INTEGRATING EXTREME WEATHER INTO TRANSPORTATION ASSET MANAGEMENT PLANS

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Integrating Extreme Weather and Adaptation into Transportation Asset Management Plans

1. Introduction

Over the past five years, the transportation community has become increasingly more concerned about the impact of climate change and extreme weather events on transportation infrastructure and services. Partly in response to major natural disasters such as Hurricanes Katrina and Irene, Superstorm Sandy, massive flooding in the Midwest and large forest fires in the west, and in part due to a growing awareness of the potential threats described in research and policy studies many transportation agencies are interested in understanding the risks associated with a changing climate. At the same time, the continuing development and use of asset management systems and performance-based decision-making in state departments of transportation (DOTs) raises questions about how such systems and decision making processes could be linked to the risks associated with climate change and extreme weather events.

The objective of this study was to develop a process for DOTs to incorporate climate change and extreme weather consideration into Transportation Asset Management Plans (TAMPS). The study investigated the limited number of examples that have done so for a variety of weather conditions (e.g., sea level rise, shoreline retreat, freeze/thawing cycles, extreme rainfall), and examined the linkage between extreme weather and climate change given a proposed FHWA rulemaking on risk-based TAMPs in response to the Moving Ahead for Progress in the 21st Century (MAP-21) legislation. In particular, the results of recent Federal Highway Administration (FHWA) pilot studies on climate change and extreme weather asset vulnerabilities were assessed for their contribution to TAMP development. The result of this study is a suggested process and template that can be used by DOT officials for considering extreme weather events and climate change (hereafter referred to as extreme weather/climate change) when developing or updating the TAMP.

2. Study Approach

The study consisted of four tasks. The first task was to review current American Association of State Highway and Transportation Officials (AASHTO) and FHWA efforts relating to state DOT TAMPs. In particular, this review emphasized the implications and requirements of the Notice of Proposed Rulemaking (NPRM) relating to asset management plans.[1] The second task identified the climate change and extreme

[1] Federal Highway Administration. "Asset Management Plan", Federal Register / Vol. 80, No. 34 / Friday, February 20, 2015 / Proposed Rules, 23 CFR Part 515, Washington D.C.

weather-related Issues relevant to the state DOT TAMP process. In particular, this review identified the climate-related "stressors" that would likely have the most impact on the infrastructure for which state DOTs are responsible. The third task developed a process for integrating climate change and extreme weather concerns in TAMPs. The adopted approach was using a template, which has been the approach used for many different topics and issues that need to be linked to the TAMP. The AASHTO TAMP Builder, a decision support tool developed by another NCHRP project, provided a useful and easy-to-use structure for integrating extreme weather/climate change concerns into the development or update of TAMPs.[2] The template was reviewed by the asset management leaders at three state DOTs— Colorado DOT, Minnesota DOT and the New York State DOT. These state DOTs were chosen primarily because of the advanced state of their asset management systems as well as their concern for extreme weather (Colorado has faced floods and wild fires; Minnesota has experienced massive flooding; and New York was subject to Super Storm Sandy, which included storm surge and coastal flooding). Comments received from the state DOT officials were used to revise the original template developed by the study team. The final task was to develop the interim and final report.

Section 3 provides an overview of the NPRM for asset management and guidance from FHWA on the development of transportation asset management systems. Examples are also provided from other studies. Section 4 describes the climate change and extreme weather stresses that could affect infrastructure and DOT operations. Section 5 examines the relationship between climate change/extreme weather variables and the transportation asset management plan (TAMP) process. Section 6 presents the major contribution of this research with is an extreme weather and climate change template. Section 7 makes recommendations based on the result of this research. One of the most important factors in incorporating such a consideration in TAMPs is how the risk associated with weather-related stresses can be considered in the TAMP process. Different methods for considering risk are provided in appendix A to this report. Appendix B presents a case study of the risk-based TAMP from the Minnesota DOT. The final section recommends next steps.

3. Notice on Proposed Rulemaking on Asset Management and Other Guidance

3.1 Notice of Proposed Rulemaking

The proposed rule on asset management establishes the basic structure of a risk-based transportation asset management plan. The minimum topics to be included in a TAMP and the process for developing the plan are identified, as are the timeframes for plan development. With regard to this study, extreme weather/climate change risks are

[2] http://www.tamptemplate.org/

mentioned as part of the risks state DOTs are to consider. The following material highlights some of the key requirements in the Notice of Proposed Rulemaking (NPRM). Where climate change and extreme weather are explicitly called out, they are so indicated:

- Asset management is defined as "a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis based on quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the life cycle of the assets at minimum practicable cost.''
- State DOTs are required to develop and implement asset management plans for the National Highway System (NHS) to improve or preserve the condition of the assets and the performance of the NHS relating to physical assets (although state DOTs are encouraged to include all highway infrastructure assets within the right-of-way).
- State asset management plans must include strategies leading to a program of projects that would: 1) Make progress toward achievement of the State targets for asset condition and performance of the NHS and 2) support progress toward the achievement of the national goals.
- With respect to required processes, each state DOT must establish a process for:
  - Conducting a performance gap analysis and identifying strategies to close gaps.
  - Conducting life-cycle cost analysis for an asset class or asset sub-groups at the network level.
  - Undertaking a risk management analysis for assets in the plan. As part of this process, state DOTs would identify and assess risks (e.g., extreme weather) that can affect asset condition or the effectiveness of the NHS as it relates to physical assets.
  - Addressing the risks to assets and to the highway system associated with current and future environmental conditions, including extreme weather events, climate change, and seismic activity, in order to provide information for decisions about how to minimize their impacts and increase asset and system resiliency. A mitigation plan for addressing the top priority risks must also be described.

- Evaluating roads, highways, and bridges that have repeatedly required repair or reconstruction due to emergency events. For assets in the asset management plan, state DOTs are required to develop an approach to address and monitor high priority risks to assets and the performance of the system.
- Developing a financial plan covering a 10-year period.
- Developing investment strategies to improve or preserve the condition of the assets and the performance of the NHS.
- Using pavement and bridge management systems to analyze the condition of Interstate highway pavements, non-Interstate NHS pavements and NHS bridges, and to determine optimal management and investment strategies.

- The TAMP should include, at a minimum, 1) asset management objectives, which should align with the agency's mission; 2) measures and targets designed to achieve and sustain a desired state of good repair over the life cycle of the assets at minimum practicable cost; 3) summary listing of the pavement and bridge assets on the NHS, including at a minimum a description of the condition of those assets for: Interstate pavement, non-Interstate NHS pavement, and NHS bridge assets; 4) performance gap identification; 5) life-cycle cost analysis; and 6) risk management analysis for assets and the highway network included in the plan, and including for those assets a summary of the statewide periodic evaluations; financial plan; and investment strategies.
- The TAMP must discuss a set of investment strategies leading to an immediate program of projects.

As can be seen by this list, a risk-based asset management plan includes a consideration of many risks, such as organizational and financial risks. There are many opportunities for considering extreme weather/climate change factors. In particular, the identification of weather-related risks, the risk assessment of the potential consequences if an extreme weather event occurs, the identification of risk mitigation strategies, and the creation of a monitoring program targeted on the highest at-risk assets each need some consideration of extreme weather/climate change factors.

Some caution should be expressed at this point in developing a process for considering extreme weather/climate change factors in the TAMP. First, as of the date of this report, the NPRM has not been promulgated in final form; the comment period was extended to allow more time for comments on the proposed rule. At this point, it is not yet determined what the final requirements will be for the TAMP rule, although it seems likely that most of what is included in the NPRM will likely be in the final rule. Second, except for those states that have conducted a statewide climate adaptation study, much of the detailed and quantitative information needed to conduct a formal risk assessment might be unavailable to many state DOTs. Even most of the states that have undertaken some form of adaptation planning have mainly looked at representative and/or pilot projects, without little effort to identify highly vulnerable assets statewide, which look at both existing and future risks (although some states are now undertaking such a study, e.g., California and Massachusetts). The risk assessment required as part of the TAMP development process will likely have to be phased over many updates of the TAMP (which is recognized in the NPRM for many aspects of the TAMP process).

3.2 Other FHWA Guidance

The FHWA has provided several guidance documents on developing a risk-based asset management plan. For example, a five-volume set of reports on risk-based asset management provided information on a variety of issues associated with adopting a risk perspective. The reports were developed by FHWA's Office of Asset Management [2012a, b; 2013a,b,c] and included:

Report 1: Overview of Risk Management, Examining Risk-based Approaches to Transportation Asset Management

Report 2: Managing Asset Risks at Multiple Levels in a Transportation Agency,

Report 3: *Achieving Policy Objectives by Managing Risks, Risks to Asset Management Policies*

Report 4: Managing Risks to Critical Assets

Report 5: Building Resilience into Transportation Assets

Report 5 is particularly relevant to establishing a strong relationship between risk-based asset management and climate change/extreme weather events. The report identified several ways in which risk-based asset management could contribute to a state DOT's responsiveness to weather-related and other natural disaster disruptions: [FHWA 2013c]

1. Provide accurate inventories of assets and their condition assists with identifying which assets are at risk for given types of events such as floods, hurricanes, or earthquakes.

2. Foster sound maintenance practices within an asset management regime such that well maintained drainage structures are better able to withstand floods; sound high-mast lights and overhead signs are more wind-resistant; bridges with well-maintained wing walls, bank protection and scour protection are more robust during high water; and pavements with cleaned under drains and catch basins drain more quickly and perform longer.

3. Establish priorities for asset repair after events.

4. Enhance capabilities of asset management staffs, which is critical when developing a post-event recovery plan.

5. Develop asset inventories and good unit-cost data that will assist with estimating recovery costs.

6. Use asset mapping and GIS capabilities to identify assets and prioritize their coordination with evacuation planning.

7. Complete inventories of traffic control devices, signs, guardrail and culverts that allows for faster development of contract plans immediately after a flood or hurricane.

8. Provide critical before-event prioritization, but also post-event recovery allocation of resources.

As noted in this report, "risk-based asset management programs serve to both prepare physical assets to withstand disasters they also complement a larger governmental and societal perspective that prepares agencies to anticipate and respond to threats." This latter result was referred to as developing a "culture of resiliency" in the agency.

For a listing of asset management publications sponsored by the Office of Asset Management, see, http://www.fhwa.dot.gov/asset/pubs.cfm

3.3 Gulf Coast, Phase II Study

The U.S. DOT/FHWA conducted a major climate change study in Mobile, AL to understand likely climate change impacts on the region's transportation system, and the types of strategies that state/regional/local officials can consider in protecting the system. This study followed a much more expansive study (Phase 1) that examined the vulnerability of the Gulf Coast to climate change, with particular attention given to storm surge and flooding. The aim of the Phase 2 study was to focus on one metropolitan area to provide much more detail on the engineering/operations/maintenance implications of a changing climate.

Detailed modeling of future climate scenarios served as a major foundation of this study. In one of the task reports, *Task 2.4 Final Report, Assessing the Sensitivity of Transportation Assets to Climate Change in Mobile, Alabama*, the study team considered the overall sensitivities of transportation assets and operations in the region to a set of climate stressors. [ICF, 2012] A "sensitivity matrix" and the "sensitivity screen" were developed to identify how different types of assets might be affected by:

1) Waves and storm surge (increased storm surge height), and relative sea-level rise (incremental increase in sea-level rise);

2) Wind (increased wind speed);

3) Precipitation (heavy rain events, drought, incremental changes in the mean); and

4) Temperature (extreme heat events, incremental changes in temperature).

Table 1 illustrates the sensitivity matrix for a subset of the assets examined, in this case, bridge superstructure. Dark orange indicates a strong relationship between a climate stressor and asset component; gray indicates very little or no sensitivity. The Task 2.4 report provides information on all of the assets examined in the study, and thus constitutes a very large data base.

3.4 FHWA Adaptation Pilot Projects

In 2013-2014, FHWA sponsored 19 pilot demonstration studies on climate change and extreme weather assessments that examined system vulnerability to a range of projects. The following are some examples of these pilot studies (summarized from a peer exchange sponsored by FHWA). [FHWA, 2014]

Maryland State Highway Administration (SHA): The Maryland SHA used road closure data; a geographic information system (GIS) database of road centerlines; National Pollutant Discharge Elimination System (NPDES) discharge data; and the FHWA Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool precipitation projections; and university-developed sea level rise maps to identify vulnerable assets. The process included three major steps:

1. Based on a GIS overlay of assets and climate stressors, Maryland SHA eliminated assets from their study that are not projected to be exposed to climate stressors.
2. Using the FHWA Vulnerability Assessment Scoring Tool (VAST) and the Maryland SHA developed hazard vulnerability index (HVI), the pilot team rated assets that were not eliminated in step 1.
3. Maryland SHA held a series of workshops with their engineers to review and modify the VAST vulnerability results. The engineers identified inundation depth and peak discharge as the most valuable vulnerability indicators and downplayed the value of the current floodplain vulnerability.

Table 1: Illustrative Sensitivity Asset-Infrastructure Matrix, Gulf Coast, Phase 2 Study

Asset Type		Sea-level Rise (SLR) and Storms			Precipitation			Temperature	
Mode	Sub-mode	Relative SLR (gradual)	Storm surge (including increased wave action and SLR impacts)	Wind	Incremental change in the mean	Increase in frequency or duration of heavy rain events	Drought	Incremental increase in the mean	Increase in frequency or duration of heat events
Bridges	Bridge (superstructure)	No sensitive relationship	Damage increases substantially when storm surge height equals low chord bridge elevation. At this point, the bridge is usually exposed to direct wave impacts on the superstructure. Recent guidance specifies that the vertical clearance of highway bridges should provide at least 1 foot of clearance over 100-year design wave crest elevation.	AASHTO LRFD specifications are based on a base wind design speed of 100 mph, although the base wind design velocity is investigated for tall structures to account for local wind conditions. ASCE 7.05 recommends a 3-second gust basic wind speed of 130 to 150 mph in the Mobile area. ASCE 7.10 recommends 140 to 175 mph, depending on the structure's risk category.	No sensitive relationship	Scour can make bridge more susceptible to collisions, wave action and other impacts.	No sensitive relationship	No sensitive relationship	Bridge pavement is usually concrete and may exhibit similar sensitivities as road concrete.

Source: [ICF International, 2012]

Oregon DOT: Oregon DOT (ODOT) used five years of maintenance dispatch data to map weather-related issues and identify "hot spots" within their system that have historically been susceptible to climate impacts. Maintenance personnel were also used to identify locations that were susceptible to weather or other environmental conditions. ODOT also used the CMIP Climate Data Processing Tool to be highly valuable for providing downscaled precipitation data at a site level. Third, ODOT is currently leading the development of sea level rise maps for the state and will continue to move the work forward until another entity takes over. ODOT used these maps to conduct an initial GIS-based screen for exposed assets by flagging assets. Based on these various sources of qualitative and quantitative data, ODOT assigned a qualitative vulnerability rating to roads within their focus areas. ODOT produced sea level rise maps and then used all of this data to assign a qualitative vulnerability rating to roads.

North Central Texas Council of Governments (NCTCOG): NCTCOG collected data on local and regional historical weather, future climate, soil and hydrology, heat island effects, and transportation asset maintenance. An index of regional criticality based on performance measurements was developed and a GIS-based screening of the region was used to identify areas that were potentially vulnerable. The study combined proxy information to develop a map of drought and heat-sensitive soils and analyzed soil moisture content as a proxy for flash flooding.

Maine DOT: The study approach consisted of: 1) selecting three modeled scenarios (no sea level rise, 3.3 feet, and 6.6 feet); using historical flooding reports and local expert knowledge to select one critical asset per town; 3) developing three adaptation design options (replace in-kind, replace with resiliency up to 3.3 feet of sea level rise, and up to 6.6 feet); and using a model to apply a depth-damage function (which describes the damage and costs for an asset at each flood elevation) to the scenarios to estimate costs.

Minnesota DOT (MnDOT): MnDOT used a methodology to assess asset vulnerability through an indicator-based scoring approach, and selected indicators for each component of vulnerability:

- Exposure indicators included stream velocity; previous flooding issues; belt width to span length ratio of bridge, culverts, and pipes; median stream belt width of roads; number of potential stream bank erosion locations; and natural drainage capacity.
- Sensitivity indicators included pavement type; scour rating; substructure condition; channel condition; culvert condition; pipe condition; and percent change in peak design flow required for overtopping.
- Adaptive capacity indicators included AADT; heavy commercial ADT; detour length; and flood control.

These examples illustrate different approaches that could be used to meet the NPRM's requirements for the identification of at–risk assets and as part of a risk assessment effort.

3.5 Federal Transit Administration (FTA) Transit/Climate Change Adaptation Pilot Studies

Similar to the FHWA climate change adaptation pilot studies, the FTA sponsored pilot studies at several transit agencies throughout the U.S. to examine different aspects of transit system vulnerability to climate change. Two of these pilot studies focused on the potential role of asset management systems as a tool for including climate change factors in decision making. In most cases, the types of climate change factors considered in the studies were similar (except in some non-coastal cases where storm surge and sea level rise were not considered). The Metropolitan Atlanta Rapid Transit Authority (MARTA) study, for example, considered higher levels of more intense precipitation (and thus flooding), higher maximum temperatures and a wider range of temperature, higher-strength winds related to more intense storms, and drought. [Amekudzi et al, 2014] The study for the Chicago Transit Authority (CTA) examined extreme heat and cold, heavy rainfall and heavy snowfall. [Peet, 2012] Table 2 from the MARTA study shows the opportunities to integrate climate change adaptation into asset management plans following the asset management technical guidance from FTA.

Table 2: Opportunities to Integrate Climate Change Adaptation into Asset Management Plans, MARTA

Asset Management Component	Key Climate Adaptation Consideration	Opportunity to Integrate Climate Change Adaptation
Asset Management Policy and Strategy	• Has the agency considered climate change in asset management goals, policies, and/or plans?	Incorporate climate change considerations into asset management goals and policies; these could be general statements concerning adequate attention of potential issues, or targeted statements at specific types of climate risk (e.g., heat waves, flooding, etc.)
Integration Strategy with Asset Management Implementation Plan	• Has the agency mapped areas vulnerable to projected climate risks? • Has the agency inventoried critical assets, created risk profiles, and developed risk mitigation strategies?	Identify vulnerability of infrastructure assets in areas susceptible to climate change impacts. Inventory critical assets and identify and implement appropriate adaptation strategies (e.g., updated design guidelines, etc.)—short- and long-term—for these assets or asset classes. These strategies should be mapped to the appropriate business unit that will oversee the lifecycle management activities of that asset or asset class.
Key Asset Management Activities	• Has the agency considered adaptation strategies at the enterprise, asset-class or lifecycle asset management planning level?	Required adaptation strategies in the near term should be identified. Key asset management activities required within the next year can be based on condition assessments where preventive maintenance is warranted to avoid exacerbation of wear and tear or damage due to anticipated climate impacts. It can also involve reactive maintenance activities due to an extreme weather event.
Financial Requirements	• Has the agency incorporated climate risk mitigation strategies into its short- and long- range plans? Capital and/or O&M budgeting process?	Costs associated with the key asset management activities (e.g., replacement parts, retrofits, labor, etc.) identified above should be estimated and incorporated into the agency's capital improvement plan and/or operations and maintenance budgets.
Continuous Improvement	• Has the agency begun monitoring asset condition in conjunction with climate change indicators to determine if/how climate change affects performance?	Monitor asset condition in conjunction with climate-related conditions (e.g., temperature, precipitation, winds, etc.) to determine how it affects performance; incorporate risk appraisal into performance modeling and assessment; flag highly vulnerable assets. Monitor asset management system to ensure effective response to climate change; possible use of climate-related performance measures or thresholds to identify when an asset has reached a critical level. Revisit lifecycle management plans for asset as appropriate based on performance monitoring.

Source: [Amekudzi et al, 2014]

3.6 Highways Agency, England, Highways Agency Climate Change Risk Assessment

Although not from the U.S., this report represents one of the more comprehensive efforts at assessing the potential impact of climate change on a transportation agency's assets. With over 4,300 miles of roadway, England's Highways Agency is similar in structure and responsibility to many of the state DOTs in the U.S. As noted in the report, "beyond the obvious paved roads, (there is) an extensive asset base incorporating bridges, junctions, tunnels, culverts and embankments, along with extensive technology infrastructure such as traffic detection equipment, variable message signs, lighting and communications" that are vulnerable to climate change. Highway Agency officials adopted a high-level strategic risk approach to determining asset vulnerability and agency adaptation strategies. Table 3 shows the expected climate-related impacts to corporate objectives. Based on this expectation, the report identifies specific actions that functional units with the agency should take to prepare for changing climatic conditions.

Table 3: Highways Agency High-Level Climate-related Risks to Corporate Objectives

Risk	Examples
Reduced asset condition and safety	Assets deteriorate more quickly due to changes in climatic conditions; assets are more badly damaged as a result of more extreme climatic conditions
Reduced network availability and/or functionality	Need for restrictions on the network to maintain safety; increased need for road works
Increased costs to maintain a safe, serviceable network	Construction/maintenance/repairs/renewal required more often; more extensive construction/maintenance/ repairs/renewal required; new (more expensive) solutions required, e.g., designs and materials/components/construction costs
Increased safety risk to road workers	Increased risk to construction and maintenance worker and traffic officers as a result of climatic change, e.g., if need to work on the network more often; if required to work on the network during extreme climatic events or if climate change requires them to perform more "risky" activities.
Increased program and quality risks duet to required changes in construction activities	More onerous design requirements; new technical solutions required with higher uncertainty, affecting project programs and/or quality
Current Highways Agency international operational procedures not appropriate	Effects of climate change require new ways of working—changed or new business processes, new skills/competencies
Increased business management costs	Need for more staff; more frequent (expensive) incidents to pay for; need for more research into ways of coping with climate change

Source: [Highways Agency, 2011]

With respect to climate variables, forecasting future climatic conditions for this study concluded that the most likely scenario would be a continuation of the changes that have been observed in the United Kingdom over the past several decades, albeit at an increased rate. And thus, "consequently, services that are demonstrably sensitive to current weather events are likely to become increasingly vulnerable in the future." Table 4 shows the climate variables and impacts that are expected to affect England's road network.

Interestingly, the report also identified the different types of assets that the Highways Agency would be responsible for and defined expected useful lives for asset types. The expected useful lives were then considered when establishing priority consideration for including climate change factors into investment priorities.

Table 4: Climate-related Factors Potentially Affecting Highways Agency Assets

Primary Climatic Changes	Outcome	Impact on Asset	Impact on Customers
Increase in average temperature	• Longer growing season and reduction in soil moisture • Reduction in fog days in winter • Reduction in icy days in winter	• Planting establishment and maintenance regime • Less need to set warning signs • Reduced winter maintenance	• Visual impact • Enhanced visibility/safety • Enhanced safety
Increase in maximum temperature	• Extreme summer temperatures	• Pavement integrity	• Affected by maintenance/renewals works/welfare issue for stranded road users
Increase in winter precipitation	• Greater snowfall if combined with near sub-zero temperatures • Fluvial/Pluvial flooding	• Potentially a need for enhanced severe winter weather capability • Drainage capacity tested	• Potential for higher incidence of snow on network/welfare issue for stranded road users • Standing water/safety and lane/road closures
Reduction in summer rainfall	• Low receiving watercourse levels	• Drainage dilution levels a concern	• Water quality
More extreme rainfall events	• Fluvial/pluvial flooding	• Drainage capacity tested	• Standing water/safety and lane/carriageway closure
Increased wind speed for worst gales	• Wind speed more frequently exceeding operational limits	• Integrity of structures and signs/signals	• Closure of exposed structures to e.g. HGVs and motorcycles
Sea level rise	• Higher frequency of extreme storm surges	• Flooding of coastal assets	• Restricted access to network

Source: [Highways Agency, 2011]

These and other references would be provided as part of the extreme weather/climate change template for those interested in knowing more about what other transportation agencies are doing with respect to vulnerability assessments. As shown in Table 4 for the

Highways Agency example, understanding what weather-related impacts might occur given changes in climatic or weather conditions is an important step in a risk assessment. The next section discusses what is known about such impacts.

Those interested in additional information on asset management and TAMPs are referred to AASHTO's *Asset Management Guide* [AASHTO, 2011] and the FHWA asset management website: https://www.fhwa.dot.gov/asset/

4 Potential Impacts of Changes in Weather and Climatic Conditions on State DOTs

Risk is defined by the International Standards Organization (ISO) as the effect of uncertainty on objectives, and is expressed in terms of the likelihood of occurrence of an extreme weather event and the consequence of damage given such an event. The quantitative measure of consequences provides a sense of magnitude of the negative impacts of failure. In some cases, the consequences of failure can be expanded beyond the immediate impact at a disrupted site, but could extend to larger economic, environmental and social impacts. The first part of this definition is a fundamental point of departure for a risk assessment...what is the likelihood that extreme weather events are going to occur? This can be expanded to include as well what types of events will cause damage or disruption to a state DOT's infrastructure and operations? It is beyond the scope of this study to examine the different ways that climate forecasts are made and how they can be used in a vulnerability assessment (for those interested, see *NCHRP 750, Volume 2, Climate Change, Extreme Weather Events and the Highway System: Impacts and Adaptation Approaches*). [Meyer et al, 2014] However, several studies have attempted to generalize what types of impacts state DOTs might experience with changing weather patterns. NCHRP 750, Volume 2 identified changes in average and extreme temperatures and precipitation levels, disaggregated by summer and winter months, as having important consequences to state DOTs, in addition to sea level rise and storm surge for those states with coasts. With respect to temperature and precipitation, the report looked at extreme events, in particular:

1. Intra-annual extreme temperature range, defined as the difference between the highest temperature of the year and the lowest; an increase in the range was projected for most regions. The average estimated changes range from a slight decrease in Florida to a 5^{o}F (3^{o}C) increase in the southeast.

2. Total number of frost days, defined as the annual total number of days with absolute minimum temperature below 32^{o}F (0^{o}C); most of the regions are projected to have decreases of one to more than three weeks in the number of

days with temperatures below freezing. The largest reductions are projected for the northern regions.

3. Number of days with precipitation greater than 0.4 inches (10 mms); generally, the northern regions are projected to see an increase and the southern regions a decrease or no change. According to the modeling, none of the changes are significant and the range across the climate models is very wide, leaving the possibility that all regions could have increases or decreases.

4. Maximum 5-day precipitation total; the maximum precipitation is projected to rise in the Northwest, Midwest, Northeast and Southeast, although the change in the northwest is virtually zero. The amounts are projected to decrease elsewhere.

The study also examined sea level rise and hurricane intensity with respect to storm surge. Observed rates of sea level rise are relatively high along the Gulf Coast and mid-Atlantic, lower along the east and west coasts, and negative in the far northwest. The NCHRP study concluded that most states are projected to have 1 foot (0.3 m) or less of relative sea level rise by 2050. Louisiana is projected to have at least 1 foot and up to 2 feet (0.3 m to 0.61 m) by 2050. The increase in eustatic sea level rise reduces the apparent decrease in relative sea level in Alaska from 9 in (0.23 m) to less than 1 in (0.025 m).

With respect to hurricanes, the number of category 4 and 5 hurricanes is expected to increase, with larger peak wind speeds and more intense precipitation, while the number of less powerful hurricanes is projected to decrease. As noted in the study, "three aspects of hurricanes are relevant to transportation: precipitation, winds, and wind-induced storm surge. Stronger hurricanes have longer periods of intense precipitation, higher wind speeds (damage increases exponentially with wind speed), and higher storm surge and waves. Increased intensity of strong hurricanes could lead to more evacuations, infrastructure damage and failure, and transportation interruptions in transportation service. The prospect of an increasing number of higher category hurricanes has serious implications for the highway system."

Similar to the Gulf Coast, Phase 2 study, the NCHRP 750 report provided a matrix that illustrated the potential impact of the different climate stressors on infrastructure and road operations and maintenance. Table 5 presents this information.

The NPRM recognizes that not all states will have the ability to forecast future climate conditions. One of the proposed requirements is to evaluate facilities and assets that have repeatedly been disrupted due to extreme events. This reflects that approach that several of the FHWA climate change adaptation pilots took in using maintenance records and other historical data to identify vulnerabilities in the system. However, this approach ignores locations on the highway network that today might not be vulnerable but with changing climatic conditions could become at-risk in the future. This suggests that as the TAMP process evolves, state DOTs should be examining ways of incorporating expected future climate and weather conditions into the analysis of network vulnerability.

Table 5: Summary of Climate Change Impacts on the Highway System

	Climatic/ Weather Change	***Impact to Infrastructure***	***Impact to Operations/ Maintenance***
Temperature	**Change in extreme maximum temperature**	• Premature deterioration of infrastructure; • Damage to roads from buckling and rutting; • Bridges subject to extra stresses through thermal expansion and increased movement.	• Safety concerns for highway workers limiting construction activities; • Thermal expansion of bridge joints, adversely affecting bridge operations and increasing maintenance costs; • Vehicle overheating and increased risk of tire blow-outs; • Rising transportation costs (increase need for refrigeration); • Materials and load restrictions can limit transportation operations; • Closure of roads because of increased wildfires
	Change in range of maximum and minimum temperature	• Shorter snow and ice season; • Reduced frost heave and road damage; • Structures will freeze later and thaw earlier with shorter freeze season lengths • Increased freeze-thaw conditions in selected locations creating frost heaves and potholes on road and bridge surfaces; • Permafrost thawing leads to increased slope instability, landslides and shoreline erosion damaging roads and bridges due to foundation settlement (bridges and large culverts are particularly sensitive to movement caused by thawing permafrost); • Hotter summers in Alaska lead to increased glacial melting and longer periods of high stream flows, causing both increased sediment in rivers and scouring of bridge supporting piers and abutments.	• Decrease in frozen precipitation would improve mobility and safety of travel through reduced winter hazards, reduce snow and ice removal costs, decrease need for winter road maintenance, result in less pollution from road salt, and decrease corrosion of infrastructure and vehicles; • Longer road construction season in colder locations. • Vehicle load restrictions in place on roads to minimize structural damage due to subsidence and the loss of bearing capacity during spring thaw period (restrictions likely to expand in areas with shorter winters but longer thaw seasons); • Roadways built on permafrost likely to be damaged due to lateral spreading and settlement of road embankments; • Shorter season for ice roads.

Table 5: Summary of Climate Change Impacts on the Highway System, cont'd

	Climatic/ Weather Change	*Impact to Infrastructure*	*Impact to Operations/ Maintenance*
Precipitation	**Greater changes in precipitation levels**	• If more precipitation falls as rain rather than snow in winter and spring, there will be an increased risk of landslides, slope failures, and floods from the runoff, causing road washouts and closures as well as the need for road repair and reconstruction; • Wet snow or rain or snow events are a major cause of avalanches. With the increased at-altitude snowfall, this heavy, wet snow or rain on snow events can be a trigger for more avalanches; • Increasing precipitation could lead to soil moisture levels becoming too high (structural integrity of roads, bridges, and tunnels could be compromised leading to accelerated deterioration); • Less rain available to dilute surface salt may cause steel reinforcing in concrete structures to corrode; • Road embankments at risk of subsidence/heave; • Drought-caused shrinkage of subsurface soils	• Regions with more precipitation could see increased weather-related crashes, delays, and traffic disruptions (loss of life and property, increased safety risks, increased risks of hazardous cargo accidents); • Closure of roadways and underground tunnels due to flooding and mudslides in areas deforested by wildfires; • Closure of roadways due to avalanches; debris field removal and other road recovery improvements likely to be significant; • Increased wildfires during droughts could threaten roads directly, or cause road closures due to fire threat or reduced visibility; • Clay subsurfaces for pavement could expand or contract in prolonged precipitation or drought causing pavement heave or cracking
	Increased intense precipitation, other change in storm intensity (except hurricanes)	• Heavy winter rain with accompanying mudslides can damage roads (washouts and undercutting) which could lead to permanent road closures; • Heavy precipitation and increased runoff can cause damage to tunnels, culverts, roads in or near flood zones, and coastal highways; • Bridges are more prone to extreme wind events and scouring from higher stream runoff; • Bridges, signs, overhead cables, tall structures at risk from increased wind speeds	• The number of road closures due to flooding and washouts will likely rise; • Erosion at road construction project sites as heavy rain events take place more frequently; • Road construction activities could be disrupted; • Increase in weather-related highway accidents, delays, and traffic disruptions; • Increase in landslides, closures or major disruptions of roads, emergency evacuations and travel delays; • Increased wind speeds could result in loss of visibility from drifting snow, loss of vehicle stability and maneuverability, lane obstruction (debris), and treatment chemical dispersion; • Lightning/electrical disturbance could disrupt transportation electronic infrastructure and signaling, pose risk to personnel, and delay maintenance activity

Table 5: Summary of Climate Change Impacts on the Highway System, cont'd

	Climatic/ Weather Change	*Impact to Infrastructure*	*Impact to Operations/ Maintenance*
Sea level rise	**Sea level rise**	• Higher sea levels and storm surges will erode coastal road base and undermine bridge supports; • Temporary and permanent flooding of roads and tunnels due to rising sea levels; • Encroachment of saltwater leading to accelerated degradation of tunnels (reduced life expectancy, increased maintenance costs and potential for structural failure during extreme events); • Loss of coastal wetlands and barrier islands will lead to further coastal erosion due to the loss of natural protection from wave action	• Coastal road flooding and damage resulting from sea-level rise and storm surge; • Increased exposure to storm surges; • Underground tunnels and other low-lying infrastructure will experience more frequent and severe flooding;
Hurricanes	**Increased hurricane intensity**	• Stronger hurricanes with more precipitation, higher wind speeds, and higher storm surge and waves are projected to increase; • Increased infrastructure damage and failure (highway and bridge decks being displaced)	• More frequent flooding of coastal roads; • More transportation interruptions (storm debris on roads can damage infrastructure and interrupt travel and shipments of goods); • More coastal evacuations

Source: [NCHRP 750, Vol. 2.]

5 Relationship Between Climate Change/Extreme Weather Variables and the TAMP Process

Table 6 shows the mapping or relationship between climate change/extreme weather events and a TAMP. The intent of Table 6 is to include such factors throughout the TAMP and corresponding agency actions. For example, some ways of integrating climate change and extreme weather events into the TAMP include:

- Identifying locations on the state-defined network where assets might be highly vulnerable to climate change-related risks due to topography, hydraulic or hydrological characteristics and/or soil conditions could be so indicated in the asset management system and identified as part of the TAMP.

- By examining the potential impacts of climate change and extreme weather on certain types of assets, the asset management system and the TAMP could identify which assets need to be monitored more closely over time. For example, some types of assets (e.g., traffic signal control boxes) might be highly susceptible to prolonged high temperatures. Culverts, which experience has shown to be some of the more vulnerable assets to extreme precipitation events, might be targeted in the TAMP for areas of the state where such events are expected to happen more often.

- Asset management systems and TAMPs could provide an important means of monitoring asset performance over time, as it relates to increasing problems caused by certain types of assets. Thus, for example, the TAMP could establish performance standards associated with assets that reflect trends in agency corrective action (e.g., number of times water flows in culverts back up).

- Current state DOT monitoring efforts, such road weather information systems (RWIS), seasonal weight restrictions, bridge scour, avalanche monitoring, etc. could be linked to the asset management system, and should be incorporated into the TAMP.

- One of the important steps in climate change adaptation planning is determining the criticality of transportation assets, that is, to what degree do facilities service a critical function in the network, economy or community? In a world of limited resources, state DOTs would want to focus their attention on those facilities considered to be most important. The asset management system and TAMP could provide criteria for defining critical facilities (which, in many cases, is already provided), and for identifying the types of risks involved if such facilities are disrupted…..although this effort could be done in system planning or some other functional area of a typical state DOT.

Table 6: Mapping of Climate Change/Extreme Weather Factors and a TAMP

Section	Climate Change/Extreme Weather Material
Asset inventory and conditions	• Summarize the climate- and weather-related conditions that affected the system historically • Identify changing climatic conditions that are likely to occur in the future.
Asset management objectives and measures	• Define the objectives of the asset management program that relate to system resiliency, redundancy, evacuation and recovery. • Identify the types of assets or network segments that will receive attention with respect to climate- and weather-related disruptions. • Define levels of service and measures relating to climate- and weather-related system operations and conditions. • Define short term and long term condition targets for resiliency, redundancy, evacuation and recovery.
Performance gap assessment	• Define short-term and long-term asset management planning horizons as they relate to climate/extreme weather factors. • Illustrate the performance gap between existing performance levels and future performance levels with respect to system disruption.
Lifecycle cost considerations	• In the context of lifecycle costs, discuss the tradeoffs associated with minimizing asset vulnerabilities as part of the normal capital program versus waiting until an extreme weather event occurs.
Risk management analysis	• Within the context for risk management, identify climate/extreme weather event risks to the system. • Identify state assets that are at most risk. • Include a risk register that provides the following for each programmatic risk – likelihood of occurrence, consequences of occurrence, and mitigation activities.
Financial plan	• Incorporate into the TAMP financial plan a strategy for funding needed improvements to reduce system risks, whether as part of normal capital investment or as a stand-alone funding initiative.
Investment strategies	• Describe typical approaches to minimizing climate- and weather-related risks.
Investment asset management process enhancements	• Identify priorities for asset management improvement as it relates to climate- and weather-related considerations. • Incorporate lessons learned from system disruptions that occur over time.

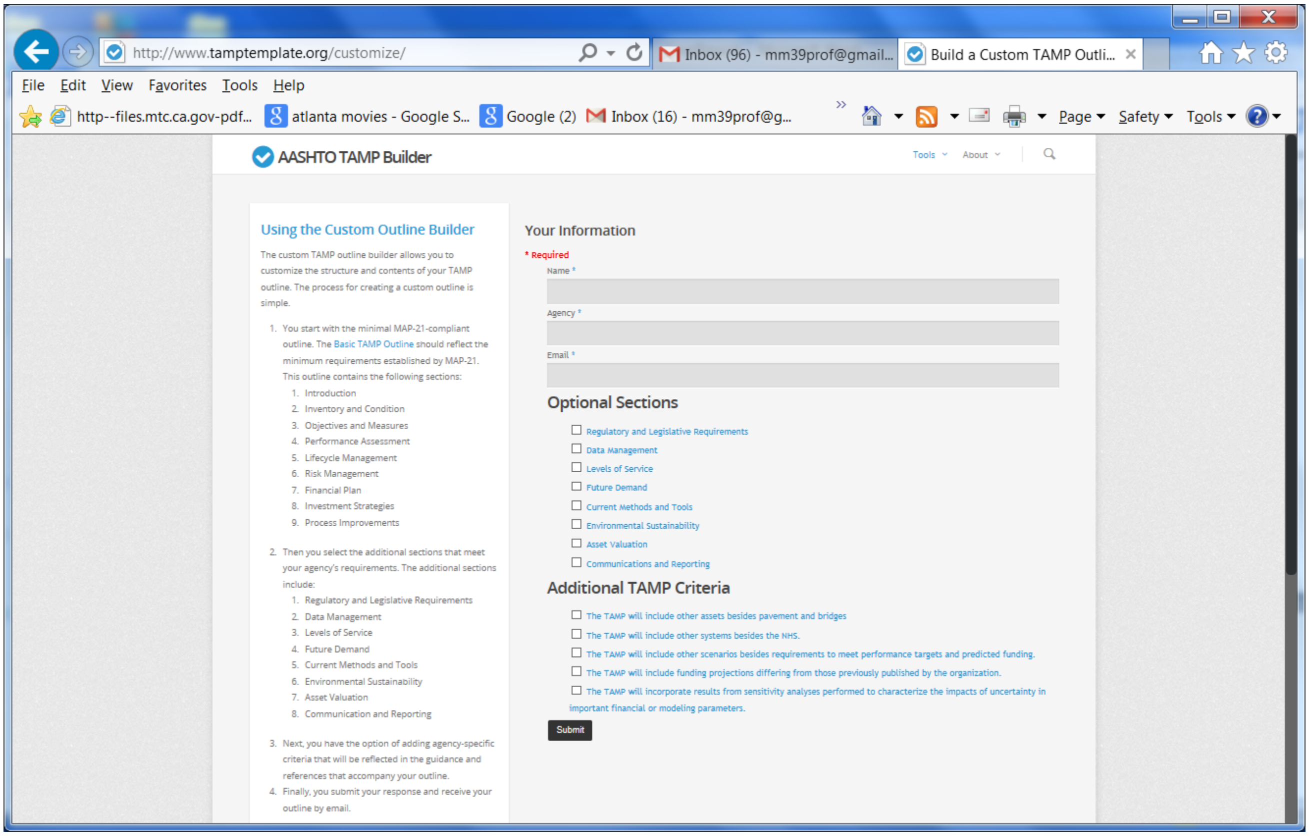
- The life cycle section of a TAMP would be a logical location for a description of the types of adaptation strategies aimed at climate change and/or extreme weather events. The TAMP could discuss lifecycle strategies and management methods that will be applied in a state for the assets considered to be most vulnerable and a description of the drivers that leads to such vulnerability.

Of all the suggested steps in Table 6, those actions relating to risk management are most critical for effectively considering climate- and extreme weather factors in asset management decision making. Such a focus on risk has been the target of FHWA's vulnerability assessment framework in its pilot studies, as well as in the Gulf Coast, Phase 2 project. In addition, much of the literature on climate change and extreme weather impacts on transportation have focused on measuring expected risks associated with different weather-related stresses. It seems likely that the development of technical tools and approaches that can be used to incorporate climate change and extreme weather factors into a risk-based asset management plan will be an important focus of efforts to accomplish such a goal. At this time, only a few agencies (and these are mostly those participating in FHWA and FTA pilot studies) have made much progress in doing so.

6 Extreme Weather and Climate Change Template

As noted earlier, the approach taken for considering extreme weather and climate change in TAMPs is to tie such considerations to the templates that are already available for TAMP development. AASHTO's TAMP Builder provides users with several different options for populating a TAMP with information that can inform decision-making on the risks associated with asset conditions. The TAMP Builder allows the user to adopt a "basic" outline that includes the minimally required sections of a TAMP (see Figure 1). These sections include:

1. Introduction
2. Inventory and Condition
3. Objectives and Measures
4. Performance Assessment
5. Lifecycle Management
6. Risk Management
7. Financial Plan
8. Investment Strategies
9. Process Improvements



Source: [http://www.tamptemplate.org/]

Figure 1: AASHTO TAMP Builder Screen

A user can also build a "custom" outline that expands upon the basic structure and adds sections including:

1. Regulatory and Legislative Requirements
2. Data Management
3. Levels of Service
4. Future Demand
5. Current Methods and Tools
6. Environmental Sustainability
7. Asset Valuation
8. Communication and Reporting

The user can also incorporate additional sections that reflect agency-specific criteria reflected in the guidance.

Three options are available for incorporating extreme weather and climate change concerns into the TAMP development process. The first option is to add questions to the existing templates for each section of the basic outline. The second option is to include extreme weather and climate change as a new optional section (in other words, adding a ninth section to the above custom outline). The third option is to add extreme weather and climate change into the “environmental sustainability” section, which is where extreme weather/climate change is currently considered albeit in a cursory fashion. All three approaches are related. For example, the questions that can serve as the basis of a stand-alone template can be nothing more than the combined questions from the individual TAMP sections. The study team examined the possibility of providing a different template for a stand-alone product versus incorporating extreme weather/climate change information into the “environmental sustainability” template. In the end, the two options were so close in terms of the desired information that it was decided to develop one template that could be used as a stand-alone product or incorporated into the environmental sustainability section. Exhibit 1 shows the first option, which is including questions into the existing TAMP Builder format. Exhibit 2 shows the second option, which is a stand-alone template.

7 Recommendations

This report has identified several questions relating to extreme weather/climate change factors that can be asked as part of the TAMP development process. Two possible formats were offered for posing these questions---incorporating them into the currently available basic outline for a TAMP or using them as a stand-alone template for those interested in focusing attention on this issue in the TAMP. The study team discussed this issue with the three states that reviewed the questions—Colorado, Minnesota and New York—and in addition contacted several other states known for their asset management programs (Georgia, Massachusetts and North Carolina) to ask them their opinion on the most desirable format. The clear consensus was that a separate template was the most desirable format. It is recommended that such a template be the final format. In addition, the AASHTO TAMP Builder is a logical platform for the template and thus it is recommended that the template be incorporated into the Builder program, or be hosted on an asset management website if Builder is no longer supported.

The templates shown in Exhibits 1 and 2 present the questions that would help guide the development of TAMPs that considers extreme weather/climate change. We are sensitive to burdening the state DOTs with too many requests for information. This is the reason the most important questions from the perspective of extreme weather/climate change considerations were indicated in bold font. It is not likely that many states would incorporate extreme weather/climate change factors into every chapter of a TAMP. As noted by one state DOT representative, the TAMP sections on inventory/condition, life-cycle analysis, risk and investment strategies are the most likely candidates for including such factors. The template is designed to be voluntary and thus the study team erred on the side of providing many questions.

In addition, as part of this study numerous asset management plans were reviewed to see if extreme weather/climate change was consciously considered at all (of course, most of the plans were adopted prior to the MAP-21 asset management rules). Only a few mentioned extreme weather/climate change events, and those were from states that had experienced weather-related disasters in recent years. With the new regulations it seems likely that as state DOTs incorporate risk considerations into their TAMPs, asset risks from changing weather patterns will become a growing concern. It will take time for the states to develop new MAP-21 asset management plans that include risk factors (with the exception being Minnesota, which is described in appendix B.)   It would be very beneficial to the evolving nature of TAMPs if an NCHRP synthesis was conducted in two years to identify best practice.

Exhibit 1: Extreme Weather/Climate Change Incorporated into the Basic TAMP Outline

The purpose of the Transportation Asset Management Plan (TAMP) Extreme Weather/Climate Change Template is to provide guidance on how to consider extreme weather impacts in a TAMP. The outline for a TAMP as presented in the AASHTO TAMP Builder (http://www.tamptemplate.org/) is used below as the basic organizational structure for the TAMP. Each section of the TAMP then offers extreme weather inputs in the form of questions that could be considered for each section. Additional information on methods and approaches that could be used for considering extreme weather factors in each TAMP section would be referenced in the respective sections. The intent of this document is to note where additional materials relating to extreme weather could be included in the TAMP outline. A sample template is found in the last section.

TAMP Basic Outline

Introduction

The Introduction of the TAMP provides the rationale for developing the plan, goals, and the role that the transportation agency's assets play in supporting a state's economy, providing necessary services to communities and connecting the state to the rest of the nation. The Introduction section should also provide an overview of the TAMP organization, and the implementation and update process. The AASHTO TAMP Builder suggests the following questions should be answered in the introduction section.

1. What is the current status of our assets?
2. What is the required condition and performance of those assets?
3. Are there critical risks that must be managed?
4. What are the best investment options available for managing the assets?
5. What is the best long-term funding strategy?

*The Extreme Weather Template would include the following questions for possible guidance on writing the Introduction of a TAMP.**

1. **Explain how your agency assets have been affected by extreme weather related events such as flooding, tornadoes, mud slides, hurricanes, straight line winds, etc. in the last three decades. Describe expected trends on how extreme weather events might change in the future?**
2. Have forecasts been made on how extreme weather events might change in the future? (e.g., more heavy precipitation for longer durations, warmer winters, etc.)?

* Questions in bold are considered higher priority additions.

Exhibit 1: Extreme Weather/Climate Change Incorporated into the Basic TAMP Outline

Inventory and Condition

The Inventory and Conditions section of the TAMP describes the assets the agency is responsible for, and provides a high level description of the current conditions of the assets. As part of the current condition description, TAMPs usually present information on condition or sufficiency ratings, replacement value, and asset age distributions. The AASHTO TAMP Builder suggests the following information be presented in the Inventory and Condition section.

A list (summary or count) of all assets for which the agency is responsible (with the possibility of a full inventory included as an appendix)

- Historic data
- Corresponding condition and performance data for those assets (likely to be presented in tabular format, with details in an appendix)
- Summary of how data on the inventory are managed (if not presented elsewhere)
- Summary of how data are used to consider adjustments to the process
- Impact of future growth on asset needs

Recommended Addition to the Inventory and Condition section:
The Extreme Weather Template would include the following questions for possible guidance on writing the Inventory and Condition section of a TAMP.*

1. **Provide a narrative and visual (e.g. table) describing the frequency, type of extreme weather, and impact of event by asset type in the last three decades. If available, discuss typical replacement costs such as labor, equipment, and materials for different types of assets.**

2. **What are the possible impacts of future extreme weather events on the agency's assets, both in terms of the possible greater intensity of such events or the likelihood of increased asset failures with deteriorating asset conditions in light extreme weather events?**

3. **Are certain types of assets more vulnerable to extreme weather events than others (e.g., culverts)?**

* Questions in bold are considered higher priority additions.

Exhibit 1: Extreme Weather/Climate Change Incorporated into the Basic TAMP Outline

Objectives and Measures

The Objectives and Measures section of the TAMP identifies the measures that will be used to track and manage asset performance. This section highlights the ways that asset management program activities are helping achieve agency goals and objectives. The AASHTO TAMP Builder suggests the following information may be presented in the Objectives and Measures section.

- Agency's objectives and measures, with discussion of the elements that link directly to asset management
- TAM program objectives
- TAM program measures linked to agency objectives
- Asset baseline conditions, reported through performance measures
- Snapshot of how the agency hopes the objectives will be met
- Agency's process for measuring, tracking, reporting and revising the measures
- If no Environmental Sustainability section has been included in the TAMP, how is the agency managing environmental risks?
- If no Communications and Reporting section has been included in the TAMP, how is the agency using measure to communicate with stakeholders and decision makers?

Recommended Addition to the Objectives and Measures section:

The Extreme Weather Template would include the following questions for possible guidance on writing the Objectives and Measures section of a TAMP, assuming there is no separate Environmental Sustainability section where extreme weather is discussed. If a separate section on environmental sustainability is provided in the TAMP, most of the questions regarding extreme weather impacts could be included in this section.*

1. **Which objectives are most susceptible to extreme weather-related risks? Has consideration been given to reducing extreme weather risks in achieving these objectives?**
2. **Have you considered performance measures that relate to asset risks and potential damage related to extreme weather events?**
3. **Does the agency have a risk tolerance policy (e.g., some facilities or assets are too important to fail?**

* Questions in bold are considered higher priority additions.

Exhibit 1: Extreme Weather/Climate Change Incorporated into the Basic TAMP Outline

Performance Assessment

The Performance Assessment section of your TAMP describes how the agency is doing with respect to measures, objectives and level of service goals that relate to asset management. It describes what is required to meet goals, and what is likely to happen given the actual budget. It also provides a description of the process by which the agency tracks performance (e.g. data collection, analysis, revision of policies or targets). The AASHTO TAMP Builder suggests the following information be presented in the Performance Assessment section.

- Relevant performance measures and current conditions, and a comparison to goals and objectives
- Projected future with respect to performance measures, given the budget
- Explanation of how these are linked to other sections of the TAMP
- Description of how these measures fit within the overall agency measures and how they support decision-making and program adjustments

If there is no Current Methods and Tools section in the TAMP, a summary of how the agency captures and analyzes data for performance monitoring should be included here

Recommended Addition to the Performance Assessment section:
The Extreme Weather Template would include the following questions for possible guidance on writing the Performance Assessment section of a TAMP.

1. **Which performance measures will be most affected by the influence of extreme weather?**
2. **Which other performance measures will be most affected by the influence of extreme weather?**
3. **How are these performance measures linked to other sections of the TAMP, and thus possibly cause a cascading effect of extreme weather impacts on the success of the TAMP?**
4. How are the potential impacts of extreme weather events considered in agency decision-making and program adjustments?

* Questions in bold are considered higher priority additions.

Exhibit 1: Extreme Weather/Climate Change Incorporated into the Basic TAMP Outline

Lifecycle Management

The Lifecycle Management section of the TAMP describes the management of the lifecycle of the agency's assets. As noted in the TAMP Builder, a lifecycle plan is a strategy for managing a group of assets with the aim of maintaining a specific level of service while minimizing costs. The AASHTO TAMP Builder suggests the following information be presented in the Lifecycle Management section.

- Plans for each asset type, or asset sub-group
- Relationship between lifecycle plans and performance measures
- Implementation of lifecycle management into the agency's decision making process

If no Asset Valuation section is included in the TAMP, a section on how the agency measures the value of assets could be included

Recommended Addition to the Lifecycle Management section:

The Extreme Weather Template would include the following questions for possible guidance on writing the Lifecycle Management section of a TAMP.

1. **How have extreme weather-related impacts been considered in the lifecycle management of the agency's assets? For example, have maintenance programs been adjusted to account for extreme weather considerations, e.g., are drainage cleaning activities conducted in anticipation of severe weather events or with greater frequency during storm seasons? Do designs for asset rehabilitation or reconstruction consider extreme weather and provide improved resiliency?**

2. **How have extreme weather-related risks to assets been identified and included in the agency's strategy to minimize damage due to extreme weather events?**

* Questions in bold are considered higher priority additions.

Exhibit 1: Extreme Weather/Climate Change Incorporated into the Basic TAMP Outline

Risk Management

The Risk Management section of the TAMP discusses the concept of risk, how it is incorporated into TAM, and the ways in which the consideration of risk informs maintenance practices, asset replacement or rehabilitation, and emergency response. The AASHTO TAMP Builder suggests the following information be presented in the Risk Management section.

- Agency-wide risk management strategy
- Risk management process for TAM

  – Risk-based asset inspections
  – Risk-based maintenance planning and practices
  – Emergency response plans
- Risk management monitoring, reporting and revising
- Risk register

Recommended Addition to the Risk Management section:
The Extreme Weather Template would include the following questions for possible guidance on writing the Risk Management section of a TAMP.

1. **How are extreme weather-related impacts considered in the agency-wide risk management strategy?**
2. **How has the risk of recurring damage and cost of future repair due to extreme weather events been considered in the risk management strategy?**
3. **How do risk-based asset inspections and monitoring take into account potential extreme weather impacts?**
4. Does your agency have a risk tolerance policy, that is, some assets should have a lower risk tolerance than others? This can help drive decisions on priorities.
5. How are extreme weather-related risks taken into account in maintenance planning and practices?
6. Have emergency response plans for extreme weather events available and have they been developed collaboratively with emergency response agencies?
7. What monitoring strategies and reporting processes related to extreme weather risks are in place to inform the agency’s risk management strategy? Are extreme weather risk monitoring and response strategies captured in the agency’s risk register?

* Questions in bold are considered higher priority additions.

Exhibit 1: Extreme Weather/Climate Change Incorporated into the Basic TAMP Outline

Financial Plan

The Financial Plan section of the TAMP details available funding for TAM activities, and the distribution of funds to date. This is done most often by asset type. The AASHTO TAMP Builder suggests the following information be presented in the Financial Plan section.

- Annual funding sources and budget
- Budgeting cycle and allocation decision process
- Overall TAM budget by activity type (e.g. maintenance, rehabilitation, data collection, etc.)
- TAM budget by asset type (and possibly sub-asset type)

Recommended Addition to the Financial Plan section:

The Extreme Weather Template would include the following questions for possible guidance on writing the Financial Plan section of a TAMP.

1. **How have agency funds been spent in responding to extreme weather events and their aftermath?**
2. **Which assets have had the greatest amount of funding allocated to reconstruction for recovery from extreme weather events?**
3. **To what extent is priority given to extreme weather-related adaptation projects?**
4. Are funds allocated to extreme weather risk monitoring/mitigation and/or programs to improve asset resiliency?

* Questions in bold are considered higher priority additions.

Exhibit 1: Extreme Weather/Climate Change Incorporated into the Basic TAMP Outline

Investment Strategies

The Investment Strategies section of the TAMP describes how the agency translates data, objectives, measures and policies into decisions about spending. At least two scenarios should be examined: 1) projected trends toward goals using the existing budget; and 2) the budget needed to meet all goals. The AASHTO TAMP Builder suggests the following information be presented in the Investment Strategies section.

- Relevant policies, objectives, measures and targets driving the investment strategy, and the reasons for the different scenarios
- Two (or more) scenarios
- Investment plan with budget levels, proposed projects, etc.

If no Future Demand section has been included in the TAMP, a description of how projected future growth is impacting the scenarios could be included here.

Recommended Addition to the Investment Strategies section:

The Extreme Weather Template would include the following questions for possible guidance on writing the Investment Strategies section of a TAMP.

1. **What are the short- and long-term financial needs associated with recovery from extreme weather events? How have these needs been reflected in the investment scenarios? And in the budget?**
2. What types of strategies for mitigating the potential impact of extreme weather events have been considered as part of the investment strategies?

* Questions in bold are considered higher priority additions.

Exhibit 1: Extreme Weather/Climate Change Incorporated into the Basic TAMP Outline

Process Improvements

The Process Improvements section describes the methods used to measure and provide input for improvements to your TAM practice. The AASHTO TAMP Builder suggests the following information be presented in the Process Improvements section.

- Process to assess and improve TAM activities
- Results of any previous findings and subsequent process adjustments

The Extreme Weather Template would include the following questions for possible guidance on writing the Process Improvements section of a TAMP.

1. **Have changes been made in the TAM process to incorporate consideration for extreme weather events?**
2. **What data or information is needed to improve the consideration of extreme weather/climate change factors in the TAMP?** For example, should failure points be calculated for each high priority asset to determine which assets have the smallest margin of error before failure occurs? Have economic loss calculations been estimated for high priority assets to guide decisions based on the amount of network and economic disruption?

* Questions in bold are considered higher priority additions.

Exhibit 2: Extreme Weather/Climate Change Incorporated into the Stand-alone Template

Introduction

1. **Explain how your agency assets have been affected by extreme weather related events such as flooding, tornadoes, mud slides, hurricanes, straight line winds, etc. in the last three decades. Describe expected trends on how extreme weather events might change in the future?**
2. **Have forecasts been made on how extreme weather events might change in the future? (e.g., more heavy precipitation for longer durations, warmer winters, etc.)?**

Inventory and Condition

1. **Provide a narrative and visual (e.g. table) describing the frequency, type of extreme weather, and impact of event by asset type in the last three decades. If available, discuss typical replacement costs such as labor, equipment, and materials for different types of assets.**
2. **What are the possible impacts of future extreme weather events on the agency's assets, both in terms of the possible greater intensity of such events or the likelihood of increased asset failures with deteriorating asset conditions in light extreme weather events?**
3. **Are certain types of assets more vulnerable to extreme weather events than others (e.g., culverts)?**

Objectives and Measures

1. **Which objectives are most susceptible to extreme weather-related risks? Has consideration been given to reducing extreme weather risks in achieving these objectives?**
2. **Have you considered performance measures that relate to asset risks and potential damage related to extreme weather events?**
3. **Does the agency have a risk tolerance policy (e.g., some facilities or assets are too important to fail?**

Performance Assessment

1. **Which performance measures will be most affected by the influence of extreme weather?**
2. **Which other performance measures will be most affected by the influence of extreme weather?**
3. **How are these performance measures linked to other sections of the TAMP, and thus possibly cause a cascading effect of extreme weather impacts on the success of the TAMP?**

Exhibit 2: Extreme Weather/Climate Change Incorporated into the Stand-alone Template

Lifecycle Management

1. **How have extreme weather-related impacts been considered in the lifecycle management of the agency's assets? For example, have maintenance programs been adjusted to account for extreme weather considerations, e.g., are drainage cleaning activities conducted in anticipation of severe weather events or with greater frequency during storm seasons? Do designs for asset rehabilitation or reconstruction consider extreme weather and provide improved resiliency?**

2. **How have extreme weather-related risks to assets been identified and included in the agency's strategy to minimize damage due to extreme weather events?**

Risk Management

1. **How are extreme weather-related impacts considered in the agency-wide risk management strategy?**
2. **How has the risk of recurring damage and cost of future repair due to extreme weather events been considered in the risk management strategy?**
3. **How do risk-based asset inspections and monitoring take into account potential extreme weather impacts?**
4. Does your agency have a risk tolerance policy, that is, some assets should have a lower risk tolerance than others? This can help drive decisions on priorities.
5. How are extreme weather-related risks taken into account in maintenance planning and practices?
6. Have emergency response plans for extreme weather events available and have they been developed collaboratively with emergency response agencies?
7. What monitoring strategies and reporting processes related to extreme weather risks are in place to inform the agency's risk management strategy? Are extreme weather risk monitoring and response strategies captured in the agency's risk register?

Exhibit 2: Extreme Weather/Climate Change Incorporated into the Stand-alone Template

Financial Plan

1. **How have agency funds been spent in responding to extreme weather events and their aftermath?**
2. **Which assets have had the greatest amount of funding allocated to reconstruction for recovery from extreme weather events?**
3. **To what extent is priority given to extreme weather-related adaptation projects?**
4. Are funds allocated to extreme weather risk monitoring/mitigation and/or programs to improve asset resiliency?

Investment Strategies

1. **What are the short- and long-term financial needs associated with recovery from extreme weather events? How have these needs been reflected in the investment scenarios? And in the budget?**
2. What types of strategies for mitigating the potential impact of extreme weather events have been considered as part of the investment strategies?

Process Improvements

1. **Have changes been made in the TAM process to incorporate consideration for extreme weather events?**
2. **What data or information is needed to improve the consideration of extreme weather/climate change factors in the TAMP?** For example, should failure points be calculated for each high priority asset to determine which assets have the smallest margin of error before failure occurs? Have economic loss calculations been estimated for high priority assets to guide decisions based on the amount of network and economic disruption?

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Appendix A: Approaches to Risk Assessment[3]

An asset is vulnerable to weather and climatic conditions if these conditions (such as intense precipitation and extreme temperatures) and their aftermath (such as floods and consecutive days of higher than 100^o temperatures) result in asset failure or sufficient damage to reduce its functionality. The *vulnerability* can thus be measured as the probability that the asset will fail given climate stressors ("there is a 90% chance the bridge in its current condition will fail with a 500-year flood"). Vulnerability primarily focuses on the condition of the asset.

Climate-related *risk* is more broadly defined in that risk can relate to impacts beyond simply the failure of the asset. It relates to the failure of that asset in addition to the consequences or magnitudes of costs associated with that failure. In this case, a consequence might be the direct replacement costs of the asset, direct and indirect costs to asset users, and, even more broadly, the economic costs to society given the disruption to transportation. The importance of broader economic costs to the risk analysis should not be underestimated. For example, if a bridge is located on the only major road serving a rural community and there is a possibility that the bridge could be washed out with major storms, the measure of consequence should include the economic impacts of isolating that community for some period of time while the bridge is being replaced.

Putting it all together, the complete risk equation is thus:

Risk = Probability of Climate Event Occurrence x Probability of Asset Failure x Consequence or Costs

One can see from the equation that low probability climate events (e.g., a category 5 hurricane hitting your community) but with high probabilities of asset failure and high consequence costs if it does could still have high risk scores. Likewise, events with lower consequence costs but greater probability of occurrence or failure could lead to similarly high risk scores.

In order to determine vulnerability as part of a risk assessment one must first determine which assets, asset types or locations are to be targeted. This is the case simply because a transportation agency will not have enough resources to climate-proof all of its assets. Understanding the likely climate stressors is clearly important to understand potential threats. However, it is also important to define the focus or purpose of the risk mitigation process. Are you going to only focus on assets that are considered most important from an interstate commerce perspective? Or are you going to identify the most vulnerable assets no matter where in the network and invest in asset protection? Or are you going to fix the weather-related problems the highway network is currently facing on the assumption that such problems will only be exacerbated in the future if you do not?

Risk scoring can support the choice and timing of adaptation investments, helping distinguish between the merits of incremental improvements versus (or in concert with) major, singular

[3] This appendix is a summary of a risk chapter found in NCHRP 750, Vol.2.

investments and providing guidance as to when implementation should occur. Particularly for assets that are expected to last beyond 2050, or even 2100, it is important to mitigate the risks of failure, deterioration, or frequent disruption due to climate hazards. For existing infrastructure, identifying high risk assets or locations provides decision makers with some sense of whether additional funds should be spent to lower future climate change-related risk when reconstruction or rehabilitation occurs. This could include conducting an engineering assessment of critical assets that might be vulnerable to climate stressors. This approach, in essence, "piggy backs" adaptation strategies on top of other program functions (e.g., maintenance, rehabilitation, reconstruction, etc.).

Several recent studies have illustrated alternative approaches to handling the uncertainty in climate events occurring. Each of these provides a possible option for considering the likelihood of climate events occurring.

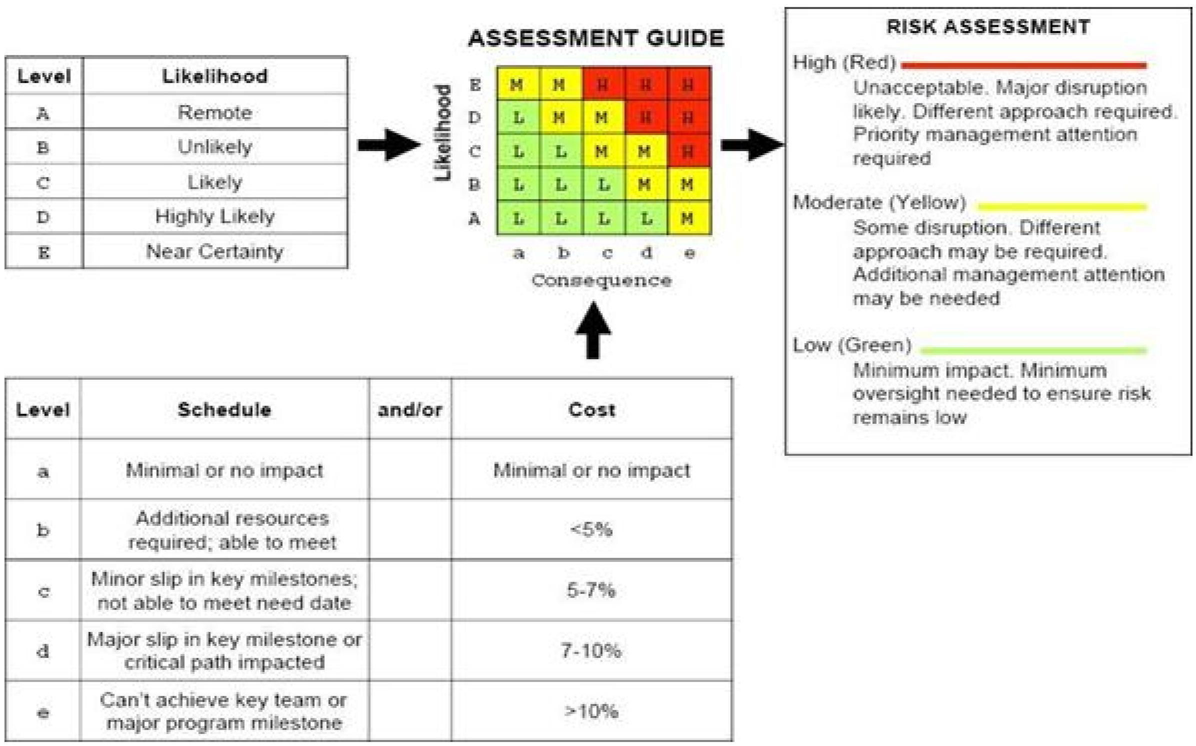
1. *Establish thresholds for climate stressors:* This approach defines thresholds for planning and design and does not worry if they will be reached. For example, common sea level rise thresholds were established for planning purposes in California [Sea-Level Rise Task Force of the Coastal and Ocean Resources Working Group for the Climate Action Team (CO-CAT) 2010], and used by the Bay Area's Metropolitan Transportation Commission (MTC) in its "Adapting to Rising Tides" report [Metropolitan Transportation Commission 2011].

2. *Ignore the timing (and thus the likelihood) of a climate event:* This approach in essence does not worry about when a climate-damaging event might occur, but simply assumes it will. Washington DOT's pilot project for the Federal Highway Administration's (FHWA's) conceptual adaptation model chose to eliminate timeframe when conducting scenario analysis, in other words they assumed the climate stressor was going to happen and did not worry about when [Washington State DOT 2011].

3. *Adopt a climate forecast as the "design" condition:* Due to limited resources, the North Jersey Transportation Planning Authority (NJTPA)/New Jersey DOT FHWA pilot project adopted a single, mid-range value for its transportation asset risk analysis. The project included the generation of high, medium, and low stressor values to bracket the range of plausible climate outcomes, which it suggested pairing with assets of high, medium, and low criticality. [North Jersey Transportation Planning Authority 2011]. Highly critical assets—those essential to system functionality, for example—would be assessed for potential vulnerability and thus risk given the asset was determined to be "critical") using the highest stressor values, assets of medium criticality with medium stressor values, and so on. This model of risk management reflects a Dutch-style approach to planning amid uncertainty, where assets that absolutely cannot fail (such as dykes and levees) are designed to withstand the most extreme events (such as the 1/10,000 year storm event). Several methods have been used to conduct a risk assessment

without the use of probabilities, falling into three major categories: risk assessment matrix, numerical scoring and probability ranges.

4. *Risk assessment matrix:* Figure A-1 is offered by the Federal Highway Administration as one way of including both the likelihood of a climate event occurring and the potential level of disruption given that the event occurs. [Federal Highway Administration, 2012] Washington State DOT used this approach in identifying which of its assets were at highest risk for different types of climate stressors. Figure A-2 shows how the different WSDOT assets could be rated with respect to risk (Washington State DOT 2011).

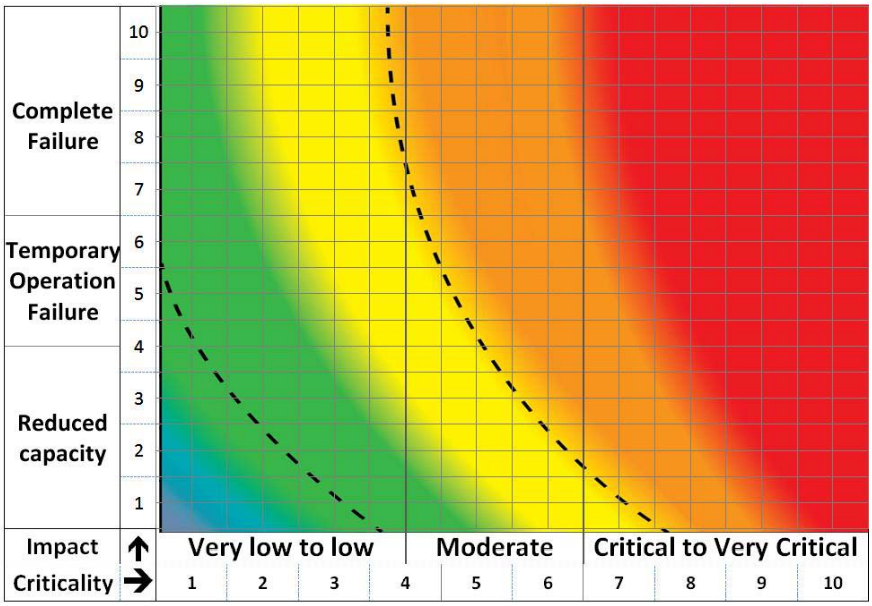


Level	Likelihood
A	Remote
B	Unlikely
C	Likely
D	Highly Likely
E	Near Certainty

Level	Schedule	and/or	Cost
a	Minimal or no impact		Minimal or no impact
b	Additional resources required; able to meet		<5%
c	Minor slip in key milestones; not able to meet need date		5-7%
d	Major slip in key milestone or critical path impacted		7-10%
e	Can't achieve key team or major program milestone		>10%

Source: [FHWA, 2012]

Figure A-1: An Approach for Considering Risk in Decision making



Source: [Washington State DOT,2011]

Figure A-2: Washington State DOT's Assessment Approach for Identifying Assets at Risk

5. *Numerical scoring:* Another approach to risk assessment is to establish criteria for the component parts of risk, and then rate each asset from the perspective of potential level of effect. For example, the UK Highways Agency developed a risk-based adaptation process that focused on four risk criteria: uncertainty, rate of climate change, extent of disruption and severity of disruption. [Highways Agency and Parsons-Brinkerhoff 2008] Each criterion was ranked on the basis of a high (3 points), medium (2 points) or low (1 point) score. For example, for extent of disruption, three points were assigned if the disruption was expected to affect 80 percent of the network or any strategic route in the network; two points for 20 to 80 percent disruption; and one point for less than 20 percent disruption. Similarly, for the severity of disruption, three points were assigned if the duration was greater than one week; two points if it was to last one day to one week; and one point if it was less than one day. Based on the risk appraisal and a combination of the different risk factors, the following concerns were identified as being potentially highly disruptive and time critical with high levels of confidence in the appraisal:

First Tier

- Pavement skid resistance
- Identifying best ways of investing resources/investment appraisals

Second Tier

- Wind actions (loads) applied to superstructures
- Designs for increased scour for foundations
- Pavement material integrity
- Strategic geographic importance of a region
- Network resilience
- Budgeting
- Staffing

Third Tier

- Pavement materials specification and construction details
- Design of pavement foundations
- Design of bearings and expansion joints
- Surface water drainage
- Attenuation and outfalls
- Pavement maintenance
- Flooding

6. *Probability ranges:* If one cannot determine an exact probability for an event occurring, this approach assigns probability ranges and links them to qualitative descriptors. The studies that have used this approach in essence state that although it is difficult to estimate with certainty that a certain event will occur say with a 60 percent probability, one can estimate with some level of confidence that the probability of the event will fall within a 55% and 90% probability range. This could then be labeled a "highly likely" probability. probability ranges, that is, "almost certain" (90 to 100% probability), "very likely" (55 to 90%), "likely" (30 to 55%), 'unlikely" (5 to 30%), and "rare" (0 to 5%).

7. *Expert opinion:* Most transportation agencies have engineering staff or consultants who are very familiar with the design of different assets. Based on years of experience with asset failures (e.g., culvert failures given intense precipitation), these engineers can provide an engineer's estimate of what it would take from a climate stressor perspective for a particular asset to fail. These failure estimates can then be used in conjunction with the probabilities of such stressor levels actually occurring.

8. *Historical analysis:* An agency could examine past records of asset failures given different weather and climate-related events. For example, a frequency curve over time showing the incidence of certain types of weather events and the resulting monetary damage to particular assets would in essence become a damage frequency curve. Such curves could be used to determine what monetary damage might occur with increasing frequency of such events in the future. The caution with this

approach, however, is that future events could be very different from past events, and thus a DOT should not rely solely on historic records.

9. *Engineering studies:* For particular types of assets and/or for locations that might be particularly vulnerable to extreme weather events the agency could conduct engineering studies that would assess the current asset condition and determine expected failures given varying stressor levels. Such studies would identify different options that could be considered to reduce the potential for failure.

10. *Scenarios:* Where the probabilities of climate-related events and the probabilities of damage to assets are known, the costs and benefits of the performance of a system over a range of climate-related possibilities are determined using expected values. This approach is in essence creating different decision tress or paths of possible outcomes. The expected value of annual damages is "the sum across the set of all possible damaging events of the product of the likelihood of a given event and the damages associated with it. Yearly expected value damage estimates are summed to estimate the total expected value over the planning period, with or without discounting as desired." [Kirshen et al, 2011]

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Appendix B: Minnesota Case Study

The Minnesota Department of Transportation (MnDOT) has one of the most advanced risk-based asset management plans in the U.S. To a large extent the development of the asset management plan benefitted from the adoption years before of an Enterprise Risk Management Framework for agency decision-making (see Figure B-1). This Framework, "establishes the standards, processes and accountability structure used to identify, assess, prioritize and manage key risk exposures across the agency." [MnDOT, 2013] A risk-based approach was used to develop the Statewide Highway Systems Operation Plan (HSOP), as well as the Statewide Long-range Transportation Plan. Developing a risk-based asset management plan thus was part of the culture in the agency. Because many of the risks associated with the general threats to agency operations and budgets had been dealt with in other plans and programs, the asset management plan strategy was to focus on assessing and developing mitigation strategies for "undermanaged" risks, where opportunities existed for improving the asset management process. Risks associated with natural events (e.g. floods, storms, earth movement), operational hazards (e.g. vehicle and vessel collisions, failure or inadequacy of safety features, and construction incidents), asset aging effects (e.g. steel fatigue or corrosion, advanced deterioration due to insufficient preservation or maintenance), adverse conditions in the economy (e.g. shortage of labor or materials, recession), staff errors or omissions in facility design, operations, or provision of services; or defective materials or equipment, lack of up-to-date information about defects or deterioration, or insufficient understanding of deterioration processes and cost drivers were identified as the major transportation-related risks.

The process DOT officials went through is illustrative of how a risk-based approach for extreme weather/climate change factors could occur. The process followed in identifying risks and risk mitigation strategies is shown in Figure B-2. MnDOT began by looking at the "global" risks such as natural events, operational hazards, etc. and the potential impacts on the asset, the public and the agency. Work Groups of technical experts were formed to describe and rate the major risks related to each asset category. Figure B-3 shows a rating scale, similar to the rating scales presented in Appendix A. Each Work Group developed a series of risk statements and risk ratings, identified risk mitigation strategies estimated mitigation costs. This process was iterative, extending over three workshops. The work groups ended up identifying the risks by asset type shown in Figure B-4. The risks in italics were considered to be those that were undermanaged by MnDOT and became the focus of the TAMP risk management strategy.

Risk management strategies were identified in a seven-step process.

Step 1: Define preferred mitigation strategy for addressing the risk identified.

Step 2: Identify data, resources, tools, and/or training required to enact the strategy.

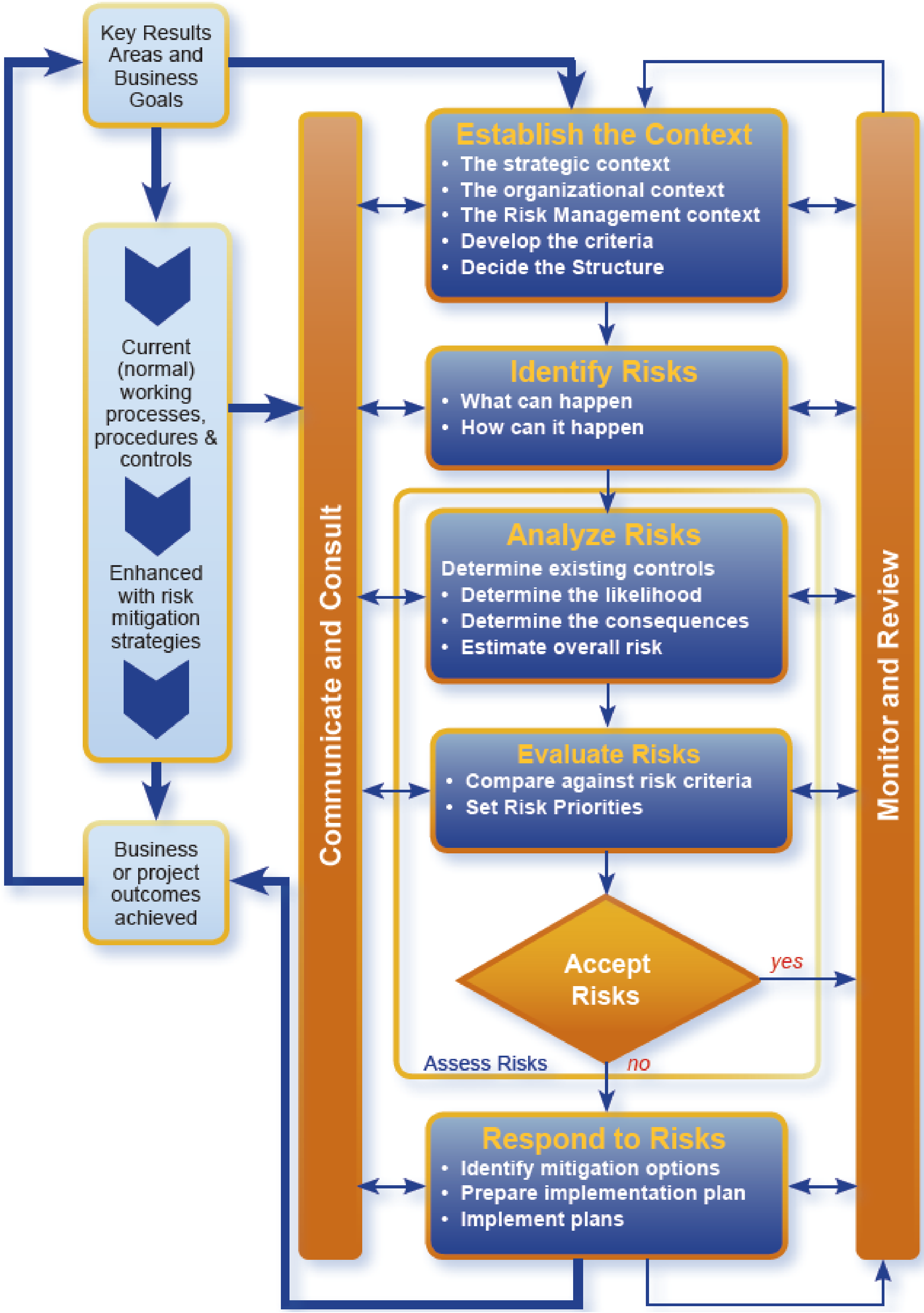

Figure B-1: Enterprise Risk Management Approach in Minnesota DOT

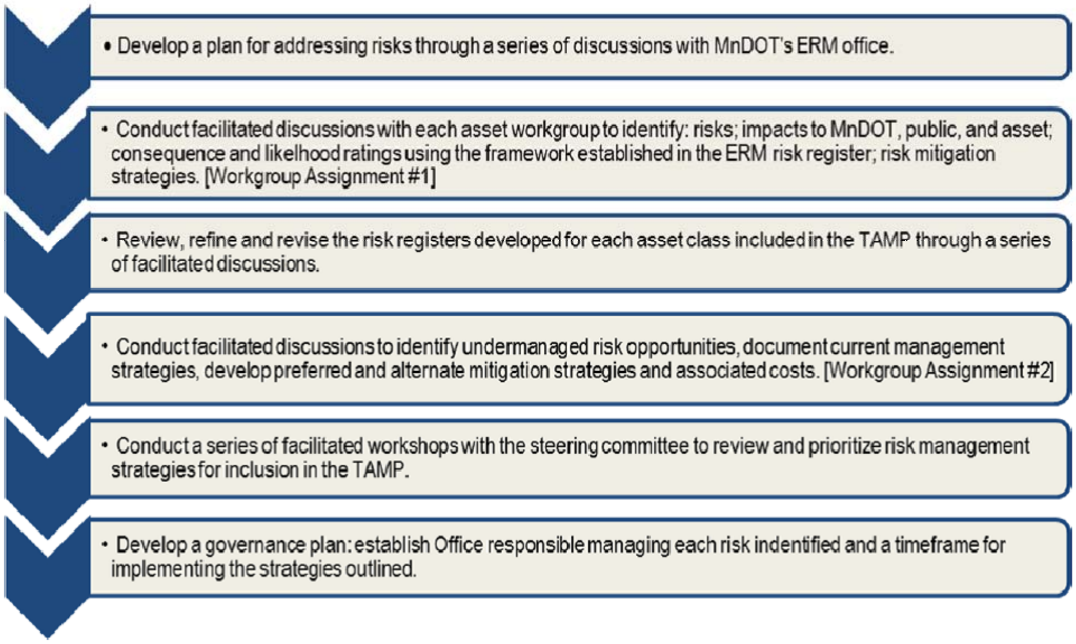

Figure B-2: Risk Identification Process, MnDOT

CONSEQUENCE RATINGS	LIKELIHOOD RATINGS AND RISK LEVELS				
	RATE	UNLIKELY	POSSIBLE	LIKELY	ALMOST CERTAIN
CATASTROPHIC	Medium	Medium	High	Extreme	Extreme
MAJOR	Low	Medium	Medium	High	High
MODERATE	Low	Medium	Medium	Medium	High
MINOR	Low	Low	Low	Medium	Medium
INSIGNIFICANT	Low	Low	Low	Low	Medium

Figure B-3: Risk Rating Matrix, MnDOT

PAVEMENTS	BRIDGES
• *Not meeting public expectations for pavement quality/condition at the state/district/local levels* • *Inappropriately managing or not managing pavements such as frontage roads, ramps, and auxiliary lanes* • Inability to meet federal requirements (such as MAP-21, GASB, etc.) • Inability to appropriately manage to lowest life-cycle cost • Premature deterioration of pavements • Significant reduction in funding • Occurrence of an unanticipated event such as a natural disaster	• *Lack of or deferred funding* • *Inability to manage to lowest life-cycle cost* • Occurrence of an unanticipated natural event • Catastrophic failure of the asset • Significant damage to the asset through manmade events • *Premature deterioration of the asset* • Shortage of workforce
HIGHWAY CULVERTS AND DEEP STORMWATER TUNNELS	**OVERHEAD SIGN STRUCTURES AND HIGH-MAST LIGHT TOWER STRUCTURES**
• *Failure/collapse of tunnel/culvert* • *Flooding and deterioration due lack of tunnel capacity* • *Lack of culvert capacity* • *Inability to appropriately manage culverts* • Inability to appropriately manage tunnels • Inappropriately distributing funds or inconsistency in culvert investments • Significant damage to culverts through manmade events	• Lack of having a mandated process for inspection • *Poor contract execution* • *Inability to manage to lowest life-cycle cost* • Significant damage to asset through manmade events • Premature deterioration of the asset • Unforeseen changes in regulatory requirements, travel demands, or technology • *Shortage of workforce*

Figure B-4: Identified Asset Risks, MnDOT

Step 3: Describe whether the strategy will reduce the likelihood of another identified risk.

Step 4: Estimate the approximate cost of implementing the preferred mitigation strategy.

Step 5: Identify whether an alternate strategy might be available that doesn't fully mitigate the risk but lowers the overall likelihood or consequence associated with the risk.

Step 6: Estimate the cost associated with the alternate strategy.

Step 7: For both strategies developed, identify the impact on likelihood and consequence of the original risk should either of the strategies be adopted.

The process resulted in the following priority investments highlighted in the TAMP.

PRIORITY LEVEL 1: HIGH PRIORITY, ADDRESS IMMEDIATELY

- Pavements: Annually track, monitor, and identify road segments that have been in Poor condition for more than five years, and consistently consider them when programming.
- Deep Stormwater Tunnels: Address the repairs needed on the existing South I-35W tunnel system.
- Deep Stormwater Tunnels: Investigate the likelihood and impact of deep stormwater tunnel system failure.
- Highway Culverts: Develop a thorough methodology for monitoring highway culvert performance.
- Overhead Sign Structures and High-Mast Light Tower Structures: Develop and adequately communicate construction specifications for overhead sign structures and high-mast light tower structures.
- Overhead Sign Structures and High-Mast Light Tower Structures: Track overhead sign structures and high-mast light tower structures in a Transportation Asset Management System (TAMS).

PRIORITY LEVEL 2: ADDRESS BASED ON ESTABLISHED PRIORITIES

- Pavements: Collect and evaluate performance data on ramps, auxiliary lanes, and frontage road pavements for the highway system in the Twin Cities Metro Area.
- Bridges: Augment investment in bridge maintenance modules and develop related measures and tools for reporting and analysis.
- Highway Culverts: Include highway culverts in MnDOT’s TAMS.
- Deep Stormwater Tunnels: Place pressure transducers in deep stormwater tunnels with capacity issues.
- Deep Stormwater Tunnels: Incorporate the deep stormwater tunnel system into the bridge inventory.
- Overhead Sign Structures: Develop a policy requiring a five-year inspection frequency for overhead sign structures, as well as related inspection training programs and forms.

PRIORITY LEVEL 3: REVISIT WHEN ADDITIONAL FUNDING BECOMES AVAILABLE

- Highway Culverts: Repair or replace highway culverts in accordance with recommendations from the TAMS.

The Minnesota DOT case study presents a good model for considering asset risks in the development of a TAMP. The use of such an approach was most likely easier in MnDOT than it might be in another state DOTs simply because MnDOT had already progressed along the learning curve on how risks could be incorporated into agency planning and decision-making. Nonetheless, the use of internal asset experts and facilitated meetings, along with a data-driven analysis process, were shown to be successful in developing a TAMP that is a national model.