Integrating Extreme Weather Risk into Transportation Asset Management

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Introduction

Extreme weather events such as heat waves, hurricanes, dust storms, and heavy rain pose a variety of serious risks to transportation systems. Not only do these events physically damage assets, they also affect network service and performance. Weather-related risks can be short-term and severe, such as the emergency conditions experienced during a hurricane, or long-term and incremental, such as degradation caused by repeated heat events. In the past year alone, transportation systems across the country have experienced failures due to extreme weather. During the summer of 2012, roads buckled in North Dakota, Wisconsin, Nebraska and North Carolina. In Washington DC, a US Airways plane was stranded on the runway as its wheels sunk into the asphalt. Nor is heat the only culprit. Following Hurricane Katrina, long-term flooding undermined Louisiana road structures. In Minnesota, a car fell into a sinkhole that resulted from underground flooding. In the context of more frequent extreme weather events, state transportation agencies should consider how they can systematically anticipate likely weather-related impacts on their assets and put in place strategies for avoiding significant damage or service disruption.

Extreme Weather Events

Extreme weather events refer to rare weather events that usually cause damage, destruction, or severe economic loss. Extreme weather events include heavy precipitation, a storm surge, flooding, drought, windstorms, extreme heat, and extreme cold (FHWA 2012). Due to the heterogeneity of weather patterns throughout the U.S., specific definitions of "extremes" vary regionally.

Transportation Asset Management is an emerging business strategy that transportation agencies can effectively leverage as a platform for evaluating and addressing extreme weather impacts. On the evaluation side, effective TAM systems collect data (such as asset condition) that are valuable in understanding which assets are vulnerable to changing weather conditions. On the risk mitigation side, transportation agencies with strong TAM systems in place are better prepared to reduce the risks of extreme weather events to the network by targeting vulnerable assets for protection, reinforcement, or rebuilding. State DOTs in the early stages of developing a TAM system could begin by using TAM data to document, analyze, and better understand the impacts of extreme weather on specific assets and on the network as a whole. As agencies increasingly adopt TAM strategies, opportunities exist to integrate consideration of weather risk into TAM objectives, data collection, performance measurement, monitoring, and resource allocation decisions. Over time, the integration of weather and climate information into TAM

Transportation Asset Management

"A strategic approach to managing transportation infrastructure...focusing on business processes for resource allocation and utilization with the objective of better decision making based upon quality information and well-defined objectives" (AASHTO 2011).

will help agencies make targeted investments or allocation decisions to increase the resilience of the network and the resilience of individual assets to extreme weather events. Eventually, an agency with a well-developed TAM in place could evaluate, monitor, and mitigate weather risks simultaneously.

In 2011, the American Association of State Highway and Transportation Officials (AASHTO) published the *Transportation Asset Management Guide: A Focus on Implementation* (referred to hereafter as the *Implementation Guide*). The *Implementation Guide* breaks TAM implementation into 14 main steps and aggregates those steps into topical chapters: set the direction; align the organization; develop the Transportation Asset Management Plan (TAMP); and processes, tools, and systems (see Figure 1). The *Implementation Guide* is not prescriptive and notes that "the [TAM] steps will overlap or may occur simultaneously" (AASHTO 2011). TAM is described as a set of strategies to help transportation agencies make smart investments that minimize life-cycle costs. The first 9 steps of the *Implementation Guide* describe the actions that an agency should take to implement TAM. The last 5 steps discuss the tools, processes, and systems that can help an agency derive maximum benefit from implementing TAM.

The *Implementation Guide* provides ample points of entry for the consideration of extreme weather events in TAM. While it is beyond the scope of this white paper to fully explore how extreme weather events should be analyzed, monitored, and addressed across all aspects of TAM, there are certain processes and tools that stand out as particularly relevant. This paper focuses on these highly relevant TAM processes and tools: articulating goals, setting objectives, developing and monitoring performance metrics, and collecting data. These items fall into Step 1 and Steps 10 through 14 of the TAM 14-step process (see Figure 1). The purpose of this paper is to examine how these elements of TAM provide a mechanism for integrating consideration of extreme weather risk into transportation agency decision making.[1]

The paper is divided into three parts.

- The *TAM, Risk, and Vulnerability* section describes the TAM framework for risk assessment and explores how extreme weather is different from other types of risk.
- The *Integration of Extreme Weather Risk into TAM: Goals, Objectives, and Performance Measures* section describes how consideration of extreme weather risk can be integrated from the beginning of the TAM process into goal setting and development of performance metrics.
- The final section of the paper, *Integration of Extreme Weather Risk into TAM: Service Planning, Life-Cycle Management, and TAM Integration,* discusses in more detail how

[1] Beyond the entry points identified in this paper, it is worth noting that the *Implementation Guide* considers weather events and the associated service disruption explicitly in several sections (for example, see section 5.1.3 Agency Mission Performance Measures and section 6.2 Life-Cycle Asset Management).

consideration of extreme weather events can be integrated into Steps 10 through 14 of the TAM process, with particular attention paid to data collection and management.

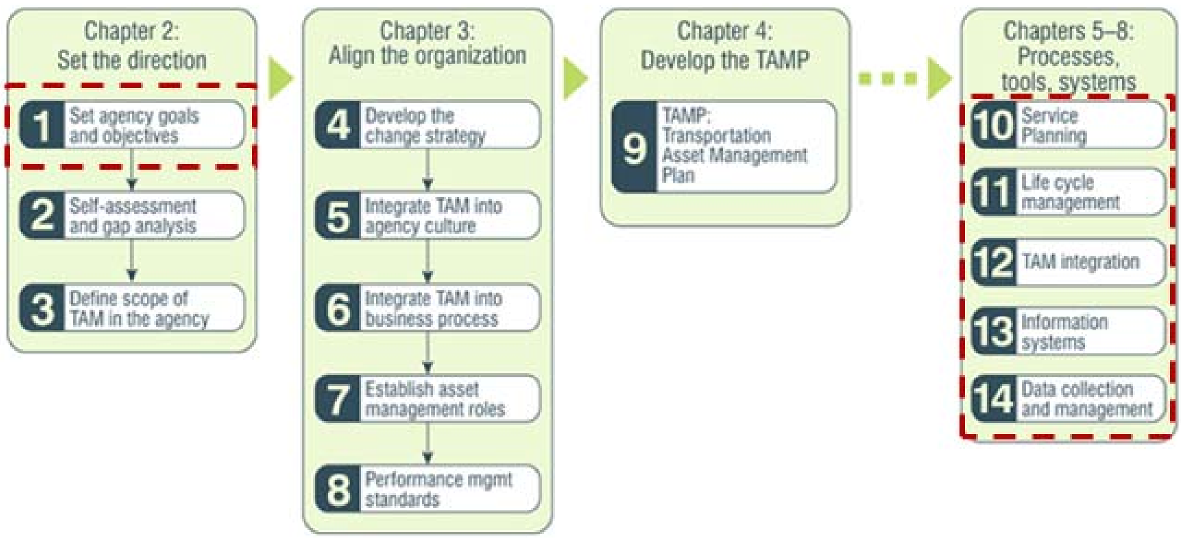

Figure 1: TAM Implementation Steps, AASHTO *Implementation Guide* (2011); red dashed lines indicate areas where extreme weather risk management should principally be integrated into the framework. This paper focuses on these steps.

TAM, Risk, and Vulnerability

TAM Context

Whether monitoring asset conditions or collecting data on road use, state Departments of Transportation (DOTs) rely on data to determine the most appropriate actions for meeting agency goals. Historically, asset management has focused on the physical serviceability of the asset. For example, in the past, asset management systems might have focused on developing and monitoring pavement condition metrics or structure sufficiency ratings. However, the *Implementation Guide* defines TAM as encompassing more than just asset maintenance and preservation. The TAM process follows "a path from the inception of the need for an asset to its creation, operation, maintenance, preservation, replacement, reconstruction, improvement, and possible eventual disposal." Importantly, the guide also notes that TAM should incorporate processes such as risk management and sustainability.

As state DOT officials increasingly focus on network operations, the ability of transportation assets to function at desired performance levels continues to emerge as a critical agency goal and a focus of asset monitoring. TAM has become one of the most important decision support systems in state DOTs. According to the *Implementation Guide*, an agency's asset management approach should address five "core questions":

- What is the current state of my assets?
- What are my required levels of service and performance delivery?
- Which assets are critical to sustained performance delivery?
- What are my best investment strategies for operations, maintenance, replacements, and improvement?
- What is my best long-term funding strategy?

One of the important characteristics of TAM as it relates to extreme weather events is the emphasis on life-cycle costs, considering the costs and benefits of an asset over its entire useful life from project inception to asset removal. Thus, any hazard or stressor that affects the future condition and performance of an asset becomes an important consideration in the timing of rehabilitation and replacement. Effective TAM requires "a history of good data, including knowledge about the assets, their condition, performance, and other characteristics that relate to the life of the asset and its ability to continue to provide reliable, safe service"(AASHTO 2011). The focus on monitoring asset condition, evaluating performance, and data-driven decision making reinforces the relevance of TAM as a platform for mitigating the impacts of extreme weather events on transportation infrastructure.

Defining and Measuring Risk in a TAM Context

Broadly defined, risk refers to the positive or negative effects of uncertainty on agency objectives (FHWA 2012a). In decision theory, it is the product of the probability of a harmful event occurring and its consequence, typically described in monetary terms. In an engineering economics framework, decision makers often compare the magnitude of a risk to the cost of avoiding that risk (e.g., improving, repairing, or replacing the asset). As Figure 2 depicts, risk management is the process of identifying, evaluating, treating, and continuously monitoring risk. For example, the Minnesota DOT (MnDOT)'s risk management program has the following steps: identify and describe risks in a "risk inventory", implement a risk-ranking methodology to prioritize risks, develop an action plan, and monitor the success of risk management efforts. At an enterprise scale, MnDOT has been evaluating budget tradeoffs based on changes in laws, regulations, and standards. During these tradeoff discussions, the agency rated risk levels and evaluated funding effectiveness in order to match funding with high-priority needs.

Figure 2: ISO's risk management framework, Source: FHWA (2012)

Transportation agencies manage many different risks at all organizational levels. For example, at the project level, risks include scheduling delays and changes in project scope. Variability in construction costs, asset degradation over time, and short-term funding allocations are common risks often experienced at the program scale. Finally, at the enterprise level, managers are often concerned with risks such as long-term trends in population growth and the long-term availability of funds. Currently, most state DOTs apply risk management practices to control costs at the project level, but not at the strategic enterprise level (FHWA 2012a). Due to the complexity of existing and emerging risks, the *Implementation Guide* recommends that advanced practitioners of TAM integrate risk management into all steps of the TAM business cycle.

Many of the elements of risk management dovetail closely with TAM. However, while the importance of risk management is clear, few resources exist to help transportation agencies integrate risk management into asset management. The *Implementation Guide* suggests giving facilities a "risk rating" based on the likelihoods of extreme events and the consequences of the event to the asset, including the impact of asset damage on the public. Figure 3 illustrates one example method for rating levels of risk based on qualitative assessments of likelihood and consequence. This type of matrix can facilitate fair comparisons between assets and help justify risk mitigation strategies. Risk ratings can also help agencies forecast the effectiveness of actions in lowering the risk of physical damage and/or the risk of disruption in performing an asset's function. Often, these ratings are based on expert and/or stakeholder input during structured workshops or focus groups. In some cases, risk ratings may be calculated based on more detailed analysis of data. Developing, monitoring, prioritizing, and taking action based on the risk ratings is an example of integrating risk management into each step of TAM.

	Consequence				
Likelihood	Insignificant	Minor	Significant	Major	Catastrophic
Very Rare	Low	Low	Low	Moderate	High
Rare	Low	Low	Moderate	High	High
Seldom	Low	Moderate	Moderate	High	Extreme
Common	Moderate	Moderate	High	Extreme	Extreme
Frequent	Moderate	High	High	Extreme	Extreme

Figure 3: Example method of categorizing risks, Source: the *Implementation Guide*

Weather Poses Unique Risks

State DOTs have long planned for fluctuations in the cost and timing of construction, availability of funding, and development of new regulations. However, extreme weather risk deserves special consideration because certain types of extreme weather are becoming more frequent and intense (IPCC, 2012). The literature contains many examples of historical and projected trends in extreme weather. For example, NOAA's US Climate Extremes Index, which calculates the percent of the country experiencing the impacts of extreme events, trended upwards between 1970 and 2011 (Lubchenco and Karl, 2012). Extreme daily precipitation events in the US have increased in frequency during the most recent 30-yr period as compared to the previous 30-yr period (Higgens et al 2011). The last decade in particular has witnessed an exceptional number of extreme weather events, with record drought, heat, and rain events occurring all over the world. Recent studies have also found that the frequency of extreme heat events is increasing globally. The weight of evidence strongly indicates that certain types of extreme weather, particularly heat waves and precipitation extremes, will significantly increase in the future (Coumou and Rahmstorf, 2012).

While individual weather events may threaten the ability of projects to finish on time and within budget, trends in extreme weather can threaten the ability of an enterprise to achieve financial, safety, and performance goals. However, it is important to note that different types of extreme weather events have different degrees of impact. Not all changes in weather result in impacts on the surface transportation system. For example, over the past several years, preliminary results from the Federal Highway Administration (FHWA) Gulf Coast Phase 2 strongly suggest that heat event impacts on transportation are much less significant than impacts from intense rainfall or storm surge.

Based on observed trends in weather and expected changes in the future, state DOTs are likely to face increased weather-related risks to their assets. Developing methods for evaluating road weather-related risk will help agencies pro-actively adapt to future weather conditions.

Integration of Extreme Weather Risk into TAM: Goals, Objectives, and Performance Measures

1 Set Goals and Objectives

The first three steps of a TAM process as shown in Figure 1 are designed to help state DOTs set useful goals and objectives, identify gaps, and define the scope of how TAM will operate within an agency. The *Implementation Guide* notes that the initial starting point for any agency is to clearly define goals and objectives which reflect TAM principals (Step 1). These goals should match the framework and culture already captured in the agency's mission and strategic goals. The *Implementation Guide* lists improved asset performance, lower costs for asset construction, and reduced infrastructure failures as examples of common TAM goals. It is important to begin considering the extreme weather risk at this stage because all subsequent steps in TAM rely on this first one.

Most TAM goals focus on ensuring reliability, performance, and efficiency without detailing specific causes of failure (like extreme weather). However, it can be helpful for agencies to articulate TAM goals based on risk management outcomes that are relevant to extreme weather events. Crafting appropriate risk-oriented TAM goals will require identifying the types of risk that cause the most damage and defining the desired outcomes. For example, a risk-oriented TAM goal might aim to increase transportation system resilience to high consequence events in a cost effective manner. Objectives supporting this goal could include prioritizing investments to fortify critical assets at high risk from extreme weather events (for example, see Figure 4). Such objectives might establish different standards for different levels of importance of individual assets. For example, an agency may deem it acceptable for less critical infrastructure to experience more frequent damage or disruption during extreme weather events. While the agency can make some assessments as to acceptable service level reductions for minor events, those assessments may be beyond the agency's control during extreme events. These decisions may become political in nature as a weather event transitions from a routine, to a regional, and even to a national crisis. While setting risk management goals, it is often helpful for agencies to identify critical infrastructure because levels of acceptable risk will differ based on asset criticality.

Key Definitions*

- **Goals** are statements that define the basic aim of a policy.
- **Objectives** are specific aspects of goals to be attained.
- **Performance metrics** are observable, quantifiable measures that align with objectives. They provide a way to track progress towards meeting objectives.

* Source: AASHTO 2002 TAM

The more specific these goals and objectives, the easier it will be for an agency to monitor progress towards meeting them. After an agency has developed a risk management goal and articulated objectives for managing weather risk, the next important step is building performance metrics in order to monitor progress.

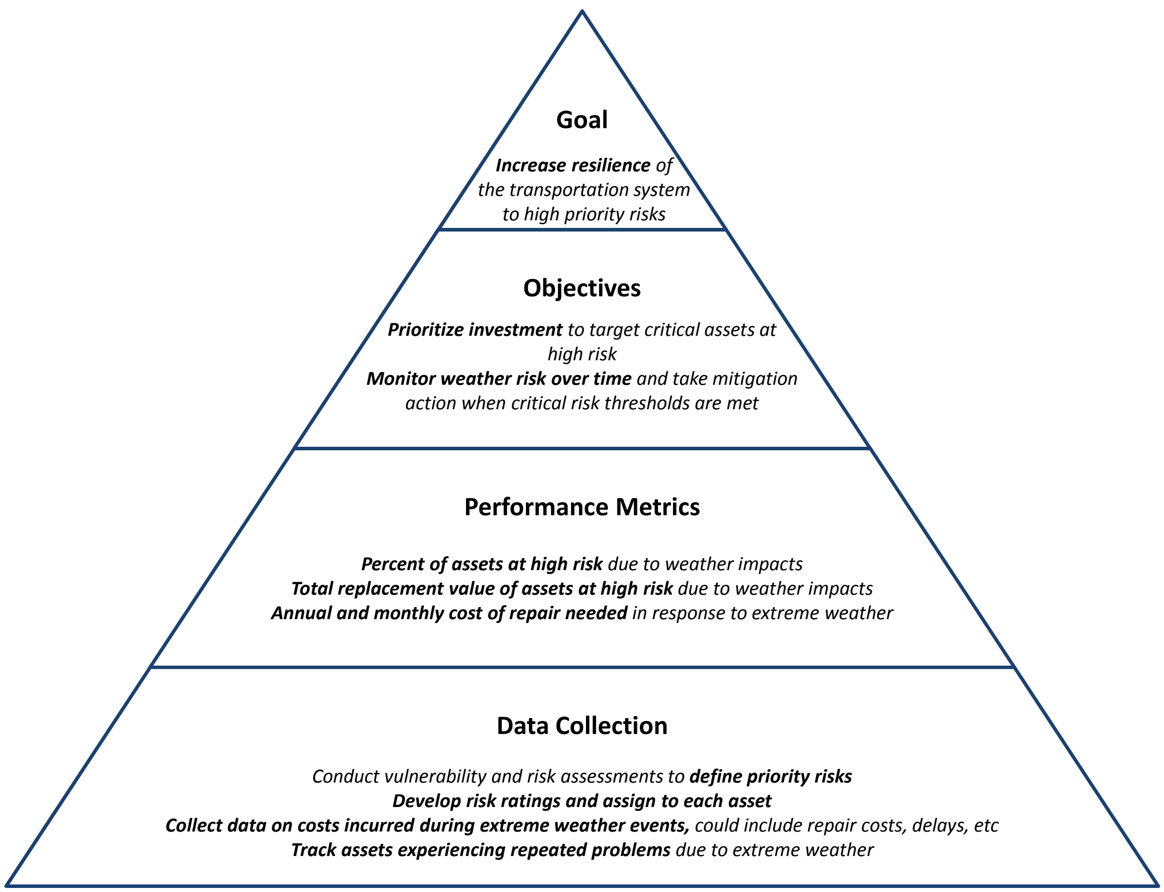

Figure 4: Example of how a risk management goal could inform the development of objectives, performance metrics, and data collection efforts designed to help manage extreme weather risk.

Integration of Extreme Weather Risk into TAM: Service Planning, Life-Cycle Management, and TAM Integration (Steps 10, 11, and 12)

Three key steps in the *Implementation Guide* assist transportation professionals with decision making tools. They focus on the critical elements of service planning (Step 10), life-cycle management (Step 11), and TAM integration (Step 12). The sections below discuss the importance of including extreme weather events in these TAM steps as well as approaches for doing so.

Relevant TAM Steps – Step 10: Enabling Process and Tools for Service Planning

10 Enabling Processes and Tools for Service

Step 10 in the *Implementation Guide* speaks to Enabling Processes and Tools for Service Planning and has four parts: Agency-wide Strategic Performance Measurement; Writing and Updating the Links to Levels of Service; Growth and Demand Factors; and Risk Management. This focus on Service Planning has numerous points of entry for users to consider extreme weather events and their associated trends. The *Implementation Guide* first lays out the importance of the Mission Perspective and identifies several potential performance measures. Among these is the explicit consideration of risk which is defined as the probability of an extreme event occurring and the associated consequences (e.g., damage to assets/facilities and service disruptions). In this latter case, disruption to one part of a road network could cause traffic diversions to other roads thus increasing congestion and travel delays in surrounding communities. In this example, the location of the direct impact (e.g., damage to a section of road) may be different from the location of the indirect impact (e.g., disruptions to alternate traffic patterns around the damaged section of roadway). When an asset provides a critical connection link, associated disruptions may occur anywhere in the network. Further, minimizing the risks of extreme events has ramifications for several of the other listed Mission performance measures including safety, mobility, accessibility, reliability, and possibly even life-cycle cost, albeit to a lesser extent. Severe weather events, such as flooding or landslides from heavy downpours and storms, can cause massive disruptions to transportation. Mobility, accessibility, and reliability of service are obviously impaired, and human lives may be at risk.

The key question for users is how to address the impact of extreme weather events in the processes and tools used for service planning. Potential answers lie in addressing each part of Step 10 with an eye toward these events. While much of a transportation professional's focus is typically on providing normally accepted operating conditions, extreme events are by their very nature outliers from the average and warrant special attention because of their potential to disrupt transportation services, the economy, and social welfare of society. As the incidence and prevalence of these severe weather events becomes greater, transportation agencies are at greater risk of failing to meet the societal transportation requirements.

An interesting parallel can be drawn to the rise in importance of advanced decision support systems to more effectively manage state DOTs' equipment assets in response to winter storms.

With highly variable and ever-changing conditions, winter storms present challenges to state DOTs; these challenges include identifying the worst disruptions to the road network and how to best distribute the available units of snow removal equipment. This kind of approach could be applied to other extreme weather events. Performance measures that are specific to particular kinds of disruptions may be used to avoid or manage the impact of extreme events.[2] While extreme events' impact on levels of service on average is unlikely to be significant due to their relative infrequency, analyzing extreme events' impacts on levels of service *during* specific events may be quite significant. Efforts to reduce the impact severity and its duration will enhance safety, provide greater transparency to service planning and increase customer satisfaction as well as minimize economic loss.

Step 10 also addresses Growth and Demand forecasts; encouraging DOTs to anticipate changes in the external environment and plan for them accordingly. An increasingly important part of the external environment is the change in extreme events. Growth in the magnitude and duration of these events needs to be addressed in much the same way that growth in travel demand is an important determinant of what assets need improvement and which do not. Trends in the incidence and prevalence of extreme events can similarly be charted and tracked. As in growth forecasts, there is uncertainty in the projections. The delivery of useable data in this area is still somewhat nascent. New information is being generated and synthesized by a variety of academic institutions and federal agencies, including FHWA. In 2009, for example, the U.S. Global Change Research Program provided probability projections of extreme rain events for the foreseeable future.[3] In the absence of more sophisticated and/or more localized projections, transportation practitioners may consider using a range of scenarios that build off of historically disruptive extreme weather and the temperature, precipitation, soil moisture, humidity, and other factors that contributed to failures in the system. This historical event information combined with future scenarios allows for consideration of future extreme weather events in lieu of predictive forecasts.

The final aspect of Step 10 is Risk Management. Under FTA's pilot adaptation program, transit agencies are learning that it is possible to understand the risks that extreme events pose. In an ongoing study in Philadelphia, for example, analyses have been undertaken to examine weather events and delays on the Manayunk/Norristown commuter rail line. From this retrospective examination, trends can be seen and baselines established to better understand future risk and its impact on the system and the city. The risk of service disruption from weather events is but one of many risks facing transportation agencies. Aging infrastructure, incidents and crashes, regulatory actions and other everyday occurrences for the transportation professional also pose significant risks to the provision of adequate service. In the simplest of formulations, these risks can be seen as

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[2] For example, see FHWA's Regional Climate Change Effects: Useful Information for Transportation Agencies. http://www.fhwa.dot.gov/environment/climate_change/adaptation/resources_and_publications/climate_effects/

[3] "Global Climate Change Impacts in the United States," USGCRP 2009.

additive and where an asset faces multiple risks; the need for investment can be seen as higher. Comprehensive tools to assist asset risk management are still limited, but as a paradigm, the concept of addressing the priority, including those from extreme weather events, is powerful.

Relevant TAM Steps – Step 11: Enabling Processes and Tools for Life-Cycle Management and Asset Preservation

Step 11 from the *Implementation Guide* focuses on the life cycle of the asset. The life cycle of an asset is fundamental to the TAM process which is critical for users to address the routine maintenance needs of infrastructure, and plan for its rehabilitation and renewal at regular intervals. Inclusion of extreme weather events will have important ramifications for life cycle considerations in the TAM process.

> **11** Enabling Processes and Tools for Life-Cycle Management and Asset Preservation

In some cases, there is good information about the impact of extreme weather on materials and infrastructure. Transit professionals in Washington, DC are increasing their design heat standards to account for an anticipated increase in extreme heat events. Asphalt pavement changes with heat are similarly well known. Other impacts are less well understood and further research is necessary. Understanding in precise terms these impacts is critical to effective life-cycle management and maintenance planning, two key parts of this step in the *Implementation Guide*.

The overall purpose of life cycle management is to assist decision makers by objectively determining the optimal economic approaches to TAM. Regular maintenance reduces cost and avoids service disruption. Planned rehabilitation can forestall asset failure, yet replacement often becomes the option of choice due to cost and timing considerations. TAM helps decision makers find that optimal approach. Extreme weather events affect this optimal approach by increasing asset degradation which will likely become worse in the future as extreme events may become more common. Research is needed to determine more precisely what degradations are likely in order to more realistically assess asset life-cycles.

The *Implementation Guide* describes a continuous improvement approach to life cycle modeling that depends on forecasting deterioration and performance, using those forecasts to improve decision making, and monitoring performance to improve the forecasts. As the availability and modeling of weather data relating to rain intensity, wind speeds, and temperature changes, for example, improves, it will become easier to integrate extreme weather into life cycle modeling.

Relevant TAM Steps – Step 12: Enabling Processes and Tools for TAM Integration

TAM integration addresses program planning, program delivery, asset valuation and depreciation, as well as acting sustainably. In part, it addresses how users can apply TAM principles in budget development, procurement, and accounting. The underlying purpose of

> **12** Enabling Processes and Tools for TAM Integration

Step 12 is to view the transportation program as a set of improvements to be made, setting objectives, making decisions, and delivering the program. Integration of extreme events in these processes will depend on its inclusion in previous steps but has clear consequences to the important activities of this step.

Program planning and program delivery will depend on the activities and considerations taken in service planning and life cycle management. Failure to include the consequential impacts of extreme events in these analyses will preclude it from consideration in Step 12. Inclusion, however, will yield benefits to the transportation network resulting in more reliable service and lower costs, and will assist the decision maker in setting objectives in program planning by considering their impacts in the trade-off analysis, and budgets resulting in a more realistic and effective program.

Transportation agencies might consider extreme events in the procurement process as part of program delivery. There are many types of procurements, but they often include asset design as well as construction. A future consideration as more data and experience is gathered is to consider the impacts of extreme events in design specifications. However, any future considerations in this area will depend on the data and analysis available for the specific types of weather events of concern.

In the planning and design of roads, "extreme events" are often considered as part of choosing engineering parameters including flood zones, fault lines, the redundancy of supporting infrastructure like power, gas, communication links, and other survivability parameters. Consideration of extreme weather events could thus appear to have a significant impact on the valuation and depreciation of assets. Assets repeatedly exposed to extreme events are likely to deteriorate more quickly and thus depreciation could be faster and valuations lower. Future work in this area should explore the consequences of this in terms of insurance and other considerations.

Integration of Extreme Weather Risk into TAM: Information Systems and Data Collection and Management (Steps 13 and 14)

It is primarily through the use of management information systems that DOT officials obtain the information necessary to make the investment and operations decisions that affect system performance. Such systems have been part of DOT management structures for decades, with an early focus on pavement and bridge asset conditions and more recent expansion into such areas as safety, maintenance, and ancillary assets such as guard rails and traffic signals. The data collection efforts that support these management systems focus on a wide range of topics. For example, the nation's bridge inventory data collection program upon which state DOT bridge management systems rely consists of the collection of well specified data items collected on specific time schedules. Similarly, most state's pavement management systems rely on the periodic collection of pavement condition data.

Figure 5 shows the concept of an integrated asset management system that obtains data from and feeds information to different decision processes in a typical DOT. Examining the potential of incorporating concerns for extreme weather and over the long term changing climatic conditions into asset management programs necessarily focuses on the different management systems that are found in a DOT and the data that is used to populate these systems.

Relevant TAM Steps – Step 13: Information Systems Enabling Decision Making

13 Information Systems Enabling Decision Making

Step 13 of the *Implementation Guide* focuses on the use of information systems to support the asset management decision making framework. As shown in Figure 5, several information systems can be part of an integrated asset management program, and many of these systems can provide important information concerning weather-related risk and asset vulnerability to extreme weather events. Given that much of the data input into information systems is spatially referenced, portions of the network that are likely to experience higher-than-normal risks to inundation or other disruptions can be identified as part of the attribute information in the management system. Thus, for example, if maintenance records show that a particular section of road is flooded more often than others given similar storm intensity, one could "flag" that section as a maintenance priority, or add extra consideration when investment priorities are being established for the capital program. Another example would be marking those culverts that have a higher than average tendency to be filled with debris due to surrounding land cover. Note that this "flag" could originate from a variety of data sources---road condition, maintenance asset performance logs or maintenance work orders. In essence, the role for information systems envisioned in this example is really one of being an early warning system, that is, identifying assets or facilities that are facing high risk of failure given extreme weather conditions, and providing DOT officials with different options for minimizing this risk.

Such an approach to the use of information systems also suggests the need for environmental monitoring systems of the assets that feed into these decision support systems, e.g., environmental sensor stations that are used in road weather information systems. Very few state DOTs have road weather information systems those existing systems are not linked with asset management systems. An important note of caution is that using existing information systems to predict risk inherently means relying on historical data, which might not always be a good indicator of future events. Historical data are certainly valuable, but as weather patterns change the past will not always be a good indicator of the future. At some point, anticipated changes will need to be incorporated into TAM.

Designing and managing information systems to collect data on extreme weather risk implies that the systems will build on the tools and approaches discussed previously in this paper. Thus, in the integrated asset management framework shown in Figure 5, “risk analysis” should be incorporated into the “analysis tools” section for asset management to act as a framework for considering extreme weather-related impacts.

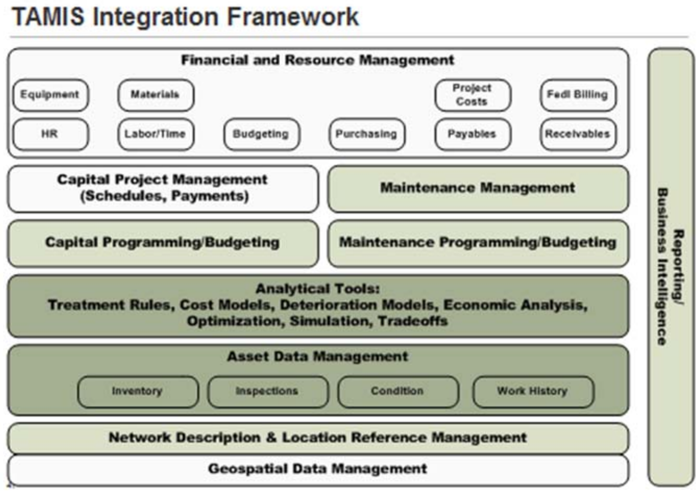

Figure 5: An integrated view of asset management in a state DOT (Source: *Implementation Guide*)

This risk analysis tool would rely on data and information from the different management systems existing within the DOT, most likely bridge, pavement, ancillary asset and maintenance management systems. This information, along with input on the risk to critical assets (which includes both an assessment of the likelihood of the extreme weather event occurring along with the likelihood that damage or loss of functionality would occur), could then be used within the information system construct to identify priority investments. For more advanced asset management systems, this information could also be used to identify different options for protecting the asset, in essence, turning the asset management system into a decision support system.

Relevant TAM Steps – Step 14: Data Collection and Management Enabling Information Systems

14 Data Collection and Management Enabling Information Systems

A recent FHWA report on risk-based asset management noted that “sound asset data lies at the heart of sound asset management decision-making” (FHWA 2012a). Step 14 of the *Implementation Guide* recognizes the importance of quality data in the overall effectiveness of TAM systems. The information systems themselves are only as good as the data used for input. As noted earlier, much of the data collected by DOTs is spatially referenced, which allows DOT managers to link the condition and performance of individual assets to the characteristics associated with a particular location. This capability will be critical for using management information systems in general and asset management in particular for dealing with extreme weather events.

While the majority of this paper focuses on TAM and asset management systems, it is important to note that state DOTs have other asset-related information systems that could be used to develop strategies for mitigating the impacts of extreme weather events. In general, these systems fall under the title of maintenance management systems (MMS) (AASHTO 2005; TRB 2012).

Although varying by agency, these systems often include information relating to asset inventory, condition assessment, performance targets, performance-based budgeting analysis, annual work program, resource needs analysis, and work order development.

As shown in Figure 5, there are four major types of asset data that are common in an asset management program—inventory, inspection, condition, and work history. Each of these data types can be an important source of data relating to potential extreme weather event impacts. Inventory data focus on the basic characteristics of each asset, and provide in some sense a reference point for the current state of the asset base. Most DOT inventories are quite extensive, with many data items relating to location, asset characteristics, asset use, and materials used in construction. The inventory database contains information relating to the vulnerability of different assets could be indicated (see previous discussion on flagging asset vulnerability). For example, a low-lying road located in a valley paralleling a stream could be flagged as being particularly vulnerable to flooding or possibly rock slides given changing weather conditions. The inventory database could also be modified to include a data item on projected future weather conditions expected in the asset location that could serve as a warning for designers when considering rehabilitation or reconstruction. Such information could be collected by state DOTs as events occur or may be available from State or local weather services or environmental agencies. Thus, if an asset is located in an area expected to experience more flooding in the future because of topography and/or land cover, a warning indicator could be attached to the relevant assets in the management system that would indicate to designers that special design considerations might be necessary at this location. If an asset were tagged as being vulnerable, these data could be utilized to target rapid surveys during and after extreme events to manage the operation of the asset and possibly the prioritization of recovery efforts.

Inspection records are particularly relevant to extreme weather event planning. This is the information that feeds directly into the maintenance and asset rehabilitation decision-making process. Inspection records apply not only to the physical condition of assets (e.g., pavement and bridge inspections), but also to any aspects of asset performance that will affect the overall function of that asset. For example, a physical inspection of a culvert might show that there are no material deficiencies that would cause it to fail. However, this same inspection might note that the culvert has large amounts of debris that blocks the ability of the culvert to carry out its primary function. Indeed, recent evidence from road failures in states affected by hurricanes and tropical storms shows that it was blockage of culverts that caused much of the problem. Using inspection data as input into an extreme weather event risk assessment framework would likely require a close examination of the current data collected as part of the DOT inspection program, and the identification of other data that, if collected, would provide a strong foundation for an effective risk analysis process.

Condition data is the foundation of most asset management systems. Along with deterioration models, condition data provides the rationale for assessing the investment needs on transportation networks. These data can be used in the context of extreme weather event planning to identify which assets are particularly vulnerable to high levels of environmental stress. The data are then used for establishing investment and maintenance priorities. The primary role for condition data in the context of extreme weather event planning would be in linking condition data to location information to show which assets are likely to be exposed to high stress levels due to an increasing frequency and intensity of such events.

Work history data can be used to identify those locations that require above average maintenance activities. If a particular type of signal equipment seems to be more affected by higher temperatures than others, higher-than-normal maintenance calls to fix such equipment should provide some indication that there is a problem with that equipment. Heat-related pavement buckling along certain sections of highway might suggest that either the materials or pavement design need to be reassessed. Continual calls for unclogging the same culverts suggests that there is something about that location that needs to be examined to reduce the amount of debris that enters the culvert. Work history data, in combination with other asset data, can provide a high level of knowledge about the underlying causes for a transportation system's performance.

Summary

The major argument presented in this paper has been that TAM provides an excellent platform for considering the impacts of extreme weather events on infrastructure condition and operations. This concept is relatively new to the transportation profession, and thus one where additional efforts are necessary to disseminate information on how TAM can serve in such a capacity. Understanding the nature and duration of service disruptions relative to the extreme weather events will be critical to further apply TAM principles and make existing services more resilient.

The *Implementation Guide* outlines 14 Steps that state officials can take to implement TAM systems in their organizations. As indicated in this paper, many of these steps can be viewed as a means to incorporate extreme weather event considerations into the TAM decision making framework. No significant restructuring of the TAM framework is needed to implement this integration. The spatial nature of much of the data used in TAM systems, combined with the results of risk analysis, can provide DOT officials with good indications of where potential problems exist. The only new element to this approach is to include a risk management perspective relating specifically to integrating extreme weather events more fully into the process. This paper's broad-scale treatment of TAM identified a number of areas where future discussion and research are necessary. These research needs are as follows:

- Identify reasonable and appropriate levels of service during extreme events (e.g., length of time out of service, impact on movement of emergency responders) and appropriate methods to measure them.

- Understand weather impacts and the resulting costs associated with them. This includes researching the impact that extreme weather events have on the deterioration of an asset's value and coding weather-related costs, where possible in financial and labor tracking systems.
- Expand existing risk mitigation approach within TAM system to explicitly address extreme weather and related risks.
- Identify and test the efficacy of extreme weather performance indicators.
- Draft guidance on how to track or obtain data on extreme weather events, particularly those with an impact on the transportation network. These data may come from national climate data centers, tools to help process weather station data, state climatologists, or from the agency's own records.

Although states will likely face different types of extreme weather in the future, one common theme unites all. Each state DOT is responsible for maintaining and preserving the massive investment that each has made in their transportation system. This system was built under the assumption that weather trends would remain steady. As weather events increase in frequency and magnitude, DOTs will find themselves spending more time recovering from such events. By putting in place a systematic process for identifying high risk assets in light of more extreme weather stresses, DOT officials can provide a more cost effective strategy for asset stewardship.

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