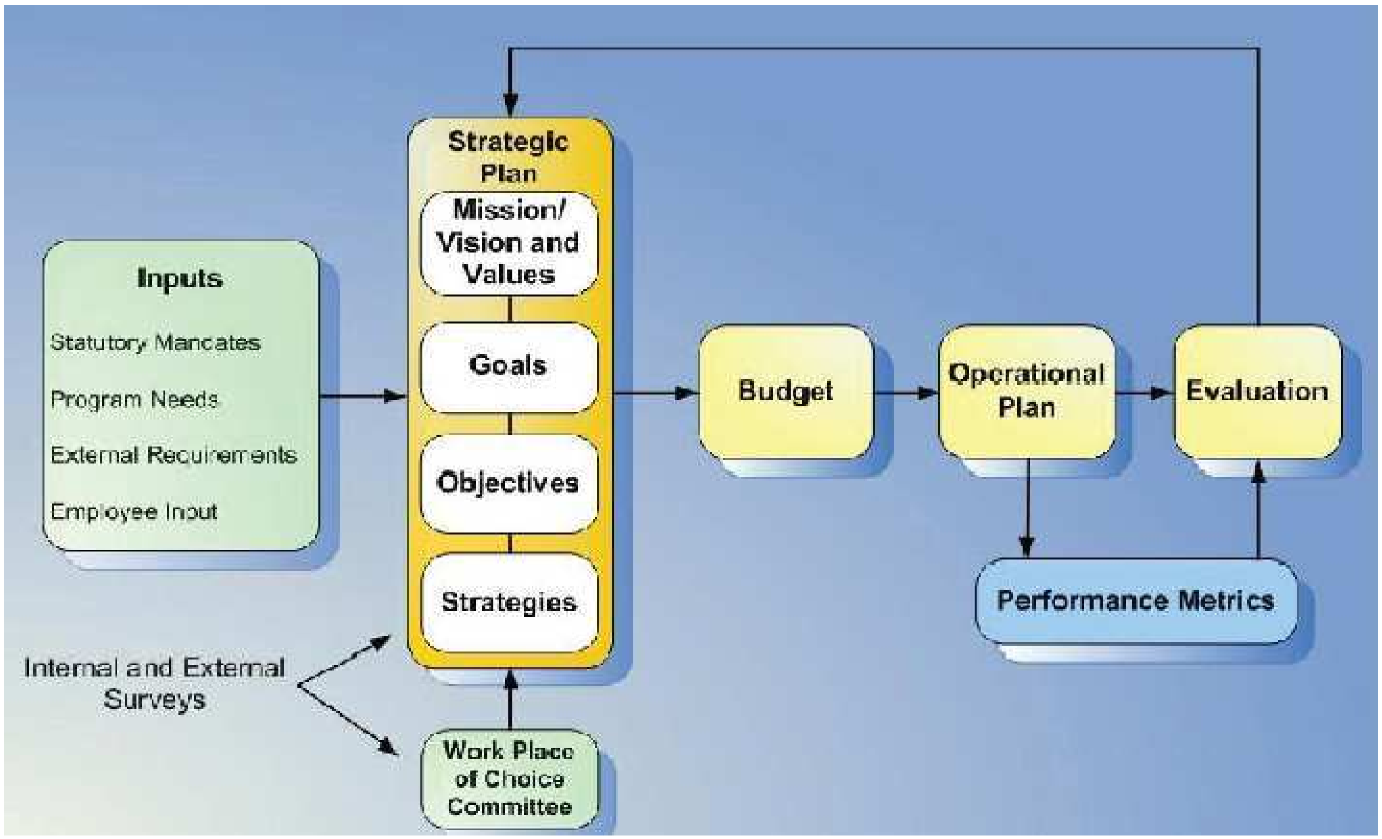
- Benchmarking seen as important way of measurement. e.g. Florida DOT's performance measures answers:
  - How we report on what we are accomplishing
  - How we are being measured by others
  - How we measure ourselves on an ongoing basis

- Several DOTs have well-integrated measurement system. E.g., LA DOTD Performance Indicator Matrix and Missouri DOT Tracker.

Louisiana DOTD Example: Performance Indicator Matrix for a Particular Objective

GOAL	Performance Indicator Matrix Deliver cost-effective products, projects, and services in a timely manner.				
Objective	**Input**	**Output**	**Outcome**	**Efficiency**	**Quality**
Objective 2.1.4: Complete 100% of the required water resources infrastructure condition and serviceability assessments (flood protection systems, dam safety, and water wells) each fiscal year through June 30, 2013.	Number of levee districts having hurricane protection systems that require assessments.	Actual number of completed assessments for levee districts having hurricane protection systems.	Percentage of required levee district assessments completed.	Percentage of all water resource infrastructure conditions and serviceability assessments completed.	Number of levee districts with an overall hurricane inspection system rating of Good, Very Good, or Excellent.
	Number of new registered water wells in the state.	Number of new registered water wells that meet construction standards.	Percentage of new registered water wells that meet construction standards.		
	Actual number of dams scheduled for inspection per year.	Actual number of dams inspected per year.	Percentage of dam safety inspections on schedule.		

Caltrans Strategic Planning Process
(Performance-Based Planning)



Performance Measurement Review

- This question sought to find out how often the performance measures are reviewed.

- Out of the 23 DOTs responding that they had performance measurement:
  - 13 responded that they review their measures annually
  - 4 responded that they review them quarterly
  - 3 responded that they review them biennially
  - 2 responded that they review them semi-annually
  - 1 reviews them when plans are updated

Role of Performance Measures in Divisions

- This question sought to find out the extent to which performance measurements are used in each divisions of the DOT.
- Planning and Programming are the most important functions for DOTs.
- More DOTs indicated having an operations division than a maintenance division.
- DOT functional units are organized in one-tier or two-tier systems.
- Performance measures are mostly used in management and planning, and not in all DOT functions.
- Different models are used for different divisions.

Major Functional Divisions within state DOTs.

Functional Division	**Tally**
Planning/Programming/Development	28
Operations	21
Design/Engineering	18
Administration	17
Maintenance	14
Finance	11
Construction	10
Public Transportation	10
Aeronautics	7
Safety	5
Motor Vehicles	5
Program Delivery	4

Performance Measures and Stakeholders

- This question sought to find out the extent to which performance measures are used to engage external stakeholders.

- 30 DOTs do use performance measures to engage with stakeholders.

- Key stakeholders are the public, legislature, governor and industries.

- Common ways DOTs engage with stakeholders include:
  - Customer Satisfaction Surveys
  - Focus groups
  - Public meetings and hearings
  - Websites

Setting Performance Targets

- This question sought to find out how agencies go about setting performance targets if they do set target levels.

- 31 DOTs do set performance targets.

- The method for target setting varies depending on what the targets are. For example:
  - Maryland DOT's overall outcome targets are established by senior leadership while output targets are determined by program managers based on funding levels.

- Benchmarking with other states is seen as a good way to set targets rather than absolute values.

Ways in which Performance Targets are developed in DOTs

How Targets are Developed	**Tally**
Upper Management	7
Program Manager	6
Funding Levels	5
Benchmarking	3
Stakeholder Input	3
Consensus	3
Historic Data and/or Past Experience	2
Customer or Public Input	2
Internal Discussion	2
Engineering Judgment	2
Expert Panel	2
Resource Management	1
Alignment with National Goals	1
Engineering Analysis	1
General Accepted Standards	1

Top Management Performance Information

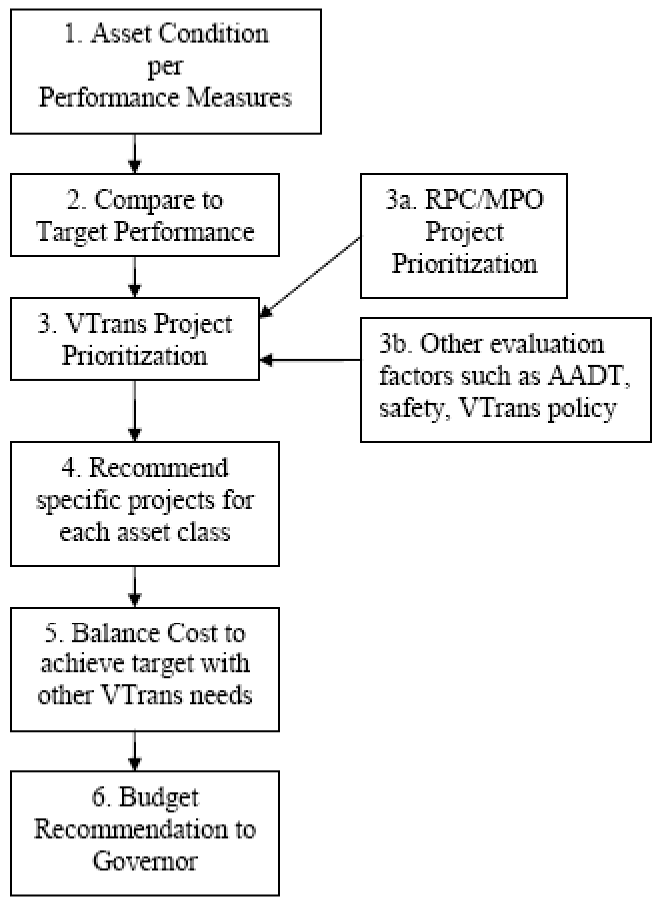
- This question sought to find out how often performance data is reviewed by top management.
- 32 DOTs responded that top management reviews performance information.
- The majority of performance information is reviewed quarterly, followed by annual, semi-annual and continuous reviews.
- Different performance information can be reviewed at different frequencies.

Asset Management

- This question sought to find out whether an agency has an asset management program and if so, to what extent the program is integrated throughout the organization.
- 27 DOTs responded that they have an asset management program in place.
- Most programs are used to monitor condition of highways and bridges.

- AM program is not integrated throughout the whole department. E.g.,
  - Colorado DOT employs different asset management programs for the three different assets (pavement, bridge, maintenance) where different software are used for managing the different assets.
- Few agencies have a well integrated system where their whole planning process is focused on asset management.
  - Vermont AoT has an asset management based program.

Vermont Agency of Transportation Budget Development Process
(Asset performance based strategic plan)



Summary (1)

- The majority of DOTs have a strategic plan in place (36 out of 39 respondents) and more than half of the responding DOTs (23 out 39) reported having performance measures tied to strategic goals and objectives.

- DOTs reported that strategic objectives are largely related to transportation system safety, system preservation and mobility. Agencies also reported to a lesser extent that employee and organizational development, customer satisfaction, economic growth and vitality and environmental quality are included in strategic objectives.

- Over 30% (13) of the responding DOTs reported that they review their performance measures annually.

- About 70% (28) of the responding agencies reported that performance measures are mostly used in management and planning, and not in all DOT functions. About half (21) of the responding DOTs reported that they use performance measures in operations, and slightly under half (18) in design and engineering.

Summary (2)

- Over 75% (30) of the responding DOTs reported that they use performance measures to engage stakeholders.
- About 80% (31) of the responding DOTs reported that they set performance targets, developed largely by upper management and program managers, and also by benchmarking and consensus, considering funding levels and stakeholder input.
- About 80% (31) of the responding agencies reported that top management reviews performance information.
- About 70% (27) of the responding agencies reported that they have an asset management program in place with most programs used to monitor the condition of highways and bridges.

Best Practices in Selecting Performance Measures and Standards for Effective Asset Management

APPENDIX 3

Best Practices in Selecting Performance Measures and Standards

SUMMARY OF BASELINE INTERVIEWS

Submitted to:
Georgia Department of Transportation
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September 20, 2009

Dr. Michael Meyer conducted interviews on the status of Transportation Asset Management (TAM) at Georgia Department of Transportation (GDOT) in March 2009. The objective was to assess the status of TAM at GDOT and also determine what top management considered as key issues for advancing TAM at GDOT. Dr. Meyer interviewed selected officials including Mr. David Crim and Mr. Steve Henry. Below is a general summary of the results of the interviews.

- In general, several officials felt that GDOT has a very good asset management program, although it was not a comprehensive definition of an asset management program. Their sense was that each office has good data and uses it to prioritize needs, but most of the asset management efforts are office-specific. For example, the maintenance office is responsible for the pavement management system, signs and markings, etc.; the bridge office is responsible for the bridge management system, and traffic operations is responsible for traffic signals.
- The GDOT Brief Book was not really considered an internal document but rather something that was developed for outside stakeholders. There were no suggestions to improve the Book, nor suggestions of other performance measures that might be useful as part of the GDOT program.
- GDOT's pavement management system was used to prioritize the pavement projects that were part of the economic stimulus package. The bridge management system was not used as much because of the need to have ready-to-go projects.
- Those interviewed are generally interested in obtaining a 100% database for condition as cost-effectively as possible. They mentioned the work that Dr. James Tsai is doing for them using video imagery for condition assessment. They also emphasized that it is important to take a ROW-to-ROW line asset management perspective. Some members of management felt very strongly that good asset management can only be done with a full universe of data and not sample data.
- Although there was an understanding of the potential role for asset management in GDOT, it was not clear to those interviewed what steps would be necessary to achieve a more comprehensive approach, if such an approach was desired.
- In responses to a question on the linkage between safety and other management systems, interviewees explained that crash statistics are used in combination with PMS and BMS information to prioritize projects.
- There was interest in knowing what other states are doing in asset management, but a feeling that what works in one state will not necessarily work in another.
- GDOT's management felt that the important thing in Georgia is to get funding flowing once again. Once funding is flowing, GDOT will be able to prioritize investments quite well.

Best Practices in Selecting Performance Measures and Standards for Effective Asset Management

APPENDIX 4

An Inventory of Asset Management Tools at the Georgia Department of Transportation

Prepared for:

Georgia Department of Transportation

Prepared by:

John Patrick O'Har, Graduate Research Assistant

Best Practices in Selecting Performance Measures and Standards for Effective Asset Management

Adjo Amekudzi, Ph.D. (PI)/Michael Meyer, Ph.D., P.E. (Co-PI)

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June 15, 2009

(Revised)

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- Introduction
- AM Tools Currently Available at GDOT
- New Directions for AM at GDOT

Introduction

- 1991 – Congress passes the Intermodal Surface Transportation Efficiency Act (ISTEA)
  - ISTEA mandated state transportation agencies to establish six infrastructure management systems for:
    - Bridges
    - Safety
    - Congestion
    - Public transportation
    - Intermodal facilities
  - Congress failed to provide funding for these mandated infrastructure management systems
  - Mandate repealed in 1995
  - Some states already began developing the infrastructure management systems and continued to use them

Introduction (2)

- 1996 – AASHTO and FHWA co-sponsor a workshop in D.C. “Advancing the State of the Art into the 21st Century Through Public-Private Dialogue”
  - Representatives from Chrysler, Wal-Mart, GTE Conrail, public utilities
  - Principles, practices, and tools of good AM that existed in private organizations could also apply to public organizations
- 1997 – 2nd workshop at Rensselaer Polytechnic Institute’s Center for Infrastructure and Transportation Studies
  - Practices, processes, and tools of AM as they apply to state DOTs further examined
- 1999 – During a reorganization effort FHWA creates Office of Asset Management

Introduction (3)

- 1999 – Government Accounting and Standards Board issues Statement No. 34
  - GASB 34 requires government agencies to report their capital assets using a historical cost and depreciation approach OR using a modified approach
  - Modified approach requires government agencies to use some sort of asset management process
- 1999 – National Conference on TAM in Scottsdale, Arizona
  - Peer exchange between state DOTs
- 2001 – 4th Conference in Madison, WI
  - "Taking the Next Step"

Introduction (4)

- 2003 – 5th Conference in Atlanta and Seattle
  - “Moving From Theory to Practice”
- 2005 – 6th Conference in Kansas City
  - “Making Asset Management Work in Your Organization”
- 2007 – 7th Conference in New Orleans
  - “New Directions in Asset Management and Economic Analysis”
- 2009 – 8th National Conference on TAM in Portland from October 19-21
  - “Putting the Asset Management Pieces Together”

Introduction (5)

- AASHTO Standing Committee on Asset Management definition of TAM:
  - “A strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well defined objectives”

AM Tools at GDOT

Tool	Highway Maintenance Management System (HMMS)
What does the tool do?	Allows GDOT to track the daily work of maintenance crews throughout the state; assimilate outstanding work on roads from inspections; allows the department to develop a work program for tracking equipment costs, labor costs, and material costs
What data does this tool use?	Biannual drainage reports, condition assessment of pipe, location of signs and pipes (coordinate info), and data from inspections (guardrail, pavement, vegetation, etc. – no coordinate info)
Which unit(s) use this tool?	Maintenance managers throughout the area and district maintenance offices
How are the results used?	To develop an annual needs based budget; an annual work program; determine the condition of pipe systems; compare actual and estimated costs with budget office costs

AM Tools at GDOT (2)

Tool	Pavement Condition Evaluation System (PACES)
What does the tool do?	A pavement condition assessment survey that rates every mile of every road each year
What data does this tool use?	Condition evaluations of roadway (asphalt and concrete)
Which unit(s) use this tool?	Area and district maintenance offices; Office of Materials and Research; data output from this tool feeds into the Georgia Pavement Management System (GPMS)
How are the results used?	To determine the overall condition of roadway; determine what work needs to be done (i.e. crack sealing, resurfacing); predict the future condition of roadway (i.e. LOS of roadway) with available funds; determine the cost of the work that needs to be done

AM Tools at GDOT (3)

Tool	Pipe Inventory
What does the tool do?	A module of the HMMS; provides a condition assessment of pipe
What data does this tool use?	Data from physical inspections of pipe – tracked with a coordinate system
Which unit(s) use this tool?	Area and district maintenance offices
How are the results used?	To determine what work needs to be done on each line of pipe

AM Tools at GDOT (4)

Tool	Highway Performance Monitoring System (HPMS)
What does the tool do?	Mandated by the FHWA to provide the department's road inventory data; sample based system consisting of 98 data items; provides a variety of data (roughness data, traffic data, AADT, etc.)
What data does this tool use?	Some of the data used include performance data, traffic counts, percent trucks, physical road data (i.e. number of lanes), etc.
Which unit(s) use this tool?	Not used much within GDOT; the department has its own road inventory database
How are the results used?	Used by the federal government in allocating funds; other data items from this tool are used within the department

AM Tools at GDOT (5)

Tool	Life Cycle Cost Analysis Tool (LCCA)
What does the tool do?	Gives a comparison of life cycle costs for different pavement types
What data does this tool use?	Quantities of materials, length of a project, unit costs, maintenance costs, time frames
Which unit(s) use this tool?	Pavement management branch
How are the results used?	Making decisions on pavement type; deciding between reconstruction and rehabilitation

AM Tools at GDOT (6)

Tool	Bridge Information Management System (BIMS)
What does the tool do?	Collects input data from bridge inspections; allows the department to retrieve certain information without going through paperwork; separate from the federally required National Bridge Inventory (NBI); collects more data than the federal government requires
What data does this tool use?	Bridge serial number, location number (latitude and longitude), rating system (0 to 9), sufficiency data (federal requirement); bridge inspection data – bridges inspected every 2 years, data gets reviewed, entered into a master database, data from previous years archived
Which unit(s) use this tool?	Bridge maintenance unit, Office of Transportation Data, upper management (for planning)
How are the results used?	Federal reporting requirements for the NBI; generating deficiency reports; input data for HMMS; determining necessary repairs; routing (vertical clearance and load requirements for oversize/overweight loads); budgeting and funding decisions

AM Tools at GDOT (7)

Tool	Benefit/Cost Tool (B/C)
What does the tool do?	Part of the project prioritization process; assigns projects a score
What data does this tool use?	Overall cost of a project (design, construction, etc.); benefits (time savings through a corridor, fuel cost); safety benefits; $ values based on national average values (commercial vs. non-commercial)
Which unit(s) use this tool?	Planning office, preconstruction office, and traffic operations office
How are the results used?	A piece of the decision-making process; everything is not based on the B/C ratio

AM Tools at GDOT (8)

- Signal System
  - Inventory of signals is maintained
  - Current inventory is not very accurate
- IT Department had a program called remedy
  - Designed to advise the department about upgrades and provide a responsive and preventative maintenance program
  - Program is not completed
- Department is in the process of upgrading the database of controllers to a new platform (SIEMENS 2070 platform)
  - 6,000 of 8,000 controllers have been upgraded
- Signals are maintained by individual districts, many of which maintain individual databases
  - Databases are strictly route identifiable and intersection identifiable (no coordinate data); only inclusive of signals on the state route system

AM Tools at GDOT (9)

- Intermodal
  - No comprehensive tools or databases for intermodal assets
  - No financial resources available
- Multimodal Transportation Planning Tool (MTPT)
  - Developed for the department at one point
  - Currently not in use
- Office of General Accounting
  - Some tools, primarily software, that are used to meet the requirements of the modified approach of GASB 34
  - Currently a homegrown tool is used to manage infrastructure assets
  - Agency in the process of implementing fixed asset management software
    - Purchased the Asset 4000 Suite from RAMI
  - Department has special needs
    - 1,000 active projects that are constantly growing and changing, large volume of information, data integration issues, software limitations
  - When to capitalize?

AM Tools at GDOT (10)

- Enterprise GIS Database
  - Enterprise GIS Manager in the process of creating an enterprise GIS Database
- 108 data sets in the database (AADT, crash locations, fatalities, traffic counts, etc.)
  - Many of the data sets are generated through scripts from the business databases
- Current database uses Oracle software and a GSRI spatial database connector
  - 200 users connecting on a regular basis
  - 17,000 users connecting on the web each month
- Enterprise GIS data architecture contains a new server and a new storage method
  - New hardware in place by end of June, then begin to move data onto servers
  - In the future all GIS data could be published as a single kml file – so it could be accessed by open source software
- Currently GDOT GIS data is accessible to the public through the TREX application
  - Not showing all layers
- New technology in development with IT using an ArcGIS server
  - Would allow someone with no GIS knowledge to mark up a map and export it as GIS data (i.e. inspection crews)

New Directions for AM at GDOT

- During the inventory survey employees made suggestions/comments regarding future possibilities of AM at the agency
  - How to relate data from current inspections to the overall condition of the roads?
  - Establish performance criteria for acceptable road conditions
  - Maintain an accurate inventory of GDOT's roads
  - Data integration
  - Establish boundaries of an AM program
  - Need a champion
  - Disconnect between inventorying and condition rating of physical infrastructure assets and the GASB 34 standard

Best Practices in Selecting Performance Measures and Standards for Effective Asset Management

APPENDIX 5(a)

Transportation Asset Management Best Practices at State DOTS: An Update to the Domestic Scan

Prepared for:

Georgia Department of Transportation

Prepared by:

John Patrick O'Har, Graduate Research Assistant

Best Practices in Selecting Performance Measures and Standards for Effective Asset Management

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June 20, 2009

(Revised)

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Florida – Scan Recap

- Florida expects increases in population, employment, and tourism
- Asset Management (AM) helps budgets get approval from state legislature
  - Department's ability to justify state's needs
- System preservation is the number one priority
  - Maintenance needs funded before capacity expansion projects

Florida – Scan Recap (2)

- Strategic Intermodal System (SIS) – concept developed by FDOT to focus resources on the most important transportation projects
  - "…intended to enhance Florida's economic competitiveness"
- No separate AM program or unit – AM considered part of planning, programming, and system maintaining
- Large investments in database support development and management systems that support AM decisions

Florida – Update

- FDOT's Asset Maintenance program – major overhaul in language and system functions
  - Standardized across all 8 districts
- Private contractors used for maintenance
  - Long term contracts – some up to 20 years
- In 2007 asset maintenance monitoring plan put in place – quality control measure
  - A summary sheet takes pass/fail marks and converts them to a score from 0 to 100
  - Minimum acceptable score is 70
  - If a contractor fails 2 inspections in row – looked into being declared non-responsible
- Originally asset maintenance contractors handled hurricane damages
  - For disasters declared federally reimbursable – federal aid $ funneled to contractors through the state
  - Federal government did not like this policy – contractors paid contingent upon federal government giving states $
  - Asset maintenance contractors no longer responsible for hurricane damages

Michigan – Scan Recap

- One of the leading agencies in the country in AM practice
- Michigan law established a statewide Asset Management Council
  - Defined asset management as an "...ongoing process of maintaining, upgrading, and operating physical assets cost-effectively, based on a continuous physical inventory and condition assessment"
- Legislative mandates from the state strong catalyst in AM program

Michigan – Scan Recap (2)

- One of the first states to develop the six management systems required by the Intermodal Surface Transportation Efficiency Act (ISTEA)
- Transportation Management System (TMS) - an "…integrated and automated decision-support tool" that provides the capability to identify conditions, analyze usage patterns, and determine deficiencies of transportation infrastructure
  - Comprehensive inventory of assets
- GPS technology in data collection
  - Working on a single statewide "Framework" or GIS base map

Michigan – Update

- AM website that is very comprehensive
  - Even provides an online interactive tutorial on AM
- For the 2nd time a transportation funding task group was formed
  - Tasked with making a recommendation to the blue ribbon panel for the governor
  - Funds are scarce
- MDOT is expanding AM to non-pavement assets such as guardrails, signposts, lights, and overhead signs
  - Department is rated by roads and bridges
  - Legislature is not interested in signposts

Michigan – Update (2)

- Agency is following the strategic plan from the AM Council
  - Gets three different entities (MDOT representatives, local community leaders, and representatives from the governor's office) together
  - Ensures that the same goals are shared - no dispute over funds
- AM is used through the council on federal-aid system roads
  - Department is looking to expand its use to non federal-aid system roads
- Task group has asked for another council to look at developing an AM program for multimodal assets
  - Lessons learned from the highway AM group can be applied to the new multimodal group

Minnesota – Scan Recap

- MnDOT does not have a separate asset management process or organizational structure
  - Uses a performance based planning and programming process
- Operations perspective for enhancing network performance
  - National leader in ITS, road pricing, travel demand management strategies, and traffic operations
- Largely decentralized
  - 8 regional offices - play an important role in selecting projects
  - Area Transportation Partnerships (ATP) establish local guidelines and priorities

Minnesota – Scan Recap (2)

- System preservation is the most important strategic direction
- Early on in the adoption of an AM process department used the AASHTO Asset Management Self Assessment Guide
- Use of performance based planning in the legislature
  - Shifted the debate from what the DOT was going to build to how the state was going to pay for it
- MnDOT produces a department scorecard
  - Provides top management and key stakeholders with an indication of the progress being made in meeting performance targets

Minnesota – Update

- Scan is still mostly up to date
- Department is beginning to work with other infrastructure assets such as signs, drainage, and signals
- MnDOT is approximately a year and half away from being able to properly forecast its needs

Minnesota – Update (2)

- Work on the 2009-2028 twenty year highway investment plan is nearly complete
  - Plan is identifying needs for preservation, mobility, safety, regional and community improvement, and economic development
  - Preservation is the main focus of the plan

Ohio – Scan Recap

- ODOT has one of the most integrated approaches to AM of any state DOT
  - No AM handbook, unit, or manager in the department
  - AM is a "core value and function" of the organization
- Effective AM is linked to budgeting, employee assessments, project selection, actively used performance measures, and implemented within a guiding policy framework
- Currently primary roads in Ohio are in very good condition – was not the case years ago
  - 1980s - roads were not in good condition
  - Late 1990s - ODOT turned this around with an integrated, comprehensive implementation of AM principles

Ohio – Scan Recap (2)

- Decisions at the department are guided by a set of principles and strategic goals linked to performance measures
- Every 2 years ODOT management updates the system goals and develops a new 10 year system preservation plan
- Citizen poll related to the condition of the road system is conducted every 2 years
- Degree to which managers and employees achieve performance targets is strongly considered in annual evaluations
- Maintenance crews have laptops equipped with GPS, and survey data (guardrail location/condition, pavement drop-off, etc.) are input into the laptop along with location data

Ohio – Update

- Main priority at the department is pursuing a pavement management system
  - In the procurement process – looking at commercial packages
  - Looking for a more robust enterprise pavement management system
- An accurate road inventory is needed to conduct an accurate pavement analysis
- Agency uses a common referencing format that is also used by local agencies – such as counties
  - Local inventories can be entered into the state database

Ohio – Update (2)

- ODOT has changed directors since the domestic scan
  - Performance measures at the department helped institutionalize asset management
- AM is tied into allocating funds and helps make good decisions
- Upper management at the department is concerned with performance on assets
  - Every month a report is generated on the organizational performance index
- Department has pulled back on evaluating employees based on whether or not performance targets have been met
- Currently the department is undergoing a reorganization
  - AM is an important part of this reorganization effort

Oregon – Scan Recap

- ODOT is in the early stages of implementing an AM system
  - AM system and the case study done in Oregon for the domestic scan was not an example of a fully operational AM process
- Strong statewide planning tradition with a long history of state level planning rules guiding individual agency actions
- Priorities for developing corridor plans, transportation system plans, and the STIP are to
  - Protect the existing system
  - Improve efficiency and capacity of existing highway facilities
  - Add capacity to the existing system
  - Add new facilities to the system
- Area Commissions on Transportation (ACTs) - act as advisory boards to ODOT and consist of local elected officials and business, industry, and public advocates

Oregon – Scan Recap (2)

- Gaps in data standards, definitions, and a lack of quality condition data for all asset categories
- ODOT officials have established a vision, mission, and organizational structure to move to "…a fully integrated AM system"
  - Legislatively required performance measures that address assets, the creation of AM teams, and changes in organizational structure and procedure
- Pilot study was conducted at one regional office to help in developing a fully integrated AM system
- Variety of major management systems in place at ODOT - challenge the department faces is that all of the systems are not linked
- Modeling tools are key to making informed policy changes
  - ODOT's economic – land use – transport model is one of the most advanced models of its kind in the U.S.

Oregon – Update

- Department is working on identifying internal business processes that were still broken
- ODOT is looking to improve the information transition between different areas
- Agency has made great strides in improving communication within groups and throughout the state
- Developing a new scoping tool - a web based GIS tool with all available asset information loaded in
- Also developing a system to allow maintenance folks in the field to update the condition of existing assets by submitting a form to change the information

Oregon – Update (2)

- AM helped the Oregon DOT work with the FHWA on implementing a 1R standard for pavement preservation projects as opposed to the 3R standard
  - Asset information and inventories have assisted in ODOT's communication with FHWA
  - More flexibility in spending money so that assets in the worst condition can be addressed first
- Department has a wide variety of databases and is in the process of integrating data
  - First priority in this process is to provide a more comprehensive inventory
  - Eventually the agency wants to have all GIS data cycle to a corporate database
  - Off-the-shelf software - has GIS capabilities and will house all roadway alignment data and asset information in a corporate warehouse

Oregon – Update (3)

- Pilot project mentioned in the domestic scan was completed
  - 80 miles of highway were inventoried
- Tremendous influence on the work plan going forward
  - When engineers think about getting data they think about 150 – 200 data elements
- ODOT developed a concept called basic inventory
  - Collects fewer data elements to keep that data collection process lean
  - Data needs to be consistent
  - Additional data can be collected over time
- ODOT has increased its statewide inventory for certain assets, but there are still some gaps
  - Eventually the agency wants to develop a statewide enterprise database

Utah – Scan Recap

- 5th fastest growing state in the U.S. – growth related pressures on the system
  - A lot of funding for capital improvements but not for system preservation
- UDOT was ahead of most of the country and published a report titled *Good Roads Cost Less* in 1978
  - Early recognition of AM faltered
- Budget levels and performance targets approved by an executive committee, the Transportation Systems Management Team (TRANSMAT), and the Utah Transportation Commission (UTC) at the strategic level.
  - At the strategic level an Asset Management System (AMS) is used to make funding allocation decisions across asset groups
  - At the tactical level separate management systems are designed and implemented for each specific asset
- Began process of developing a comprehensive AM program with the self-assessment survey that is part of the AASHTO TAM Guide

Utah – Scan Recap (2)

- Important component of UDOT's AM system is the way costs and cost uncertainties are incorporated into the analysis
  - Integration of data and analysis is completed at the strategic level with the AMS
  - AMS gives UDOT management the ability to perform scenario analysis
- "Harmonization" - consists of a manual process of examining all the projects that have been selected for investment to determine if projects can be combined or maintenance deferred
- System preservation program is still in an evolutionary stage
  - Developed a hierarchy for funding allocation
  - Provided assurance to state legislators that existing roads are being systematically monitored with cost effective investments

Utah – Update

- The Asset Management System (AMS) for pavements and bridges not yet fully integrated
  - Still pulling condition assessment data from individual databases
  - Each year unit costs, treatment types, and update triggers (conditions that justify treatments) are updated
- As of last year the department hired an outside vendor to collect pavement condition data
  - Challenges in the first year using an outside vendor – Department switched vendors
  - Vendors’ vans have automated distress collection capabilities and are equipped with GPS to provide location data

Utah – Update (2)

- UDOT does not have robust GIS capabilities
- System preservation program is as close to completed as you can get
  - Adjustments are constantly made to road treatments and funding gaps
- “Harmonization” is not really used at the department and is still on the to-do list
- Cross-asset analysis is still done
  - Department has yet to do a sensitivity analysis or a reality check
- Scenario analysis is constantly used
- AM system was in place and is still working
  - Making improvements to the AM tools to make them more useful
- Department is really concentrating on the pavement and bridge model
  - In the future plans to add culverts and other assets

Best Practices in Selecting Performance Measures and Standards for Effective Asset Management

APPENDIX 5(b)

Asset Management
Best Practices/Lessons Learned
Utah/Indiana/Georgia Peer Exchange/Scan

FINAL REPORT

Submitted to:
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INTRODUCTION

This report summarizes the highlights of the Asset Management Best Practices/Lessons Learned Utah-Indiana-Georgia Peer Exchange/Scan, held from August 24 to 26, 2009. The purpose of the Peer Exchange was to provide an opportunity for these states to share best practices and lessons learned from their respective efforts to institute working asset management programs, policies and procedures. The objective was for each participating state to gain practical information leading them to implement the next steps in a maturing Asset Management program. The Peer Exchange was facilitated by the Federal Highway Administration (FHWA), and officials from Georgia Department of Transportation (GDOT) and Indiana Department of Transportation (INDOT) were hosted by the Utah Department of Transportation (UDOT).

The Peer Exchange included the following participants:

UTAH DOT
Ahmed Jaber, Director of Systems Planning & Programming
Tim Rose, Director of Asset Management
Bill Lawrence, Director of Finance
Austin Baysinger, Asset Modeling Engineer
Gary Kuhl, Pavement Management Engineer
Kevin Nichol, Planning Statistics Engineer
Russ Scovil, Pavement Condition Engineer

INDIANA DOT
Brad Steckler, Director of Program Engineering
Dwane Myers, Greenfield District Planning Director

GEORGIA DOT
Georgene Geary, State Materials and Research Engineer
Jane Smith, State Transportation Data Administrator
Mike Clements, State Bridge Maintenance Engineer
Eric Pitts, Assistant State Maintenance Engineer

FHWA
Brain Cawley, Utah ADA
Paul Ziman, Utah Area Engineer
David Unkefer, Indiana Division Engineering Services Team Leader
Dan Keefer, Indiana Division Asset Management Program Manager
Dana Robbins, Georgia Division Technology Applications Team Leader
Francine Shaw-Whitson, Headquarters Asset Management Office, Evaluation and Economic Investment Team Leader

GEORGIA INSTITUTE OF TECHNOLOGY
Adjo Amekudzi, Associate Professor, Transportation Systems Program

> "We get a lot of projects done. We spend a lot of money. But we are not sure we are getting the best value on the dollar."
> *- State DOT Upper-level Manager*

Status of Current Asset Management Programs and Next Steps for Deployment
INDOT, GDOT and FHWA Participants
FHWA Utah Office/8-24-09 (1-2:30 PM)

UDOT

FHWA Utah participants gave an overview of UDOT's Asset Management (AM) program highlighting UDOT's streamlined strategic goals and performance measures, and explaining that all work plans that funnel up through each department must align with one of these goals. The agency put in a lot of effort and time to simplify their original list of goals to four final goals. UDOT's final four goals are:

1. Take care of what we have
2. Make the system work better
3. Improve safety
4. Increase capacity

(www.udot.utah.gov/main/)

FHWA explained that although the Utah Division Office has worked with UDOT to align their programs to allow them to qualify for FHWA funding, UDOT is the driving force behind their AM program. He pointed to a positive response from the Utah State Legislature indicating that UDOT receives $800-900 million per year from their Legislature for highway funding. He emphasized that the drive must come from the DOT leadership. The FHWA puts in about $200 million annually toward highway funding. UDOT has bonding authority to move projects forward. UDOT is currently doing a significant amount of capacity expansion using state funds. Federal funds are going largely toward preservation. The American Recovery and Reinvestment Act (ARRA) has moved forward a backlog of preservation projects. A lot of Utah State funds cannot be applied towards preservation projects. UDOT is working with the State Legislature to elevate the importance of preservation projects, particularly because there is a wave of bridges that are coming due for preservation. FHWA Headquarters explained that several DOT experiences indicate that State Legislatures are more sensitive to the needs and priorities of DOTs when they understand how their decisions affect the State DOT program. FHWA emphasized that it is in the best interest of DOTs to educate their Legislatures on Asset Management. UDOT does a lot of marketing to their state legislators through an annual report that is particularly tailored to these stakeholders. The agency is also transparent to the public, and makes most of their material, including change orders, freely available on the Web. UDOT goes through a project selection process based on engineering, environmental and socioeconomic criteria. The Transportation Commission approves the projects.

> "Asset Management is a continuous journey. It does not end. It is always about improving what you have."
> *-UDOT Director of Systems Planning and Programming*

INDOT

An INDOT official stated that many state DOTs have been struggling with a better way to make investment decisions because resources are drying up and DOTs have to figure out a more efficient way of doing things. INDOT has developed a vision of where they want to be. They do Asset Management and want to take it the next step by making it more structured and quantitative. INDOT uses HERS ST to calculate the economic impacts of projects that have been selected, and would like to refine its use for project selection. They use several analytical tools that are not integrated. There is a lot of data collected and there needs to be QC/QA (i.e., quality control/quality assurance) on the data, as well as better reliability in the use of the data. INDOT found it extremely helpful to go through the Transportation Asset Management Self Assessment Survey with FHWA. Therefore, they have a good idea of their status and where they want to be. INDOT acknowledged that one of the challenges to executing an organized Transportation Asset Management program is the organizational structure of the agency. INDOT has a strong bridge inspection program. Purdue University has been involved in developing code for the bridge management software, dTIMS, (Deighton Total Infrastructure Management System), which is currently being tested. INDOT has a FWD (i.e., falling weight deflectometer) program, and pavement condition data (rutting, IRI) is collected by a contractor, using video. In 2005, INDOT started down the road of good asset management. They had a maintenance section and a pavement section. In 2005, they started a systems section. They emphasized that automation is important. They also emphasized the importance of getting a leader who will champion Transportation Asset Management in order for it to get established. At the same time, there must be a simultaneous building of the culture and structure that will continue to work beyond this champion. The staff needs to be able to demonstrate money savings and demonstrate that the system is getting better over time. FHWA Headquarters indicated that one way to sell Transportation Asset Management is to tie it to the pending Highway Bill. Asset Management will be required, it is just not clear what form it will be in.

GDOT

GDOT discussed their pavement management system, Georgia Pavement Management System (GPAMS), and their Bridge Information Management System (BIMS). They explained that they have several systems, though there is no integrated system for a comprehensive asset management process. Condition data is collected for every state road in Georgia by a team of maintenance engineers who rate the same roads every year. There are 18,100 center line miles of state roads in GA. Three independent visual inspections are done for projects that are recommended for treatment. The visual inspections are heavily resource intensive. There is a friction program. Cores are sometimes done after projects have been selected for preventative maintenance. IRI is not used because it is not sensitive enough to pavement deterioration, especially where the pavement has a low IRI. All inspections done are fed into the Maintenance Management System which is used to build budgets on what work needs to be done. There is currently a lot of deferred maintenance. GDOT aims to maintain 85% or above of all pavements at 70 PACES rating.

Performance prediction models have been developed for each roadway segment. The system supports resource allocation decisions. GA is required by law to allocate resources equitably across their congressional districts. There are 13 congressional districts and seven geographic districts. GPAMS ranks projects based on several criteria and prioritizes across and within congressional and geographic districts. Other maintenance work is prioritized first by safety, and then by other criteria. BIMS is a good bridge inventory system but there are no procedures for prioritizing bridge work. There is a GIS viewer (TREX) that displays project data. There is much data and a desire for more. However, there is duplication in data collection efforts and definitions and terminology are not similar across the different departments. Data integration has yet to occur. Access to data in different departments can be difficult. There needs to be a business data plan and it needs to be top driven. There needs to be leadership in this area.

FHWA Headquarters pointed out that most states have pavement management systems and bridge management systems, but are not using them for resource allocation.

Funding, Budgeting and Finance Issues Meeting (Highlights)
Bill Lawrence, UDOT Director of Finance
UDOT/8-24-09 (3-4 PM)

- UDOT explained their budgeting and financing process. Budgeting is done annually. Budget allocations for the current year were done by matching percentages to the previous year's budget.
- UDOT has a maintenance program (orange book program), rehabilitation program (purple book program) and reconstruction program (blue book program).
- UDOT uses dTIMS as a program development tool and goes in to the Legislature with a defensible budget.
- The original Design-Build contract on I-15 had an asset management element in it which was a key to moving Asset Management forward in UDOT.
- The report "Good Roads Cost Less" helped to transition UDOT culture from worst-first to preservation strategy.
- UDOT's resource allocation occurs within 9 operations and safety programs and not across the programs. The asset management program is largely focused on the pavement preservation program. A bridge preservation program will be added this year.

> "The Self Assessment Tool was tailored to be more applicable to UDOT."
> *-UDOT Director of Systems Planning and Programming*

Leadership, Political, Organizational and Institutional Issues (Highlights)
Mr. Ahmad Jaber, UDOT Director of Systems Planning & Programming
UDOT/8-25-09 (8-9 AM)

- Asset Management is a continuous journey. It does not end. It is always about improving what you have.
- In the mid-90s, new leadership began to look at changing the culture in the Department.
  - They looked at project management.
  - They looked at moving from a heavily centralized to a decentralized operation. (There were areas where it was felt that decentralization would not be efficient, e.g., ROW, structures -- too few people).
  - The I-15 project -- Design-Build -- was seen as an opportunity to implement asset management. There was interest in changing the way business was managed.
  - In ~2001, senior leadership decided to have a workshop on Asset Management. They had a 2-day workshop on the current status of Asset Management in the agency and where to go. They had an opportunity to review the TAM Guide and fill the TAM Self-Assessment Tool to determine where they were and where they would like to go. The Self Assessment Tool was tailored to be more applicable to the Department. A consultant was hired to facilitate the workshop. Asset Management helped the organization to understand where they were (at the time) and where they needed to go.
  - The strategic plan was created prior to Asset Management at UDOT and Asset Management became the tool to implement the strategic plan.

- The Strategic Plan is shared with the Legislature every year. UDOT presents the Strategic Plan to the Legislature (transportation interim committee) every year.

- UDOT educates the Legislature and staff on various issues using Asset Management. For example, with the prevailing budget crunch, UDOT educated both the Legislature and staff on the potential impacts of the budget shortfall. Level 2 roads were not programmed for improvements because of lack of funds. (Level 1 roads have AADT > 2,000 and/or AADT > 500 trucks while level 2 roads have AADT < 2,000 and AADT < 500 trucks). UDOT chose to concentrate their resources on 96% of the VMT. Asset Management is used to educate the Transportation Commission. UDOT officials make recommendations, and the Transportation Commission then decides on the policy for the available funding.

UDOT has developed an Asset Management Implementation Plan -- a roadmap for implementing Asset Management. The implementation plan was developed by the executive leaders of the Headquarters and all four regions.

- UDOT has performance measures on the Web.

- UDOT uses the dTIMS Asset Management model to develop their pavement and bridge preservation plans.

- UDOT has developed an Asset Management Implementation Plan – a roadmap for implementing asset management. The implementation plan was developed by the executive leaders of the Headquarters and all four districts.

- The tension between DOT Headquarters and districts is reduced by having staff who have worked in both places.

- Last year, UDOT decided to hire a new vendor (Fugro-Roadware) to collect some of their pavement management data because they were having problems with data quality with the old vendor.

UDOT Asset Management Overview (Highlights)
Tim Rose, UDOT Director of Asset Management
8-26-09 (9-10AM)

- UDOT has integrated all their systems except the Maintenance Management System, as shown in Figure 1. As they retired their legacy systems, they made sure that their new systems fit into a common framework.
- The integrated system dTIMS gives the following
  - A bridge preservation plan
  - A system (i.e., pavement) preservation plan
  - A system-wide preservation plan for pavements and bridges (Statewide prioritized 20-year plan)
- UDOT is in the process of determining deterioration curves for culverts.
- Data collection is part in house, part contracted out.
- UDOT is working to add a structural number to their pavement model.
- Systems Planning and Programming: There has not been as strong a push to get cross asset tradeoff analysis going because most of the money allocated is allocated to various programs, e.g., preservation versus capacity.
- UDOT tries to make everything transparent. The executive director has been in the position for 7 years.

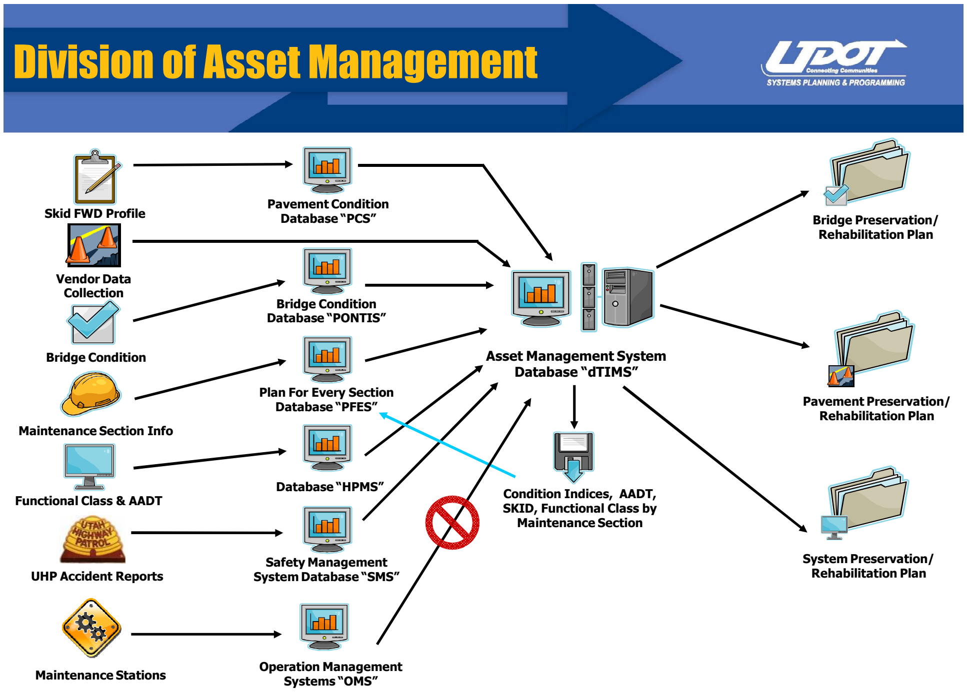

Figure 1: Integration of UDOT's Infrastructure Management Systems (Courtesy of Utah DOT)

- Asset Management is a business decision championed by top leadership. It deals with questions such as the following: Is it the right business approach? Does it serve us as an agency? Is this the best decision for the agency? Does it help us to serve customer needs at lower costs?
- The "Good Roads Cost Less," philosophy, developed in the 70s, still drives most of what UDOT does.
- To implement Asset Management, you have to get buy in from the bottom and the top, and from the regions or districts. One cannot successfully implement Asset Management without understanding and addressing how financial decisions are made and the control that different individuals have. Ultimately there must be a clear command structure for decisions to be made effectively.
- UDOT started using dTIMS in 2002-2003 and only started seeing the benefits really about two years ago.
- UDOT Changes
    - Some painful changes were necessary.
    - These changes included the combination of construction and maintenance folks into one business unit.
    - The EPM (i.e., Electronic Program Management) System began in 1989. The first several years were difficult.
    - Asset Management is marketed to the public using the strategic plan and executive dashboard systems.
    - The key is to start with what you have.
    - The UDOT mission is "connected communities."

Asset Management is a business decision championed by top leadership.

Debriefing
UDOT, GDOT, INDOT, FHWA
August 26, 2009

GDOT
Research
Data

- GDOT keeps records on every public road in Georgia (117,237 centerline miles). The basic road data feeds every application. There are 17,240 locations around Georgia for traffic counts. The intent is to bring in bridges and railroad crossing data. Every road in Georgia has an associated AADT (i.e., Average Annual Daily Traffic). GeorgiaSTARS is a traffic program produced for GA which makes traffic count data available to everyone.
- In the past two years, GDOT has been able to implement a traffic polling system obtained from FDOT. South Carolina is using the same polling system.
- A QC/QA program for traffic has been instituted using FHWA's 10 rules.
- Work is being done to get all the Road Characteristics (RC) data onto relatable linear referencing systems.
- GPAMS gets a once a year dump from the RC (road characteristics) file.

Lessons Learned

- Working with other states tends to be people dependent. When people leave, you have to start over.
- There is duplication of efforts in collecting and maintaining data. Steps are being taken by individual offices to eliminate some of the duplication but there is no Department-wide plan.
- There are multiple opportunities for IT to work better with various divisions within the department. IT applications should be driven by business functions instead of technology.

INDOT

INDOT has a partnership with Purdue University where it pays them to do research on various topics. Professor Labi and a couple of students were commissioned to do research on cross asset tradeoffs. The research is about prioritizing projects once they are selected, in order to get the greatest benefits. The research developed a menu of ways in which INDOT can maximize benefits. Every project has to be converted into a common measure. Each project has eight attributes that can be weighted in importance. The research generates an ordered list of projects. The research report is available on the Purdue University transportation research website.

Asset Management involves systematically identifying and prioritizing the best opportunities for improving agency practice, and implementing these improvements.

FHWA (Resources Available)
Engineering-Economic Analysis Tools available through FHWA:

HERS-ST Workshop (can include an Executive Overview)
- New Mexico is using HERS-ST in their LR Planning
- Oregon is using HERS-ST in their LR Planning and TIP design

REALCOST (Life Cycle Cost Analysis Software)
- Project-based analysis – LCC for 8 alternatives of a project

BCA.NET
- Web-based tool that allows one to look at different benefits and costs of projects

Economic Analysis for Decision Makers
- Helps to identify where one can apply economic analysis in one's planning and programming processes

(www.fhwa.dot.gov/infrastructure/asstmgmt/invest.cfm)

Summary Remarks
UDOT, GDOT, INDOT, FHWA
8/26/09

Strategic
- Identify preservation categories. For example, UDOT has identified Interstate, Level 1 and Level 2 roads to prioritize investments based on AADT, truck traffic and VMT.
- Simple strategic goals are easier to remember and apply throughout the agency
- There is a need for champions to change the culture and institutionalize these changes so that as people move on the system can continue.
- Using a third party to facilitate change has been found effective.
- Holding people accountable for measures is good practice.
- Asset Management is a journey – decide what you want to accomplish looking at both technology and organization.
- The philosophy "Good roads cost less" has been found to be an effective one for building a culture of asset management.
- Developing trust with regions and districts is going to be central to implementing an effective asset management system.

Be realistic about what you can deliver.

- Have performance-based systems in place to meet any funding requirements that come with reauthorization.
- Having formalized processes in writing is necessary to maintain continuity as people move on to other positions and agencies.
- With an effective asset management system, you can demonstrate cost-effectiveness.
- Transparency of processes is important. However, it is also important to let the public know that plans are fluid documents.
- The Transportation Asset Management (TAM) system must be integrated across all classes of work.
- Identify what the opportunity costs are: the dollars saved by doing something and the dollars saved by not doing something. Measure your savings and use them as a guide in the progressive implementation of TAM.
- Get public/customer input into plans, ideas, etc.
- To avoid perverse incentives and negative outcomes, include a measure for cost effectiveness when distributing resources among different districts, and reward cost effectiveness.

Tactical

- Be realistic about what you can deliver.
- Models are only one part of a TAM program. They are important, but only one part.
- Asset Management tools are not black boxes. It is important to document and keep track of and be able to explain what you are doing with your tools.
- Ensure that confidence levels in data and models are good.
- In models that identify a menu of treatments, classes or categories of treatments may work better than detailed treatments because of the type of data being fed into the models.

Georgia

- Bridges are data rich. However there is a need to identify procedures to program bridge work.
- It is important to look at data to understand ways in which duplication can be eliminated. There is also a need to identify areas where efficiencies can be gained: for example, coordinating efforts among different business units.
- Complete self-assessment survey (tailor self assessment tool to GDOT). Make sure to document what occurs during the self assessment. It is helpful to have everyone in the same room. INDOT had over 100 people do the self assessment.

Have performance-based systems in place to meet any funding requirements that come with reauthorization.

Conclusions: Advancing Asset Management Practice at GDOT

The discussions held during the UDOT/INDOT/GDOT Best Practices/Peer Exchange indicate that GDOT will possibly benefit from two main steps to advance Transportation Asset Management in the agency:

1. Conduct a **self assessment exercise**.

   UDOT tailored the self assessment tool to suit their particular needs, opportunities and constraints. Thus, the information obtained from the self assessment exercise was very valuable for developing an Asset Management Implementation Plan well suited to their needs. It would be worthwhile for GDOT to tailor the self assessment tool to their needs. The purpose of the self assessment would be to gather information for an asset management implementation plan, i.e., a plan that identifies the best opportunities for GDOT to make changes to achieve higher levels of cost effectiveness.

2. Develop an **Asset Management Implementation Plan**.

   Based on the discussions held during the Best Practices/Peer Exchange, the Implementation Plan could possibly include some or all of the following:

   - Streamline strategic goals
   - Develop performance measures that align strategic goals with work at all levels of the agency
   - Develop analytical procedures for the bridge database
   - Integrate data
   - Integrate analysis tools

Best Practices in Selecting Performance Measures and Standards for Effective Asset Management

APPENDIX 6

Effects of Performance Uncertainty on Bridge Project Ranking in Transportation Asset Management

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ABSTRACT

Understanding the dominant factors of uncertainty and sensitivity in project prioritization can help refine investment priorities to address high risk and benefits. It can also be used in developing procedures for setting performance standards that are data-driven and transparent. This study reviews risk applications in Transportation Asset Management as they apply to project prioritization, and develops a case study to demonstrate the importance of addressing uncertainty in bridge project ranking procedures. The study uses data from the National Bridge Inventory and applies Multiple Attribute Decision Making (MADM) principles to address performance uncertainty and prioritize bridges for investment. Scenarios with and without uncertainty are compared to demonstrate the impact of incorporating performance uncertainty on project ranking outcomes. The study also demonstrates the impacts of data disaggregation on project ranking outcomes. The results show the importance of considering the effects of performance uncertainty and data aggregation in project ranking.

Keywords: Bridge ranking, performance, uncertainty, risk

INTRODUCTION

Several agencies are incorporating uncertainty in Transportation Asset Management (TAM) (1;2;3;4;5;6) in order to include risk as part of their decision-making criteria. The Office of Infrastructure of the City of Edmonton in Canada, for example, uses risk as a basis for their infrastructure strategy. In addressing their infrastructure gap (i.e., the difference between capital requirements and available funding), Edmonton has developed a risk assessment methodology to help quantify the risk of asset failure and relate this to investment levels (7). Main Roads in Queensland, Australia incorporates risk in bridge maintenance decision making, and England's Department for Transport (DfT) has incorporated risk assessment methods into its project prioritization process (1;2). Using risk in decision making helps agencies to prioritize the highest risks and benefits for investment.

Project prioritization, a key function of Transportation Asset Management or Infrastructure Management Systems, makes use of various project programming approaches. The most basic of these approaches is simple subjective ranking based on engineering judgment. More complex project programming processes use mathematical models to perform more comprehensive analyses, taking into account various factors influencing project selection. Although these models are more complex, and more difficult to develop and interpret, they provide a better solution than more basic subjective project rankings (8). However, because of data limitations, several agencies use subjective or objective ranking methods for project prioritization, coupled with expert engineering judgment. Objective ranking methods may apply Multi Attribute Decision Making (MADM) methods to capture decision criteria such as asset condition, demand, and consequences of failure to prioritize projects for investment. The availability of historic performance data opens the door to addressing performance uncertainty and refining the results of project ranking to identify the highest-risk assets.

This paper presents a case study to highlight the importance of considering performance risk and using disaggregate data in project ranking, where data is available. First, the paper reviews basic concepts of uncertainty and risk, and discusses several examples of project prioritization applications that address uncertainty. Using data from the U.S. National Bridge Inventory (NBI), a scenario analysis is conducted to examine the effects of performance risk and data disaggregation/aggregation on project ranking outcomes, and the implications for investment decision making.

UNCERTAINTY, RISK AND TRANSPORTATION ASSET MANAGEMENT

Uncertainty is an inherent element of the decision-making process when choices are made based on incomplete knowledge (6) or when there is inherent randomness in the system under consideration (9). Subjective uncertainty is a function of the analyst's limited knowledge whereas objective uncertainty comes about from inherent randomness in a system. Subjective uncertainty is reducible with the acquisition of more knowledge, while objective uncertainty is irreducible (9, 10). Uncertainties that can be quantified in terms of their probabilities and severity (or magnitude) of occurrence are referred to as risks.

Risk assessment and risk management are often considered interchangeable, but they are distinct. Risk assessment refers to the process of measuring risks in a quantitative and empirical manner (11;6). Risk management, which usually follows risk assessment, is a qualitative process that involves judging the acceptability of risks (11) within any applicable legal, political, social, economic, environmental, and engineering constructs (6). Risk assessment and risk management are important components of any asset management process (8). Risk is inherent to the transportation planning and development process. Transportation plans include the political risks, such as the adverse impacts of a transportation project on a local community, and funding risks, i.e. the availability of funds. Risk can be considered in any part of the TAM process or during any portion of the life cycle of an asset. Many times it is best to consider risk throughout the entire transportation planning and development process, but other times it is more appropriate to consider risk during the latter stages of the process (8).

Transportation asset management has been defined as a strategic resource allocation framework that allows transportation organizations to manage the condition and performance of transportation infrastructure cost effectively (12). Nearly all transportation agencies practice some degree of TAM. However, not all agencies use the term asset management and there is no universally adopted structure to asset management. Even so, the FHWA has identified key elements of transportation asset management processes, including: goals and policies, asset inventory, condition assessment and performance monitoring, alternatives analysis and program optimization, short and long range plans, program implementation, and performance monitoring (13). Asset management systems provide an effective platform for monitoring the condition, or performance, of infrastructure assets throughout their life-cycle. As such, these TAM systems are an effective platform for incorporating the risks that are associated with transportation infrastructure.

EXAMPLES OF RISK APPLICATIONS IN BRIDGE MANAGEMENT

In light of the collapse of the I-35 W bridge in Minneapolis, Minnesota (14), there has been growing interest in incorporating risk into bridge management systems. Cambridge Systematics, in collaboration with Lloyd's Register, a firm that specializes in risk management in the marine, oil, gas, and transportation sectors, developed a highway bridge risk model for 472,350 U.S. highway bridges, based on National Bridge Inventory (NBI) data. The model used Lloyd's Register's Knowledge Based Asset Integrity (KBAI™) methodology, implemented on Lloyd's Register's asset management platform, Arivu™ (15). Risk is defined as the product of failure and consequence of failure. However, failure is not defined as catastrophic failure, but rather as performance failure, such as bridge service interruption, which includes emergency maintenance or repair, or some form of bridge use restriction. The model then predicts the mean time until a service interruption occurs. A highway bridge risk universe, as shown in Figure 1, can be visualized using the Arivu™ platform (15).

Probability of service interruption is calculated based on three risk units: deck, superstructure, and substructure. The probability that each one of these units would cause a service interruption is calculated; probabilities are then added together to determine the overall probability that a bridge will experience a service interruption in the next year. Consequences of service interruption are determined using a number of bridge characteristics, such as ADT, percentage of trucks, detour distance, public perception, and facility served, that indicate the relative importance of the bridge to the network and users of the system. The consequence of service interruption is dimensionless, which allows the user to define the characteristics used to determine the relative importance of the bridge (15). This model can be used to prioritize bridge investments, minimize risk, and prioritize bridge inspections.

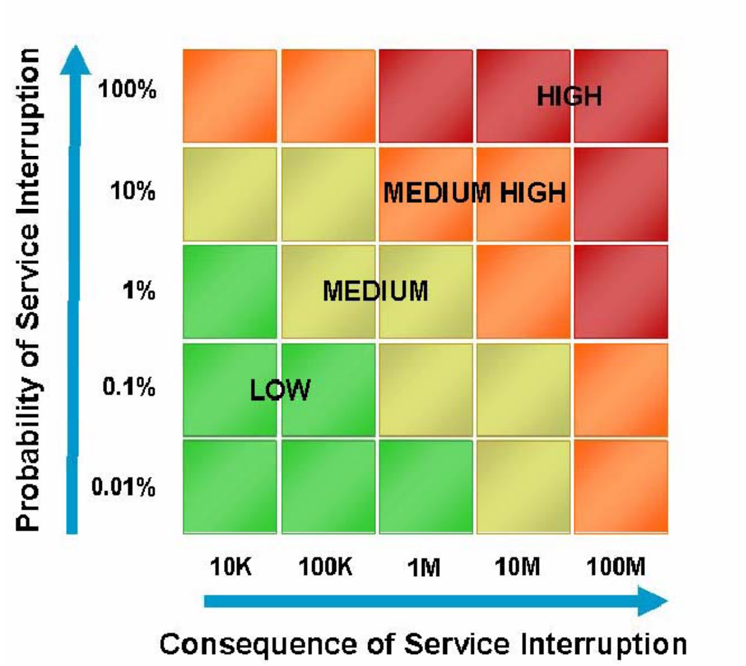

FIGURE 1 Highway bridge risk universe
Source: (15)

In another study, an analysis of past NBI ratings to predict bridge system preservation needs was done for the Louisiana Department of Transportation and Development (LaDOTD) (16). At the time, the LaDOTD was transitioning to the AASHTO's PONTIS bridge management software. PONTIS requires detailed element level bridge inspection data known as Commonly Recognized (CoRe) elements. Collecting element level bridge inspection data takes years; so, an innovative approach was developed using readily available historic NBI data. Deterioration processes of three NBI elements were studied to develop element deterioration models. Bridge preservation plans and cost scenarios were developed using readily available NBI data along with current LaDOTD practice and information (16). This study illustrated the use of NBI data to evaluate long-term performance of bridges under various budget scenarios.

Dabous and Alkass (17) developed a method to rank bridge projects based on MAUT. For capital budgeting needs, decision makers often use rankings to prioritize investment in transportation projects. Several different methods can be used to prioritize bridge projects, including benefit cost ratio (BCR) analysis, California Department of Transportation's Health Index (18), or the FHWA's Sufficiency Rating (SR) formula (19). Based on interviews with bridge engineers and transportation decision makers, MAUT was selected as a prioritization methodology since it allowed decision makers to include multiple and conflicting objectives, incorporating both qualitative and quantitative measurements. Utility functions were developed using the Analytical Hierarchy Process (AHP) and the Eigenvector approach. A case study was developed to demonstrate the potential application of this method (17).

RESEARCH METHODOLOGY

A case study was developed based on NBI data for selected bridges in Georgia. The case study demonstrated the importance of incorporating uncertainty, and of using disaggregate versus aggregate data in prioritization where disaggregate data is available. Furthermore, this case study illustrated the impacts of data quality on investment prioritization, which highlights the importance of investing in high-quality data collection techniques.

The NBI data was obtained from the FHWA website in American Standard Code for Information Interchange (ASCII) format; the NBI data was from 1992 through 2009 (20). Using the record format, also available on the FHWA website (20), and the *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nations Bridges* (19), this ASCII data was converted into Excel format using a script in the SPSS ® statistical analysis software.

The Georgia Department of Transportation (GDOT) uses an internally developed bridge prioritization formula as one of the inputs for allocating funds for bridge investment (21). This bridge prioritization formula is multi-criteria in nature and takes into account a range of factors of bridge condition and performance, as shown in Table 1. GDOT assigns each bridge an overall score based on this formula and using engineering expert judgment. GDOT maintains a proprietary Bridge Information Management System (BIMS) that contains data elements for each state or locally owned bridge in Georgia. The data elements contained in the BIMS are identical to or based on the data elements in the NBI.

TABLE 1 GDOT Bridge Prioritization Formula – Parameter Descriptions and Point Values

Variable	Description	Point Values
HS	Inventory Rating	0, 13, 25, 35
ADT	Average Daily Traffic	1, 3, 6, 10, 15, 21, 27, 35
BYPASS	Bypass/detour length (Also accounts for posting, ADT, and % trucks)	0, 10, 18, 25
BRCOND	Bridge Condition – based on condition of deck, superstructure, and substructure	0, 10, 15, 20, 25, 30, 35, 40
Factor	Weighting Factor – based upon functional classification, i.e., interstate, defense, NHS	1.0, 1.3, 1.5, 1.8
TimbSUB	Timber Substructure	0, 2, 5 (state owned)
TimSUP	Timber Superstructure	0 or 2
TimbDECK	Timber Deck	0 or 2
POST	Bridge Posting	0 to 5
TEMP	Temporary Structure Designation	0 or 2
UND	Underclearance	0, 1, 2, 3, 4, 5, 6
FC	Fracture Critical	0 or 15
SC	Scour Critical	0, 1, 2, 3, 4, 5, 6
HMOD	Inventory Rating less than 15 tons for HMOD truck	0 or 5
Narrow	Based on number of travel lanes, shoulder width, length, and ADT	0 or 30

Source: Adapted from (21)

GDOT is in the process of collecting more detailed element level CoRe data (21). Without more detailed element level data, it is difficult to develop bridge deterioration models, especially at the project level. Sun et. al. (16) developed deterioration matrices and used Markov chains to model bridge deterioration. Although this approach is feasible, it is more applicable at the network level. In their analysis, bridges were grouped into four major categories: concrete, steel, pre-stressed concrete, and timber; deterioration matrices were then developed for each group. Since individual bridges are being ranked using the NBI data, rather than groups of bridges, it was deemed more appropriate to use a methodology that applies Multiple Criteria Decision Making (MCDM) principles, similar to that applied by Dabous and Alkass (17).

In GDOT's bridge prioritization formula (Equation 1), certain variables or attributes are scored and weighted based upon their relative levels of importance. Four attributes in the formula are weighted. This indicates that these attributes, HS, ADT, BYPASS, and BRCOND, are likely considered more important to decision makers at GDOT than the rest of the attributes.

$$Score = \{(HS + ADT + BYPASS + BRCOND) \times Factor\} + TimbSUB + TimbSUP + TimbDECK + POST + TEMP + UND + FC + SC + HMOD + Narrow$$

(Equation 1)

Table 2 shows the attributes used in the prioritization scenarios and their associated NBI data items. Seven bridges were randomly selected for analysis for the case study. The attributes in Table 2 were selected for analysis since the other attributes are relatively much less important for the seven bridges, i.e., these attributes do not contribute to the scoring of a bridge.

TABLE 2 Attributes and Associated NBI Items

Attribute	NBI Data Item (s)
HS	66
ADT	29
BYPASS	19
BRCOND	58 (Deck) 59 (Superstructure) 60 (Substructure)
HISTORIC	Based on: 58, 59, 60
POST	70
TEMP	103
FC	92A
SC	113
Narrow	Based on: 28A (# of lanes) 29 (ADT) 49 (length) 51 (width)

HISTORIC is based on past bridge condition data (NBI items 58, 59, and 60). Although 18 years of historic NBI bridge condition data is not enough to develop a detailed deterioration model, it is sufficient to identify bridges that are deteriorating at a more rapid rate than others. The slopes of the historic bridge condition data were calculated in Microsoft ® Excel based on the linear regression lines for the deck, superstructure, and substructure condition rating data plotted versus time. Average slope is simply the average of the slopes of the condition data plotted against time for the deck, superstructure, and substructure, respectively. Only bridges with negative average slopes, i.e., bridges that worsened in condition rating over time, received an attribute value. The attribute value of these bridges is the absolute value of the slope. The normalized attribute value is based on the largest negative slope from the deterioration gradients. Scenarios that used aggregate HISTORIC data averaged the slopes of the condition ratings for deck, superstructure, and substructure; scenarios that used disaggregate condition rating data did not.

'Narrow' is based on the number of travel lanes on the bridge (NBI item 28A), the bridge's ADT (NBI item 29), the bridge's length (NBI item 49), and the bridge's width (NBI item 51). The bridge's length and width are reported to the nearest tenth of a meter and were converted to feet (19). A bridge is considered narrow if its shoulders are less than 3 feet (assuming lanes are 12 feet wide), the total length of the bridge is greater than 400 feet, and the bridge's ADT is greater than 2000 (21).

FC (NBI item 92A) is coded Y for the first digit if critical features, whose failure would likely cause the bridge or a portion of the bridge to collapse, need special inspections or special emphasis during inspections (19). SC (NBI item 113) identifies the current status of the bridge as it relates to its vulnerability to scour. This item is coded from 0 to 9, T, U, or N. However, only codes 0 to 4 indicate scour criticality, with 0 being the most severe, i.e., a bridge is scour critical and has failed (19).

Ranking Method

Similar to the method developed by Dabous and Alkass (17), the ranking method developed was based on four tiers of elements. The first level consisted of the overall goal of cost-effective resource allocation. The second level consisted of the objectives required to achieve that goal:

- Maximize condition preservation
- Minimize extent of disruption
- Minimize critical failures
- Minimize restrictions

The third level consisted of the criteria or attributes used to evaluate the objectives:

- BRCOND
- HS
- ADT
- BYPASS
- FC
- SC
- TEMP
- Narrow
- Post

The last level consisted of the alternatives or utilities for each bridge. Figure 2 shows the structure of the tiered approach used in this case study. Through the use of an MCDM scoring method that uses the simple additive weighting (SAW) method, each attribute was assigned a weight and a score, varying between 0 and 1. This is achieved by normalizing all scores and weights. The scoring method used for each attribute depended on whether the attribute is a benefit attribute, i.e., higher is better, or a cost attribute, i.e., lower is better. Table 3 shows whether an attribute is a cost benefit attribute.

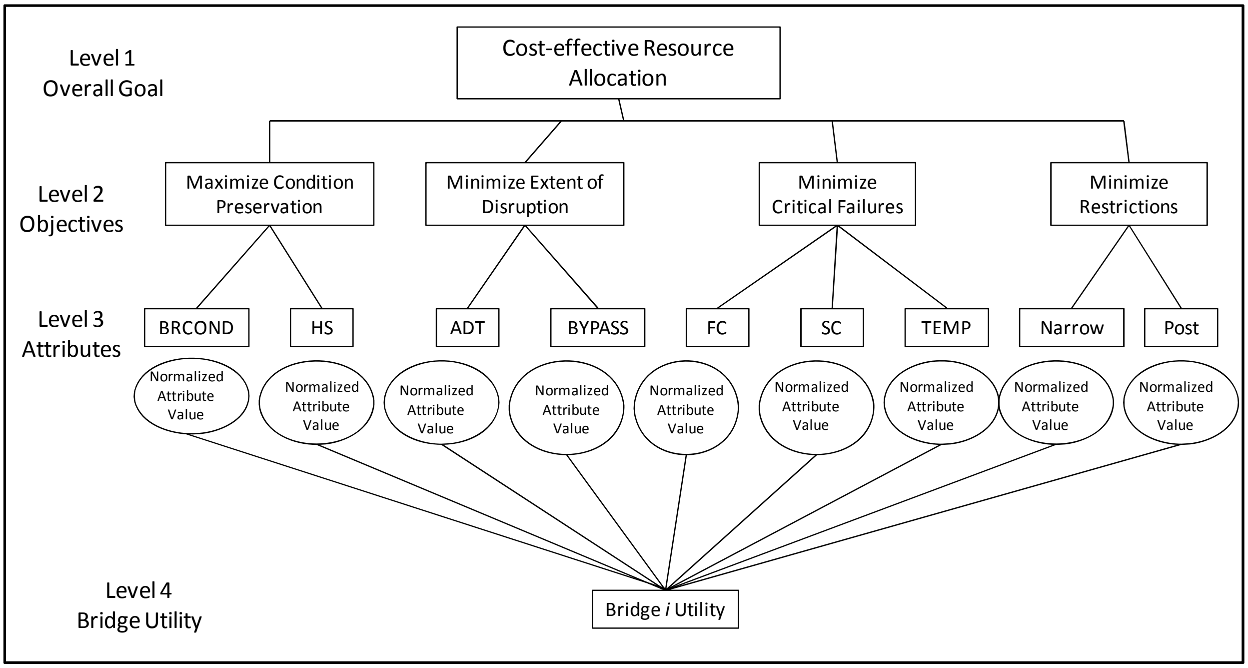

FIGURE 2 Structure of the hierarchy process used in the prioritization method.
Source: Adapted from (17)

Three prioritization scenarios are presented in this case study. A baseline scenario, i.e., scenario 0, incorporates aggregate bridge condition data. The first scenario incorporates disaggregate condition data without past bridge condition data. The second and third scenarios both incorporate uncertainty and performance risk by including past bridge condition. Scenario 2 incorporates aggregate past bridge condition in addition to aggregate snapshot, or current, bridge condition. The third scenario incorporates disaggregate snapshot bridge condition and disaggregate past bridge condition.

TABLE 3 Attribute Identification: Cost or Benefit

Attribute	NBI Data Item (s)
HS	Benefit
ADT	Cost
BYPASS	Cost
BRCOND	Benefit
HISTORIC	Cost
POST	Benefit
TEMP	Cost
FC	Cost
SC	Benefit
Narrow	Cost

Analysis

The weights assigned to each bridge in the ranking method are dependent upon the "Factor" assigned to each bridge in GDOT's formula (21). There are four possible factors: 1.0, 1.3, 1.5, or 1.8. Table 4 shows how the weighting factor is determined for each bridge. Based on the factors, normalized attribute weights on the scale of 0 to 1 were calculated for each scenario.

TABLE 4 Weighting Factor Descriptions

Factor	Description
1.8	Interstate routes
1.5	National Highway System and Defense Highway routes
1.3	Routes with ADT > 10,000
1.0	Routes not in the preceding 3 categories, i.e., factors of 1.8, 1.5, or 1.3

The baseline scenario utilized aggregate data, which was estimated by averaging the condition ratings of the deck, superstructure, and substructure condition ratings. Scenario 1 utilized disaggregate bridge condition data, i.e., bridge condition ratings for the deck, superstructure, and substructure were used individually. Instead of one attribute for bridge condition rating, there are now three, which altered the weights used in scenario 1. The weights used in the baseline scenario and scenario 1 are shown in Table 5.

TABLE 5 Attribute Weights for Baseline Scenario and Scenario 1

Baseline Scenario

Factor of 1.8

HS	ADT	BYPASS	BRCOND	POST	TEMP	FC	SC	Narrow
0.15	0.15	0.15	0.15	0.08	0.08	0.08	0.08	0.08

Factor of 1.5

HS	ADT	BYPASS	BRCOND	POST	TEMP	FC	SC	Narrow
0.14	0.14	0.14	0.14	0.09	0.09	0.09	0.09	0.09

Factor of 1.3

HS	ADT	BYPASS	BRCOND	POST	TEMP	FC	SC	Narrow
0.13	0.13	0.13	0.13	0.1	0.1	0.1	0.1	0.1

Factor of 1

HS	ADT	BYPASS	BRCOND	POST	TEMP	FC	SC	Narrow
0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11

Scenario 1

Factor of 1.8

			BRCOND							
HS	ADT	BYPASS	Deck	Sup	Sub	POST	TEMP	FC	SC	Narrow
0.15	0.15	0.15	0.03	0.06	0.06	0.08	0.08	0.08	0.08	0.08

Factor of 1.5

			BRCOND							
HS	ADT	BYPASS	Deck	Sup	Sub	POST	TEMP	FC	SC	Narrow
0.14	0.14	0.14	0.03	0.05	0.05	0.09	0.09	0.09	0.09	0.09

Factor of 1.3

			BRCOND							
HS	ADT	BYPASS	Deck	Sup	Sub	POST	TEMP	FC	SC	Narrow
0.13	0.13	0.13	0.03	0.05	0.05	0.1	0.1	0.1	0.1	0.1
Factor of 1										
			BRCOND							
HS	ADT	BYPASS	Deck	Sup	Sub	POST	TEMP	FC	SC	Narrow
0.11	0.11	0.11	0.02	0.04	0.04	0.11	0.11	0.11	0.11	0.11

The second scenario incorporated uncertainty; performance risk is included as an attribute that accounts for past bridge condition, HISTORIC. The inclusion of an additional attribute altered the weights used. Only bridges that worsened in condition rating over this time-period, i.e., bridges with negative average slopes, received an attribute value for past bridge condition. The normalized attribute value is based on largest negative slope from the deterioration gradients. For the second scenario, the average slope values, i.e., aggregate data, were used to determine the attribute values. Scenario 3 utilized disaggregate data for snapshot (current) bridge condition rating and also for past bridge condition rating. Once again, disaggregate meant that instead of using the average of deck, superstructure, and substructure, individual attributes were used for deck, superstructure, and substructure. This altered the weights used in scenario 3 and the individual deck, superstructure, and substructure slope values, i.e., disaggregate data, were used to determine the attribute values. Table 6 shows the weights used in scenarios 2 and 3.

TABLE 6 Attribute Weights for Scenarios 2 and 3

Scenario 2									
Factor of 1.8									
HS	ADT	BYP	BRCOND	HISTORIC	POST	TEMP	FC	SC	Narrow
0.13	0.13	0.13	0.13	0.13	0.07	0.07	0.07	0.07	0.07
Factor of 1.5									
HS	ADT	BYP	BRCOND	HISTORIC	POST	TEMP	FC	SC	Narrow
0.12	0.12	0.12	0.12	0.12	0.08	0.08	0.08	0.08	0.08
Factor of 1.3									
HS	ADT	BYP	BRCOND	HISTORIC	POST	TEMP	FC	SC	Narrow
0.11	0.11	0.11	0.11	0.11	0.09	0.09	0.09	0.09	0.09
Factor of 1									
HS	ADT	BYP	BRCOND	HISTORIC	POST	TEMP	FC	SC	Narrow
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Scenario 3													
Factor of 1.8													
			BRCOND			HISTORIC							
HS	ADT	BYP	Deck	Sup	Sub	Deck	Sup	Sub	POST	TEMP	FC	SC	Narrow
0.13	0.13	0.13	0.03	0.05	0.05	0.03	0.1	0.1	0.07	0.07	0.1	0.07	0.07

Factor of 1.5													
			BRCOND			HISTORIC							
HS	ADT	BYP	Deck	Sup	Sub	Deck	Sup	Sub	POST	TEMP	FC	SC	Narrow
0.12	0.12	0.12	0.02	0.05	0.05	0.02	0.1	0.1	0.08	0.08	0.1	0.08	0.08
Factor of 1.3													
			BRCOND			HISTORIC							
HS	ADT	BYP	Deck	Sup	Sub	Deck	Sup	Sub	POST	TEMP	FC	SC	Narrow
0.11	0.11	0.11	0.02	0.05	0.05	0.02	0.1	0.1	0.09	0.09	0.1	0.09	0.09
Factor of 1													
			BRCOND			HISTORIC							
HS	ADT	BYP	Deck	Sup	Sub	Deck	Sup	Sub	POST	TEMP	FC	SC	Narrow
0.1	0.1	0.1	0.02	0.04	0.04	0.02	0	0	0.1	0.1	0.1	0.1	0.1

RESULTS

As mentioned previously, GDOT uses an internally developed prioritization formula as one of the inputs for ranking bridges for investment (21). This formula assigns a score to each bridge that the Department uses, together with engineering expert opinion and other decision support elements, to allocate investments. While the Department's rankings are developed based on point scores, the rankings developed for this case study utilized actual data from the NBI, with the exception of the TEMP and Narrow attributes, which are binary, i.e., the aforementioned conditions exist or do not exist. In the scenarios developed in this case study, actual data are used in the ranking criteria and as such, bridges with lower utility values rank higher, as opposed to scoring with points, in which case bridges with larger point values receive higher overall scores and priority.

The baseline scenario incorporates aggregate snapshot bridge condition data. For illustrative purposes, Table 7 shows the attribute values, their respective normalized values, and each bridge's overall utility for the baseline scenario. The results of the rankings developed in the baseline scenario are shown below in Table 8. Scenario 1 incorporates disaggregate bridge condition data, i.e., bridge condition data for deck, superstructure, and substructure. Table 8 also shows the results of the rankings developed in the first scenario. There are no differences in the utility values or rankings between scenarios 0 and 1. Therefore, scenario 1 results in no differences from the baseline scenario. Even though scenario 1 incorporates disaggregate (deck, superstructure, and substructure) data, the overall weight assigned to the three bridge condition attributes is the same as in scenario 1 (see Table 5).

TABLE 7 Baseline Scenario Attributes, Normalized Attribute Values, and Bridge Utilities

Bridge ID	251-0026-0		117-0019-0		269-0020-0		255-0017-0		185-0010-0		021-0123-0		021-0124-0	
Criteria	Att	Norm Val	Att	Norm Val	Att	Norm Val	Att	Norm Val	Att	Norm Val	Att	Norm Val	Att	Norm Val
HS	12.90	0.5909	18.85	0.8636	12.90	0.5909	12.90	0.5909	12.90	0.5909	21.83	1.0000	21.83	1.0000
ADT	5200	0.4000	15960	0.1303	2080	1.0000	6590	0.3156	3170	0.6562	44430	0.0468	44430	0.0468
BYPASS	13.67	0.0455	6.835	0.0909	22.99	0.0270	9.942	0.0625	16.78	0.0370	0.6214	1.0000	0.6214	1.0000
BRCOND	5	0.6845	5.667	0.7738	4.667	0.6310	7	0.9524	5.667	0.7738	6	0.8214	6.3333	0.8690
POST	3	0.6000	4	0.8000	3	0.6000	3	0.6000	3	0.6000	5	1.0000	5	1.0000
TEMP	2	0.0000	0	1.0000	2	0.0000	2	0.0000	2	0.0000	0	1.0000	0	1.0000
FC	0	1.0000	0	1.0000	0	1.0000	0	1.0000	15	0.0000	0	1.0000	0	1.0000
SC	5	0.5556	9	1.0000	9	1.0000	9	1.0000	9	1.0000	3	0.3333	3	0.3333
Narrow	0	1.0000	30	0.0000	30	0.0000	0	1.0000	30	0.0000	30	0.0000	30	0.0000
Utility	0.52		0.61		0.54		0.59		0.41		0.70		0.70	

TABLE 8 Normalized Rankings Compared to Scenario 1 and 2 Rankings

Bridge ID	Factor Used	Scenario 0 Utility	Scenario 0 Ranking	Scenario 1 Utility	Scenario 1 Ranking
185-0010-0	1	0.41	1	0.41	1
251-0026-0	1.5	0.52	2	0.52	2
269-0020-0	1	0.54	3	0.54	3
255-0017-0	1.5	0.59	4	0.59	4
117-0019-0	1.3	0.61	5	0.61	5
021-0123-0	1.8	0.7	6	0.7	6
021-0124-0	1.8	0.7	6	0.7	6

The second scenario is the first of two scenarios that incorporated uncertainty and performance risk by accounting for past bridge condition. An additional attribute, HISTORIC, was included in scenario 2. Although this changed the weights assigned to each attribute (see Table 6), the factor used, i.e., the relative importance of each attribute, did not change, assuming that past bridge condition is equally as important as the HS, ADT, BYPASS, and BRCOND attributes. The rankings developed in scenarios 2 and 3 are shown in Table 9. All of the utilities and all but one of the rankings are different between scenarios 1 (which has the same rankings as the baseline scenario) and 2. These rankings demonstrate that incorporating past bridge condition, i.e., rate of bridge deterioration, can change the utility of a bridge and therefore change the prioritization.

Scenario 3 also incorporated uncertainty and performance risk by incorporating past bridge condition. However, unlike scenario 2, which also incorporated past bridge condition, scenario 3 incorporated disaggregate snapshot (current) bridge condition as well as disaggregate past bridge condition. Although the weights for the attributes in scenario 3 are different from scenario 2 (see Table 6), the overall weights assigned to the snapshot bridge condition attributes and the past bridge condition attributes are the same as in scenario 2 so that meaningful comparisons can be made between scenarios 2 and 3.

TABLE 9 Normalized Rankings Compared to Scenario 1 and 2 Rankings

Bridge ID	Scenario 0 Ranking	Factor Used	Scenario 2 Utility	Scenario 2 Ranking	Scenario 3 Utility	Scenario 3 Ranking
185-0010-0	1	1	0.47	1	0.47	1
251-0026-0	2	1.5	0.47	1	0.51	3
269-0020-0	3	1	0.49	2	0.5	2
255-0017-0	4	1.5	0.64	5	0.64	5
117-0019-0	5	1.3	0.56	3	0.61	4
021-0123-0	6	1.8	0.63	4	0.69	6
021-0124-0	6	1.8	0.64	5	0.7	7

Disaggregation of both the snapshot and past bridge condition data notably impacts the results of the rankings; all but one of the utilities are different between scenarios 3 and 4 and all but one of the rankings is different. This highlights the importance of incorporating disaggregate data when available. In addition, the result of data disaggregation between scenarios 2 and 3 has a more significant impact than data disaggregation between the baseline scenario and scenario 1, in which there was no difference in utilities or rankings between the scenarios. This demonstrates the significance of incorporating both uncertainty in terms of bridge deterioration (versus deterministic, i.e., snapshot condition data) and disaggregate data.

Table 9 shows that accounting for uncertainty by incorporating bridge deterioration rather than simply treating bridge condition deterministically notably changed the utilities and rankings for the case study bridges. It is also likely that incorporating this uncertainty on the overall bridge prioritization would result in a different outcome. The results of the prioritization outcomes are as good as the input data used for the exercise. Given that past condition data is easily obtainable, it can be incorporated into the prioritization exercise to refine the prioritization results.

CONCLUSIONS

This paper reviewed risk applications in TAM systems as they apply to project prioritization, and developed a case study to prioritize selected bridges using the Multi Attribute Utility Theory (MAUT) technique. Using data from the NBI, three prioritization scenarios were developed for seven bridges in Georgia.

GDOT's internally developed bridge prioritization formula (21) utilized aggregate data in terms of bridge condition. The scenarios developed in this case study, specifically scenario 3, demonstrate the importance of incorporating disaggregate data where it is available. Data disaggregation can impact the utilities and hence the rankings of bridges. In addition, disaggregate data can result in differences in overall bridge prioritization as well. This being the case, where it is available, disaggregate bridge condition data, i.e. data for deck, superstructure, and substructure, should be used in prioritization efforts.

Scenarios 2 and 3 incorporated uncertainty by including past condition data whereas the original GDOT formula does not (21). As opposed to incorporating bridge condition deterministically, i.e., only including current (snapshot) bridge condition data, scenarios 2 and 3 account for performance risk by including attribute(s) that are based on the slopes, i.e. linear regression, of bridge condition data. Incorporating uncertainty in scenarios 2 and 3 significantly altered the utilities and rankings of the selected case study bridges. In scenario 3 when disaggregate snapshot condition data was used in combination with disaggregate past condition data the impacts on the utilities and rankings were particularly noteworthy.

An important component of the MAUT prioritization methodology is decision-maker input. Decision-makers determine the relative importance of certain attributes, influencing the weights of these attributes (see Table 5 and Table 6). A change in the relative importance of certain attributes, the "Factor" used in this case study, results in a change in weight of these attributes. The number of attributes used also influences the weight since all attributes are weighted on a 0 to 1 scale. Although this appears to be subjective, it allows decision-makers flexibility in determining which attributes are more important than others. Given that the goals, objectives, and the criteria used to meet these goals and objectives vary from one transportation agency to another, giving the decision-maker the ability to adjust attribute weights in this type of prioritization effort is one of the strengths of this methodology.

Only seven bridges were selected for the case study developed in this paper. There are over 17,000 bridges in the NBI database in Georgia (20). This being the case, without applying the methodology to all of the bridges (or a representative sample) in Georgia, it is difficult to determine the impact of approaches used in the three scenarios developed on the overall bridge prioritization. The intent of the study however was to examine the potential effects of incorporating performance uncertainty and disaggregate data on project prioritization that would be generally applicable to bridge ranking by various agencies. The fact that there were notable changes in the rankings in multiple scenarios, particularly scenario 3, indicates that it is worth considering performance uncertainty and data disaggregation when prioritizing projects.

The past condition data used in this analysis involved the use of past NBI condition ratings. Past element level bridge inspection data would allow for the development of more accurate deterioration models. The deterioration curves developed in this analysis were based on linear regression. However, many DOTs do not yet have the resources to collect the element level CoRe data that is necessary for more advanced deterioration and forecasting models such as AASHTO's PONTIS. Even so, NBI condition rating data is reported to the FHWA by DOTs on an annual basis, along with other useful data items such as ADT, bypass length, and inventory rating. Since these NBI data items are readily available to many transportation agencies, they can be used to develop prioritization frameworks. In addition, the results of any risk-oriented prioritization framework can be used to allocate funds and set performance standards. For example, bridges with an overall utility value of 0.5 or less, including performance risk, may be considered as the standard trigger for investment.

ACKNOWLEDGEMENT

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Best Practices in Selecting Performance Measures and Standards for Effective Asset Management

APPENDIX 7

TRANSPORTATION PERFORMANCE MANAGEMENT:

A RESOURCE CATALOG

SUBMITTED TO
GEORGIA DEPARTMENT OF TRANSPORTATION

SUBMITTED BY
GEORGIA INSTITUTE OF TECHNOLOGY
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2011

Executive Summary

The field of performance management in transportation is rapidly evolving and many-faceted. Guidance, case studies and tools representing the state of the field are abundant but also spread out across a wide literature. This Performance Management Resource Catalog (the Catalog) compiles and categorizes the various resources available to help State Departments of Transportation develop and improve their performance management programs.

Catalog Organization

The Catalog is organized as collection of seven color-coded sections, each grouping and tabulating resources according to a common theme of performance management. Each section further categorizes resources by topic within its theme, and provides separate sub-sections for guidance, case studies, and tools according to topic. For each topic, resources are presented in a tabular format, including information in four columns: whether the resource offers guidance, case studies, or tools; the topic within the theme; the document where relevant information is found; and the relevant page numbers within that document. This format is summarized in the figure at right.

Thematic Section Organization

	Topic	Reference	Pages
Guidance	Overview	Most Recent	Vol. Pp.
	• Details	Others	Vol. Pp.
	Topic	**Reference**	**Pages**
Cases	Overview	Most Recent	Vol. Pp.
	• Details	Others	Vol. Pp.
	Topic	**Reference**	**Pages**
Tools	Overview	Most Recent	Vol. Pp.
	• Details	Others	Vol. Pp.

A given topic may have many relevant resources listed, in which case the most recent or most relevant resource is listed first. Also, the same resource may appear several times in the Catalog, if it is relevant to multiple topics. This method is used so that practitioners can easily search for resources by topic. Transportation agencies will be able to use the Catalog as a basis for accessing the appropriate resources as they refine their performance management programs.

Thematic Sections:

1. Strategic Planning

Strong performance management programs are linked to strong strategic plans. Specifically, performance measures and targets are the tools with which an agency can track progress toward its strategic goals and objectives. This section lists resources for creating focused strategic plans. Its topics include definitions for performance-based planning, visioning, and how to set goals and objectives.

2. Performance Measures

Appropriate performance measurement will help an agency focus its data collection efforts on collecting the information that is most relevant to tracking progress toward strategic goals. This section table lists resources for the design of simple, measurable, and actionable performance measures. The topics of this section include how to select and organize measures step by step; specific measure formulations for outputs such as infrastructure condition and system efficiency, and outcomes such as accessibility, and environmental, economic and community impacts; and how to deal with "attribution issues," that is the question of how much of a measured outcome can be attributed to agency actions. This is the largest section of the Catalog.

3. Performance Targets

Performance targets provide short-term mile-markers along the road to achieving strategic goals. This section lists resources for setting targets that are both achievable and ambitious, thus helping an agency to make visible progress within a constrained budget.

4. Funds Allocation and Programming

Performance-based resource allocation makes targets achievable; it lends consistency and accountability to agency processes. This table lists resources to help an agency make efficient use of a constrained budget. Topics include innovative funding sources and how to set priorities for project selection.

5. Organizational Structure

The success and longevity of a performance management program depends on an organizational context that supports and sustains it. This section provides resources for creating such a context, dealing with topics of both intra-agency structure and inter-organizational cooperation.

6. Data

High quality performance measures can only be effective with high quality data. This section provides resources for developing robust data collection, analysis and management processes. Topics include how to structure data collection responsibilities, what types of data are needed for different types of measures, and how to link condition data to performance information.

7. Communicating With Stakeholders

A successful performance management program will gradually increase the transparency and accountability of transportation decision making. This is accomplished primarily through the various means of communication with both internal and external stakeholders. Topics in this section include how to build relationships with legislators, how to strengthen trust with customers (system users), and how to increase employee buy-in to the performance management program.

THEME 1: STRATEGIC PLANNING

	Topic Description	Reference	Pages
	What is Performance-based Planning	Hendren and Meyer 2006	1-2 – 1-3
Guidance 	How to Address Federal Planning Regulations	NCHRP Report 551 (Cambridge Systematics 2006)	60-61
	How to Identify Visions and Goals	NCHRP Report 618 (Cambridge Systematics, Inc. et al. 2008)	7-8
	How to Link Planning and Performance Measurement		
	• Long-term Performance Goals	NCHRP Report 551 (Cambridge Systematics 2006)	86-87
	• Performance measures to support short- and long-term plans	NCHRP Report 551 (Cambridge Systematics 2006)	67-69
	• Using Performance Measurement to Inform Policy Development	NCHRP Report 551 (Cambridge Systematics 2006)	62
	Linking Planning and Operations at a State DOT	NCHRP Report 664 (Cambridge Systematics 2010)	28-31

THEME 2: PERFORMANCE MEASURES

	Topic Description	Reference	Pages
	How to select and organize measures, step-by-step		
Guidance	**1.** Evaluate existing measures and identify gaps	NCHRP Report 551 (Cambridge Systematics 2006)	Vol II: 7-8, 11-14
		Strategic Performance Measures for State Departments of Transportation: A Handbook for CEOs and Executives (TransTech Management 2003)	8
	2. Set Selection Criteria		
	• What makes a good measure	NCHRP Report 551 (Cambridge Systematics 2006)	Vol I: 25-27, Vol II: 14-16, 44-52
		Operations-Oriented Performance Measures for Freeway Management Systems (Brydia et al. 2007)	40-41
		Strategic Performance Measures for State Departments of Transportation: A Handbook for CEOs and Executives (TransTech Management 2003)	8
	• How many measures are needed	Ibid. (TransTech Management 2003)	9
	3. Formulate candidate measures and measure categories		
	• What types of measures are needed for different decisions?	NCHRP Report 664 (Cambridge Systematics et al. 2010)	2-6

	o Asset Management	NCHRP Report 551 (Cambridge Systematics 2006)	Vol I: vi, 52-58, 68-69, 74-79, Vol II: 16-18, 52-58
	o System Operations	NCHRP Report 618 (Cambridge Systematics et al. 2008)	11-12
		Operations-Oriented Performance Measures for Freeway Management Systems (Brydia et al. 2007)	35-37
		NCHRP Report 551 (Cambridge Systematics 2006)	12
	o Agency Processes	(AASHTO 2006)	38
	o Environmental Impact		
	▪ Energy and Resource Conservation	Hendren and Meyer 2006	1-6
	▪ Air Quality	(Brydia et al. 2007)	64-73
	o Community Impact	Community Impact Assessment Quick Reference (FHWA 2008-2011)	Chapter 5
	▪ Impacts of Air Quality on Health	(Brydia et al. 2007)	56-64
	• How to align various measurement efforts within and outside of the agency	NCHRP Report 664 (Cambridge Systematics 2010)	20-31
		NCHRP Report 551 (Cambridge Systematics 2006)	Vol II: 8-9, 63-67,

		Measuring Performance Among State DOTS (AASHTO 2006)	34
	4. Assess and select measures	NCHRP Report 551 (Cambridge Systematics 2006)	Vol I: 18-20, 44-54, 74-79
	Topic Description	**Reference**	**Pages**
Cases	**<u>Physical Condition</u>**	Infrastructure Reporting and Asset Management: Best Practices and Opportunities (Amekudzi and McNeil 2008)	
	• Pavement Condition in Minnesota – Compatibility with planning functions	o Xie and Levinson. "The Use of Road Infrastructure Data for Urban Transportation Planning: Issues and Opportunities."	94-95
	• Bridge Health: Visual Inspection vs. Structural Monitoring	o Vanderzee and Wingate. "Structural Health Monitoring for Bridges."	178-182
	• Ohio DOT: Pavement and bridge measures to reduce network deficiencies over time	o Evans L. "Performance Driven Asset Management at a State DOT"	154-156
	<u>System Efficiency</u> • Measuring Network Wide Performance: 21 Case studies	NCHRP Report 664 (Cambridge Systematics 2010)	Appendix B: 40-75
	<u>Agency Processes</u>		

	• A prototype ‘Project Delivery’ comparative performance measure for Delaware, Florida, Missouri, New Mexico, Ohio, Virginia, and Washington State	(AASHTO 2006)	41-52
	Environmental Quality		
	• CalTrans	Hendren and Meyer 2006	2-3
	Topic Description	**Reference**	**Pages**
Tools	**Physical Condition**		
	• Pavements		
	o International Roughness Index	On the Calculation of International Roughness Index from Longitudinal Road Profile (Sayers 1995)	1-12
		AASHTO PP 37-04	1-5
		HPMS Field Manual (FHWA 2010)	4-83 – 4-84
	o Present Serviceability Rating	Ibid. (FHWA 2010)	4-85
	• Bridges o CoRe Elements o Bridge Health Index	AASHTO Commonly-Recognized Bridge Elements (Thompson 2000)	1-13
	• Other Assets		
	System Efficiency		
	• Recommended Minimum Freeway Performance Measures for Traffic Management Center operations	Operations-Oriented Performance Measures for Freeway Management Systems (Brydia et al. 2007)	48-49

	• Quick Reference guide to selected mobility and reliability measures	NCHRP Report 618 (Cambridge Systematics et al. 2008)	14
	• Delay		
	o Incident Duration	Operations-Oriented Performance Measures for Freeway Management Systems (Brydia et al. 2007)	51-52
	o Recurring and Non-recurring delay	Ibid.	52
	o Delay per Traveler (annual hours)	NCHRP Report 618 (Cambridge Systematics et al. 2008)	14, 15, 18, 22, 23, 60,
	o Total Delay (person-minutes)	Ibid.	14, 17, 18, 21, 22, 23, 34, 60
	o Misery Index (MI)	Ibid.	18, 50, 60
	• Mobility		
	o Speed	Operations-Oriented Performance Measures for Freeway Management Systems (Brydia et al. 2007)	52
	o Throughput (Person or Vehicle)	Ibid.	52-53
	o Travel Time: link, reliability, trip	Ibid.	53
	o Travel Time Index (TTI, Unitless)	NCHRP Report 618 (Cambridge Systematics et al. 2008)	14, 15, 16, 18, 20, 22, 23, 60, 62
	o Travel Rate Index (TRI)	Ibid.	15, 60

	o Freight Mobility	Hendren and Meyer 2006	1-6
	• Reliability		
	o Reliability	NCHRP Report 618 (Cambridge Systematics et al. 2008)	11-13
	o Buffer Index (BI, %)	Ibid.	14, 16, 50, 57, 60,
	o Planning Time Index	Ibid.	14, 16, 60, 62
	o Percent Variation	Ibid.	16, 18, 50, 57, 60
	• Congestion		
	o Congested Travel (vehicle-miles or percent)	NCHRP Report 618 (Cambridge Systematics et al. 2008)	14, 17, 18, 22, 23, 60,
	o Congested roadway (miles or percent)	Ibid.	14, 17, 18, 22, 23, 60,
	• Security	Henderen and Meyer 2006	1-6
	• Accessibility	NCHRP Report 551 (Cambridge Systematics 2006)	12
	o As a related to Quality of Life, Livability and Security	Hendren and Meyer 2006	1-6

o Locational Mobility/Reliability – related to equity	NCHRP Report 618 (Cambridge Systematics et al. 2008)	12, 13
o Accessibility Measure (opportunities within acceptable travel time)	NCHRP Report 618 (Cambridge Systematics et al. 2008)	14, 17, 18, 22, 23, 60
<u>Environmental Measures</u>		
• Emissions	(Brydia et al. 2007)	80-85
• Land Use	NCHRP Report 664 (Cambridge Systematics 2010)	38
<u>Community Impacts</u>	Community Impact Assessment Quick Reference (FHWA 2008-2011)	Chapter 6
• System and Network Measures	NCHRP Report 664 (Cambridge Systematics 2010)	38
• Safety	(AASHTO 2006)	39
• Customer Satisfaction o "Road Rallies"	NCHRP Report 660 (Cambridge Systematics 2010)	34
	(Brydia et al. 2007)	45, 47, 50-51
	Hendren and Meyer 2006	1-5
	TransTech Management (2003)	5-6

THEME 3: SETTING TARGETS

	Topic Description	Reference	Pages
Guidance	Step by Step Process	NCHRP Report 666 (Cambridge Systematics 2010)	I-22
		NCHRP Report 551 (Cambridge Systematics 2006)	95; Volume II 29-36
	Attribution Issues– the extent to which system performance can be attributed to agency actions	NCHRP Report 551 (Cambridge Systematics 2006)	69-71
	Structuring Tradeoffs	Ibid.	81
	Setting Targets based on Available funding	Ibid.	81-82
	Addressing GASB Requirements	Ibid.	82-85
	Aligning with Customer Expectations	NCHRP Report 660 (Cambridge Systematics 2010)	34-35
	Travel-Time and Mobility Thresholds and Targets	NCHRP Report 618 (Cambridge Systematics et al. 2008)	19-20
	Forecasting Future Mobility and Reliability Performance	NCHRP Report 618 (Cambridge Systematics et al. 2008)	41-50
	Alternatives Analysis for reducing travel time and delay, and for improving reliability	NCHRP Report 618 (Cambridge Systematics et al. 2008)	51-54
	Using Travel Time information in decision making	NCHRP Report 618 (Cambridge Systematics et al. 2008)	55-68

THEME 4: FUNDS ALLOCATION AND PROGRAMMING

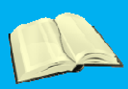
	Topic Description	Reference	Pages
Guidance 	**<u>How to implement programs and projects</u>**		
	• What are the characteristics of a programming process	Urban Transportation Planning (Meyer and Miller 2001)	565-619
	• How to set priorities for project selection		570-587
	o Goals Achievement		571-572
	o Numerical Ratings (Benefit/cost, net present worth, etc)		572
	o Priority Indexes		573-578
	o Programming Evaluation Matrix		578-584
	o Systems Analysis Techniques (Multiobjective, multicriteria optimization)		585-586
	What are some innovative financing/nontraditional funding sources	Urban Transportation Planning (Meyer and Miller 2001)	597-602
	What does a framework for performance-based resource allocation look like	NCHRP Report 666 (Cambridge Systematics 2010)	I-1 – I-3
	What are Public/Private Partnerships	Urban Transportation Planning (Meyer and Miller 2001)	49-51
	How to relate planning to the programming and budgeting process	Urban Transportation Planning (Meyer and Miller 2007)	73

	How to link resource allocation to policy objectives	NCHRP Report 551 (Cambridge Systematics 2006)	61-62
	How to evaluate cost-effectiveness	Urban Transportation Planning (Meyer and Miller 2007)	505-508
	How to determine the timing and amount of future funding	Urban Transportation Planning (Meyer and Miller 2007)	587-597
	What are some funding considerations for target setting	NCHRP Report 551 (Cambridge Systematics 2006)	Volume 2 pp. 32-33
	How to use performance measures for multimodal and multi-strategy investment prioritization	NCHRP Report 664 (Cambridge Systematics 2010)	13-19
	How to evolve financial structure for transportation projects	Urban Transportation Planning (Meyer and Miller 2007)	48-51
	What are some key characteristics of an evaluation in a decision-oriented planning process	Urban Transportation Planning (Meyer and Miller 2007)	486-488
	How to account for uncertainty in evaluation	Urban Transportation Planning (Meyer and Miller 2007)	519-523
	Topic Description	**Reference**	**Pages**
Cases 	Political Linkage: Maryland General Assembly transportation revenue program.	NCHRP Report 551 (Cambridge Systematics 2006)	62
	Portland Oregon: Linking Asset Decisions to Community Values to address a Funding Gap	Bugas-Schramm, P. (In Amekudzi and McNeil 2008)	56-63
	Ohio DOT: Reducing pavement and bridge deficiencies over time.	Evans L. “Performance Driven Asset Management at a State DOT” in Amekudzi and McNeil 2008	154-156
	City of Edmonton, Alberta Canada: Using degradation	Haas, Tighe, Falls and Jeffray. “Long Term	165-171

	modeling to analyze alternative funding scenarios	Performance Modeling Life Cycle Analysis and Investment Planning for Sidewalk Networks” In Amekudzi and McNeil 2008	
	Albany, NY New Visions Planning: Public Participation in Evaluation	Urban Transportation Planning (Meyer and Miller 2007)	530-538
	Urban Corridor Analysis in Salt Lake City: Multimodal Transportation Study	Urban Transportation Planning (Meyer and Miller 2007)	538-546
	Benefit/Cost Analysis of Light Rail in Portland, OR	Urban Transportation Planning (Meyer and Miller 2007)	546-550
	Evaluation of Implemented Programs and Projects (Ex Post Evaluation)	Urban Transportation Planning (Meyer and Miller 2007)	550-556
	Optimization for project programming, incorporating public input (Case Study from Seattle, Local Transportation Tax programming)	to program projects in the era of communicative rationality (Lowry 2010)	91-100
	Topic Description	**Reference**	**Pages**
Tools 	Allocating Resources for Asset Management		
	• Evaluating Investment Levels and Trade-offs	NCHRP Report 545 (Cambridge Systematics 2005)	4-6, 14-21
	• Identifying Needs and Solutions		24-25
	• Evaluating and Comparing Options		28-29
	• AssetManager NT		36-42
	o Testing		49-54
	o Improvements		55-59
	• AssetManager PT		42-48

	o Testing		49-54
	o Improvements		55-59
	Structural Monitoring for Bridges can save money over Visual Inspection	Vanderzee and Wingate. “Structural Health Monitoring for Bridges.” (Amekudzi and McNeil 2008)	178-182
	What are the characteristics of a comprehensive cost-benefit analysis	Urban Transportation Planning (Meyer and Miller 2007)	488-501
	What are single-objective comparative assessment methods	Urban Transportation Planning (Meyer and Miller 2007)	512-516
	What are multi-objective comparative assessment methods	Urban Transportation Planning (Meyer and Miller 2007)	516-519
	What are some concepts of transportation planning economics	Urban Transportation Planning (Meyer and Miller 2007)	508-511

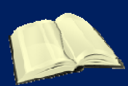
THEME 5: ORGANIZATIONAL ISSUES

	Topic Description	Reference	Pages
 **Guidance**	**<u>Internal Organization and Human Resources</u>**		
	How to obtain executive and senior-level leadership	NCHRP 8-36, Task 47 (Padgette 2006)	2-2 – 2-3
		NCHRP Report 660 (Cambridge Systematics 2010)	28-29, 38
	What are some examples of consolidated and decentralized performance management activities	NCHRP Report 660 (Cambridge Systematics 2010)	39
		NCHRP 8-36, Task 47 (Padgette 2006)	2-3 – 2-5, 2-7 – 2-10
	What are the staffing needs for performance management activities	NCHRP 8-36, Task 47 (Padgette 2006)	2-4 – 2-7
	How to obtain employee buy-in	(Bremmer et al. 2005)	180
		NCHRP Report 660 (Cambridge Systematics 2010)	30-32, 39
		NCHRP 8-36, Task 47 (Padgette 2006)	2-16 – 2-17
	How to ensure employee accountability	(Bremmer et al. 2005)	181
		NCHRP Report 660 (Cambridge Systematics 2010)	29-30, 39
		NCHRP 8-36, Task 47 (Padgette 2006)	2-13 – 2-14
	How to maintain program continuity	NCHRP 8-36, Task 47 (Padgette 2006)	2-15 – 2-16
	How to align performance measures across the agency	NCHRP Report 551 (Cambridge Systematics 2006)	63-66

	How to link overall agency goals and performance measures to staff performance	A CFO's Handbook on Performance Management (Cambridge Systematics 2010)	13-15
	<u>Inter-Organizational Issues</u>		
	How to create peer groups among DOTs for comparative performance measurement	(AASHTO 2006)	4, 26, 30-33
	How to align with other jurisdictions on performance measurement	NCHRP Report 551 (Cambridge Systematics 2006)	66
	How to use performance management to build bridges with state legislators	NCHRP Report 660 (Cambridge Systematics 2010)	39-40
	How to engage public in performance measurement	NCHRP Report 660 (Cambridge Systematics 2010)	40-41
	Topic Description	**Reference**	**Pages**
Cases 	Organization of performance measurement programs within thirteen agencies	NCHRP 8-36, Task 47 (Padgette 2006)	B-1 – B-32
	Linking planning and operations at a State DOT: Oregon Transportation Plan, Washington State Gray Notebook	NCHRP Report 664 (Cambridge Systematics 2010)	Chapter 7
	A prototype 'Project Delivery' comparative performance measure" for Delaware, Florida, Missouri, New Mexico, Ohio, Virginia, and Washington State	(AASHTO 2006)	41-52
	Performance-based Contracts for road maintenance: lessons from New Zealand	Tighe, Manion, Yeaman, Rickards and Haas. "Using Performance Specified Maintenance Contracts: Buyer/Seller Beware" in Amekudzi and McNeil 2008	108-114

	Peer-to-Peer Scenario – Multistate Partnership for System Operations: Mid-Atlantic Operations Study, I-95 Vehicle Probe Study	NCHRP Report 664 (Cambridge Systematics 2010)	Chapter 5
	Megaregional Partnership: San Joaquin Valley Regional Blueprint	NCHRP Report 664 (Cambridge Systematics 2010)	Chapter 6
	Interagency Development of Performance Standards for Managing Materials, Wastes, and Contamination Under Oregon's Bridge Program	(Armstrong & Levine 2006) *Journal of the Transportation Research Board*	176-177
	Topic Description	**Reference**	**Pages**
Tools 	How to design training programs	NCHRP Synthesis 362 (RandolphMorgan Consulting LLC 2006)	29-31
	How to write a Memorandum of Understanding	(Homeland Security SAFECOM)	3-8
	A guide to Best Practices for contract administration	(Office of Federal Procurement Policy 1994)	2-18

THEME 6: DATA

	Topic Description	Reference	Pages
 **Guidance**	**<u>Data Collection</u>**		
	How to structure data collection responsibilities	NCHRP 8-36, Task 47 (Padgette 2006)	2-7 – 2-9
	What to measure: outputs vs. outcomes	Performance Measures for Complete, Green Streets: A Proposal for Urban Arterials in California (MacDonald, Sanders, Anderson 2010)	37-38
	When to measure	Performance Measures for Complete, Green Streets: A Proposal for Urban Arterials in California (MacDonald, Sanders, Anderson 2010)	40
	What types of data are needed		
	• System preservation	NCHRP Report 551 (Cambridge Systematics 2006)	31
	• Operations and management		31
	• Capacity expansion		32
	• Air quality monitoring and measurement	Operations-Oriented Performance Measures for Freeway Management Systems (Byrdia et al. 2007)	73-80
	• Travel time, mobility and reliability measures	NCHRP Report 618 (Cambridge Systematics et al. 2008)	

o Potential sources of travel time, delay, and reliability data		27
o Travel-time data collection methods by required investment		28-29
• Customer-related		
o Measuring customer needs: objective data	NCHRP REPORT 487 (Stein and Sloan 2003)	13-14
o Measuring customer needs: subjective data		14-15
o Customer grouping and segmentation		17-20
o Survey Techniques		21-28
• Non-traditional performance measures		
o Context-sensitive performance measures	NCHRP W69 - Performance Measures for Context Sensitive Solutions: A Guidebook for State DOT's	7-8
▪ Pedestrian safety and walkability	Performance Measures for Complete, Green Streets: A Proposal for Urban Arterials in California (MacDonald, Sanders, Anderson 2010)	22-23, 25-26
▪ Bicyclist safety and bikability	Modeling Capacity Flexibility of Transportation Networks (Chen & Kasikitwiwat 2011)	24, 26-27

▪ Psychological well-being		28
▪ Economic vitality		28-29
▪ Environmental benefits		29-32
o System flexibility		107-109
How to forecast future performance: mobility and reliability	NCHRP Report 618 (Cambridge Systematics et al. 2008)	41-50
<u>Data Management</u>		
How to structure data management responsibilities	NCHRP 8-36, Task 47 (Padgette 2006)	2-7 – 2-9
How to store and manage data	NCHRP 8-36, Task 47 (Padgette 2006)	2-9 – 2-10
<u>Data Analysis</u>		
How to structure data analysis responsibilities	NCHRP 8-36, Task 47 (Padgette 2006)	2-7 – 2-9
Linking Condition Data and Performance Information	Little, R. “A Clinical Approach to Infrastructure Asset Management” in Amekudzi and McNeil 2008	120-122
Air Quality Monitoring and Measurement	(Brydia et al. 2007)	73-80
Assigning Values	Performance Measures for Complete, Green Streets: A Proposal for Urban Arterials in California (MacDonald, Sanders, Anderson 2010)	41-44
Importance of information and Analytic Tools	NCHRP Report 551 (Cambridge Systematics 2006)	43-44

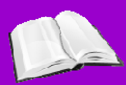
	Topic Description	Reference	Pages
 **Cases**	Integrated Corridor Management (ICM) Projects: Maryland I-270, Minnesota I-394	NCHRP Report 664 (Cambridge Systematics 2010)	49-53
	Identifying Performance Data to support Strategic Goals: Florida DOT Strategic Intermodal System	NCHRP Report 664 (Cambridge Systematics 2010)	59-60
	Combining Subjective and Objective Data: Portland Oregon, Florida DOT	NCHRP REPORT 487 (Stein and Sloan 2003)	44-45, 59-61
	Data Business Plans in Florida	Llort and Golden in Transportation Research Circular Number E-C115 (Hall 2007)	19-21
	Caltrans – Performance Measures Framework for Complete, Green Urban Arterials	Performance Measures for Complete, Green Streets: A Proposal for Urban Arterials in California (MacDonald, Sanders, Anderson 2010)	79-81
	Non-motorized Modes		
	• Oregon DOT Complete Streets	Performance Measures for Complete, Green Streets: A Proposal for Urban Arterials in California (MacDonald, Sanders, Anderson 2010)	45-47
	• Vermont Pedestrian and Bicycle Policy Plan		47-50
	• The Florida Reliability Method		51-52
	City of Edmonton, Alberta Canada: Linking Condition Data to Performance Models	Haas, Tighe, Falls and Jeffray. "Long Term Performance Modeling Life Cycle Analysis and Investment Planning for Sidewalk Networks" In Amekudzi and McNeil 2008	165-171

	The Role of Senior Management in Performance Measurement (CalTrans Data Management for GoCalifornia Plan)	Iwasaki in Transportation Research Circular Number E-C115 (Hall 2007)	22-24

Tools	Topic Description	Reference	Pages
	RAILER- a member of the Engineered Management System (EMS) family of products, for condition reporting and maintenance planning on short-line railroads.	Grussing and Uzarski, “Framework for Short-Line Railroad Track Asset Management and Condition Reporting” in Amekudzi and McNeil 2008	172-176
	Pavement Condition Assessment	A Study of Manual vs. Automated Pavement Condition Surveys (Timm & McQueen 2004)	9-27
	Automated sensing – Automatic Road Analyzer (ARAN)	TransView (2010). “ARAN – Automated Road Analyzer” (April 2, 2011).	<http://www.transview.org/aran/>
	Image Pattern Recognition	Using Image Pattern Recognition Algorithms for Processing Video Log Images to Enhance Roadway Infrastructure Data Collection (Tsai 2009)	7-13, 18-24
	Bridge Health: Visual Inspection vs. Structural Monitoring	Vanderzee and Wingate. “Structural Health Monitoring for Bridges.” (Amekudzi and McNeil 2008)	178-182
	Customer Surveys	NCHRP REPORT 487 (Stein and Sloan 2003)	21-28
	Microsimulation Modeling		
	Data warehouses/data marts	Transportation Research Circular Number E-C115 (Hall 2007)	VDOT Case P64. WSDOT Case P68
	Bi-level Network Capacity Models	Modeling Capacity Flexibility of	109-116

		Transportation Networks (Chen & Kasikitwiwat 2011)	
	Methodology for Measuring Service Quality using Objective and Subjective Indicators	A methodology for evaluating transit service quality based on subjective and objective measures from the passenger's point of view (Eboli & Mazzulla 2011)	174-176
	Geographic Information Systems (GIS)		
	• Alaska DOT HAS-GIS Interface project	Transportation Research Circular Number E-C115 (Hall 2007)	31-32
	• Minnesota DOT Spatial Analysis		52

7. Communicating with Stakeholders

	Topic Description	Reference	Pages
	Stakeholder Engagement		
Guidance 	Building Relationships with Legislators	NCHRP Report 660 (Cambridge Systematics 2010)	39-40
	Visibility and Credibility to the Public	NCHRP Report 660 (Cambridge Systematics 2010)	35-36, 40-41
		NCHRP 8-36, Task 47 (Padgette 2006)	2-13 – 2-14
	Strengthening Trust with Stakeholders and Customers	TransTech Management (2003)	4
	Using Customer Needs to Drive Transportation Decision Making: Chapter 8, Guidelines for Practitioners.	*NCHRP REPORT 487(* Stein and Sloan 2003)	85-101
	Using Customer Opinions to Shape Strategic Management Direction	TransTech Management (2003)	5
	Interests of Different Stakeholders	NCHRP Report 551 (Cambridge Systematics 2006)	Volume 2 P8: Figure 2.
	External and Internal Buy-In	NCHRP Report 551 (Cambridge Systematics 2006)	87-89
	Reporting		
	Challenges with Reporting	(Bremmer et al. 2005)	179-180
	Attribution Issues– the extent to which system performance can be attributed to agency actions	NCHRP Report 551 (Cambridge Systematics 2006)	69-71

	Steps to Keeping Customers Informed	*NCHRP REPORT 487(* Stein and Sloan 2003)	98-101
	Topic Description	**Reference**	**Pages**
Cases 	Community Engagement in Portland Oregon: Linking Asset Decisions to Community Values	Bugas-Schramm, P. (In Amekudzi and McNeil 2008)	56-63
	Case Studies in Customer Analysis in Agency Work, including methods of outreach and application of customer data to performance measures for several DOTs	*NCHRP REPORT 487(* Stein and Sloan 2003)	65-80
	An internet portal for large group participation in transportation programming decisions (Case Study from Seattle, Local Transportation Tax programming)	Lowry 2008	156-165
	Iowa DOT: reporting to agency decision makers	Smadi, O. “Communicating the Results of Integrated Asset Management: Iowa DOT Case Study.” (Amekudzi and McNeil 2008)	86-92
	Example Reporting Methods for Eight DOTs	NCHRP 8-36, Task 47 (Padgette 2006)	2-12 (Table 2.3)
	Topic Description	**Reference**	**Pages**
Tools 	Customer Surveys	*NCHRP REPORT 487(*Stein and Sloan 2003)	21-28
	Dashboards Agency Report Cards Websites Reports	(Bremmer et al. 2005)	179-180

	Reporting on Customer Preferences, Florida DOT	*NCHRP REPORT 487*(Stein and Sloan 2003)	59-61

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