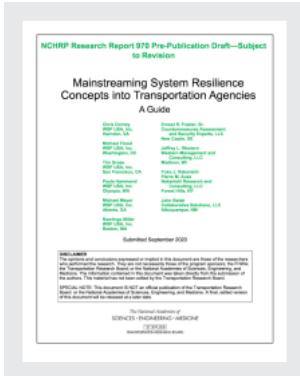


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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed, and implementable research is the most effective way to solve many problems facing state departments of transportation (DOTs) administrators and engineers. Often, highway problems are of local or regional interest and can best be studied by state DOTs individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

Recognizing this need, the leadership of the American Association of State Highway and Transportation Officials (AASHTO) in 1962 initiated an objective national highway research program using modern scientific techniques—the National Cooperative Highway Research Program (NCHRP). NCHRP is supported on a continuing basis by funds from participating member states of AASHTO and receives the full cooperation and support of the Federal Highway Administration (FHWA), United States Department of Transportation, under Agreement No. 693JJ31950003.

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Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ADAP	Adaptation Decision-Making Assessment Process
BCA	Benefit Cost Analysis
CDOT	Colorado Department of Transportation
CEO	Chief Executive Officer
CFR	Code of Federal Regulations
CMM	Capability Maturity Model
COOP	Continuity of Operations Plan
CORDEX	Coordinated Regional Climate Downscaling Experiment
CPTED	Crime Prevention Through Environmental Design
CRP	Cooperative Research Program
CSET	Cybersecurity Evaluation Tool
DHS	Department of Homeland Security
DOT	Department of Transportation
ER	Emergency Response and Emergency Relief (FHWA program)
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
GCM	Global Climate Model
GHG	Greenhouse Gas
GIS	Geographic Information System
HSEEP	Homeland Security Exercise and Evaluation Program
ICS	Industrial Control System
IT	Information Technology
LCP	Least Cost Planning
LOCA	Localized Constructed Analogues
MAP-21	Moving Ahead for Progress in the 21st Century Act
MMS	Maintenance Management System
MPO	Metropolitan Planning Organization
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
O&M	Operation and Maintenance

ODOT	Oregon Department of Transportation
P3	Public-Private Partnership
QA/QC	Quality Assurance/Quality Control
RCP	Representative Concentration Path
SGR	State of Good Repair
TAM	Transportation Asset Management
TAMP	Transportation Asset Management Plan
TEACR	Transportation Engineering Approaches to Climate Resilience
TMC	Traffic Management Center
TRB	Transportation Research Board
TSA	Transportation Security Administration
TSMO	Transportation System Management and Operations
USDOT	US Department of Transportation
USGS	US Geological Survey
VHD	Vehicle Hours of Delay

Summary

Transportation officials throughout the country are considering transportation system resilience to any form of disruption as a critical component of their agency's policy and program decision-making. This is due primarily to a recognition that a reliable and sustainable transportation system is needed to fulfil their agency's mission and goals. In addition, however, as has been seen in many major system disruptions, the public perception of the effectiveness of their agency often relates to how the agency responds to small and large disruptions.

The purpose of this guide is to provide transportation officials with a self-assessment tool to assess the current status of an agency's efforts to improve the resilience of the transportation system through the mainstreaming of resilience concepts into agency decision making and procedures. The tool can be applied to a broad array of natural and human-caused threats to transportation systems and services. It focuses on such threats and describes actions to minimize the consequences of the related disruptions. The guide looks at resilience not only from an agency perspective (and thus focusing on the types of responsibilities these agencies have), but also from a societal perspective. This latter perspective introduces into the assessment such issues as the transportation-related economic, social, public health, and financial implications of system disruptions.

The self-assessment tool is based on a resilience framework, the Framework for Enhancing Agency Resilience to Natural and Anthropogenic Hazards and Threats (FEAR-NAHT), hereafter referred to as the Framework. The Framework consists of the following steps:

Step 1: Assess Current Practice

Step 2: Organize for Success

Step 3: Develop an External Communications Strategy and Plan

Step 4: Implement Early Wins

Step 5: Understand the Hazards and Threats

Step 6: Understand the Impacts

Step 7: Determine Vulnerability/Risk and Prioritize Responses

Step 8: Identify Actions to Enhance Resilience

 Step 8A: Assess Strategies for Enhancing Emergency Response Capabilities

 Step 8B: Identify Enhancements to Operations and Maintenance Activities

 Step 8C: Undertake Detailed Assessments of Exposed Assets and New Projects

 Step 8D: Integrate into Asset Management

Step 9: Program and Implement Resilience Measures

Step 10: Monitor and Manage System Performance

The self-assessment tool consists of a set of questions relating to the capabilities of an agency related to each step. For example, for Step 8A: *Assess Strategies for Enhancing Emergency Response Capabilities*, questions are asked concerning an agency's efforts to identify and improve its current efforts at providing emergency response to major disruptions. The tool allows the users to score on a scale of 1 to 3 how their agency is doing with respect to each factor. An overall score for each step and

for the entire agency allows managers to (1) assess the current status of the agency's capabilities for improving transportation system resilience and (2) identify actions that could be taken to enhance these capabilities.

The guide also provides guidance on how individual functional responsibilities in a transportation agency can be improved. Recommended actions are provided for:

- Policy development/agency leadership and management
- Planning
- Project development/engineering
- System and traffic operations
- Construction
- Maintenance
- Asset management
- Emergency response/agency preparedness
- Public outreach/communications

Although each self-assessment step provides very specific recommended actions targeted for that step, the following themes run throughout the guide.

- **Collaboration** – Given the multi-agency, multi-participant, and multi-disciplinary nature of many resilience actions and efforts, many of the factors emphasize the level to which your agency has made the effort to collaborate with partner agencies and other groups.
- **Communication** – Partly due to the need for collaboration as noted above, but also recognizing the importance of external communication to inform key stakeholders and constituency groups, many factors focus on the degree to which your agency's communication strategy is effective and inclusive of the many different resilience roles and contributions of your agency.
- **Data collection and analysis** – Given that resilience projects and strategies will compete with other demands for resources in your agency, many of the assessment factors focus on the need to provide evidence-based information that justifies resilience investment.
- **Hazard and threat assessment** – By its very nature, system resilience reflects the degree to which a transportation system can withstand stresses placed upon it. Whether such stresses occur today (e.g., riverine floods that close major highways) or whether they are part of a long-term trend (e.g., sea level rise), mainstreaming resilience efforts into an agency's functions requires an understanding of the nature, scope, and magnitude of expected system disruptions. The term "hazards" is used in the guide to refer to transportation stresses caused from natural sources (e.g., flooding or wildfire hazards). The term "threats" is used in the guide to refer to transportation system stresses caused from human sources (e.g., cyberattacks).
- **Institutional capacity** – Mainstreaming any effort, action, or initiative in an agency requires institutionalizing it in the organizational structure, considering how leaders use information, and evaluating how standard operating procedures can be changed to lead to the desired results. Many of the self-assessment factors relate to how resilience concepts and efforts have been institutionalized (that is, mainstreamed) into the structure of your agency.
- **Leadership** – Most transportation agencies are structured in a hierarchy with very clear lines of authority and responsibility. Thus, many of the self-assessment factors reflect the degree to which an agency's leadership is directing, supporting, and adopting resilience initiatives. Without leadership support very little of any significance is likely to happen.

- **Professional training and professional development** - Providing resilience-related training and professional development opportunities for staff in different functional areas is an important strategy for improving the human resource capabilities of your agency in promoting resilience-oriented actions.

Chapter 1: Introduction

Transportation system resilience has always been a critically important—if under recognized—characteristic of effective system performance. It is becoming more so with the growing awareness of the consequences of natural and human-caused system disruptions. In the case of extreme weather, events over the years have demonstrated (often with tragic consequences) that many state department of transportation (DOT) assets, as well as other public and private assets, are at risk.

Consider the following:

- According to the U.S. National Weather Service, the U.S. experienced 14 weather and climate disaster events in 2019 (the last full year reported before publication) having losses exceeding \$1 billion per event. The years 2011 and 2016 each had 16 such events. The U.S. experienced a total of \$258 billion in weather disasters from 1980 to 2019, including tropical cyclones, severe storms, riverine floods, freeze, drought, and wildfires. Weather disasters in 2017 set a new record for cumulative costs in one year of over \$306 billion (with Hurricanes Harvey, Irma and Maria alone accounting for just over \$265 billion of this total). Over the past 40 years, the frequency of billion-dollar disasters has increased from an annual average of 6.5 events over the entire 40 years to an annual average between 2015 and 2019 of 13.8 events.¹
- With respect to human-caused disruptions, terrorist attacks against the New York City subway system and Brussels transit system in 2016 and other attacks in London, Brussels, St. Petersburg (Russia) in 2017 highlighted how vulnerable transportation systems can be to physical attacks.
- The past several years have also seen disruptive cyberattacks against transportation services in states (the Colorado Department of Transportation in 2018), cities (Atlanta and Baltimore in 2017), and private firms (Maersk in 2017).

These natural and human-caused events resulted in significant damage and disruption to communities, transportation systems, and to the organizations that provide mobility. The accumulated experience of state DOTs to such disruptions and the importance of a high-performing and reliable transportation system to the nation, states, and communities have increased the interest of transportation officials in what steps they can take to enhance the resilience of the transportation system. With that in mind, this guide presents a tool that can be used to assess the status of a transportation agency's capabilities with respect to resilience actions and strategies. It also identifies actions to enhance an agency's contribution to a more resilient transportation system.

This chapter is organized as follows. The first section describes the purpose of the guide. The next section provides a definition of resilience that serves as the foundation for the recommendations in the guide. The section after this describes some key characteristics of resilience and of disruptive events themselves that serve as important points of departure for identifying appropriate transportation agency responses. The remaining three sections identify relationships between this research and other resilience research projects, the intended audiences, and the organization of the guide.

¹ National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI), 2020. U.S. Billion-Dollar Weather and Climate Disasters. Retrieved June 30, 2020, 2020 from <https://www.ncdc.noaa.gov/billions/>

Purpose of the Guide

The purpose of this guide is to provide transportation officials with a benchmark that can be used to assess the current status of an agency's efforts to create a more resilient transportation system. It also identifies actions and strategies to enhance and mainstream resilience actions into their agencies. The guide is organized around the Framework for Enhancing Agency Resilience to Natural and Anthropogenic Hazards and Threats (FEAR-NAHT), the Framework, a 10-step process that can be used to identify where changes in an organization and in collaborative institutional relationships should be made to better mainstream resilience efforts (see Chapter 2 for a detailed description of the Framework). The Framework has evolved over the experiences and lessons learned from many studies on system resilience and adaptive transportation system design. It focuses on the institutional tools, governance steps, policies, processes, data, performance measures, work plans, and funding support a transportation agency should consider to enhance its resilience efforts and evolve the culture of the agency to one where system resilience is part of the standard way of doing business.

Purpose of the Guide

This guide provides transportation officials with a tool that can be used to assess how their agency is currently doing with respect to actions that lead to a more resilient transportation system, and that identifies strategies to enhance and mainstream such actions in their agency.

The combination of the Framework and a self-assessment methodology described in the following chapters leads to the self-assessment tool proposed in the guide. The tool can be applied to a broad array of natural and human-caused threats to transportation systems and services. It focuses on these threats, and describes actions that can be taken to minimize the consequences of system disruptions. The guide looks at resilience not only from an agency perspective (and thus the types of responsibilities these agencies have), but also from a societal perspective. This latter perspective introduces into the assessment such issues as the transportation-related economic, social, public health, and financial implications to society.

It should be noted that the self-assessment tool is based on key analysis steps and factors identified by this research project. They reflect the results of an extensive literature review, case studies, and the conclusions/lessons learned from the Transportation Resilience Innovations Summit and Exchange (RISE Conference), an international conference on transportation system resilience held in October, 2018. However, the usefulness and effectiveness of any self-assessment tool reflects an agency's ability to adjust the tool to make it more targeted to the circumstances facing that agency. Thus, although the tool presented in this guide offers ranges in the level of agency capability with respect to mainstreaming resilience concerns into decision making, guide users may need to adjust the tool to meet their unique needs and circumstances.

Defining Resilience and Other Key Terms

The concept of "system resilience" is found in many different fields, including environmental science, ecology, community structure, organization theory, management science, and the built environment. In addition, in the context of transportation, resilience encompasses many different types of strategies --- network redundancy, back-up systems, adaptive design, and the like. The following key terms are common to many of the definitions of resilience in these fields, and especially to those relating to the built environment and transportation. These concepts are also important for the types of strategies and actions proposed in this guide.

What is a resilient transportation agency? The following definition is offered by the Federal Highway Administration (FHWA):

A resilient transportation agency is one that has, "...the ability to anticipate, prepare for, and adapt to changing conditions; and withstand, respond to, and recover rapidly from disruptions."²

Notice that this definition, which this report adopts, focuses on the abilities and capabilities of an organization's efforts to enhance transportation system resilience, that is, a system that withstands, responds to, and can recover from disruptions.

It is important to note that resilience to natural hazards (including extreme weather, climate change, and the like) and resilience to cyber or other human-caused threats are similar in concept, but somewhat different in application. Different professions and disciplines are involved and each brings its own perspectives on terminology and definitions. Given this, it is important to have a common understanding of how terms are used in this document. When used in this report, these words have the following meanings:

Adaptation: Used especially in the context of climate change and extreme weather, adaptation means taking steps to adapt a community or targeted assets prior to a disruption event to minimize the impacts, if not avoid them altogether. An example would be increasing the diameter of new culverts in areas likely to experience increased flooding in the future.

Emergency/Incident Management: Efforts to prepare for and respond to disruptive incidents or events. This has been a focus of many DOTs as part of their transportation system management and operations strategy. The emphasis tends to be on the hazards or incidents of today and not on longer-term, chronic threats due to climate change. An example might be a DOT's emergency response service---efforts to respond to crashes and other incidents in order to save lives and return the system to normal operations as quickly as possible.

Exposure: The presence of infrastructure in places and settings where it could be adversely affected by hazards and threats, for example, a road in a floodplain.³

Hazard and Threats: Stresses on transportation system performance and condition. Whether such stressors occur today (e.g., riverine flooding that closes major highways) or whether they are part of a long- term trend (e.g., sea level rise), mainstreaming resilience efforts into an agency's functions requires an understanding of their nature, scope, and magnitude. The term "hazards" is used in the guide to refer to transportation stressors originating primarily from natural causes (e.g., flooding or wildfire hazards). The term "threats" is used in the guide to refer to transportation system stressors caused by human actions (e.g., the cyberattack threat).

Mitigation: Actions taken to reduce the contributors to potential impacts. When considering climate change, however, mitigation has a different meaning. In the climate change context, mitigation refers

² Federal Highway Administration (FHWA). 2015. Transportation System Resilience to Extreme Weather and Climate Change – Executives, Adaptation to Climate Change in Transportation Systems Management, Operations, and Maintenance, Publication FHWA-HOP-15-024. Nov. Washington DC. Retrieved June 30, 2020 from <https://ops.fhwa.dot.gov/publications/fhwahop15024/index.htm>

³ This definition is adopted from the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report. 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

to strategies and actions to reduce the emission of greenhouse gases (GHGs) that contribute to climate change, whereas adaptation is focused on actions that can be taken to prevent or minimize the impacts (i.e., the climate science community's use of the term adaptation is more akin to the term mitigation as used in system resilience planning). This report adopts the use of the terms mitigation and adaptation as used by the climate science community when discussing climate-related hazards; the word mitigation is used as defined above when discussing other hazards and threats.

Recovery: Steps or stages a system goes through to regain the major functions of the system to pre-disruption performance and/or condition. For example, community recovery after an earthquake often includes the financial support, medical services, debris removal, and longer term re-investment needed to replace damaged structures and infrastructure.

Resilience: The characteristic of a system that allows it to absorb, recover from, or more successfully adapt to adverse events.

Resilience-oriented Agency: The ability of an organization to prepare and plan for, manage, and recover from expected transportation system disruptions.

Resilience Program: A set of organizational actions, strategies, and efforts that collectively lead to a more resilient transportation system.

Risk: A combination of the likelihood of exposure and some measure(s) of the consequences of a disruption to the transportation system caused by that exposure.

Uncertainty: The degree to which a future condition or system performance cannot be forecast. Both human-caused and natural disruptions, especially for longer term climate changes, are by their very nature uncertain events (as no one knows for sure exactly when and where and with what intensity they will occur). Sensitivity tests using multiple plausible scenarios of future conditions can help one understand the range of uncertainty and its implications. This approach is used routinely when working with climate projections to help understand the range of possible conditions given different future (uncertain) GHG emission scenarios.

Vulnerability: Per FHWA, "the degree to which a system is susceptible to or unable to cope with adverse effects of climate change or extreme weather events."⁴

Workforce Resilience: As a critical component of institutional capacity, workforce resilience includes both the staff mindset toward accepting and supporting agency resilience efforts, and the physical and mental health of the workforce.

Each of these concepts is found throughout this guide. For example, the self-assessment tool includes a step where vulnerabilities to the transportation system are estimated for different types of hazards. From this, the guide then encourages practitioners to identify types of adaptation, mitigation, and recovery strategies that could be considered to lower such risks.

⁴ FHWA. 2014. "FHWA Order 5520."Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events." Dec. 15. Retrieved June 30, 2020 from <https://www.fhwa.dot.gov/legsregs/directives/orders/5520.cfm>

Relationship to Other Resilience Research and Guidance

A plethora of transportation system resilience guidance materials has been developed over the past several years. Many such materials address resilience from a societal perspective (e.g., community resilience), which encompasses all types of community-supportive infrastructure including transportation networks. Others examine very specific hazards/threats (e.g., cyberattacks) or targeted functions within a transportation agency (e.g., system operations or emergency response). Still others focus on one aspect of the resilience self-assessment tool presented in this guide (e.g., vulnerability/risk assessments). More detail on how the guide relates to this other guidance can be found in Appendix A. It is important to understand that this guide presents an overarching/all-encompassing approach designed specifically for DOTs. The guidance/tools for other agencies and organizations can fit into various points of the guide's self-assessment tool where appropriate.

An important context for the material included in the guide is that much of the information on resilience strategies and actions comes from research conducted under the auspices of the Transportation Research Board's (TRB's) Cooperative Research Programs (CRPs). The research focusing on system resilience was particularly helpful (see TRB <http://www.trb.org/Main/Blurbs/166648.aspx>). Also of note is that this research project was conducted in concert with two other projects:

- NCHRP Project 20-59(54), "Transportation System Resilience: Research Roadmap and White Papers". This study resulted in a strategic plan for research on transportation system resilience including the identification of research problem statements.
- NCHRP Project 20-59(55), "Transportation System Resilience: CEO Primer & Engagement". This study developed a primer for transportation executives entitled "Resilience: A DOT Imperative." The primer provides a high-level guide for DOT officials on how to incorporate resilience into agency operations. Where appropriate, guidance from the primer is referenced in this guide.

The crosswalk between the CEO Primer & Engagement and this guide is particularly relevant in that both focus on similar concepts but are aimed at different audiences.

Table 1 compares the major topics included in both. As shown, there is a very close connection between the two documents in terms of the topics covered.

Intended Audiences

The primary intended audiences for the guide includes:

- Transportation officials/leaders who want to understand how to evolve their agency to be more resilient-oriented.
- Transportation agency staff who are responsible for system resilience-related functional areas within transportation agencies.

Although the focus is on transportation agency leadership and staff, others who are interested in system resilience might find the document insightful. These include, (1) non-transportation organizations or community officials who interact with transportation agencies during the response to disruptions and (2) stakeholders who are concerned about making their communities more resilient. With this in mind, the document is written to be accessible to non-transportation professionals.

Table 1: Comparison Between the CEO Primer and this Guide

Topical Areas in the CEO Primer (Aimed at CEOs)	Topical Areas in this Guide (Aimed at Agency Managers and Staff)
Integrating Resilience Throughout Your Agency	Mainstreaming Transportation Agency Resilience Capabilities Assess Current Practice (Step 1) Organize for Success (Step 2) Implement “Early Wins” (Step 4) Understand the Hazards and Threats (Step 5) Understand the Impacts (Step 6) Determine Vulnerability/Risk and Prioritize (Step 7)
Planning and Programming	Program and Implement Resilience Measures (Step 9); Monitor and Manage System Performance (Step 10); and Planning Functional Area
Asset Management	Integrate into Asset Management (Step 8D)
Design and Engineering	Undertake Detailed Assessments of Exposed Assets and New Projects (Step 8C)
Operations and Maintenance	Identify Enhancements to Operations and Maintenance Activities (Step 8B); Assess Capabilities for Enhancing Emergency Response and Agency Preparedness for Disruptions (Step 8A)
Agency Communications	Develop an External Communications Strategy and Plan (Step 3)
Cybersecurity	Cybersecurity examined throughout

Guide Organization

The guide is organized largely according to the steps in the Framework. Note that each of the chapters describing these steps (chapters 3 to 16) presents the types of agency characteristics that represent the highest level of resilience capability (or as used in the guide, maturity) for that particular step as well as the types of agency characteristics that represent lower levels of maturity. Each chapter also includes strategies that can be used to proceed from a lower level of maturity to a higher one. For each step, where it is appropriate, a discussion is provided on both natural hazards and human-caused threats.

In addition, although the self-assessment steps are presented in a logical sequence of what should come first before other steps are undertaken, in some cases, the steps could occur in parallel. For example, Step 8A, *Assess Strategies for Enhancing Emergency Response Capabilities*, is placed where it is because any enhancements to such capabilities relate to gaining a better understanding of the types

of impacts that are expected (analyzed in Steps 5 to 7). However, some actions could occur for Step 8A prior to this (indeed, many are ongoing at DOTs already).

The guide is organized in the following chapters:

Chapter 2: A Framework and Self-Assessment Tool for Mainstreaming Transportation Agency Resilience Capabilities—Overview of the Framework and the DOT self-assessment tool.

Chapter 3: Assess Current Practice (Step 1)—Understanding and assessing current practices in a DOT as they relate to fostering and mainstreaming system resilience.

Chapter 4: Organize for Success (Step 2)—Establishing organizational structures, relationships, protocols and interorganizational partnerships that support resilience efforts.

Chapter 5: Develop an External Communications Strategy and Plan (Step 3)—Creating new strategies and amending current actions to make the case for system resilience and supporting other agency resilience efforts.

Chapter 6: Implement “Early Wins” (Step 4)—Identifying resilience-oriented strategies and actions that can be undertaken in the short-term and often without great cost.

Chapter 7: Understand the Hazards and Threats (Step 5)—Identifying the types of hazards and threats likely facing the transportation system.

Chapter 8: Understand the Impacts (Step 6)—Identifying the likely impacts and consequences of the different hazards and threats on the DOT, state, communities, the economy, etc.

Chapter 9: Determine Vulnerability/Risk and Prioritize (Step 7)—Identifying where more detailed facility-level adaptation assessments need to be undertaken first due to the seriousness of a type of hazard or threat or because of the significance of the facility or asset.

Chapter 10: Identify Actions to Enhance Resilience (Step 8)—Introduction of Step 8, which consists of four sub-steps.

Chapters 11: Assess Strategies for Enhancing Emergency Response Capabilities (Step 8A)—Identifying improvements to the emergency response program, including enhancing the effectiveness of partnerships with other participants.

Chapter 12: Identify Enhancements to Operations and Maintenance Activities (Step 8B)—Identifying how any agency’s operations and maintenance efforts can be enhanced to contribute to the resilience program and strategy.

Chapter 13: Undertake Detailed Assessments of Exposed Assets and New Projects (Step 8C)—Conducting more detailed assessments that evaluate adaptation options for specific assets/projects (recommendations are made on how to do the assessments).

Chapter 14: Integrate into Asset Management (Step 8D)—Integrating resilience concerns and concepts into an agency’s asset management program so that investment decisions supported by the program consider system resilience as an important prioritization factor.

Chapter 15: Program and Implement Resilience Measures (Step 9)—Incorporating resilience projects and support for resilience strategies into the agency budget, capital investment programs, and operations budgets.

Chapter 16: Monitor and Manage System Performance (Step 10)—Establishing performance measures on transportation system resilience and internal organizational output measures that can be used to monitor progress toward a more resilient transportation system.

Chapter 17: Mainstreaming Resilience into Agency Practice—Incorporating the different strategies identified in the self-assessment into different functional activities in a DOT.

As noted earlier, Appendix A presents information on how the guide relates to this other resilience research and guidance. Individual templates for the strategies that can be considered by functional DOT units are provided in Appendix B.

How to Use the Guide: A Roadmap

Transportation agencies will likely exhibit very different levels of maturity with respect to how resilience concerns are integrated into the different functional responsibilities in the agency. For example, it is likely that an agency's emergency response capability will be at a higher maturity level (based on the assessment criteria in this guide) with respect to system resilience because there has been a long history of organizations focusing on this topic. Conversely, it is likely that many of the latter steps in the Framework---undertaking detailed adaptive designs, integrating resilience into asset management processes, and monitoring transportation system resilience with adopted metrics---will be in the most need of improvement since many of these topics are relatively new to the field. Given that every agency will be different, the self-assessment tool is designed to allow transportation officials to enter into the self-assessment process in several different ways.

1. **For those agencies just starting out**.....you should begin with Step 1 and proceed through all ten steps. The intent is for the self-assessment tool to provide a systematic and comprehensive examination of your agency's capabilities in all aspects of transportation system resilience.
2. **For those agencies who consider themselves to have strong resilience-oriented capabilities** It would still be useful to begin at Step 1, which assesses what your agency is currently doing with respect to transportation system resilience. Based on this determination, you can then jump to the steps in the self-assessment tool where you think additional effort might be necessary or use the functional area templates in Chapter 17 to identify specific actions to enhance your capabilities where you believe there might be gaps.
3. **For those agencies (or agency managers) concerned about specific agency functional areas and how resilience-oriented concerns could be better mainstreamed**.... again, you are still encouraged to start with Step 1 to get a good sense of what your agency is currently doing with respect to resilience-oriented efforts. The functional area templates in Chapter 17 also provide very useful guidance on what agency managers should consider to enhance capabilities in their functional area responsibility. Asking your managers responsible for each functional area to examine these templates in order to identify actions they could take would also be a good place to start for improving your agency's resilience capabilities.

As suggested above, no matter how capable you might think your agency is with respect to resilience, the self-assessment tool is designed to find areas where such efforts can be enhanced.

Chapter 2: A Framework and Self-Assessment Tool for Mainstreaming Transportation Agency Resilience Capabilities

The Framework gathers in one sequence of steps the various activities that will enhance an agency's resilience efforts to natural and human-caused hazards and threats. The Framework guides transportation officials in, (1) understanding what their agency is currently doing with respect to resilience, (2) identifying where new or modified actions could be taken to enhance these efforts, and (3) recommending steps that can be taken to implement these actions. A variety of other resilience frameworks (discussed later) have touched on various aspects of an organizational perspective on resilience. However, most have never really connected all of the different steps into one overall agency resilience self-assessment perspective (or they have done so at such a high level as to be of limited value to those responsible for implementing actions).

Some key characteristics of the Framework include:

- Both human-caused (e.g., cyberattacks) and natural disruptions (e.g., riverine flooding), are considered, including a focus on future climate changes.
- Both chronic (e.g., permanent inundation due to sea level rise) and acute (e.g., storm surge) hazards and threats are considered.
- Every major functional area within a DOT is found in the tool given that all will have a role in making the transportation system more resilient. Strategies are offered that cross typical agency lines of responsibility.
- The importance of external stakeholders is noted, given that planning for and responding to disruptions often requires the participation of many different agencies, organizations, communities, and groups. Effective resilience programs require multi-disciplinary collaborative efforts.
- The benefits, costs, and community impacts of having a resilient transportation system (or not) are found throughout the assessment tool. The implications of a compromised transportation asset affect more than just the DOT. Community safety, economic, and social impacts, and in a broad sense quality of life, can be affected as well.

These characteristics are integrated throughout the guide where appropriate.

The next section presents an overview of the Framework and the steps that can be taken to enhance agency resilience efforts. This section introduces each step of the Framework, which are the topic of a subsequent chapter. This section is followed by an example showing how the Framework's steps relate to an effort by the Oregon Department of Transportation (ODOT) to prepare for a significant earthquake in the western portions of the state. The next section presents the self-assessment tool, which can be used to determine the status of a DOT's resilience efforts and to identify the strategies for improving these efforts. The chapter ends by describing how each chapter associated with a step in the Framework is organized.

The Framework Overview

Figure 1 shows how the Framework is structured. As noted earlier, the flow in the steps is linear, implying that preceding steps should be completed prior to undertaking the next step. In many cases this is a requirement. For example, one cannot really understand the impacts of potential threats and hazards (Step 6) without knowing what they are (Step 5). However, in some cases, DOT officials could address a particular step without necessarily fully completing a prior step. For example, one could

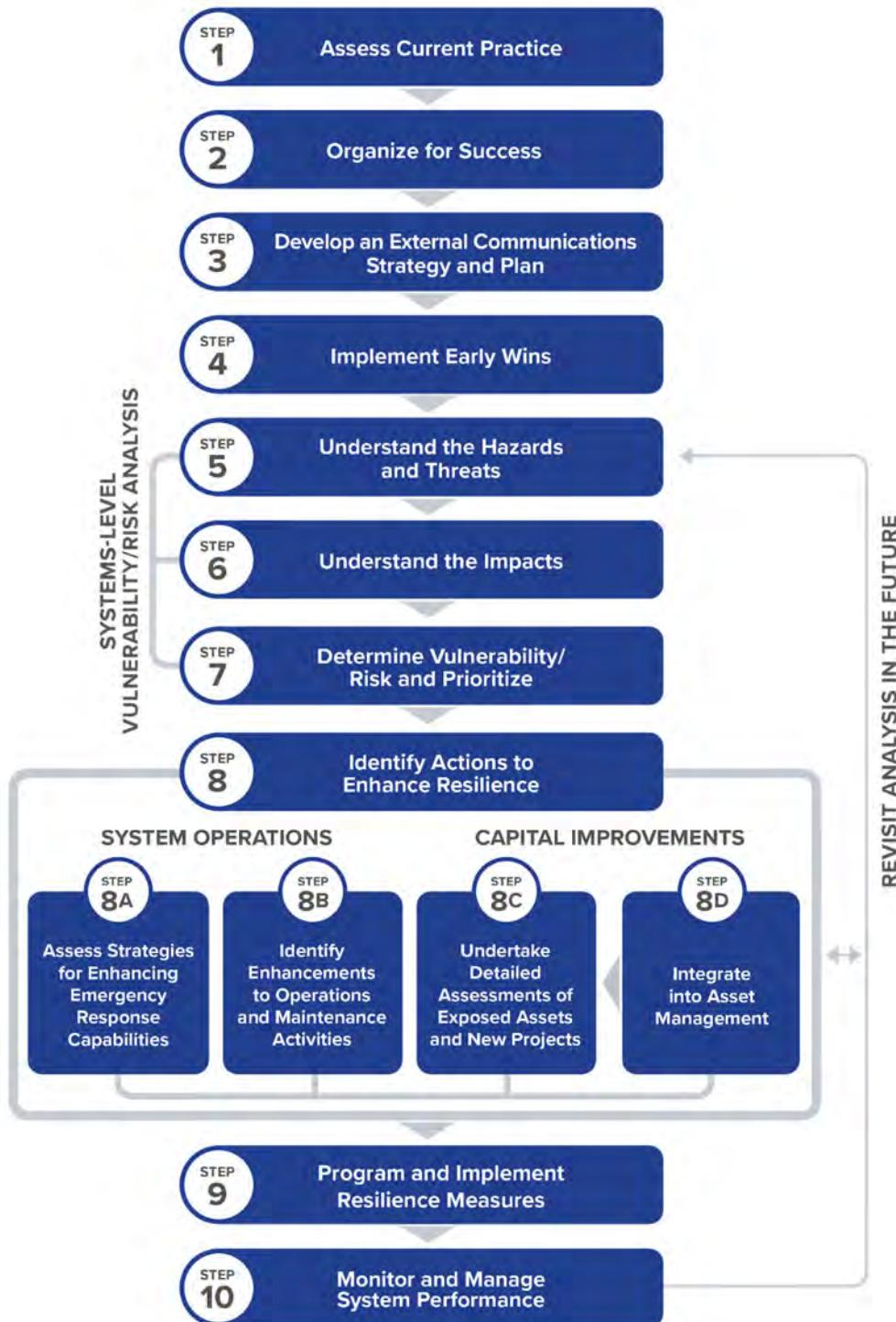


Figure 1: Framework for Enhancing Agency Resilience to Natural and Anthropogenic Hazards and Threats (FEAR-NAHT: The Framework)

develop an effective resilience communication strategy for the agency (Step 3) without necessarily conducting a self-assessment of how the agency is organized for success (Step 2). It would help to have conducted prior steps in such cases, but it is not a prerequisite to do so. Nonetheless, a sequential approach using all the steps is highly recommended when using the self-assessment tool. Specific steps within the Framework include:

Step 1: Assess Current Practice

Understanding the current state-of-practice of your organization's resilience activities is a basic point-of-departure for determining where enhancements to these efforts can occur. All units within a transportation agency should be the focus of such an assessment. This chapter also identifies some of the major characteristics of a resilience-oriented agency.

Step 2: Organize for Success

One of the results of Step 1 is identifying where new or modified institutional structures or mechanisms can lead to more effective and efficient resilience actions. The focus of improving organizational capability is both internal (What can the agency do better?) and external (How can the agency better interact with key partners and stakeholders to improve collective efforts to improve the resilience of the transportation system?). This chapter examines strategies for developing improved organizational capability from the perspective of an organization's structure and information flow.

Step 3: Develop an External Communications Strategy and Plan

One of the lessons learned from many DOT experiences with system disruptions is that effective communications among the many different participants responding to an incident or disruptive event is critical to overall success. This step examines how such communications and information exchange can be improved. Importantly, this step also includes efforts to inform/educate/ highlight the DOT's efforts at improving transportation system resilience to the public and other key stakeholders. This encompasses making a case for investments that improve system resilience.

Step 4: Implement Early Wins

As part of an overall strategy for improving resilience capability, transportation agencies should be identifying and implementing strategies/actions that can be taken in the short term, with low costs, and limited need for time-consuming data analysis. The reasons for this are many. First, such actions can lead to immediate improvements in system resilience, ultimately the goal of a DOT's efforts. Second, it indicates that the DOT is in fact moving forward in its stated strategy. Third, it sends a message to DOT employees that the agency is serious and is willing to make changes. Fourth, it provides the public and others (e.g., legislators) with a "visual" of what types of actions fall under the agency's overall strategy. Finally, early implementation of resilience actions could reveal barriers/constraints that need to be overcome in order to make later implementation more successful. This chapter provides guidance on how to identify such early wins.

For the following three steps, it is important to note that Step 5 is the first step in a systems-level vulnerability or risk analysis. The systems-level analysis encompasses Steps 5 through 7 of the Framework. In a systems level analysis, hazards and threats are identified (Step 5), their consequences understood (Step 6), a vulnerability or risk score (inclusive of exposure and consequence information) is assigned to each asset (Step 7), and assets are prioritized for more detailed study (based upon their vulnerability; also Step 7).

Step 5: Understand the Hazards and Threats

This step examines and understands the sources and magnitude of the likely hazards and threats facing a transportation system. This is a prerequisite for developing a more resilient transportation system. This step examines the nature and likely characteristics of the types of hazards and threats facing the transportation system and, importantly, what these hazards and threats might be in the future when conditions could be very different. These conditions will vary from state to state.

Step 6: Understand the Impacts

Knowing the sources and expected magnitude of likely hazards and threats is an important precursor to answering the question, "So what?" This step, the second in the systems-level vulnerability/risk analysis portion of the Framework, provides ways of examining the impacts and consequences of different hazards and threats. Different types of hazards and threats will likely have very different impacts and consequences to the agency, surrounding communities, and to broader societal and economic systems. This step provides a broad perspective on documenting these impacts.

Step 7: Determine Vulnerability/Risk and Prioritize Responses

This step represents the culmination of the systems-level vulnerability/risk analysis. Once potential hazards/threats are understood along with their consequences, specific assets within the transportation system that are more vulnerable or at-risk (i.e., have greater exposure and/or higher consequences of failure) need to be identified and prioritized for more detailed study of adaptation options. This step identifies the assets where more detailed assessments should be first conducted (i.e., those that are most vulnerable). A prioritization is needed because there are likely to be too many asset vulnerabilities for a given DOT to address all at once given resource constraints.

Step 8: Identify Actions to Enhance Resilience

This step identifies the projects, strategies, and actions that an agency could take to improve transportation system resilience. State DOT experience with system resilience activities has shown that the following agency functional areas are strong candidates for making improvements: (1) emergency response, (2) operations and maintenance programs, (3) project design and development (assuring a more adaptive design approach), and (4) asset management plans and programs.

Step 8A: Assess Strategies for Enhancing Emergency Response Capabilities

Most DOTs have developed protocols and relationships within the agency itself and with other partners for responding to incidents and disasters. Such response is very much part of the system resilience capabilities of DOTs. This step identifies actions and strategies that can be taken to enhance current emergency response capabilities in light of a better understanding of the likely impacts and consequences of disruptions (from Step 7). By its very nature, this step will be multi-hazard, multi-participant, and multi-disciplinary. In addition, this step examines how prepared an agency itself is to survive major disruptions (e.g., cyberattacks).

Step 8B: Identify Enhancements to Operations and Maintenance Activities

Operations and maintenance (O&M) efforts within a transportation agency are often the first groups affected by system disruption. In a reactive sense, managing detoured traffic and removing debris after an event are important actions that are the responsibility of the transportation agency. However, one can also view O&M in a proactive way, that is, what can a DOT do to minimize future disruptions? For example, making sure culverts are debris-free--a maintenance function--has been shown to be a critical factor in reducing the likelihood of culvert failure. Making sure evacuation

operational plans and institutional partnerships are in place can minimize the level of disruption experienced when key network links have failed. This step looks at the types of actions you can take to ensure your agency's O&M efforts are best positioned to enhance transportation system resilience.

Step 8C: Undertake Detailed Assessments of Exposed Assets and New Projects

This step conducts the detailed assessments of exposed assets identified and prioritized in Step 7. In addition, new capital improvement projects (including those delivered through the asset management program) should also undergo detailed assessments. These assessments will vary by type of hazard or threat and with the level of resources that are available for conducting the assessments. For example, doing a detailed assessment for a cyberattack threat will utilize very different methods and approaches than one focusing on future flood risks. The results of this step will be a set of actions/strategies/ projects that should be implemented by your agency.

Step 8D: Integrate into Asset Management

This step recognizes the important role that asset management has in transportation agencies for monitoring asset condition (and tracking other considerations) and for feeding such information into investment priorities. The factors associated with this step focus on how resilience concepts, in particular the vulnerability or risk scores, can be incorporated into asset management recommendations so that they will be considered as part of the investment prioritization process. This step also considers how the asset management system can be used to help monitor and manage resilience investments and their performance.

Step 9: Program and Implement Resilience Measures

Resilience projects will likely be part of the normal project programming process although this step assumes that some special considerations be given when doing so. Such consideration might also be applied to projects being undertaken for purposes other than enhancing resilience but that incorporate resilience treatments. Ultimately, influencing the types of projects implemented by the agency is one of the most important output measures for an agency's resilience program.

Step 10: Monitor and Manage System Performance

Many transportation agencies have adopted performance-based decision-making and program management approaches for identifying the most cost effective investments. Such approaches are data-driven, performance-based, and results-oriented. This step examines how resilience concepts can be incorporated into transportation system performance monitoring and how agency actions aimed at enhancing the resilience component of this performance can be better managed.

State DOT Example Application of the Framework

Table 2 shows how the different steps in the Framework are found in an effort by the Oregon DOT (ODOT) to develop a strategy for minimizing damage and recovering from a large earthquake. This effort was undertaken by ODOT in advance of the development of the Framework yet it illustrates the approach remarkably well. That said, it is limited to a single hazard whereas the Framework recommends a multi-hazard approach for all of the steps. Note too that although ODOT's effort is portrayed in Table 2 as a logical and systematic sequence of steps, in reality, ODOT's efforts occurred over several decades and depended to a large extent on the interest, energy, and often voluntary efforts of individual DOT officials supported by ODOT leadership. Also, not all of the Framework steps

Table 2: Example of the Framework Concepts Applied to Seismic Hazards by Oregon DOT

THE FRAMEWORK STEP	WHAT DID/IS OREGON DOT DOING WITH RESPECT TO SEISMIC HAZARDS?
Assess Current Practice (Step 1)	There was no systematic nor agency-wide assessment at the beginning. However, the state bridge engineer in the 1990s determined that the national design code for seismic bridge design was inadequate for Oregon and the DOT adopted more stringent requirements. ODOT is now considering what other functions (besides emergency response) should be examined.
Organize for Success (Step 2)	ODOT did not look at organizational issues at the start. ODOT supported several seismic vulnerability studies with consultants and with a state university. An ODOT "resilience officer" was appointed primarily because of a state effort to have such a person in each agency. ODOT is continuing to improve their processes and procedures, especially for emergency response.
Develop an External Communications Strategy and Plan (Step 3)	ODOT did an initial study in 1990 that portrayed a dismal picture of the possible impacts of an earthquake. This was not published nor discussed in public. However, once the legislature became interested and when several earthquakes and tsunamis happened in other parts of the world, ODOT decided to release the report. ODOT considered the report and associated communications efforts as an important foundation for what they have been doing since. ODOT officials are meeting with the Areawide Transportation Commissions and Metropolitan Planning Organizations (MPOs) to talk about what they can be doing to assess the vulnerability of their own systems. Resilience has now become part of the lexicon of the agency and is found in ODOT's state plans and policy statements.
Implement Early Wins (Step 4)	ODOT officials noted two "early wins": <ul style="list-style-type: none"> • Changed the bridge design criteria as noted above • Starting in the 1990s, for bridge projects that were going to occur anyway, ODOT added small cost incremental improvements to make the bridges more fail-proof. Six such projects were done to understand what the costs of such a mitigation strategy might be.
Understand the Hazards and Threats (Step 5)	The genesis of the ODOT concern came from the bridge engineer who was listening to scientists and other experts on what an earthquake could mean to Oregon. A seismic study was later commissioned specifically focusing on transportation and ODOT looked at what other state DOTs were doing in terms of earthquake impacts. A tsunami in Japan in 2011 hit the Oregon coast causing renewed interest in protecting the coast and those that live there.
Understand the Impacts (Step 6)	In the early 1990s, ODOT officials did not feel they knew enough about the seismic impacts on bridges so they adopted an approach from another state DOT that predicted damage from different sized earthquakes. However, not knowing if this approach was appropriate for Oregon, ODOT funded a study to develop its own approach in 1990. The focus, just on bridges, was used to develop an ODOT-specific method for prioritizing vulnerable bridges. This study was published in 2005 and received considerable attention in state government. ODOT funded another study to estimate the economic impact of earthquake-caused disruption to the economy in different state regions. A network model was used, including traffic estimates, to include impacts on mobility and freight movement in the study. A major conclusion of the study was that, depending on

	<p>the size of the quake, there will likely be some parts of the state where the economy would take 7 to 8 years to recover; in some parts there would be very limited road access for up to 3 years.</p> <p>A third study was then undertaken to identify the most vulnerable sections of the state highway system. Landslides were included in addition to bridges. The focus of the study was on lifeline corridors. Impact cost estimates were made for those highway segments where the most disruption was expected to occur. Time costs of detours were used as surrogates for economic costs. Vulnerable lifeline corridors were described and vulnerable route segments identified.</p> <p>In 2013, the legislature passed a resolution for there to be a study on "Resilient Oregon." Each state agency was asked to participate; ODOT contributed 60 volunteers (all modes, all units) to help write the transportation chapter for this report. The chapter explained possible impacts of an earthquake to the transportation system.</p>
Determine Vulnerability /Risk and Prioritize (Step 7)	<p>The lifeline study identified three tiers of lifeline corridors, with the performance metric being roads should not be closed any longer than three weeks (the best estimate for how long Oregonians could "shelter in place" before the disruption became unbearable). Cost information from pilot projects was used to estimate an overall cost of about \$5 billion, much in excess of the estimated capital funds available. The capital needs list was prioritized into three tiers of \$1 billion each (called a triage system).</p> <p>The study has become the overall strategy for the state and for ODOT. The recovery focus is on Medford, OR which, according to analysis, will likely survive an earthquake. The airport, roads, and other infrastructure are being prepared to be the point of national emergency response after the quake. Because of this, ODOT prioritized two highway corridors, SR97 and SR 58, as the focus of vulnerability assessments.</p>
Enhance Emergency Response Capabilities and Operations/ Maintenance Activities (Steps 8A and 8B)	<p>Two notable actions were taken by ODOT to enhance emergency response and system operations capabilities.</p> <ul style="list-style-type: none"> • The earthquake study showed the vulnerability of Oregon's coast to tsunamis and the potential isolation of communities due to the failure of state roads. In order to prepare for the consequences, ODOT doubled the size of three maintenance stations to store emergency supplies of food and fuel, asset replacement materials, and undertook other pre-positioning of equipment. • ODOT has created a second center of system operations in Bend, OR east of the Cascades and out of the impact zone. ODOT located redundant command and control capabilities in the district office and has complete backup of all personnel, financial, and budgetary files.

Undertake Detailed Assessments (Step 8C)	Detailed assessments were conducted on SR 97 and SR 58, focusing on bridges and landslides. ODOT estimated that the total cost for the required investment was \$35 million all of which has been programmed (note that this is focused just on seismic protection). This cost represented 20% of the entire Phase 1 project list for the state.
Integrate into Asset Management (Step 8D)	Projects developed as part of the seismic program have been incorporated into ODOT's transportation asset management program. (Note: this is one pathway for tying adaptation into asset management--after a project is built, feeding it back in to asset management for monitoring, however, another key pathway exists which is to feed in the vulnerability scores from Step 7 into the asset management process).
Program and Implement Resilience Measures (Step 9)	<p>ODOT projects have been prioritized in the capital program, both as incremental improvements to projects that were going to occur anyway, as well as a resilience-specific set of projects.</p> <p>Without knowing how much additional funding might be available, ODOT modified its strategy and started talking to Areawide Transportation Commissions and MPOs to encourage their own studies and investment programs. A regional planning agency in the southern part of the state did not agree with the project schedule that had projects in their area scheduled as part of Phase 3 (likely not implemented for 20 to 30 years). The agency undertook its own study that identified routes to provide access into the region after an earthquake for a total investment of \$5 to \$6 million; the ODOT estimate had estimated \$50 million. ODOT had focused its efforts only on state highways. The planning agency assumed providing access to key sites by both state and local highways, including using roads in California. The agency used as much of the ODOT-protected road as possible but the focus was on finding the least costly options, not the investment that resulted in the shortest travel time.</p> <p>ODOT is working with other counties to see if they can adopt the same approach. Three counties have done so, and many others have studies underway. ODOT is working with Portland Metro to help in the Portland metropolitan area on this topic.</p> <p>ODOT will continue to fund resilience projects on their prioritized investment list as money is identified.</p>
Monitor and Manage System Performance (Step 10)	No metrics have been developed at the system resilience-level, but ODOT's bridge management system is used to monitor bridge condition and changes over time.

Source: ODOT officials interviewed, December 2018.

were undertaken as part of ODOT's overall strategy. Keeping these important caveats in mind, the ODOT experience nevertheless provides a tangible example to understand the Framework.

The Resilience Capability-Maturity Model

A capability maturity model (CMM) serves as the basis for the self-assessment tool presented in this guide. The CMM concept was developed for the information technology (IT) industry primarily because of the need to match the requirements for software use to the ability of the organization and of staff to utilize it appropriately. Although originally developed for organizations that were outcome-oriented and service-focused, CMM has now spread to other industries and sectors.

The key concepts of a CMM approach include:

- *Influence Factors* -- the variables/factors that can enhance or degrade successful implementation, collaboration, or organizational change. These are called by different names in different CMM tools; some call these “domains” others “causal variables.” In this self-assessment tool, they are referred to as “factors.” The factors in the guide were identified through this research project.
- *Maturity Level* -- the combined set of actions/strategies/policies/planning history that represents a user-specified level of maturity (in this case relating to resilience). Different models usually identify from four to six levels of maturity. Knowing your current maturity level serves as a “point of departure” for the analysis, and is the focus of the self-assessment tool for each step in the Framework and for the agency as a whole.
- *Maturation* – changing the level of maturity by using strategies targeted at specific influence factors. For example, establishing formal institutional mechanisms for fostering collaboration is likely an important step in institutionalizing what may have been ad hoc previously.⁵

The self-assessment tool is based on these basic principles and concepts. After the self-assessment tool has been applied, all functional areas within an agency that have a role in fostering a more resilient transportation system will have been examined and gaps in resilience capability identified. The self-assessment provides users with an ability to enhance resilience activities within the agency and to strengthen partnerships with others (in the terms of the CMM, both are considered efforts to enhance organizational maturity).

Three levels of organizational maturity with respect to resilience efforts are defined in the self-assessment tool.⁶ Level 1: We use maintenance data to schedule maintenance efforts. The only system resilience use of maintenance data is in reporting to the FHWA requirements on repeated disruptions and repairs on the National Highway System (NHS).

- Level 2: We use a maintenance management system for all state highways and use this information to schedule maintenance actions. If those collecting the data find poor asset

⁵ Federal Highway Administration (FHWA). 2016. “Transportation Performance Management Capability Maturity Model,” Office of Transportation Performance Management. Retrieved June 30, 2020, from <https://www.tpmtools.org/wp-content/uploads/2016/09/tpm-cmm.pdf>

⁶ In practice, there is likely to be a continuum of agency maturity because many different attributes can be mixed and matched. In fact, some CMM frameworks use 4 or 5 maturity levels. For purposes of this self-assessment tool, three maturity levels are chosen for ease of understanding and tool application.

conditions or potential risks to asset performance, the findings are reported to other agency units or to the Chief Engineer. We track repeat failure and maintenance events as part of federal reporting requirements for declared emergencies. We do not use this information to identify priority maintenance actions.

- Level 3: We systematically collect “asset at-risk” data as part of our maintenance data collection efforts for all state highways. We review this maintenance data and use it as an input into decision making. We track all repeat failures or maintenance efforts and consider it in prioritizing maintenance actions.

As seen in the maturity levels for this factor, the higher levels of maturity are much more involved with the collection and use of the data. Level 1 represents only a limited use of the data --- reporting on repeated disruptions. Level 3, on the hand, indicates a repeated use of maintenance data for resilience-related decisions.

Table 3 shows generally what these different maturity levels mean in terms of typical activities (the specific definitions of different maturity levels will vary by the factor being considered). Level 3 maturity efforts are presented in this guide as the ideal, that is, the highest level of resilience capability for each step in the Framework. The guide realizes that achieving this high level might take time and resources. Thus, recommended actions are offered if the agency wants to only reach Level 2. Each chapter in the guide describes the maturity levels for each factor associated with that assessment step.

A specific example for an actual factor in the guide is provided below to help illustrate the concept. This factor and its associated maturity levels are found in Step 1: *Assess Current Practice*.

Are maintenance data reviewed to identify assets with previous impacts/repeat failures?

- Level 1: We use maintenance data to schedule maintenance efforts. The only system resilience use of maintenance data is in reporting to the FHWA requirements on repeated disruptions and repairs on the National Highway System (NHS).
- Level 2: We use a maintenance management system for all state highways and use this information to schedule maintenance actions. If those collecting the data find poor asset conditions or potential risks to asset performance, the findings are reported to other agency units or to the Chief Engineer. We track repeat failure and maintenance events as part of federal reporting requirements for declared emergencies. We do not use this information to identify priority maintenance actions.
- Level 3: We systematically collect “asset at-risk” data as part of our maintenance data collection efforts for all state highways. We review this maintenance data and use it as an input into decision making. We track all repeat failures or maintenance efforts and consider it in prioritizing maintenance actions.

As seen in the maturity levels for this factor, the higher levels of maturity are much more involved with the collection and use of the data. Level 1 represents only a limited use of the data --- reporting on repeated disruptions. Level 3, on the hand, indicates a repeated use of maintenance data for resilience-related decisions.

Table 3: Illustrative Concepts in Resilience Maturity Levels

MATURITY LEVEL	GENERAL DESCRIPTION
Level 1 (lowest level)	<ul style="list-style-type: none"> • Resilience is championed by an individual or unit within the agency but very little attention is given to resilience in agency policies and procedures. • Responsibility has been established for developing resilience-oriented decision support tools and procedures. • Agency policies/goals/technical directives have been established directing consideration of resilience in agency functions. • Required data bases and tools needed for considering resilience have been identified and steps taken to develop the needed capability, although this will likely be done (at this level) by individual functional groups or for specific agency responsibilities. • Those needed within and external to the agency to implement the steps necessary for more systematic consideration of resilience have been identified and initial efforts made to include them in the development process have been undertaken. • Staff are aware of the need to include resilience in their unit's activities and understand the technical requirements for doing so (even though the data and tools might not be available). • To the extent appropriate or needed, formal partnerships and/or arrangements have not been made with agencies/groups external to the agency to support the effort.

Level 2	<ul style="list-style-type: none"> • Gaps in agency capabilities have been identified and steps initiated to fill these gaps. • An assessment has been made on how resilience considerations will be included in agency decision-making. • Standard operating procedures have started to be changed to provide for integrated consideration of resilience across all agency functions. • Data/tools/methods have been developed and used in support of decision making, especially in helping agency officials understand where system vulnerabilities and risks exist. • Tools are used to systematically examine a range of threats using the most up-to-date data and methods. The results of the analysis are used in agency decision making. • Agency staff understand how the results of their resilience efforts affect other functional areas in the agency. • To the extent appropriate or needed, partnerships and/or arrangements have been initiated with agencies/groups external to the agency to support the resilience effort. Some of these arrangements have been formalized.
Level 3 (highest level)	<ul style="list-style-type: none"> • Processes/procedures/methods for resilience have become institutionalized within all functional areas of the agency. • Resilience considerations have been incorporated into policies, guides, and standard operating procedures. • State-of-the-practice databases/analysis tools/methods are available for vulnerability/risk assessments. Such assessments are conducted periodically considering the latest science/data relating to system disruptions. • Resilience-related strategies/actions/designs have been implemented. • Top executives and senior managers support the consideration of resilience in agency actions. This support has been communicated to agency staff. • Staff are well prepared to consider resilience in their areas of responsibility. • To the extent appropriate or needed, partnerships and/or arrangements have been initiated with agencies/groups external to the agency to support the resilience effort. These arrangements have been formalized and periodic meetings with the partners occur so as to identify how to make these partnerships more effective.

Figure 2 shows how the self-assessment tool can be used. The tool recognizes that there are more sophisticated and less sophisticated ways to undertake strategies to enhance resilience activities. The CMM reflects this with a scoring system based on 1 to 3 that rates how your agency is doing with respect to each factor in the assessment step being considered. As noted earlier, both natural and human-caused hazards are part of the assessment, where appropriate. More points are provided (i.e., more maturity shown) for the more sophisticated and complete approaches for each factor in a step.

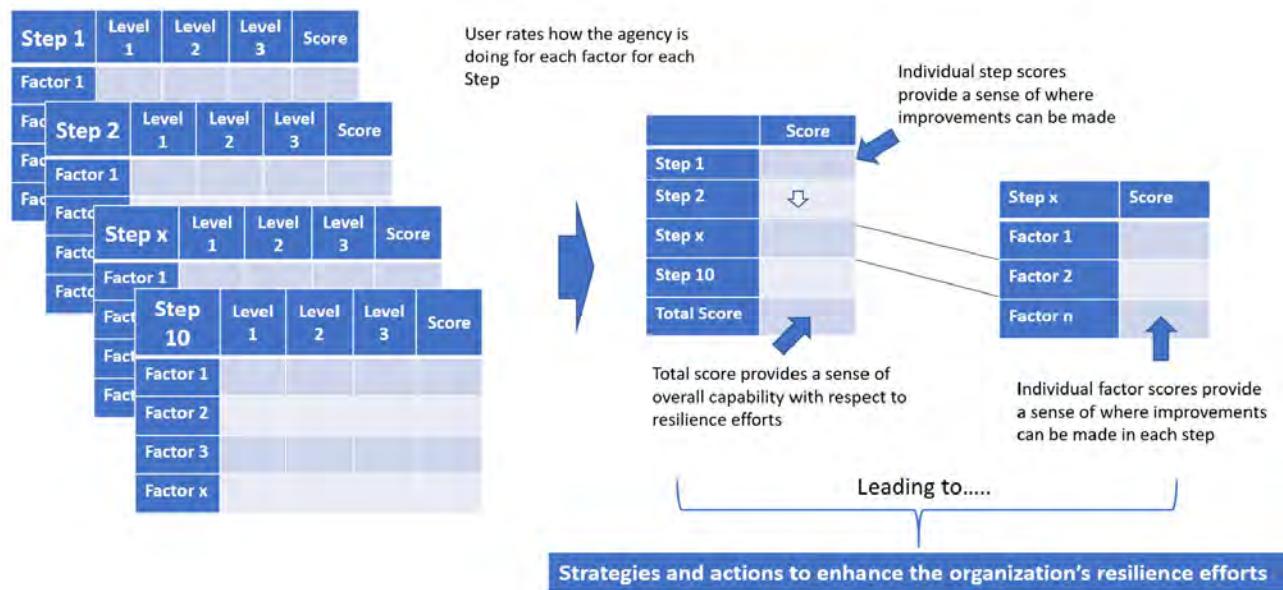


Figure 2: Overview of the Self-assessment Tool for Assessing Organizational Resilience Efforts

A total score is then summed across all the steps to determine how mature the organization is with respect to undertaking resilience-oriented activities and efforts. The scoring system not only provides agency managers with some sense of where they are with respect to overall agency capabilities, but by the nature of the scoring, it allows managers to identify which steps (or functions within an agency) need attention; and for individual steps, which factors within each step could be improved.

An example illustrates the scoring approach. You have conducted a self-assessment using all 10 steps of the tool. The scores for each step are as follows:

Self-assessment Tool Step	Score	Max Score	% of Max Score
Step 1: Assess Current Practice	27	36	75%
Step 2: Organize for Success	24	33	73%
Step 3: Develop an External Communications Strategy and Plan	24	27	89%
Step 4: Implement Early Wins	18	27	67%
Step 5: Understand the Hazards and Threats	16	27	59%
Step 6: Understand the Impacts	13	24	54%
Step 7: Determine Vulnerability/Risk and Prioritize	5	12	42%
Step 8A: Assess Strategies for Enhancing Emergency Response Capabilities	37	45	82%
Step 8B: Identify Enhancements to Operations and Maintenance Activities	14	24	58%
Step 8C: Undertake Detailed Assessments of Exposed Assets and New Projects	11	24	46%
Step 8D: Integrate into Asset Management	12	30	40%
Step 9: Program and Implement Resilience Measures	10	24	42%
Step 10: Monitor and Manage System Performance	8	24	33%
Total Agency Score	219	357	61%

The interpretation of different total agency scores is as follows:

> 80%	Your agency has made important strides in mainstreaming resilience actions in its efforts. There are still some areas where improvements can be made. Management should focus on these areas and on strategies to maintain and possibly enhance existing actions.
50–79%	Your agency has strength in several areas as they relate to resilience efforts, but there are many others where improvements should be made. Management should identify the priorities for making such improvements (following the recommended strategies presented in each chapter).
< 50%	There are many areas where your agency can make improvements in its overall resilience strategy. Management should identify the priorities for making such improvements (following the recommended strategies presented in each chapter).

The example agency has an overall score of 61%, which is at the low end of the medium maturity level. This suggests that there is much work to be done to mainstream resilience efforts into this agency's transportation decision-making and programs. The scoring for individual steps suggests the agency is doing a good job in developing an external communications strategy and in enhancing its emergency response capabilities--- two assessment results that would not be unexpected in most transportation agencies. However, these higher scores do not mean that enhancing these activities is unnecessary. The guide still recommends strategies for making enhancements to those activities identified in the self-assessment as being at a high level of maturity. The underlying concept is that periodic examination of all agency actions contributing to a resilient transportation system is an important foundation for a resilience-oriented agency. Strategies for doing so are found in the respective chapters for each step.

The guidebook recommends strategies for making enhancements to those activities that are identified in the self-assessment as being at a high level of maturity. The underlying concept is that periodic examination of all agency actions contributing to a resilient transportation system is an important foundation for a resilience-oriented agency.

There are many steps where much improvement can occur for this example agency (these are shown in red on the graphic). As indicated, many of these steps occur later in the Framework and represent the actual implementation of resilience-oriented actions. This result represents a likely outcome of many initial transportation agency self-assessments in that many of the preceding steps have not yet led to implemented actions.

Identifying actions to enhance the maturity of the agency's efforts in a particular step, although coordinated at the agency level, could very well occur in parallel given the different functional unit staff involved. For example, two of the lowest scores for this agency — *Undertake Detailed Assessments of Exposed Assets and New Projects* (Step 8C), and *Monitor and Manage System Performance* (Step 10) --- could involve staff from project development/design/environment and planning/asset management, respectively.

It is important to recognize that the scoring system might vary slightly from one agency to the next because of the different organizational structures of DOTs. The self-assessment tool is designed to be adaptive to the needs and context of every transportation agency. Thus, although the same score may have somewhat different meanings for different agencies, the variation will likely be small. There may also be "bottleneck" effects where all scores are high except for one step in the middle. This is one of

the most important results of the self-assessment ... identifying where inadequate action or even inaction is constraining other resilience efforts.

Note that the self-assessment tool can be used by any transportation agency but is geared for state DOTs and roadway assets. An agency can choose to customize the maturity model by only using those factors considered most relevant to the agency or develop its own factors based on experience and expertise in the agency. In addition, weights could be assigned to those steps or factors considered more important than others.

As shown above, the self-assessment tool compares the overall agency score and the scores for individual steps to a range to define a current maturity level. The boundaries in the scores of the maturity level can be defined by the agency, for example, 0 to 49, 50 to 79, and 80 to 100 for the above agency. Or, the ranges indicated in this guide can be used by default. The explanation for the ranges found in the guide is as follows. The upper boundary of the Level 1 maturity classification assumes a score of 1 point in 2/3's of the factors for the Level 1 factors plus a score of 2 points for each of the other 1/3 of the factors in the Level 2 maturity. Thus, assume there are nine factors in a step; six (2/3's of the factors) are rated as "1" and 3 (1/3 of the factors) are rated at the Level 2 maturity level, and thus getting a score of "2" per factor. The upper range of the Level 1 maturity level is thus $(6 \times 1) + (3 \times 2) = 12$. So the range is 0 to 12 for Level 1 maturity. Similarly, the lower boundary of the Level 3 maturity classification comes from a score of "3" for each of the 2/3s of the nine factors at the Level 3 maturity and a score of "2" for each of the 1/3 of the nine factors at the Level 2 maturity. The lower bound becomes $(3 \times 6) + (2 \times 3) = 24$. Thus, the lower boundary of the Level 3 maturity level is 24 and the range is 24 to 27. The Level 2 maturity is the range that remains, or 13 to 23.

Recommended Actions to Maintain the Highest Level of Agency Resilience Capability

Each step description in the guide presents strategies that an agency can use to maintain a Level 3 maturity assuming that it has achieved such a score. The intent of these strategies is that an agency should not stop improving its resilience efforts just because it has achieved the highest maturity level. The highest level of capability focuses on continual improvement in agency capability and taking actions that lead to a more resilient transportation system. For example, assume your agency has determined it has reached a Level 3 maturity for Step 1: *Assessing Current Practice*. The following actions can be taken to maintain this level.

- Periodically reassess the capability of your agency's units with respect to their role in transportation system resilience. This could be done in-house or by bringing in a third- party evaluator to conduct the assessment.
- Continue to monitor the resilience of the transportation system and consider changes in this performance when making changes in the agency to enhance your current capability.
- Participate in and/or lead meetings with partner agencies and groups to reinforce the importance of collaboration and coordination in enhancing system resilience.
- Reinforce the resilience "mindset" among your staff by conducting role playing exercises that involve participants from a range of internal and external stakeholders, including community and system user representatives.

- Update staff professional development and training opportunities to include the latest thinking and concepts in system resilience. Incorporate these concepts into agency succession planning.
- Maintain situational awareness of rapidly changing cyber and physical security exposures that impact agency resilience.

Note that an agency can be at Level 3 maturity and still obtain scores of 2 in some factors. If such is the case, a strategy or a set of action steps can be identified to improve the factors that were rated with a “2”.

Recommended Actions to Achieve Higher Levels of Resilience Capability

If your agency was rated at Levels 1 or 2 maturity, you can take steps to continue your evolution toward a more resilience-oriented agency. In such cases, agency managers should identify which of the factors in the assessment were most lacking and determine priorities for improving your agency’s organization. Each step description offers a table as a template to determine which steps your agency can take to improve your agency’s resilience identified through the self-assessment efforts, who should be responsible, the timeframe for the implementation, and expected outcomes (see Table 4 for an example associated with Step 1: *Assess Current Practice*).

Table 4: Actions to Achieve Higher Levels of Resilience Capability for Step 1: Assess Current Practice

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Conduct a self-assessment of your agency’s current resilience efforts.			
	Conduct self-assessments of specific agency functions that are particularly relevant to system resilience, for example, using the FHWA capability maturity assessment tools described earlier.			
	Incorporate transportation system resilience into agency plans and policy statements in order to institutionalize a resilience “mindset” into agency staff.			
	Establish a formal process for reviewing and updating the emergency operations plan.			
	Develop a process for conducting after-action and after-event reports that are used to identify corrective actions.			
	Develop a process for reviewing maintenance data to identify chronic disruptions to different assets.			
	Review threat/hazard exposure and/or vulnerability/risk studies to understand potential disruptions to your transportation system and possible demands on your agency.			
	Review staff roles and responsibilities to identify how they relate to enhancing system resilience. Develop a strategy for institutionalizing system resilience into staff roles.			
	Review the performance of your agency’s project design standards and begin the process of making design criteria more adaptive to expected future hazards and threats.			

	Develop a human resource development and succession plan that focuses on preparing the current and future agency staff for resilience-oriented activities.			
	Assess training/professional development programs and incorporate concepts relating to transportation system resilience into course materials.			
	Begin the process of undertaking (or at least examining) some of the subsequent steps in this guide and determine if your agency has the capability to undertake such efforts. Where necessary, identify strategies to provide such capability.			

NOTE: As seen in Table 4, some of the rows are indicated in green. Step 4 of the self-assessment tool, *Implement Early Wins*, is an important part of an agency strategy to jumpstart the implementation of a system resilience program. By its very nature, these early wins can include actions that might be found as well in other steps of the tool. For example, including staff from different units in your agency in developing an external communication strategy is an important action that could be identified as part of Step 3: *Develop an External Communications Strategy and Plan*. However, it could also be considered an “early win” in an agency’s strategy and thus be also considered as part of Step 4: *Implement Early Wins*. The guide indicates in green those actions in other steps that could be considered as part of an “early wins” strategy. In some sense, Step 4 is viewed as partly a “gathering” spot for such efforts.

Chapter 3 Assess Current Practice (Step 1)

The first step in the self-assessment tool is understanding the current state-of-practice in your agency as it relates to resilience. Resilience-related efforts to date in most transportation agencies have focused on emergency response and incident management, undoubtedly very important program responsibilities. As noted in chapter 2, however, enhancing transportation system resilience involves all units within a transportation agency, including efforts in policy direction, planning, project development/design, construction, operations, maintenance, asset management, and communications. Before identifying where your agency should focus on enhancing its resilience-related capabilities, you must first understand where you are starting from.



Assess Current Practice

The concept of examining an organization's capability or effectiveness from the perspective of its structure, processes, procedures, information flows, and level of collaboration is not new. Indeed, such an assessment has been the basis of most systematic efforts to change an organization or to foster innovative practices. This assessment can be done internally through formal (usually management-led) efforts having a mandate to improve agency effectiveness or productivity. Alternately, it can be done with external third-party participation to lend an unbiased perspective on the assessment. The assessment includes understanding the mandate of each unit in the agency, an analysis of what that unit has done to achieve the goals associated with that mandate, and an examination of the types of plans and strategies unit managers can use to achieve these goals in the future.

Capability Factors and Levels of Maturity

Factor 1.1 Has your agency conducted and documented a self-assessment of what it can do to better integrate concerns for transportation system resilience into agency functions?

This factor focuses on the level of attention agency management has given to identifying and implementing actions to improve the agency's capabilities with respect to transportation system resilience.

- Level 1: We are using this self-assessment tool/process to identify where my agency could implement changes to enhance our resilience activities.
- Level 2: We have already used and documented a self-assessment tool/process to identify where my agency could implement changes to enhance our resilience activities.
- Level 3: We have used and documented a self-assessment tool/process to identify where my agency could implement changes to enhance our resilience activities. Such changes have been implemented. The self-assessment tool/process is used at least every 3 years to identify further enhancements to our resilience efforts.

Factor 1.2 As part of your self-assessment process, have you examined best practices from other agencies and organizations?

Identifying best practices from peer organizations is one of the most common strategies for identifying possible actions to improve many aspects of your agency's performance. This is particularly true when the focus of the self-assessment is on a topic that is relatively new to an organization such as resilience.

The distinction in the levels of maturity for this factor reflect the level of effort your agency is making to seek examples of resilience best practice from other agencies.

- Level 1: We identify best practices primarily from the literature and from what we hear at conferences and meetings.
- Level 2: We have proactively identified function-specific best practices from other organizations and have used them as indicators to measure our progress in specific functional areas.
- Level 3: We have proactively identified best agency-wide practices from other organizations and used them as benchmarks to measure our own progress. Agency leadership is involved in this comparison and identification of improvements to the agency.

Factor 1.3 FHWA has developed self-assessment tools for transportation system operations areas aimed at improving the performance and reliability of the road system. Have you used any of these tools to improve the system operations capabilities of your agency?

This factor recognizes that other function- or topic-specific self-assessment tools have been developed and offered for use in transportation agencies. FHWA has developed several such tools for very specific resilience-related topics, including:

- Road Weather Management
- Planned Special Events
- Traffic Incident Management
- Traffic Management
- Traffic Signal Management
- Work Zone Management

Given the agency capabilities reflected in the FHWA tools relate in a broad sense to transportation system resilience, the different levels of maturity for this factor are defined by the level to which the FHWA self-assessment tools have been used in your agency. Note that the users of this guide could add tools to this list that have been developed since publication of this guide (or others that they are aware of) that relate to transportation system resilience.

- Level 1: We have used one such tool.
- Level 2: We have used two or three such tools.
- Level 3: We have used all of the FHWA self-assessment tools.

Factor 1.4 Have you used the Cybersecurity Evaluation Tool (CSET) or an equivalent tool to improve the cybersecurity performance of your agency's enterprise and industrial control cyber systems (ICS)?

Cybersecurity has become an ever more important concern for transportation agencies as traffic operations and management systems increasingly rely on electronic and internet resources for command and control. In addition, many of an agency's administrative and financial processes work off of connected computers. Several disruptive cyberattacks against transportation agencies have occurred in recent years. This factor reflects the actions your agency has taken to assess your cybersecurity status. It relates the self-assessment of this threat to the use of tools that have been developed by the

Department of Homeland Security (DHS) or other equivalent tools. The major distinction among the maturity levels is the level of protection your agency has provided based on the cybersecurity assessments that have been conducted.

Note: Given the importance of cybersecurity to many functional responsibilities in a transportation agency, cybersecurity factors will also be found in many of the other steps in this guide.

- Level 1: We have cybersecurity controls in place and are familiar with cybersecurity principles; however, we have not used a specific industry standard-backed self-assessment tool.
- Level 2: We have completed the self-assessment for all agency ICS and IT systems. We are in the intermediate stages of coordinating our ICS and IT system security with other relevant agencies in our jurisdiction.
- Level 3: We have fully assessed the cybersecurity of our ICS and IT systems. The information has been used to coordinate effectively the cybersecurity of all such systems in partner agencies (e.g., all state agencies).

Factor 1.5 Do you continually review and update your agency's resilience-oriented operations plans?

Responding to system disruptions is one of the traditional transportation agency responsibilities in transportation system resilience. Most transportation agencies have developed emergency operations plans and protocols for dealing with such disruptions --- from responding to crashes on the road network to large-scale network disruptions due to natural and human-caused disasters. The assumption in this factor is that emergency operations plans do exist. The distinction in the levels of maturity in this factor reflect the level of effort to review and update these plans on a periodic basis.

Note that a similar factor is found in Step 8B: *Identify Enhancements to Operations Maintenance Activities*. In that case, the review and updates are targeting specific plans, e.g., incident response plans or Disaster Recovery Plans. The factor in this step relates to your agency's efforts in general to update all operations plans that focus on enhancing system resilience.

- Level 1: We review operations plans on an ad hoc basis, primarily when the manager responsible for a relevant area decides it is time to do so. The updates are thus focused on a particular resilience functional responsibility and are not agency-wide.
- Level 2: We have adopted standard operating procedures for updating operations plans on a set cycle. These updates are done for all resilience-oriented operation plans in our agency.
- Level 3: We have achieved a Level 2 maturity. In addition, our plan update process is done in collaboration with external partners who will be working with our agency's staff in responding to emergency events. External input is proactively sought in critiquing our procedures and processes to provide an "outside" perspective on where we can improve our operations.

Factor 1.6 Are after-action reports created after major incidents and disruptions?

Effective institutional learning relies partly on reviewing agency efforts immediately after an incident or organizational change so as to take advantage of staff memories of what happened and why. These are called "after-action" reports, or, if no written document exists, debriefings. Many agencies often develop after-action reports as part of traffic crashes and incidents. However, this factor relates to all

types of network or system disruptions. The distinction among the different levels of maturity reflects the degree to which such after-action reports are formalized within agency procedures.

- Level 1: We do not have standard operating procedures for after-action reports, although some sections or functional areas do so on an ad hoc basis. We often have formal debriefings after major disruptions but no written documentation is produced that reflects the actions taken in response to the recommendations surfacing from these debriefings.
- Level 2: We have developed standard operating procedures for producing after-action reports for transportation system disruptions, where such reports must be produced within a relatively short period of time (e.g., one week) after the incident or disruption. These reports are internally focused, often target the functional units involved in response, and are undertaken by agency staff.
- Level 3: We have reached a Level 2 maturity. In addition, reports are collaboratively produced by all the organizations involved with the incident or disruption. This is undertaken only for disruptions that reach a threshold level of magnitude or extent. The after-action reports not only examine how our agency's actions could be improved, but also how the collaboration with our partner agencies could be enhanced.

Factor 1.7 Are after-action reports reviewed systematically and analyzed for prospective corrective actions?

The focus of this factor is on the degree to which after-action reports actually influence the identification and implementation of corrective actions. Preceding actual action, however, is the need for agency management and leadership to review the reports. The different levels of maturity are thus defined in this factor by the extent to which after-action reports are reviewed by agency staff and top management. As in the above factor, this review could be categorized by level and scale of disruption. For example, traffic safety managers would be the primary reviewers of after-action reports for traffic incidents. For major system disruptions, the responsibility for reviewing after-action reports might be the top leadership of the agency.

- Level 1: After-action reports are reviewed by front-line staff who are the primary responders to an incident or disruption. No formal actions are typically taken.
- Level 2: After-action reports are reviewed by front-line staff and the leadership of the relevant functional units. Formal action is taken by the unit managers to improve that unit's abilities in future incident or disruption responses.
- Level 3: We have achieved a Level 2 maturity. In addition, reports are provided to top management on desired corrective actions across the agency.

Factor 1.8 Are maintenance data reviewed to identify assets with previous impacts / repeat failures?

The maintenance function in a transportation agency provides an important contribution to a transportation system's condition and performance. Although the different elements of maintaining the condition and performance of transportation assets will often be found in different units among transportation agencies, the data collected as part of the maintenance program can provide important input on where potential failures do and could occur. For example, experience with road failures during

heavy precipitation events has shown that keeping culverts clear of debris is an important strategy for minimizing culvert washouts.

Expedited removal of downed trees and other debris, replacing signs, and bringing signals back into operation after a major storm are critical steps in returning the road network and individual assets back to pre-event operational levels. For those agencies using a maintenance management system (MMS), the database provides potentially insightful information on where potential asset failures might occur in the future and could also provide input into the transportation asset management process and plan development.

Federal requirements for reporting repeatedly damaged facilities on the National Highway System (NHS) are an important consideration in this factor. Repeatedly damaged facilities are defined as “roads, highways, and bridges that have required repair and reconstruction activities on two or more occasions due to natural disasters or catastrophic failures resulting in emergencies declared by the Governor of the State or the President ... a catastrophic failure is a sudden failure of a major element or segment of a road, highway, or bridge due to an external cause ... the failure must not be primarily attributable to gradual and progressive deterioration or lack of proper maintenance” (FHWA 2018). The distinction in the different levels of maturity in this factor is defined by the degree to which maintenance data and information is used to identify priority actions to remove or mitigate the risk of future asset failures.

- Level 1: We use maintenance data to schedule maintenance efforts. The only system resilience use of maintenance data is in tracking repeat failure and maintenance events as part of federal reporting requirements for declared emergencies.
- Level 2: We use a maintenance management system for all state highways and use this information to schedule maintenance actions. If those collecting the data find poor asset conditions or potential risks to asset performance, the findings are reported to other agency units or to the Chief Engineer. We do not use this information to identify priority maintenance actions.
- Level 3: We systematically collect “asset-at-risk” data as part of our maintenance data collection efforts for all state highways. We review this maintenance data and use it as an input into decision-making. We track all repeat failures or maintenance efforts and consider it in prioritizing maintenance actions.

Factor 1.9 Have you examined human/physical threats, natural hazards, and cyber threats as potential sources of vulnerabilities to your transportation system?

One of the major themes of the guide is that a transportation agency concerned about transportation system resilience needs to examine the range of potential threats against the system (Step 5 discusses how this can be done). Such threats can come from many sources. Most transportation agencies have considerable experience in responding to traffic crashes, storm-related impacts, and other such disruptions. There is less experience with cyber threats and with other human-caused sources of system disruptions (e.g., terrorist attacks or pandemics). In some cases, transportation agencies do not play a lead role in response. For example, terrorist attacks immediately fall into the realm of national security and enforcement agencies. In many states, the security of the cyber network is the responsibility of some other state agency. However, even in these two examples, the transportation system can be the target of such attacks, and thus transportation agencies need to make efforts to protect against, minimize disruptions associated with, and recover quickly from such disruptions.

The distinction in the different levels of maturity in this factor is defined as the extent to which your agency has examined different sources of threats to system operations.

- Level 1: We have systematically examined one of these sources of disruption (human/physical threats, natural hazards, and cyber threats) with respect to its impacts on agency activities.
- Level 2: We have systematically examined 2 of these sources of disruption with respect to their impacts on agency activities.
- Level 3: We have systematically examined each of these sources of disruption with respect to their impacts on agency activities. Natural hazards have been evaluated with respect to future climate changes in addition to considering today's conditions.

Factor 1.10 Have you reviewed your agency's design criteria to assess their adequacy for enhancing system resilience?

One aspect of preparing for future threats to transportation system resilience is making sure that projects are designed to provide the best possible chances of surviving extreme environmental and human-caused threats. For example, most design standards have traditionally been based on historical data. However, future environmental conditions in the case of climate change will likely be very different than what has occurred in the past. This has led to an interest in the transportation profession on adaptive project design.

In addition, design criteria reflect a range of concerns and interests in project design such as providing safe movement of people and goods, assuring material durability over time given weather and vehicle use of a facility, promoting aesthetically-pleasing project characteristics in areas where such is desired, minimizing environmental impacts on nearby communities and environmentally-sensitive areas, and the like. This factor focuses on the extent to which system or facility resilience is a concern when a project is designed (note that Step 8C provides more discussion on adaptive design). The distinction in the different levels of maturity in this factor is defined as the extent to which your agency's design criteria have been examined from the perspective of how they result in a project that is more resilient to disruptions.

- Level 1: We have examined design criteria only relating to specific types of disruptions (e.g., flooding, extreme heat, and cyberattacks).
- Level 2: We have examined all relevant design criteria from an all-hazards perspective for their adequacy to recent observed events.
- Level 3: We have examined all relevant design criteria from an all-hazards perspective for their adequacy to recent events and future projected changes due to climate change.

Factor 1.11 Have you reviewed staff roles and responsibilities to identify how they relate to enhancing system resilience?

An effective organizational structure for carrying out the programs aimed at enhancing transportation system resilience is an important ingredient to agency success. And, as part of organizational structure, staff members understanding what they are supposed to do and how this relates to agency goals become a critical foundation for successful agency efforts. This factor examines your agency's efforts at

incorporating transportation system resilience into staff job descriptions or talent profiles. For example, one state DOT noted at a recent conference that every job description in the agency has an element related to emergency/disaster response.

Workforce resilience means preparing your agency for future challenges and having agency staff who are aware of and prepared for these challenges. Training and development opportunities are important for doing this. With respect to agency managers, such knowledge and awareness needs to be incorporated into succession planning. In addition, workforce resilience could also include examining how long-term exposure to stressors could affect staff physical and mental well-being. This has been a particular concern for security, emergency response, and public safety agencies. The distinction in the different levels of maturity in this factor is defined as the level of effort your agency has taken to incorporate system resilience efforts into staff responsibilities and formal job descriptions.

- Level 1: We have conducted a review of staff roles and responsibilities agency-wide for one-third of the staff directly involved in resilience-oriented activities.
- Level 2: We have conducted a review of staff roles and responsibilities agency-wide for two-thirds of the staff directly involved in resilience-oriented activities.
- Level 3: We have conducted a review of staff roles and responsibilities agency-wide for all staff positions directly involved in resilience-oriented activities. This review has led to changes in our succession plan.

Factor 1.12 Have you examined your training/professional development programs for their coverage of resilience?

One of the traditional ways an agency enhances organizational capacity for achieving its goals is to provide training and professional development opportunities for its staff. In this way, an agency exposes the staff to new policy requirements, new tools and analysis methods, processes and procedures, and the latest technologies. In the context of system resilience, this could entail introductions to key concepts in system resilience, an overview of the latest policy and planning requirements, descriptions of the tools and analysis methods used to assess vulnerability and risks, assessment of the different types of actions a transportation agency could take to enhance system resilience, and exposure to institutional strategies for fostering collaboration and partnerships in delivering system resilience actions. The distinction in the different levels of maturity in this factor is defined as the level of effort your agency has taken to incorporate system resilience concepts into its training and professional development efforts.

- Level 1: We have asked course instructors or module developers of all our courses to assess their individual course material to identify opportunities for incorporating resilience topics into participant learning.
- Level 2: We have conducted a systematic assessment of those courses most directly related to transportation system resilience (e.g., system operations, asset management, or performance management) and have developed modules on how system resilience fits into the course material.
- Level 3: We have conducted a systematic assessment of all our courses and have developed modules on how system resilience fits into course material.

Table 5 summarizes the factors that are included in the self-assessment tool for Step 1. The maturity levels for each factor are presented in the descriptions of each factor. The total score for this step is found by summing the number of points given for each factor.

Recommended Actions to Maintain the Highest Level of Agency Resilience Capability

The highest level of capability for "Assessing Current Practice" focuses on continual improvement in agency capability and actions leading to a more resilient transportation system. If your agency has reached a Level 3 maturity level, the steps that can be taken to maintain this level include:

- Periodically reassess the capability of your agency's units with respect to their role in transportation system resilience. This could be done in-house or by bringing in a third- party evaluator to conduct the assessment.
- Continue to monitor the resilience of the transportation system and consider changes in this performance when making changes in the agency to enhance your current capability.
- Participate in and/or lead meetings with partner agencies and groups to reinforce the importance of collaboration and coordination in enhancing system resilience.
- Reinforce the resilience “mindset” among your staff by conducting role playing exercises that involve participants from a range of internal and external stakeholders, including community and system user representatives.
- Update staff professional development and training opportunities to include the latest thinking and concepts in system resilience. Incorporate these concepts into agency succession planning.
- Maintain situational awareness of rapidly changing cyber and physical security exposures that impact agency resilience.

If you did not score a “36” in the assessment (a perfect score in Level 3 efforts), identify those factors that were rated lower and identify a strategy or action steps to improve these particular components of Step 1.

Table 5: Assessment Table for Step 1: Assess Current Practice

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
1.1 Have you conducted and documented a self-assessment of your agency focusing on how effectively resilience is incorporated into agency functions?	We are using this self-assessment tool/process to identify where my agency could implement changes to enhance our resilience activities.	We have already used and documented a self-assessment tool/process to identify where my agency could implement changes to enhance our resilience activities.	We have used and documented a self- assessment tool/process to identify where my agency could implement changes to enhance our resilience activities. Such changes have been implemented. The self- assessment tool/process is used at least every 3 years to identify further enhancements to our resilience efforts.
1.2 As part of your self-assessment process, have you examined best practices from other agencies and organizations?	We identify best practices primarily from the literature and from what we hear at conferences and meetings.	We have proactively identified function-specific best practices from other organizations and have used them as indicators to measure our progress in specific functional areas.	We have proactively identified best agency-wide practices from other organizations and used them as benchmarks to measure our own progress. Agency leadership is involved in this comparison and identification of improvements to the agency.
1.3 FHWA has developed self-assessment tools for transportation system operations areas aimed at improving the performance and reliability of the road system. Have you used any of these tools to improve the system operations capabilities of your agency?	We have used one such tool.	We have used two or three such tools	We have used all the FHWA self-assessment tools.
1.4 Have you used the Cybersecurity Evaluation Tool (CSET) or an equivalent tool to improve the cybersecurity performance of your agency's enterprise and industrial control cyber systems (ICS)?	We have cyber security controls in place and are familiar with cybersecurity principles; however, we have not used a specific industry standard-backed self-assessment tool.	We have completed the self- assessment for all agency ICS and IT systems. We are in the intermediate stages of coordinating our ICS and IT system security with other relevant agencies in our jurisdiction.	We have fully assessed the cybersecurity of our ICS and IT systems. The information has been used to coordinate effectively the cybersecurity of all such systems in partner agencies (e.g., all state agencies).

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
1.5 Do you review and update your resilience-oriented operations plans?	We review operations plans on an ad hoc basis, primarily when the manager responsible for a relevant area decides it is time to do so. The updates are thus focused on a particular resilience functional responsibility and are not agency-wide	We have adopted standard operating procedures for updating operations plans on a set cycle. These updates are done for all resilience-oriented operation plans in our agency.	We have achieved a Level 2 maturity. In addition, our plan update process is done in collaboration with external partners who will be working with our agency's staff in responding to emergency events. External input is proactively sought in critiquing our procedures and processes to provide an "outside" perspective on where we can improve our operations.
1.6 Are after-action reports created after major incidents and disruptions?	We do not have standard operating procedures for after-action reports, although some sections or functional area do so on an ad hoc basis. We often have formal debriefings after major disruptions but no written documentation is produced that reflects the actions taken in response to the recommendations surfacing from these debriefings.	We have developed standard operating procedures for producing after-action reports for transportation system disruptions, where such reports must be produced within a relatively short period of time (e.g., one week) after the incident or disruption. These reports are internally focused, often target the functional units involved in response, and are undertaken by agency staff.	We have reached a Level 2 maturity. In addition, reports are collaboratively produced by all the organizations involved with the incident or disruption. This is undertaken only for disruptions that reach a threshold level of magnitude or extent. The after-action reports not only examine how our agency's actions could be improved, but also how the collaboration with our partner agencies could be enhanced.
1.7 Are after-action reports reviewed systematically and analyzed for prospective corrective actions?	After-action reports are reviewed by front-line staff who are the primary responders to an incident or disruption. No formal actions are typically taken.	After-action reports are reviewed by front-line staff and the leadership of the relevant functional units. Formal action is taken by the unit managers to improve that unit's abilities in future incident or disruption responses.	We have achieved a Level 2 maturity. In addition, reports are provided to top management on desired corrective actions.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
1.8 Are maintenance data reviewed to identify assets with previous impacts / repeat failures?	We use maintenance data to schedule maintenance efforts. The only system resilience use of maintenance data is in tracking repeat failure and maintenance events as part of federal reporting requirements for declared emergencies. ⁷	We use a maintenance management system for all state highways and use this information to schedule maintenance actions. If those collecting the data find poor asset conditions or potential risks to asset performance, the findings are reported to other agency units or to the Chief Engineer. We do not use this information to identify priority maintenance actions.	We systematically collect "asset at-risk" data as part of our maintenance data collection efforts for all state highways. We review this maintenance data and use it as an input into decision making. We track <u>all</u> repeat failures or maintenance efforts and consider it in prioritizing maintenance actions.
1.9 Have you examined human/physical threats, natural hazards, and cyber threats as potential sources of vulnerabilities to your transportation system?	We have systematically examined one of these sources of disruption (human/physical threats, natural hazards, and cyber threats) with respect to its impacts on agency activities.	We have systematically examined 2 of these sources of disruption with respect to their impacts on agency activities.	We have systematically examined each of these sources of disruption with respect to their impacts on agency activities. Natural hazards have been evaluated with respect to future climate changes in addition to considering today's conditions.
1.10 Have you reviewed your agency's design criteria to assess their adequacy for enhancing system resilience?	We have examined design criteria only relating to specific types of disruptions (e.g., flooding, extreme heat, and cyberattacks)	We have examined all relevant design criteria from an all-hazards perspective for their adequacy to recent observed events.	We have examined all relevant design criteria from an all-hazards perspective for their adequacy to recent events and future projected changes due to climate change.
1.11 Have you reviewed staff roles and responsibilities to identify how they relate to enhancing system resilience?	We have conducted a review of staff roles and responsibilities agency-wide for one-third of the staff directly involved in resilience-oriented activities.	We have conducted a review of staff roles and responsibilities agency-wide for two-thirds of the staff directly involved in resilience-oriented activities.	We have conducted a review of staff roles and responsibilities agency-wide for all staff positions directly involved in resilience-oriented activities. This review has led to changes in our succession plan.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
1.12 Have you examined your training/professional development programs for their coverage of resilience?	We have asked course instructors or module developers of all our courses to assess their individual course material to identify opportunities for incorporating resilience topics into participant learning.	We have conducted an assessment of those courses <u>most directly related to transportation system resilience</u> (e.g., system operations, asset management, or performance management) and have developed modules on how system resilience fits into the course material.	We have conducted a systematic assessment of <u>all our courses</u> and have developed modules on how system resilience fits into course material.
Score Range	Description of Agency Maturity in Assessing Current Practice		
0 to 16	Your agency is emerging into this area and has taken initial steps to grow awareness and understanding of the types of "assessing current practice" strategies it can implement.		
17 to 31	Your agency has implemented several "assessing current practice" strategies, not so much as part of an agency-wide strategy but rather at the initiative of agency staff.		
32 to 36	Your agency has reached a very high level of maturity in assessing current practice and implementing an "assessing current practice" strategy. Major focus should be on maintaining and enhancing existing efforts when appropriate and take advantage of new opportunities as they become available.		

Recommended Actions to Achieve Higher Levels of Resilience Capability

If you scored at Level 1 or 2, you can take steps to continue your evolution toward a more resilience-oriented agency. In such cases, agency managers should identify which of the factors in Table 5 were most lacking and determine priorities for improving your agency's organization. Table 6 is offered as a template to determine which steps your agency can take to improve your agency's resilience through self-assessment efforts, who should be responsible, the timeframe for the implementation, and expected outcomes.

Table 6: Actions to Achieve Higher Maturity for Step1: Assess Current Practice

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Conduct a self-assessment of your agency's current resilience efforts.			
	Conduct self-assessments of specific agency functions that are particularly relevant to system resilience, for example, using the FHWA capability maturity assessment tools described earlier.			
	Incorporate transportation system resilience into agency plans and policy statements in order to institutionalize a resilience "mindset" into agency staff.			
	Establish a formal process for reviewing and updating the emergency operations plan.			
	Develop a process for conducting after-action and after-event reports that are used to identify corrective actions.			
	Develop a process for reviewing maintenance data to identify chronic disruptions to different assets.			
	Review threat/hazard exposure and/or vulnerability/risk studies to understand potential disruptions to your transportation system and possible demands on your agency.			
	Review staff roles and responsibilities to identify how they relate to enhancing system resilience. Develop a strategy for institutionalizing system resilience into staff roles.			
	Review the performance of your agency's project design standards and begin the process of making design criteria more adaptive to expected future hazards and threats.			
	Develop a human resource development and succession plan that focuses on preparing the current and future agency staff for resilience-oriented activities.			
	Assess training/professional development programs and incorporate concepts relating to transportation system resilience into course materials.			
	Begin the process of undertaking (or at least examining) some of the subsequent steps in this guide and determine if your agency has the capability to undertake such efforts. Where necessary, identify strategies to provide such capability.			



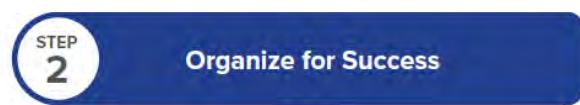
Possible actions for "Implement Early Wins"

Useful References

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Chapter 4: Organize for Success (Step 2)

Step 2 recognizes that any successful program or policy initiative depends on an effective organizational structure, an assignment of and accountability for program responsibilities, and on having the resources necessary to achieve program objectives. In this case, organizing for success includes both internal governance and leadership capabilities as well as the external institutional arrangements that foster effective collaborations with partner organizations. In this case, governance is distinguished from leadership in that it includes the institutional structures and channels of authority and responsibility within an organization. Leadership, on the other hand, refers to the characteristic of individual managers and staff that allows them to influence the overall direction of policy development and implementation.



Capability Factors and Levels of Maturity

Factor 2.1 Does your agency have a resilience strategy/program?

One of the most important indicators of organizational attention on transportation system resilience is the existence of a resilience strategy and/or program. This could include a formal policy statement and program elements, dedicated staff and leadership for fostering a more resilient transportation system, and dedicated funding to resilience-oriented projects and strategies. The different levels of maturity are defined in this factor by the degree to which your agency has developed and formally implemented a structured resilience strategy.

- Level 1: We have made a commitment to transportation system resilience, but implementing this “strategy” relies on the efforts of individual units that have responsibility for resilience-related activities. It is the responsibility of each unit to do the best they can to improve transportation system resilience. There is no overall leadership and accountability for the success of our agency’s resilience efforts.
- Level 2: We have adopted a formal strategy for transportation system resilience and have developed a program of actions throughout the agency. Coordination occurs among the functional unit efforts so as to ensure that collaborative, agency-wide resilience initiatives are successful. The degree of formal coordination and leadership accountability is also part of other factors below.
- Level 3: We have achieved a Level 2 maturity. In addition, there are agency efforts to enhance resilience capabilities by focusing on organizational structure, staff responsibilities, internal and external coordination and information flow protocols, and professional development/training. The strategy is agency-wide and centrally coordinated. The level of participation of top agency managers in this coordination is part of another factor below.

Factor 2.2 Has a document describing your resilience strategy/program been developed?

One indicator of having an organizationally-adopted resilience strategy/program is the development of a document that describes its intent, program content, and measures of success. Such a document could be used internally to expose agency staff to the agency’s efforts in system resilience or used externally to provide key stakeholders or the general public with an understanding of what the agency is doing.

The different levels of maturity are defined in this factor by the degree to which written documentation of your agency's resilience efforts has been developed.

- Level 1: Information on my agency's resilience program is scattered across multiple internally-focused documents. The content is usually the responsibility of individual units. The documents are not regularly updated.
- Level 2: We have a single document that contains sections on each of our agency's resilience responsibilities. The document is not regularly updated.
- Level 3: We have a formal, publicly-available document that comprehensively describes all aspects of our agency's resilience strategy. Updates to the document are made on a regular basis, most often with updates centralized in a unit with such a responsibility.

Factor 2.3 Has leadership of the resilience strategy/program been assigned in your agency?

Assigning clear accountability for the responsibility of a resilience strategy is an important factor leading to successful program implementation and operation. Those agencies that have adopted a pro-active resilience strategy have either assigned or created a position in the agency having such a responsibility. This has occurred by either giving leadership responsibilities to an existing unit head or by creating a cross-unit position that can coordinate agency resilience activities. The different levels of maturity are defined in this factor by the degree to which the leadership of the resilience strategy in your agency has been formally assigned to an individual, group, or unit.

- Level 1: Leadership of the resilience strategy/program rests solely with the managers of the individual units having roles in our resilience efforts. This means, for example, that the head of traffic operations is responsible for resilience efforts in that unit; the head of planning is responsible for such efforts in planning; and the like. No single person has been designated to lead our agency's resilience strategy/program.
- Level 2: We have assigned specific leadership responsibilities for resilience efforts to one or more staff members as part of their job responsibilities. The resilience efforts of these staff members are reported to top management on a periodic basis.
- Level 3: We have established a central leadership role (either a management position or an office/department) whose primary responsibility is the resilience strategy/program. This leadership position has authority and accountability to direct our agency's resilience efforts.

Factor 2.4 Have staff been assigned to support the agency's resilience strategy/program?

One of the indicators of a serious agency commitment to any particular program area is the assignment of staff in support of its implementation and operation. This could include temporary staff assignments to the resilience program (e.g., during a start-up phase) to a full-time staff commitment. One measure of such commitment is how formal staff responsibilities have been defined (e.g., incorporated into job descriptions). The different levels of maturity are defined in this factor as the degree to which staff resources have been dedicated to the agency's resilience efforts.

- Level 1: We rely on existing staff in those units having responsibility for resilience-related activities to support our resilience efforts. These staff members understand that part of their job is to improve

our resilience program. However, these staff do not meet regularly to coordinate efforts in the agency and to identify improvements to the strategy/ program.

- Level 2: We have achieved a Level 1 maturity. We have also established a means of exchanging information amongst staff and to coordinate resilience efforts where necessary. Staff meetings occur regularly to identify improvements to our agency's resilience strategy/ program.
- Level 3: We have assigned dedicated staff to the resilience strategy/program whose primary job responsibility is implementing the program. These staff members understand that part of their job is to improve our resilience program. There are examples where this staff has produced reports or other recommendations to improve our agency's resilience strategy/program. The staff reports to the resilience strategy/program leadership.

Factor 2.5 Has some mechanism been established (e.g., an advisory group/task force/council) to coordinate resilience efforts?

Resilience efforts will likely occur in many functional units in a transportation agency. Thus, the development of an agency-wide resilience strategy and its implementation will involve a variety of agency interests and a range of perspectives of what resilience means to your agency's efforts. Most transportation agency efforts to establish a resilience strategy have included the creation of some form of coordinating mechanism to provide leadership on the agency's activities, a sounding board for new ideas, and accountability for making sure the strategy is implemented successfully. The different levels of maturity are defined in this factor by the degree to which formal coordination among different agency units occurs for the agency's resilience efforts.

- Level 1: We rely on ad hoc efforts, usually occurring as the responsibility and initiative of the unit leads. Such coordination happens on an as-needed basis.
- Level 2: We have created an advisory group with representatives from the relevant resilience-related units. To the extent an identified staff lead for resilience has been established, this group works with this position to support resilience strategy implementation. The advisory group meets as needed.
- Level 3: We have achieved a Level 2 maturity. In addition, the coordinating group includes a broader representation of our agency's functional units and district offices and has been assigned more resources to accomplish its mandate. The group works with the staff lead for resilience and resources have been provided to the advisory committee and agency lead to undertake initiatives to enhance our agency's resilience efforts. The group meets on a set schedule.

Factor 2.6 Is the agency CEO/Director aware of, and involved in, the resilience program?

The interest and involvement of the agency chief executive officer (CEO) in any agency initiative conveys the importance of that initiative to the agency staff. Those agencies that have made the most progress in implementing a resilience strategy have usually included the active involvement of the CEO and other top management officials. The different levels of maturity are defined in this factor by the degree to which the CEO is aware of the agency's resilience strategy/program and monitors the progress in its implementation.

- Level 1: The CEO/director is aware of the resilience strategy/program and is updated during normal agency performance reviews. No formal plan for conveying information on the strategy/program to future CEOs/directors has been developed.
- Level 2: The CEO/director is aware of the resilience strategy/program and regularly monitors its implementation. Special briefings are provided on different aspects of the resilience program. No formal plan for conveying information on the strategy/program to future CEOs/directors has been developed.
- Level 3: The CEO/director is aware of the resilience strategy/program, regularly monitors its implementation, and often speaks publicly about our agency's efforts. As part of the resilience program, there is a formal plan to convey information on the strategy/ program to new CEOs and top agency leaders.

Factor 2.7 Are department heads within the agency aware of and involved in the resilience program?

Similar to the above factor, department head interest and participation in the agency's resilience strategy is a strong indicator of a well-thought-out program. The different levels of maturity are defined in this factor by the degree to which department heads are involved in your agency's resilience efforts.

- Level 1: Department heads are aware of the resilience program and are primarily involved in resilience efforts in their own units. They do not participate in a collaborative, agency-wide resilience strategy.
- Level 2: Department heads are aware of the resilience program and are members of an agency-wide task force/ advisory committee to guide agency resilience efforts. Department heads have participated in professional development opportunities on resilience.
- Level 3: We have achieved Level 2 maturity. In addition, department heads have been involved in collaborative agency efforts to enhance our resilience program. Department heads are encouraged to identify budget requests for activities that will enhance our agency's resilience efforts.

Factor 2.8 Have resilience-related job responsibilities been assigned to agency staff?

Some transportation agencies have assigned resilience responsibilities (usually in relation to emergency response) to every staff member in the agency. This not only establishes areas of expertise and capability in the agency for resilience efforts, but conveys to the staff (and to others outside the agency) that resilience is a core value of the organization. The different levels of maturity are defined in this factor by the degree to which system resilience responsibilities have been incorporated into staff responsibilities.

- Level 1: We have assigned specific resilience job responsibilities only to operations and maintenance staff and the staff responsible for managing the resilience program.
- Level 2: We have assigned each staff member within the organization specific job responsibilities with respect to resilience, even if nothing more than to be on stand-by for emergency response efforts.

- Level 3: We have assigned each staff member within the organization specific job responsibilities with respect to resilience and provided appropriate training. Several staff are cross-trained to assist with tasks different than their typical day-to-day functions during emergency events.

Factor 2.9 Does your agency use quality assurance/quality control processes in managing your resilience program?

Many of the activities and efforts to enhance the resilience activities of your agency will involve the use of asset and system performance data and the implementation of processes that require dedicated and motivated staff participation. Quality assurance/quality control (QA/QC) processes are an important check on the credibility and effectiveness of such data use and process implementation. This factor focuses on the existence of such QA/QC processes as part of your agency's resilience efforts.

- Level 1: We use QA/QC processes for some of the data collection efforts that have traditionally been part of our agency's data collection efforts (e.g., pavement and bridge management systems).
- Level 2: We have included QA/QC processes for every data collection effort associated with our resilience program. We have assigned staff responsibilities for conducting such QA/QC.
- Level 3: We have achieved Level 2 maturity. In addition, we have included QA/QC processes as part of every resilience effort in our agency, not just data collection efforts. It is part of the standard operating procedures for establishing new resilience programs. The QA/QC processes are written and are reexamined periodically for their effectiveness in assuring credible resilience actions.

Factor 2.10 Has your agency been working closely with local jurisdictions in supporting efforts to develop more resilient communities?

Transportation agencies not surprisingly focus the majority of their attention on the transportation system for which they are responsible. However, in many cases, other agencies and local governments seek their input and advice on topics given the technical expertise and competence of agency staff. This can be true in the general topic of resilience. This factor reflects the degree to which your agency adopts a leadership role in resilience efforts within your jurisdiction. This leadership role will be constrained by staff and budget resources, but taking a leadership role can also occur by interacting with communities from the perspective of providing technical guidance and speakers for resilience forums. The different levels of maturity are defined in this factor by the degree to which your agency has adopted a leadership role in fostering community resilience, including a resilient transportation system. This includes the level to which staff responsibilities have been assigned to working with local communities.

- Level 1: We will respond to local community requests for presentations or technical material on resilient transportation systems as staff resources allow. Our focus in these efforts is on a resilient transportation system.
- Level 2: We have provided technical support for a small number of communities seeking advice on resilient infrastructure and, more generally, on resilient communities. This interaction occurs on the discretion of individual unit managers.
- Level 3: We have assigned staff as liaisons to communities seeking technical help in developing more resilient infrastructure and supporting actions. This is an effort to place our agency in a leadership

position with respect to enhancing resilience considerations in all decision-making. We actively market our willingness to help local communities (within staff constraints).

Factor 2.11 Has coordination occurred with federal, state, and local agencies involved in setting climate adaptation policy?

Climate change and extreme weather concerns require non-traditional forms of collaboration and partnership. Agencies involved with climate change adaptation have often established relationships with climate scientists (often with the state university), environmental and natural resource agencies, environmental advocacy groups, professional organizations interested in adaptive design, and the like. Although representing just one source of disruption to transportation system resilience, including climate change and extreme weather concerns in the agency's resilience strategy is an indication of a level of maturity to develop a proactive all-hazards approach to system resilience. The different levels of maturity are defined in this factor by the type of coordination that has occurred with others in developing a climate change adaptation policy and strategy.

- Level 1: Our coordination has been limited to commenting on proposed legislation, regulations, and permitting requirements that will affect my agency. In essence, we respond only when asked to. We have very limited to no coordination with local government resilience and adaptation planning.
- Level 2: Our coordination has been limited to commenting on proposed legislation, regulations, and permitting requirements that will affect the agency. Proactive monitoring of these policies occurs, but feedback is primarily reactive. We have actively undertaken some coordination with local government resilience and adaptation planning.
- Level 3: We are proactive in influencing proposed resilience legislation, regulations, and permitting requirements that will affect our agency's resilience efforts. Wherever possible, agency staff serve on relevant committees and boards helping to set such policies. Coordination with local government adaptation planning efforts is standard practice.

Table 7 shows the factors that are included in the self-assessment tool for Step 2. The maturity levels for each factor are presented in the descriptions of each factor.

Table 7: Assessment Table for Step 2: Organize For Success

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
2.1 Does your agency have a resilience strategy/program?	We have made a commitment to transportation system resilience, but implementing this “strategy” relies on the efforts of individual units that have responsibility for resilience-related activities. It is the responsibility of each unit to do the best they can to improve transportation system resilience. There is no overall leadership and accountability for the success of our agency’s resilience efforts.	We have adopted a formal strategy for transportation system resilience and have developed a program of actions throughout the agency. Coordination occurs among the functional unit efforts so as to ensure that collaborative, agency-wide resilience initiatives are successful. The degree of formal coordination and leadership accountability is also part of other factors below.	We have achieved a Level 2 maturity. In addition, there are agency efforts to enhance resilience capabilities by focusing on organizational structure, staff responsibilities, internal and external coordination and information flow protocols, and professional development/training. The strategy is agency-wide and centrally coordinated. The level of participation of top agency managers in this coordination is part of another factor below.
2.2 Has a document describing your resilience strategy/program been developed?	Information on my agency’s resilience program is scattered across multiple internally-focused documents. The content is usually the responsibility of individual units. The documents are not regularly updated.	We have a single document that contains sections on each of our agency’s resilience responsibilities. The document is not regularly updated.	We have a formal, publicly-available document that comprehensively describes all aspects of our agency’s resilience strategy. Updates to the document are made on a regular basis, most often with updates centralized in a unit with such a responsibility.
2.3 Has leadership of the resilience strategy/program been assigned in your agency?	Leadership of the resilience strategy/program rests solely with the managers of the individual units having roles in our resilience efforts. This means, for example, that the head of traffic operations is responsible for resilience efforts in that unit; the head of planning is responsible for such efforts in planning; and the like. No single person has been designated to lead our agency’s resilience strategy/ program.	We have assigned specific leadership responsibilities for resilience efforts to one or more staff members as part of their job responsibilities. The resilience efforts of these staff members are reported to top management on a periodic basis.	We have established a central leadership role (either a management position or an office/department) whose primary responsibility is the resilience strategy/program. This leadership position has authority and accountability to direct our agency’s resilience efforts.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
2.4 Have staff been assigned to support the agency's resilience strategy/program?	We rely on existing staff in those units having responsibility for resilience-related activities to support our resilience efforts. These staff members understand that part of their job is to improve our resilience program. However, these staff do not meet regularly to coordinate efforts in the agency and to identify improvements to the strategy/ program.	We have achieved a Level 1 maturity. We have also established a means of exchanging information amongst staff and to coordinate resilience efforts where necessary. Staff meetings occur regularly to identify improvements to our agency's resilience strategy/ program.	We have assigned dedicated staff to the resilience strategy/program whose primary job responsibility is implementing the program. These staff members understand that part of their job is to improve our resilience program. There are examples where this staff has produced reports or other recommendations to improve our agency's resilience strategy/program. The staff reports to the resilience strategy/program leadership.
2.5 Has some mechanism been established (e.g., an advisory group/task force/council) to coordinate resilience efforts?	We rely on ad hoc efforts, usually occurring as the responsibility and initiative of the unit leads. Such coordination happens on an as-needed basis.	We have created an advisory group with representatives from the relevant resilience-related units. To the extent an identified staff lead for resilience has been established, this group works with this position to support resilience strategy implementation. The advisory group meets as needed.	We have achieved a Level 2 maturity. In addition, the coordinating group includes a broader representation of our agency's functional units and district offices and has been assigned more resources to accomplish its mandate. The group works with the staff lead for resilience and resources have been provided to the advisory committee and agency lead to undertake initiatives to enhance our agency's resilience efforts. The group meets on a set schedule.
2.6 Is the agency CEO/director aware of and involved in the resilience program?	The CEO/director is aware of the resilience strategy/program and is updated during normal agency performance reviews. No formal plan for conveying information on the strategy/program to future CEOs/directors has been developed.	The CEO/director is aware of the resilience strategy/program and regularly monitors its implementation. Special briefings are provided on different aspects of the resilience program. No formal plan for conveying information on the strategy/program to future CEOs/directors has been developed.	The CEO/director is aware of the resilience strategy/program, regularly monitors its implementation, and often speaks publicly about our agency's efforts. As part of the resilience program, there is a formal plan to convey information on the strategy/ program to new CEOs and top agency leaders.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
2.7 Are department heads within the agency aware of and involved in the resilience program?	Department heads are aware of the resilience program and are primarily involved in resilience efforts in their own units. They do not participate in a collaborative, agency-wide resilience strategy.	Department heads are aware of the resilience program and are members of an agency-wide task force/ advisory committee to guide agency resilience efforts. Department heads have participated in professional development opportunities on resilience.	We have achieved Level 2 maturity. In addition, department heads have been involved in collaborative agency efforts to enhance our resilience program. Department heads are encouraged to identify budget requests for activities that will enhance our agency's resilience efforts.
2.8 Have resilience-related job responsibilities been assigned to staff?	We have assigned specific resilience job responsibilities only to operations and maintenance staff and the staff responsible for managing the resilience program.	We have assigned each staff member within the organization specific job responsibilities with respect to resilience, even if nothing more than to be on stand-by for emergency response efforts.	We have assigned each staff member within the organization specific job responsibilities with respect to resilience and provided appropriate training. Several staff are cross-trained to assist with tasks different than their typical day-to-day functions during emergency events.
2.9 Does your agency use quality assurance/quality control processes in managing your resilience program?	We use QA/QC processes for some of the data collection efforts that have traditionally been part of our agency's data collection efforts (e.g., pavement and bridge management systems).	We have included QA/QC processes for every data collection effort associated with our resilience program. We have assigned staff responsibilities for conducting such QA/QC.	We have achieved Level 2 maturity. In addition, we have included QA/QC processes as part of every resilience effort in our agency, not just data collection efforts. It is part of the standard operating procedures for establishing new resilience programs. The QA/QC processes are written and are reexamined periodically for their effectiveness in assuring credible resilience actions.
2.10 Has your agency been working closely with local jurisdictions in supporting efforts to develop more resilient communities?	We will respond to local community requests for presentations or technical material on resilient transportation systems as staff resources allow. Our focus in these efforts is on a resilient transportation system.	We have provided technical support for a small number of communities seeking advice on resilient infrastructure and, more generally, on resilient communities. This interaction occurs on the discretion of individual unit managers.	We have assigned staff as liaisons to communities seeking technical help in developing more resilient infrastructure and supporting actions. This is an effort to place our agency in a leadership position with respect to enhancing resilience considerations in all decision-making. We actively market our willingness to help local communities (within staff constraints).

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
2.11 Has coordination occurred with state, federal, and local agencies involved in setting climate adaptation policy?	Our coordination has been limited to commenting on proposed legislation, regulations, and permitting requirements that will affect my agency. In essence, we respond only when asked to. We have very limited to no coordination with local government resilience and adaptation planning.	Our coordination has been limited to commenting on proposed legislation, regulations, and permitting requirements that will affect the agency. Proactive monitoring of these policies occurs, but feedback is primarily reactive. We have actively undertaken some coordination with local government resilience and adaptation planning.	We are proactive in influencing proposed resilience legislation, regulations, and permitting requirements that will affect our agency's resilience efforts. Wherever possible, agency staff serve on relevant committees and boards helping to set such policies. Coordination with local government adaptation planning efforts is standard practice.

Score Range	Description of Agency Maturity in Organizing for Success
0 to 15	Your agency is emerging into this area and has taken initial steps to grow awareness and understanding of the types of "organizing for success" strategies it can implement.
16 to 28	Your agency has implemented several "organizing for success" strategies, not so much as part of an agency-wide strategy but rather at the initiative of agency staff.
29 to 33	Your agency has reached significant maturity in organizing and implementing an "organizing for success" strategy. Major focus should be on maintaining and enhancing existing efforts when appropriate, and take advantage of new opportunities as they become available.

Recommended Actions to Maintain the Highest Level of Agency Resilience Capability

The highest level of capability for "Organize for Success" focuses on continual improvement in agency capability and actions for this agency characteristic. If your agency has reached Level 3, the highest level of agency capability, the following recommended actions focus on maintaining this level:

- Periodically reassess the organization of your agency's resilience efforts with respect to different roles in transportation system resilience. This includes periodically assessing the organizational structure that has been created to guide your agency's efforts. This could be done in-house or by bringing in a third-party evaluator to conduct the assessment.
- Periodically reassess your QA/QC processes as they relate to your agency's resilience efforts to assure they are providing credible information for resilience-oriented decision-making.
- Update written documentation describing your resilience program as new developments occur.
- Continually involve agency staff in identifying actions that will improve the efficiency and effectiveness of your agency's resilience efforts.
- Assess the leadership responsibilities for the resilience program on a periodic basis to assure the current assignment of responsibilities is effective and that resilience actions are indeed being implemented. Similarly, assess staff responsibilities and actions to identify improvements to the processes and procedures that are the foundation of your resilience program. Are the staff providing the needed support to the resilience program in effective and efficient ways?
- Periodically obtain input from agency leaders on the appropriateness, timeliness, and quality of information provided to them on the status and performance of the resilience program. Make changes as needed.
- Provide input and briefings to new managers in the agency on the resilience program, the organizational responsibilities and structure for the program, and expected benefits and outcomes.
- Continue to monitor the resilience of the transportation system and consider changes in this performance when making organizational changes in your agency.
- Periodically assess resilience partnerships with local communities from the perspective of your agency's leadership in fostering more resilient communities.
- Participate in and/or lead meetings with partner agencies and groups to reinforce the importance of collaboration and coordination in enhancing system resilience and in evaluating the effectiveness of collaborative efforts.
- Update staff professional development and training opportunities to include the latest thinking and concepts in system resilience.

If you did not score a "33" in the assessment (a perfect score in Level 3 efforts), identify those factors that were rated lower and identify a strategy or action steps to improve these particular components of Step 2.

Recommended Actions to Achieve Higher Levels of Resilience Capability

If you scored at Level 1 or 2, you can take steps to continue your evolution toward a more resilience-oriented agency. In such cases, agency managers should identify which of the factors in Table 7 were most lacking and determine priorities for improving your agency's organization. Table 8 is offered as a template to determine

which steps your agency can take to improve your agency's resilience capabilities, who should be responsible, the timeframe for the implementation, and expected outcomes.

Table 8: Actions to Achieve Higher Maturity for Step 2: Organize for Success

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Establish a formal resilience strategy/ program. This might require legislative approval or, at a minimum, agency directives and guidance.			
	Prepare a written document describing your resilience strategy/program. This documentation should describe the rationale for the program, how it is structured, expected outcomes, and ultimate benefits to your jurisdiction.			
	Assign leadership responsibilities of the resilience strategy/program in your agency. This might be structured as a central authority for all resilience efforts or the assignment of responsibilities for individual components of the program.			
	Assign staff to support the resilience strategy/program. Such assignments should be clear in terms of how activities contribute to program objectives and QA/QC procedures that should accompany staff efforts.			
	Create an institutional mechanism to coordinate resilience efforts. Such a mechanism (e.g., task force, coordinating committee, and the like) would be given a clear mandate and expected products as they relate to your agency's resilience program			
	Involve the agency CEO/director in the resilience program. Periodically reassess the usefulness of the information provided to the CEO with respect to the types of decisions he/she must make relating to the resilience program.			
	Involve department heads in the resilience program. This could be part of a formal coordinating group or frequent meetings to coordinate resilience activities.			
	Assign resilience-related job responsibilities to agency staff job descriptions and talent profiles. Enhancing transportation system resilience should be part of all relevant staff job activities, both for			

Useful References

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Chapter 5: Develop an External Communications Strategy and Plan (Step 3)

Step 3 recognizes the importance of effective external communications in supporting and advancing your agency's resilience strategy. An effective external communications strategy focuses on developing partnerships before disruptions occur (when developing resilient strategies, plans and projects), during incident response (when coordinating emergency response, and recovery), and after events with communities, policy makers, businesses, and general system users (What are the next steps? What are the lessons learned? etc.).

STEP
3

Develop an External Communications Strategy and Plan

This step is positioned in the early phase of the Framework in recognition of the need for successful program implementation to be supported by numerous external partners and enabling groups (such as legislatures). Effective external communications that illustrate and explain the benefits of your agency's resilience strategy will be an important foundation for your agency's efforts to develop collaborative partnerships that will support your program. As it relates to those who provide funding and other resources to your agency, such communications can enable changes in agency practices and in the types of projects funded in the capital program. The intent of this step is to examine both communications to a range of audiences in response to an incident as well as how an agency should communicate with external audiences to build a case for investment in resilience.

Every effective communications plan identifies the audiences that are targeted for different types of information and marketing materials. With respect to resilience these audiences will vary by purpose of the communications efforts. For example, if an agency is seeking additional funding for a new resilience initiative, the audiences might be the governor, governor's staff, legislators, legislative staff, partner agencies, industry and professional groups, and the general public. The content of the information would likely focus on the expected benefits of investing in a resilience strategy. The intent of a communications plan is thus to identify the different audiences that would be the focus of external information, the messages that might be sent, and the different media that could be used.

For those using the self-assessment tool for this step, note that efforts to enhance internal coordination through improved communications was part of Step 2: *Organize for Success*. Effective external communications will also be an important consideration in other steps of the Framework. Such consideration relates primarily to the need for communication channels among the different agencies that participate in collaborative resilience actions. For example, several factors in Step 8A: *Assess Strategies for Enhancing Emergency Response Capabilities* relate to the communication interactions among the agencies involved in incident or disaster response. Similarly, the factors in other steps that relate to cyberattacks against an agency's command-and-control capabilities include concerns about disruptions to an agency's communications systems.

Capability Factors and Levels of Maturity

Factor 3.1 Does your agency have an external communications strategy that supports your resilience program?

The first factor examines the depth and breadth of your agency's external communications strategy as it supports all aspects of your agency's resilience efforts (which, as noted above, are found in other self-assessment steps). Developing an external communications strategy includes understanding the audiences for communications efforts, the major purposes for different components of such efforts, and how the strategy supports individual resilience actions of your agency. The major distinction among the maturity levels of this factor are defined as the degree to which your agency has developed and formally implemented an external communications strategy.

- Level 1: Our external communications strategy is primarily based on resilience-related information provided by different agency units. Depending on the audience, this information is compartmentalized to specific agency actions (e.g., emergency response).
- Level 2: We have developed an external communications strategy based on an agency-wide perspective of what resilience means to the transportation system and to society in general. This strategy includes targeted resilience information for different audiences. The strategy focuses on past system disruptions/impacts and the benefits of avoiding or minimizing such impacts in the future.
- Level 3: We have achieved a Level 2 maturity. In addition, we update our strategy annually based on feedback on the effectiveness of past efforts and lessons learned from our agency's resilience accomplishments. It includes information on future key hazards and threats to the transportation system including climate change and how our agency is dealing with these issues.

Factor 3.2 Has your agency published a communications plan or documented the strategy in some other way as part of your external communications strategy?

Documenting your external communications plan serves several purposes. First, it describes how your agency is going to reach out to groups and agencies that are important to support your agency's efforts. Second, it serves as a benchmark on which success or some level of progress in implementing your communications strategy can be determined. Third, the document itself becomes an important educational/marketing/informational resource to explain why resilience is so important to your agency and to the communities the transportation system serves. Finally, if updated periodically, it can be an important means of conveying the latest agency successes and helping to make the business case for investments in a more resilient transportation system. The major distinctions among the maturity levels in this factor reflect the degree to which formal documentation on external communications is available and the level of agency coordination in developing related documents.

- Level 1: Documentation on external communication efforts is the responsibility of individual units in our agency. Thus, this information is scattered across multiple documents and is utilized as needs arise. Documents are updated at the discretion of unit managers.
- Level 2: We have developed an agency document that contains sections on each of our agency's unit-specific external communications efforts. The document is updated infrequently. It is not widely

circulated outside our agency and it is primarily used to communicate to agency staff how we are reaching out to external groups.

- Level 3: We have a publicly-available document (a plan) that comprehensively describes all aspects of the resilience communications strategy. Updates to the document are made on a regular basis. The document is widely circulated as part of our efforts to raise awareness of our agency's resilience efforts.

Factor 3.3 To what extent has staff from different units in your agency been involved in the development of the external communications strategy?

Given that many different units in your agency have a role in developing and implementing an agency-wide resilience strategy, an effective and credible communications strategy should include participation from your agency of those units most knowledgeable about on-going and needed resilience efforts. Not only does this help in developing a strategy that is based on what your agency is actually doing (and thinking of doing), but it provides another means of obtaining “buy-in” to your agency’s resilience efforts from agency staff. This factor does not mean that every unit within your agency needs to participate in developing the external communications strategy, but rather opportunities for such involvement should be available and participation encouraged by agency leadership. The major distinction among the different maturity levels in this factor reflects the degree to which opportunities are provided for different staff across your agency to participate in the development and on-going updates to the communications strategy.

- Level 1: We ask different units in our agency to provide input as the external communications strategy is developed and updated. This participation, which is used to highlight what my agency is doing to enhance transportation system resilience, is informal.
- Level 2: We have a process for developing the external communications strategy that includes the participation of different agency units. Such participation is requested by the agency’s CEO. Updates to the strategy, however, are primarily done by our agency’s communications/information office.
- Level 3: We have a formal mechanism (e.g., task force, committee, or the like) to guide the development of the external communications strategy that has representation from resilience-related units in our agency. The process of developing and updating the communications strategy includes the involvement of this group.

Factor 3.4 Does your external communications strategy provide information on the general topic of resilience as well as background on the natural and human-caused hazards and threats facing the transportation system?

One indicator of having an inclusive external communications strategy is whether it covers the full range of resilience concerns facing the transportation system. This includes providing information on the topic of transportation system resilience and more detailed information on the types of hazards and threats facing the system. In addition, the strategy should explain how your agency will address each of these threats and hazards, and what this means to the businesses and residents in my jurisdiction. The distinction among the levels of maturity reflects the breadth of information provided in the materials and information produced as part of the communications strategy.

- Level 1: We focus our communications strategy in general terms on what transportation system resilience means to our agency.
- Level 2: We include information in our communications strategy on past hazards and associated system disruptions. We emphasize what such disruptions have meant to transportation system performance.
- Level 3: We include information on current and future hazards and human-caused threats facing the transportation system in our communications strategy. In addition, we explain what such hazards and threats mean to the transportation system, system users, and to society in general. We update our communications information every year with examples of the latest efforts by our agency to make the system more resilient.

Factor 3.5 Does your agency's external communications strategy include multiple means of outreach (written materials, web-based capabilities, social media, speaker's bureau, and the like)?

Key constituency groups and stakeholders for your agency utilize different means of obtaining and digesting information. A fully engaged strategy for outreach should capitalize on the different means of providing information to interested parties and of allowing feedback/input from these groups. The major distinction among the maturity levels reflects the degree to which the external communications strategy includes a range of media and tools for disseminating information and providing channels of feedback.

- Level 1: We focus our communication efforts on a few means of providing outreach and information dissemination.
- Level 2: We use all communication means of providing information on resilience efforts in my agency.
- Level 3: We have achieved Maturity Level 2. In addition, we use our media outreach to not only disseminate resilience information but also to provide opportunities for different groups to give us input on what we are doing as well as on what we should be doing.

Factor 3.6 Does the external communications strategy include a social media outreach capability?

A robust and comprehensive external communications strategy should include a range of means to communicate and disseminate information on your agency's resilience efforts. In today's communications environment, this needs to include social media. This could include many different outreach capabilities--Twitter feeds, an agency Facebook page, blogs, to apps targeting different market segments. The distinction among the different levels of maturity for this factor reflects the degree to which the use of social media is incorporated into the external communications strategy.

- Level 1: We use social media as an important means of conveying information to the public during emergencies and system disruptions.
- Level 2: We use social media updates to provide information on agency resilience efforts to many different audiences. These updates focus on both examples of how we respond to disruptions as well as more general information on how important system resilience is to the day-to-day lives of our citizens.

- Level 3: We target our resilience-oriented social media efforts on different market segments. The social media capability allows for input and feedback during policy development, project development, and project construction. Public feedback is sought on resilience priorities and long-term investment in resilience projects.

Factor 3.7 Does your agency's website include information on your resilience strategies, programs, and projects?

Resilience actions and programs are often based on comprehensive, evidence-based, and collaborative efforts to develop internal and external support for these programs. An agency website is often the major means of conveying information making use of a familiar and easy-to-use information platform. A website can also provide an ability for external groups to offer comments on your agency's resilience efforts and/or to respond to targeted questions on resilience priorities, programmed actions, or ongoing resilience initiatives. The major distinction among the maturity levels for this factor sis the level to which resilience information is provided on your agency's website.

- Level 1: We include resilience-related information on our website as part of our general information dissemination. Such information is provided by agency resilience-oriented units on an ad hoc basis.
- Level 2: We have a resilience section on our webpage. Resilience information is updated on the website on a quarterly basis with information requests to all units in our agency having resilience roles.
- Level 3: We have achieved a Maturity Level 2. In addition, the webpage is part of an integrated approach in linking this information to strategic outreach efforts and for providing information on hazards and threats facing the transportation system. The webpage provides capabilities for external individuals and groups to provide input into our resilience efforts.

Factor 3.8 Does your agency have a point of contact /spokesperson on resilience topics, including a contact for incident responses?

Having an informed and consistent voice and point of contact for resilience topics provides an important foundation for your external communications strategy. This point of contact can help support rolling out new resilience policies, coordinate multi-agency partnerships in disaster response, and provide information on the hazards and threats facing the transportation system. This point of contact that is trusted by the media can also serve as a credible source of information on major traffic incidents which will also feed into public perception of your agency's competence. The distinctions among the maturity levels in this factor reflect the level of engagement and scope of duties assigned to the contact person and efforts to ensure consistent messaging.

- Level 1: We have assigned resilience points of contact in each of our agency's resilience-oriented units. There is coordination among these staff on the resilience "message" for our agency. A separate point of contact is responsible for coordination/outreach during emergencies and major disruptions.
- Level 2: We have a point of contact for all resilience efforts in our agency. This contact relies on resilience information from individual agency units which is often produced in response to urgent requests for such information. A separate point of contact is responsible for coordination/outreach during emergencies and major disruptions.

- Level 3: We have achieved a Maturity Level 2 except that now we have identified a single point of contact for all resilience actions (including during emergencies and major disruptions). This point of contact also works with other agencies to ensure consistent and coordinated resilience messaging. During emergencies or major incidents, this point of contact is responsible for coordinating and leading communications among the various agencies involved.

Factor 3.9 Has your agency coordinated your external communications strategy with other partner agencies?

As is noted throughout the guide, many resilience efforts include the collaborative efforts of many different agencies. A good example includes the efforts of different agencies in responding to major crashes. For resilience more broadly, consistent messages could relate to the identification of the hazards and threats facing the transportation system and other sectors; the actions of public agencies in responding to associated risks; the costs to your agency, system users, and to society in general of system disruptions; and the types of actions the public and businesses can take to support system resilience. The distinction among the maturity levels for this factor relates to degree of coordination that occurs in making the resilience message and resilience information consistent across all relevant agencies.

- Level 1: We monitor the information dissemination and communication relating to resilience efforts of partner agencies. The messaging and the type of information provided by these efforts is considered when we develop our own communication materials.
- Level 2: A mechanism for coordinating resilience information among relevant agencies has been created. This coordination group serves as a means of exchanging information and ideas on how resilience information should be disseminated to various audiences.
- Level 3: We have achieved Maturity Level 2. In addition, the coordination group prepares materials and webpage information that is used by each agency participating in the group to provide consistent messaging.

Table 9 shows the factors that are included in the self-assessment tool for Step 3. The maturity levels for each factor are presented in the descriptions of each factor.

Recommended Actions to Maintain the Highest Level of Agency Resilience Capability

The highest level of capability for external communication includes a fully-integrated, active, and enabled strategy to provide information to and opportunities for input from key stakeholders and constituencies. If your agency has reached Level 3, the highest level of agency capability, the following recommended actions focus on maintaining this level.

- Periodically assess the external communication strategy in light of new developments in your agency's resilience efforts. This assessment might be led by internal staff or possibly by a third party reviewer.
- Periodically assess the success and failures in communication strategies to identify those that have been effective and those that may need to be adjusted or discarded from use. This will permit the agency to emphasize those communication strategies that have been proven successful.

- Possibly as part of the previous recommendation, survey targeted audiences to determine which resilience information is reaching them and if they understand the messages that are trying to be conveyed.
- Continue to support a broader communications strategy that includes other agencies to promote consistent messaging on the importance of resilience in the transportation system
- Update and refine the information disseminated on your agency's resilience efforts. Updates should occur on a set schedule.
- Update and refine the media which use this information (e.g., your agency's website) Make sure old information is removed/updated on a regular basis to ensure that the most recent information is provided.

Table 9: Assessment Table for Step 3: Develop an External Communications Strategy and Plan

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
3.1 Does your agency have an external communications strategy that supports your resilience program?	Our external communications strategy is primarily based on resilience-related information provided by different agency units. Depending on the audience, this information is compartmentalized to specific agency actions (e.g., emergency response).	We have developed an external communications strategy based on an agency-wide perspective of what resilience means to the transportation system and to society in general. This strategy includes targeted resilience information for different audiences. The strategy focuses on past system disruptions/impacts and the benefits of avoiding or minimizing such impacts in the future.	We have achieved a Level 2 maturity. In addition, we update our strategy annually based on feedback on the effectiveness of past efforts and lessons learned from our agency's resilience accomplishments. It includes information on future key hazards and threats to the transportation system including climate change and how our agency is dealing with these issues.
3.2 Has your agency published a communications plan or documented the strategy in some other way as part of your external communications strategy?	Documentation on external communication efforts is the responsibility of individual units in our agency. Thus, this information is scattered across multiple documents and is utilized as needs arise. Documents are updated at the discretion of unit managers.	We have developed an agency document that contains sections on each of our agency's unit-specific external communications efforts. The document is updated infrequently. It is not widely circulated outside our agency and it is primarily used to communicate to agency staff how we are reaching out to external groups.	We have a publicly-available document (a plan) that comprehensively describes all aspects of the resilience communications strategy. Updates to the document are made on a regular basis. The document is widely circulated as part of our efforts to raise awareness of our agency's resilience efforts.
3.3 To what extent has staff from different units in your agency been involved in the development of the external communications strategy?	We ask different units in our agency to provide input as the external communications strategy is developed and updated. This participation, which is used to highlight what my agency is doing to enhance transportation system resilience, is informal.	We have a process for developing the external communications strategy that includes the participation of different agency units. Such participation is requested by the agency's CEO. Updates to the strategy, however, are primarily done by our agency's communications/information office.	We have a formal mechanism (e.g., task force, committee, or the like) to guide the development of the external communications strategy that has representation from resilience-related units in our agency. The process of developing and updating the communications strategy includes the involvement of this group.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
3.4 Does your external communications strategy provide information on the general topic of resilience as well as background on the natural and human-caused hazards and threats facing the transportation system?	We focus our communications strategy in general terms on what transportation system resilience means to our agency.	We include information in our communications strategy on past hazards and associated system disruptions. We emphasize what such disruptions have meant to transportation system performance.	We include information on current and future hazards and human-caused threats facing the transportation system in our communications strategy. In addition, we explain what such hazards and threats mean to the transportation system, system users, and to society in general. We update our communications information every year with examples of the latest efforts by our agency to make the system more resilient.
3.5 Does your agency's external communications strategy include multiple means of outreach (written materials, web-based capabilities, social media, speaker's bureau, and the like)?	We focus our communication efforts on a few means of providing outreach and information dissemination.	We use all communication means of providing information on resilience efforts in my agency.	We have achieved Maturity Level 2. In addition, we use our media outreach to not only disseminate resilience information but also to provide opportunities for different groups to give us input on what we are doing as well as on what we should be doing.
3.6 Does the external communications strategy include a social media outreach capability?	We use social media as an important means of conveying information to the public during emergencies and system disruptions.	We use social media updates to provide information on agency resilience efforts to many different audiences. These updates focus on both examples of how we respond to disruptions as well as more general information on how important system resilience is to the day-to-day lives of our citizens.	We target our resilience-oriented social media efforts on different market segments. The social media capability allows for input and feedback during policy development, project development, and project construction. Public feedback is sought on resilience priorities and long-term investment in resilience projects.
3.7 Does your agency's website include information on your resilience strategies, programs, and projects?	We include resilience-related information on our website as part of our general information dissemination. Such information is provided by agency resilience-oriented units on an ad hoc basis.	We have a resilience section on our webpage. Resilience information is updated on the website on a quarterly basis with information requests to all units in our agency having resilience roles.	We have achieved a Maturity Level 2. In addition, the webpage is part of an integrated approach in linking this information to strategic outreach efforts and for providing information on hazards and threats facing the transportation system. The webpage provides capabilities for external individuals and groups to provide input into our resilience efforts.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
3.8 Does your agency have a point of contact/spokesperson on resilience topics, including a contact for incident responses?	We have assigned resilience points of contact in each of our agency's resilience-oriented units. There is coordination among these staff on the resilience "message" for our agency. A separate point of contact is responsible for coordination/outreach during emergencies and major disruptions.	We have a point of contact for all resilience efforts in our agency. This contact relies on resilience information from individual agency units which is often produced in response to urgent requests for such information. A separate point of contact is responsible for coordination/outreach during emergencies and major disruptions.	We have achieved a Maturity Level 2 except that now we have identified a single point of contact for all resilience actions (including during emergencies and major disruptions). This point of contact also works with other agencies to ensure consistent and coordinated resilience messaging. During emergencies or major incidents, this point of contact is responsible for coordinating and leading communications among the various agencies involved.
3.9 Has your agency coordinated your external communications strategy with other partner agencies?	We monitor the information dissemination and communication relating to resilience efforts of partner agencies. The messaging and the type of information provided by these efforts is considered when we develop our own communication materials.	A mechanism for coordinating resilience information among relevant agencies has been created. This coordination group serves as a means of exchanging information and ideas on how resilience information should be disseminated to various audiences.	We have achieved Maturity Level 2. In addition, the coordination group prepares materials and webpage information that is used by each agency participating in the group to provide consistent messaging.
Score Range	Description of Agency Maturity in an External Communications Strategy		
0 to 12	Your agency is emerging into this area and has taken initial steps to grow its capabilities in communicating resilience to external agencies and stakeholders		
13 to 23	Your agency has implemented several effective external communication strategies, not so much as part of a comprehensive agency-wide approach but rather due to the initiative of agency staff.		
24 to 27	Your agency has reached significant maturity in establishing and maintaining an effective external outreach strategy and plan and has created processes and platforms that provide for consistent information to be provided to interested parties.		

- Meet with communications leads from peer transportation agencies to learn about new communications strategies and innovative ways of conveying resilience information. Explore the possibility of jointly developing background material on system resilience for use by all peer agencies.
- Participate in national resilience meetings to share the experiences of the external communication strategy and get input/feedback from state and national agency staff engaged in similar programs.

Recommended Actions to Achieve Higher Levels of Resilience Capability

If you scored at Level 1 or 2, you are just starting your evolution toward a more resilience-oriented external communications strategy. In such a case, communications leads within the agency should identify which of the factors in Table 9 were most lacking based on scoring and determine priorities for improving external communications as part of your resilience efforts. Table 10 is offered as a template to determine which steps your agency can take to improve your agency's resilience capabilities, who should be responsible, the timeframe for implementation, and expected outcomes.

Table 10: Actions to Achieve Higher Maturity for Step 3: Enhance External Communications Capabilities

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Conduct a self-assessment of your agency's resilience-oriented external communication efforts.			
	Conduct self-assessments of the external communications role of those agency units that are particularly relevant to system resilience. Examine what roles these units can play in your agency's overall resilience communications strategy.			
	Create a coordination mechanism in your agency to contribute to the development of an external communications strategy.			
	Create a common point of contact for requests for resilience information.			
	Make sure your agency's communication strategy for major incidents/disruptions is clearly understood by agency staff. If not already, evolve the point(s) of contact for incident response into your point of contact for overall resilience information.			
	Examine the possibility of creating a coordinating mechanism (or participating in an existing one) among partner agencies to coordinate the resilience message and in producing common resilience material.			
	Prepare a written document describing your resilience external communications strategy (e.g., a communications plan). This documentation should describe the rationale for the program, how it will be structured, target audiences, action items, and implementation responsibilities.			
	Seek input from the public, key stakeholders, and other constituencies on the type of resilience information they would like to receive. Use this input to develop targeted outreach tools and media to provide such information.			

	Develop documentation that clearly outlines the intent, benefits, and expected outcomes of your agency's resilience program and ensure that all agency personnel are aware of the key messages in this material.			
	Prepare and utilize graphic material to summarize the benefits of resilience programs that can be used in social media outreach efforts.			
	Establish a social media account that disseminates information relating to resilience.			

 Possible steps for “Implement Early Wins”

Useful References

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Chapter 6: Implement “Early Wins” (Step 4)

Incorporating resilience strategies and concepts into a transportation agency does not necessarily require costly actions and detailed technical analyses that are implemented over a long period of time. In some cases, changes can occur in the daily operations of an agency, or existing processes might exist that allow changes in procedures to occur over months rather than years. This step refers to such changes as “early wins.”



Short-term changes are important to an agency for the following reasons:

- Early wins provide a first step to an overall change strategy for an organization’s evolution to a more resilience-oriented culture.
- Such changes convey to staff that the agency is serious in becoming a more resilience-oriented agency.
- In many cases, the identification of the early wins involves asking staff what steps can be taken to enhance system resilience thereby involving staff members in the efforts to change agency procedures. This leads to a better understanding of what system resilience actually means in terms of day-to-day activities.
- Early wins provide the agency communications strategy with concrete actions that can be pointed to as steps the agency has taken to improve its system resilience efforts.
- Similarly, such early wins illustrate to agency partners and other key stakeholders (such as legislators) that the agency is serious about enhancing its transportation system resilience efforts.
- In many cases, early wins will focus on operations and maintenance changes whose benefits will be apparent in the short term. For example, changes to improve the efficiency of agency response to major incidents or disasters will provide evidence of the benefits of the actions taken.
- Step 10 in the Framework examines how the agency has incorporated resilience-oriented performance measures into decision making. Doing so could be one of the “early wins” and thus could be viewed as performance test beds.

The first bullet above is an important building block for a sustainable and impactful strategy to bring about change in an organization. This concept is also an important foundation for the recommendations in the CEO Primer (Matherly et al 2020). As noted earlier, this step is a place-holder for early wins identified in other steps (indicated in each chapter by green shaded rows in the recommended actions templates). As other steps in the self-assessment tool are completed, the early wins can be moved into the overall ‘to-do’ table for Step 4.

Agency leadership could identify a wide range of actions that could be considered as “early wins.” Given the emphasis of this guide on an agency-wide perspective and a resilience-oriented agency culture, these actions could occur anywhere in the agency. The following self-assessment is based on those early wins identified as part of this research, and that have been identified by transportation agencies as actions that showed short-term benefits. Users of the self-assessment tool are encouraged to consider

the range of actions they have taken to enhance their agency's system resilience efforts and to incorporate these actions in the self-assessment process.

Capability Factors and Levels of Maturity

There are many early wins that can occur by functional area (e.g., emergency management) and agency concerns (e.g., cybersecurity). Note that agency interaction with communities and other agencies are highlighted in other steps. For example, agency efforts to reach out to local communities to help in developing resilience strategies were part of Step 2. However, such factors could also be part of this step if an agency should so desire. Where such early wins are more related to specific areas, they are considered in other steps; the factors that follow are more general.

Factor 4.1 Has your agency undertaken a systematic effort to identify those actions that could be implemented quickly and that would enhance system resilience?

This factor focuses on the degree to which your agency has systematically examined the opportunities for implementing early wins. Thus, the range of agency maturity relating to this factor reflects the degree to which the agency has formally identified such opportunities. For example, in many agencies, the responsibility for improving program delivery rests with program managers. In some examples of transportation agency efforts to enhance system resilience, the initiative for such efforts came from the operating unit.

- Level 1: We have informally identified where early win improvements can be made. The responsibility for implementing rests with the respective functional units. No written documentation has yet been produced.
- Level 2: We have undertaken a systematic assessment for (up to) two of our agency's units. Written reports have been prepared that indicates the recommended steps and how they will be implemented.
- Level 3: We have undertaken a systematic assessment for all our agency's units. A written report has been produced that is available for both agency staff and for stakeholders to understand the need and purpose for implementing the recommended actions.

Factor 4.2 Has your agency adopted a policy where new projects are to explicitly consider resilience in terms of design and operations?

Experience in those agencies that have successfully implemented agency-wide resilience strategies suggests that one of the most important initial steps is making a statement to agency leadership, staff, and key stakeholders that your agency is serious about mainstreaming resilience into agency business practices. This is most often takes the form of a policy statement or the adoption of resilience-oriented goals and objectives. The projects could range from major capital investments to reconstruction and rehabilitation of existing assets. The levels for this factor relate to the degree to which all projects are viewed from a resilience perspective and what types of hazards and threats are part of the assessment.

- Level 1: Only major projects (e.g., over a certain estimated cost) consider resilience in their design. The assessment considers only historical and current hazards and threats.
- Level 2: Only major projects consider resilience in their design. The assessment considers both historical/current and future hazards and threats.

- Level 3: All new projects consider resilience to current and future hazard and threats.

Factor 4.3 Has your agency pursued betterments when reconstructing facilities that have been damaged by extreme weather events?

Improving the project design of a damaged asset as part of its restoration is referred to as including betterments in the design. When an asset is damaged as part of a federally-declared disaster, the state can apply for FHWA's Emergency Relief (ER) funds to help pay for unusually heavy expenses resulting from extraordinary conditions. A state has three options for the use of these funds: (1) replace the project as it was originally designed (even though the project did not meet design standards), (2) reconstruct the facility using current design standards, or (3) reconstruct the facility at a higher level of design to account for projected future climate changes. FHWA requires applicants for betterments to demonstrate that, "the [design] feature is economically justified to prevent future recurring damage. The economic justification must weigh the cost of the betterment against the risk of eligible recurring damage and the cost of future repair." (FHWA 2019d) If federal ER funds are not available for the repair of an asset, state or local funding could also be used for betterments. The levels for this factor focus on how institutionalized the process is for justifying betterments in this program.

- Level 1: Our approach to ER projects is at least to design the project to current design standards. We recognize the logic of improving the design of a project to account for future threats and hazards. When applying for FHWA ER funds, we consider the use of betterments on a case-by-case basis. We use whatever benefit/cost methodology that best illustrates the return on investment for the use of such funds. This decision is a stand-alone decision specific to each disaster declaration, and the initiative for doing so is usually done on an ad hoc basis.
- Level 2: We have developed an institutionalized approach for determining the eligibility of betterments (using ER funds) to cover the gap between current standards and a more resilient design. This approach has been applied in previous applications. The applicable future risk is directly related to the event that caused the initial failure. This includes a standardized benefit/cost methodology that is applied for all project applications. So far, this approach has not been applied for non-ER projects.
- Level 3: We have developed an institutionalized standard operating procedure for pursuing betterments as part of all of our ER project reconstruction efforts. All possible future risks are considered when justifying the use of betterment funds. We routinely consider the use of other funds (regular federal-Aid or state funds) to cover the gap between current standards and a more resilient design. In addition to ER projects, we apply the same approach for non-federally funded reconstruction projects in response to facility failure.

Factor 4.4 Does your agency have a program for periodically cleaning culverts and other drainage infrastructure to make sure they will function as designed?

Experience from around the nation for extreme precipitation events has indicated that culverts, gullies, and storm drains tend to be highly vulnerable to capacity limitations caused by debris. Culvert vulnerability became particularly noticeable after the remnants of Hurricane Irene hit Vermont causing considerable damage to the state's transportation system. Many of the locations most damaged were at culverts, which were washed away. Note that there are federal requirements for bridge inspection, but not for culvert maintenance, so the need to clean and inspect culverts is often lower on the priority list.

- Level 1: We have an agency strategy that identifies where culverts and other drainage treatments are blocked or where sufficient debris has accumulated. Drainage treatment and culvert maintenance occurs when resources permit.
- Level 2: We have a culvert and drainage maintenance program that identifies and cleans those assets located on our critical roadways on a periodic basis (not a one-time effort).
- Level 3: We have such a program that when combined with our culvert condition inspection program provides our best effort at protecting against culvert failure statewide on all roadways under our jurisdiction.

Factor 4.5 Has your agency developed a strategy of pre-positioning equipment, materials, and other resources to respond to a disruption and/or support recovery?

Agencies involved in recovery operations have found that the pre-positioning of equipment, materials, and staff has been an effective strategy in bringing the transportation system back into operation expeditiously. This is particularly important in areas where, due to geographic constraints or network characteristics, network redundancy is limited.

- Level 1: We have undertaken a study of where such resources could be best positioned for such a purpose. We expect to implement the study recommendations within the year.
- Level 2: We have adopted such a strategy and have prepositioned the necessary resources to improve our response and recovery efforts in 1 or 2 locations where we expect facilities to be disrupted.
- Level 3: We have such a strategy and have already prepositioned the necessary resources to improve our response and recovery efforts statewide.

Factor 4.6 Has your agency developed and approved joint agreements or understandings with other agencies to share resources (e.g., staff and equipment) during emergencies?

Major disasters often require resources beyond the capability of state and local agencies. It is common to have agreements in place among many different organizations and agencies to provide temporary support during the period immediately following a disruption (a good example of this is the sharing of resources among utility companies in order to recover power). This factor recognizes the importance of such agreements, in particular with surrounding jurisdictions that could help or be part of the response strategy. For example, the response to major disasters that occur near state boundaries could very well rely on the transportation system in the neighboring state for such things as bringing in relief supplies or having detour routes using the other state's road network (and thus the need for signing).

Note that this factor is focused on resource-sharing. Agreements that ensure a local asset owner conducts work to the same standard as a DOT is a different type and also useful to resilience. For example, if your agency clears its culverts and a locality does not, both could suffer from flooding. This could also be extended to private sector actors and their transportation assets. The maturity levels for this factor are distinguished by how formal the arrangements are and the breadth of outreach to partner agencies.

- Level 1: We have ad hoc mutual support arrangements with other transportation agencies. The actual support depends on the circumstances and the ability of partner agencies to offer aid.
- Level 2: We have formal agreements with other transportation agencies to provide mutual support during emergencies. Logistics responsibilities and communication protocols have been established.
- Level 3: We have achieved Level 2 maturity and, in addition, identified and adopted agreements with all the agencies we think could help us in improving transportation system resilience during emergencies (not just other transportation agencies). This includes those who we have worked with for many years (such as emergency response organizations) and those that we have worked with before but not necessarily in the area of system resilience (e.g., metropolitan planning organizations).

Factor 4.7 Has your agency developed agreements or understandings with FEMA regarding procedures and requirements when a disaster has been declared?

Federally-declared disasters usually involve a major role for FEMA. One of FEMA's primary objectives in response to a disaster is to minimize the loss of life and put in place as quickly as possible the services and networks needed to assure recovery. Although FEMA provides near-term resources for handling an emergency, it too must respond to rules and requirements in terms of the justification for resources expended. Some state DOTs, for example, have expressed frustration in satisfying the requirements for filling out the forms and other paperwork associated with federal emergency aid. The distinction in level of maturity for this factor is the degree to which agreements with FEMA are in place to support effective interactions.

- Level 1: We have met with FEMA officials and have reached an understanding of the key procedures, protocols, and requirements when a disaster occurs. We are in the process of formalizing this agreement.
- Level 2: We have agreements in place with FEMA that are intended to expedite and make our response and recovery effort more effective.
- Level 3: We have achieved a Level 2 maturity. In addition, agency staff have received training on how FEMA procedures are to be undertaken. Agency response involving FEMA interaction has been institutionalized in agency standard operating procedures.

Factor 4.8 Have you participated in AASHTO, FHWA, or other professional association resilience efforts?

One of the most effective means of learning about potential early win actions is to hear what other agencies have been doing successfully. Organizations such as AASHTO and FHWA provide many outlets and opportunities for transportation officials to identify possible strategies for their own agency. The distinction in the level of maturity for this factor is the degree to which your agency comprehensively seeks information on what other agencies are doing.

- Level 1: We regularly monitor the information outlets of these organizations to identify the latest information on system resilience.

- Level 2: We attend professional and industry meetings that examine transportation system resilience and staff members serve on resilience-oriented committees. Our representatives on the resilience-oriented committees are very active in suggesting efforts and guidance that would be useful to our agency and to others.
- Level 3: We have participated actively in committees, peer exchanges, and the like in order to bring back “best practice” to our agency.

Factor 4.9 Has your agency implemented any resilience-related strategies beyond those listed in this step’s factors that can be considered “early wins” during the past two years?

One sure indication of how mature an agency is with respect to implementing early wins is the extent to which such actions have been taken. The level of maturity distinction made in this factor is the number of “early win” actions that your agency has taken in the past two years.

- Level 1: We have implemented up to two early win actions.
- Level 2: We have implemented three or four such actions.
- Level 3: We have implemented at least five such actions.

Table 11 shows the factors that are included in this self-assessment for Step 4. The maturity levels for each factor are presented in the descriptions of each factor.

Recommended Actions to Maintain the Highest Level of Agency Resilience Capability

The highest level of capability for “Implement Early Wins” focuses on systematically and periodically identifying strategies and actions that can be implemented quickly and without significant organizational resources. If your agency has reached Maturity Level 3, the highest level of agency capability, the following recommended actions focus on maintaining this level.

- Periodically reassess the capability of your agency’s units with respect to their role in implementing early wins. This could be done in-house or by bringing in a third-party evaluator to conduct the assessment.
- Assess the effectiveness of your agency’s program to clean culverts. Estimate the benefits of this program from the perspective of costs foregone associated with a smaller number of disruptions. Continue to monitor the level to which the culvert maintenance program achieves its objectives.
- Monitor the effectiveness of your agency’s efforts to use betterment funds when applying for ER funding. Keep abreast of the latest regulations and technical guidance on how such an application can be made. Assess your agency’s information resources in support of the betterment funding request (e.g., making improvements to data collection and data archiving on the expenditure of agency resources during disruptions to justify later federal reimbursement).
- Monitor the pre-positioning of equipment, materials, and other resources to ensure that these resources remain viable in the event of a system disruption. Simulate different types of system disruptions to test the viability of the pre-positioning strategy.

Table 11: Assessment Table for Step 4: Implement Early Wins

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
4.1 Has your agency undertaken a systematic effort to identify those actions that could be implemented quickly and that would enhance system resilience?	We have informally identified where early win improvements can be made. The responsibility for implementing rests with the respective functional units. No written documentation has yet been produced.	We have undertaken a systematic assessment for (up to) two of our agency's units. Written reports have been prepared that indicates the recommended steps and how they will be implemented.	We have undertaken a systematic assessment for all our agency's units. A written report has been produced that is available for both agency staff and for stakeholders to understand the need and purpose for implementing the recommended actions.
4.2 Has your agency adopted a policy where new projects are to explicitly consider resilience in terms of design and operations?	Only major projects (e.g., over a certain estimated cost) consider resilience in their design. The assessment considers only historical and current hazards and threats.	Only major projects consider resilience in their design. The assessment considers both historical/current and future hazards and threats.	All new projects consider resilience to current and future hazard and threats.
4.3 Has your agency pursued betterments when reconstructing facilities that have been damaged by extreme weather events?	Our approach to ER projects is at least to design the project to current design standards. We recognize the logic of improving the design of a project to account for future threats and hazards. When applying for FHWA ER funds, we consider the use of betterments on a case-by-case basis. We use whatever benefit/cost methodology that best illustrates the return on investment for the use of such funds. This decision is a stand-alone decision specific to each disaster declaration, and the initiative for doing so is usually done on an ad hoc basis.	We have developed an institutionalized approach for determining the eligibility of betterments (using ER funds) to cover the gap between current standards and a more resilient design. This approach has been applied in previous applications. The applicable future risk is directly related to the event that caused the initial failure. This includes a standardized benefit/cost methodology that is applied for all project applications. So far, this approach has not been applied for non-ER projects.	We have developed an institutionalized standard operating procedure for pursuing betterments as part of all of our ER project reconstruction efforts. All possible future risks are considered when justifying the use of betterment funds. We routinely consider the use other funds (regular federal-Aid or state funds) to cover the gap between current standards and a more resilient design. In addition to ER projects, we apply the same approach for non-federally funded reconstruction projects in response to facility failure.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
4.4 Does your agency have a program for periodically cleaning culverts and other drainage infrastructure to make sure they will function as designed?	We have an agency strategy that identifies where culverts and other drainage treatments are blocked or where sufficient debris has accumulated. Drainage treatment and culvert maintenance occurs when resources permit.	We have a culvert and drainage maintenance program that identifies and cleans those assets located on our critical roadways on a periodic basis (not a one-time effort).	We have such a program that when combined with our culvert condition inspection program provides our best effort at protecting against culvert failure statewide on all roadways under our jurisdiction.
4.5 Has your agency developed a strategy of pre-positioning equipment, materials, and other resources to respond to a disruption and/or support recovery?	We have undertaken a study of where such resources could be best positioned for such a purpose. We expect to implement the study recommendations within the year.	We have adopted such a strategy and have prepositioned the necessary resources to improve our response and recovery efforts in 1 or 2 locations where we expect facilities to be disrupted.	We have such a strategy and have already prepositioned the necessary resources to improve our response and recovery efforts statewide.
4.6 Has your agency developed and approved joint agreements or understandings with other agencies to share resources (e.g., staff and equipment) during emergencies?	We have ad hoc mutual support arrangements with other transportation agencies. The actual support depends on the circumstances and the ability of partner agencies to offer aid.	We have formal agreements with other transportation agencies to provide mutual support during emergencies. Logistics responsibilities and communication protocols have been established.	We have achieved Level 2 maturity and, in addition, identified and adopted agreements with all the agencies we think could help us in improving transportation system resilience during emergencies (not just other transportation agencies). This includes those who we have worked with for many years (such as emergency response organizations) and those that we have worked with before but not necessarily in the area of system resilience (e.g., metropolitan planning organizations).
4.7 Has your agency developed agreements or understandings with FEMA regarding procedures and requirements when a disaster has been declared?	We have met with FEMA officials and have reached an understanding of the key procedures, protocols, and requirements when a disaster occurs. We are in the process of formalizing this agreement.	We have agreements in place with FEMA that are intended to expedite and make our response and recovery effort more effective.	We have achieved a Level 2 maturity. In addition, agency staff have received training on how FEMA procedures are to be undertaken. Agency response involving FEMA interaction has been institutionalized in agency standard operating procedures.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
4.8 Have you participated in AASHTO, FHWA, or other professional association resilience efforts?	We regularly monitor the information outlets of these organizations to identify the latest information on system resilience.	We attend professional and industry meetings that examine transportation system resilience and staff members serve on resilience-oriented committees. Our representatives on the resilience-oriented committees are very active in suggesting efforts and guidance that would be useful to our agency and to others.	We have achieved a Level 2 maturity. In addition, agency staff have received training on how FEMA procedures are to be undertaken. Agency response involving FEMA interaction has been institutionalized in agency standard operating procedures.
4.9 Has your agency implemented any resilience-related strategies beyond those listed in this step's factors that can be considered "early wins" during the past two years?	We have implemented up to 2 such strategies.	We have implemented 3 or 4 such strategies.	We have at least 5 such strategies.
Score Range	Description of Agency Maturity in Implementing Early Wins		
0 to 12	Your agency is emerging into this area and has taken initial steps to grow awareness and understanding of the types of early wins it can implement.		
13 to 23	Your agency has implemented several early win strategies, not so much as part of an agency-wide strategy but rather at the initiative of agency staff.		
24 to 27	Your agency has reached significant maturity in identifying and implementing an early wins strategy. Major focus should be on maintaining and enhancing existing efforts when appropriate, and take advantage of new opportunities as they become available.		

- Periodically reassess joint agreements with other agencies and with FEMA to identify improvements and enhancements to make such agreements more effective.
- Participate in and/or lead meetings with partner agencies and groups to reinforce the importance of collaboration and coordination.
- Maintain situational awareness of rapidly changing cyber and physical security exposures that impact agency resilience and where short-term changes could provide a more resilient cyber system.
- Continue to participate in professional meetings and other information exchange opportunities to stay abreast of innovative early win actions taken by others that might be applied in your agency.

Recommended Actions to Achieve Higher Levels of Resilience Capability

If you scored at Level 1 or 2, you can take steps to continue your evolution toward a more resilience-oriented agency. In such cases, agency managers should identify which of the factors in Table 11 were most lacking and determine priorities for improving your agency's organization. Table 12 is offered as a template to determine which steps your agency can take to improve your agency's resilience capabilities, who should be responsible, the timeframe for the implementation, and expected outcomes.

Table 12: Actions to Achieve Higher Maturity for Step 4: Implement Early Wins

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Undertake a systematic effort/study to identify early wins to enhance system resilience.			
	Assign staff responsibilities and/or establish an organizational mechanism for identifying early wins to enhance resilience efforts.			
	Develop or enhance your existing culvert cleaning program.			
	Pursue betterments when reconstructing facilities affected by federally-designated disasters/ emergencies.			
	Develop a strategy to pre-position equipment, materials, and other resources to respond to a disruption and/or support recovery. If such a strategy exists, continue to monitor the viability of this pre- positioning in relationship to different types of disruptions.			
	Develop agreements or understandings with FEMA on procedures and requirements when a disaster has been declared.			
	Participate in AASHTO, FHWA, or other professional association resilience efforts.			
	Develop joint agreements or understandings for sharing resources with other agencies during emergencies.			

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Chapter 7: Understand the Hazards and Threats (Step 5)

This step considers the level at which and the procedures used by your agency to identify the potentially disruptive hazards or threats facing your transportation system. Many transportation agencies have achieved some level of understanding of the top hazards and threats to their system, even if it is simply based on institutional knowledge or drawing upon hazard mitigation processes driven by the state's emergency management department.



Understanding potential hazards and threats translates to having a comprehensive picture of those that constitute the greatest concern across the system. This is particularly important as the preferred strategies for mitigating the hazards and threats may, in fact, change when the analysis is expanded to include the collection of affected assets. For example, one strategy might be appropriate for a given hazard or asset, but another might be more cost-effective in reducing the impacts across a few hazards or reducing the hazard across several assets. The first step in this process is to identify comprehensively which assets in the transportation system may be exposed.

This chapter focuses on two important pathways to assess agency resilience readiness and maturity:

- The depth and breadth of the technical work (for example, the tools and resources used, availability of data, etc.); and
- The maturity of the agency to conduct the technical work and integrate the results into its practices.

A fully mature agency will have conducted a sophisticated, well-vetted all-hazards exposure analysis that consider the interdependencies across other sectors. The recommendations from these analyses will have been institutionalized within the agency. This information is a critical part of the systems-level vulnerability or risk analysis (comprising Steps 5 to 7 of the Framework), the prioritization of detailed asset level assessments (Step 8C), and investment decisions (Step 9).

Capability Factors and Levels of Maturity

The maturity levels are presented in the descriptions below for each factor and then summarized in the self-assessment table.

Factor 5.1 Have you established a working group for a system-wide assessment?

To ensure that the analyses draw on and are driven by the most up-to-date information, practices, resources, and tools, it is important to include subject matter and agency experts in the self-assessment process. Note that Step 2: *Organize for Success* included a factor focusing on whether an institutional mechanism has been created to lead your agency's resilience strategy. In contrast, this factor focuses on the existence of a working group to guide the system-wide assessment of hazards and threats.

Given the interdependencies between transportation and other sectors, informed transportation decisions will also often require discussions with other agencies. In addition, collaboration with the

private sector can provide an important source of data such as from providers of traffic and navigation apps that collect hazard impacts in real-time (e.g., data that can be used to identify incidence hot spots for poor visibility during a dust storm event). Establishing a working group provides a forum for sharing data, resources, and knowledge that collectively are indispensable for understanding hazards and threats. Further, a working group can be an important source of information and agency guidance for the self-assessment steps that follow.

The levels of maturity in this factor are distinguished by the degree to which your agency has formed and utilized a working group to guide the system-wide assessment.

- Level 1: We have identified agency participants and formed an ad hoc working group to guide the hazard and threats analysis scope and milestones. Our working group is largely composed of internal unit representatives.
- Level 2: We have formed a formal working group to guide the hazard and threats analysis scope and milestones. The working group has identified key technical capabilities to support this self-assessment and enlisted representatives from other agencies to participate in the working group. The working group has (or will) prioritize the recommendations from the analysis.
- Level 3: We have achieved Level 2 maturity. In addition, the working group has formed subcommittees as needed to draw on external technical experts to support the technical assessment, including experts on climate science, environmental impacts, and cybersecurity specialists. The working group has also identified roles and responsibilities for implementing the findings, including establishing an on-going institutional responsibility for the working group.

Factor 5.2 Have you identified natural hazards that may impact your transportation system?

Table 13 shows examples of natural hazards that may impact the transportation. An event might include multiple hazards such as a tropical storm with heavy winds, precipitation, and coastal flooding. Although Table 13 covers most of the primary natural hazards in the U.S., your agency may need to consider additional hazards. For larger regions, hazards will likely vary by geography. Importantly, natural hazards often result in physical damage to an asset and/or lead to disruptions in system operations. It is important to identify hazard exposure that could lead to both types of impacts.

The process of identifying hazards can include: (1) internal agency workshops and discussions, (2) review of available resources and reports;⁷ (3) review of maintenance records; and (4) interviews with key agency staff to discuss past experiences. It is also important to identify how natural hazards may change over time. For some natural hazards, climate change may already be influencing the stressor, such as increased incidents of extremely hot days. This presents a disconnect between today's conditions and the design values and environmental conditions that were considered during the design and construction of existing assets. Moving forward, future changes in climate may impact the robustness of today's designs as well as the integrity of existing assets. Because of this, it is important that climate-related hazards are projected for change over the coming century. This also translates to other hazards where external drivers may affect the frequency and/or magnitude of the event (e.g., land cover change in a watershed can affect riverine flooding potential).

⁷ This can include traffic incident reports, after-action report, and emergency reimbursement forms.

There are numerous data resources for this effort (see box). For example, NOAA's Storm Event Database can be used to assess whether tornadoes have occurred within your region. It is also important to identify any hazard data that has been vetted and peer-reviewed for use in your region. By using accepted data, you will provide consistent messaging to the public with usable outcomes that are easily transferable to other agencies also conducting assessments. However, if the data is inadequate, outdated, or not appropriate for your analyses, then the reasoning for not using this data should be documented with a discussion of how the findings may differ based on data choice.

- Level 1: We have reviewed hazard mitigation plans and reached out to our agency's maintenance staff for their knowledge of past "hot spots" of exposure. We have also reviewed guidance documents on asset sensitivity to hazards such as that available on FHWA's website (USDOT's Sensitivity Matrix).
- Level 2: We have achieved a Level 1 maturity. In addition, we have reviewed after-action reports and analyzed maintenance response records to identify past events that resulted in disruptions to the transportation system.
- Level 3: We have achieved a Level 2 maturity. In addition, we have analyzed future climate changes that might affect the transportation system. This has included reviewing national/state/local hazard reports and reaching out to specialists (e.g., climate scientists) and other experts on individual stressors.

Factor 5.3 Have you identified physical or human-caused threats that may impact your agency?

Examining disruption threats against a transportation system and/or your agency also includes those that might originate from human causes, either intentional or not (see Table 13). World-wide, terrorist attacks against transportation systems have caused significant disruptions to system operations as well as fatalities/injuries often resulting in significant economic impacts. Although not as prevalent in the United States as found in other countries, domestic terrorists have targeted U.S. transportation systems as well, especially public transit services. Physical attacks against command and control facilities could cause a loss of system management abilities that result in operational disruptions (e.g., a 2014 arson attack against the Federal Aviation Administration [FAA] regional operations center in Aurora, Illinois closed Chicago airspace and caused the rerouting of air travel for three weeks).

In addition to possible human-caused physical attacks against your agency, transportation officials should also consider the possible disruptive effects of public health emergencies that could affect system operations and/or employee availability. An example of this is the 2020 COVID-19 virus pandemic (coronavirus) that significantly affected international and domestic travel. In its worst manifestation, pandemics could cause the physical quarantine of entire communities which would require blocking and monitoring of roads and transit access. In addition, many of the national, state, and local pandemic transportation-related plans examine the challenges of transportation agencies providing services during pandemic/epidemic outbreaks when many of their staff are sick or taking care of family members.

Although transportation agencies have an important role to play in identifying potential physical threats and strategies to protect against them, the lead role in such efforts is usually held by law enforcement agencies. Therefore, effective efforts for this factor include participation in multi-agency planning and

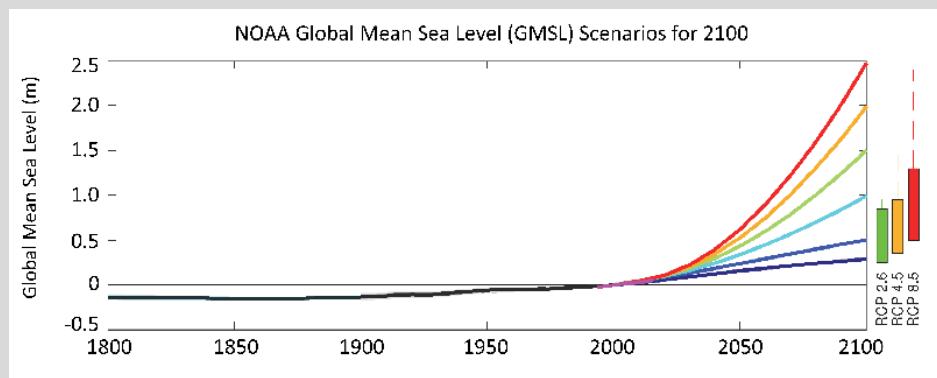
Table 13: Example Natural Hazards and Threats that may Impact a Transportation System

Natural Hazards		Human-Related Threats	
<u>Winds</u>	<u>Precipitation</u>	<u>Winter Storms</u>	Cyber attacks
Severe winds*	Fluvial flooding (including Dam failures, riverine flooding, flash flooding)*	Ice storms*	Public health emergencies
Tornadoes*		Blizzards*	Terrorism
Dust storms*	Pluvial flooding (such as from extreme rainfall, snowmelt)*		Pandemics
<u>Temperature</u>		<u>Coastal Environment</u>	Unintentional / accidental harm
Extreme temperatures*		Sea level rise causing tidal flooding and inundation*	
Warming average annual and/or seasonal temperatures*		Storm surge*	
Freeze-thaw days*	<u>Geohazards</u>	Tsunami*	
	Volcanic eruptions	Coastal cliff retreat*	
	Earthquakes and seismic activity	Coastal erosion*	
	Subsidence/sinkholes		
	Landslides and mudslides*		
	Rockfalls*	<u>Other Hazards</u>	
	Permafrost thaw*	Wildfires*	
		Droughts*	

The Basics of Modeling Coastal Flooding

Coastal flooding is directly affected by relative sea level (i.e., local conditions), which is calculated as the combination of global mean sea level rise, regional conditions, and local conditions. Global mean sea level rise is largely due to the thermal expansion of warming seawater and meltwater from glaciers and ice sheets. Regional conditions that affect changes in relative sea level primarily include changes in regional ocean currents, while local conditions may include ground settling, upstream flood control, erosion, and uplift/subsidence. Rising sea level can translate to higher high tides and an increase in high-tide flooding.

Federal Interagency Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Task Force, a joint task force of the National Ocean Council (NOC) and the U.S. Global Change Research Program (USGCRP), developed scenarios of global-mean sea level and provided regionalized global scenarios for the United States coastline. The six global mean sea level rise scenarios developed are shown in the figure below. There is higher probability that the lower sea level rise scenarios will occur over the coming century (e.g., under the RCP4.5, the lowest scenario of 0.3 meters by 2100 has a 94% chance of occurring while the intermediate-low of 0.5 meters by 2100 has a 73% chance of occurring). The USACE Sea Level Rise Calculator and NOAA Sea Level Rise Viewer are public tools that translate the global mean sea level rise to local conditions.



There are models routinely used to simulate coastal flooding during storm events such as a hurricane or nor'easter under current and future sea levels. The winds of a coastal storm can produce a surge of water that moves towards the coastline. The height and inland extent of the surge depends on numerous factors such as storm intensity, forward speed, size, angle of approach, central pressure of the storm, and coastal features. In transportation assessments, generally one of two surge models is used: (1) Sea, Lake, and Overland Surges from Hurricanes (SLOSH), a two-dimensional hydrodynamic circulation model that simulates storm surge for hurricane forecasts (NOAA uses SLOSH operationally, hence it is computationally efficient and can be run under a variety of storm simulations such as storm track, intensity, speed, and size); and (2) ADvanced CIRCulation (ADCIRC), a more sophisticated very high-resolution finite element model that combines rain, pressure and winds fields to predict storm surge and flooding. In addition to the surge, some assessments may further capture wave actions as simulated by Simulating WAves Nearshore (SWAN), a high-resolution regional wave model.

field exercises. The distinctions in the maturity levels for this factor reflect the degree to which your agency has examined all possible physical threats to the transportation system, and the level to which your agency interacts with the agencies charged with security and protection of critical infrastructure.

- Level 1: We are aware of the types of physical threats that confront the agency and its employees including concerns about crime, terrorism, assault, and those relating to CBRNE (chemical, biological, radiological, nuclear, and explosives). This awareness lies primarily in the operations unit in my agency. We maintain a security awareness program.
- Level 2: We have achieved a Level 1 maturity. In addition, we have consulted with outside professionals in law enforcement, Department of Homeland Security (DHS), Transportation Security Administration (TSA), the transportation security industry, and public health agencies to identify specific threats to our agency's assets and operations.
- Level 3: We have achieved a Level 2 maturity. In addition, we participate in a working group(s)/coordinating committee(s) consisting of security, enforcement, transportation, public health, and other sector representatives whose focus is on protecting critical infrastructure and mission-critical operations. We actively participate in the development and updates of the State Hazard Mitigation Plan. We also participate in field exercises and drills that simulate physical attacks against transportation infrastructure.

Factor 5.4 Have you identified cyber threats to your agency?

As transportation agencies and their command and control systems become ever more dependent on digital and internet-based communications, they become more vulnerable to cyberattacks. The February/March, 2018 cyberattack against the Colorado DOT is an example of the type of threat such attacks represent to transportation agencies. At its worst, over half of CDOT's computers were affected by ransomware malware affecting almost every unit in the agency. Traffic operations computer networks had been separated from CDOT's business network by a next generation firewall which detected and blocked the ransomware from entering its network. Thus, traffic command and control centers were not attacked. The agency adopted a four-phase strategy in response: containment, eradication, recovery, and sustainment.⁸

This factor reflects the extent to which your agency has systematically and routinely examined your internet and digital network resources to identify potential threats. The distinctions among maturity levels reflects the degree to which this assessment has been comprehensive and the level to which you have taken a "future-oriented" perspective on the likely characteristics of such threats. Note that factors similar to this one are also found in other steps in the self-assessment tool.

- Level 1: We have reviewed resident information technology (IT) systems and the potential targeting against these systems. The history of attacks against each system has been documented.

⁸ Colorado DOT, 2018. CDOT Cyber Incident After-Action Report. July 17. Denver, CO. Retrieved June 30, 2020 from <https://www.colorado.gov/pacific/dhsem/atom/129636>

- Level 2: We have achieved a Level 1 maturity. In addition, we have consulted with outside professionals in government and industry to identify all information system weaknesses and points of failure.
- Level 3: We have achieved a Level 2 maturity. In addition, we have considered how cyber threats may evolve in the future. This includes maintaining constant vigilance through daily assessments of the “Internet of Things” (IoT) and the cyber universe. We have engaged ‘white hat’ hackers to attack our IT systems to determine weaknesses.

Factor 5.5 Have you identified relevant hazard metrics by asset type?

For asset exposure analyses, it is important to identify relevant hazard metrics to determine whether current and future environmental conditions exceed the design parameters associated with each asset type (see text box for FHWA recommendations on asset types¹¹). Design standards and discussions with engineers are generally an appropriate path for identifying relevant hazard metrics. For example, a state design manual may require a culvert to be built to withstand a stream flow rate at the 10% annual exceedance probability (also known as the 10-year return period). The value of this rate is generally provided in the design manual developed using a baseline set of observations over a given time period. However, these values will change in response to such factors as changing environmental conditions and land use and, in fact, may fluctuate depending on what years are used to represent the observational record. This is particularly important in regions where there has been a statistically-significant change in values over the historic record.

FHWA Recommended Asset Types

- Roadway Pavement
 - Bridges
 - Culverts
 - Signage
 - Guard rails
 - Intelligent Transportation System (ITS) components
 - Lights
 - Weigh stations
 - Rest Areas
-

At most agencies designed standards have been updated and enhanced to higher standards over time. This translates to older assets having been built with outdated parameters given today’s standards. This factor catalogues appropriate hazard metrics by asset type and may also include corresponding time periods that align with any variations in design standard values. A more comprehensive understanding of hazard metrics also includes expanding your effort to review past engineering studies that have identified asset failures and empirical research.

The distinctions in maturity levels reflect the extent to which your agency has reviewed design manuals and standards for different asset types in light of expected threats and the level to which past failures have been examined and lessons learned incorporated into your agency’s standard operating procedures and guidelines.

- **Level 1:** We have reviewed design manuals to infer critical thresholds applicable to each asset type. We have used these resources to identify the hazard metrics and thresholds that, if exceeded, could damage our assets.

The Basics of Climate Projections

Global climate models (GCMs) are mathematical models that characterize the Earth system processes (atmosphere, ocean, cryosphere, and land surface) to simulate past and future climate. GCMs are developed and run at research institutions around the world, where each climate model uses a distinct set of algorithms to simulate large-scale to small-scale processes. GCMs can be run to simulate several scenarios that represent changes in radiative forcing over time linked to plausible changes in land use, population, fossil fuel use, etc., that correspond to different greenhouse gas concentrations in the Earth's atmosphere. These scenarios have been developed by the international climate community and are used to drive climate models. The climate impact community currently focuses on four representative concentration pathways (RCPs) in considering how future society may evolve, considering equivalent carbon dioxide concentrations:

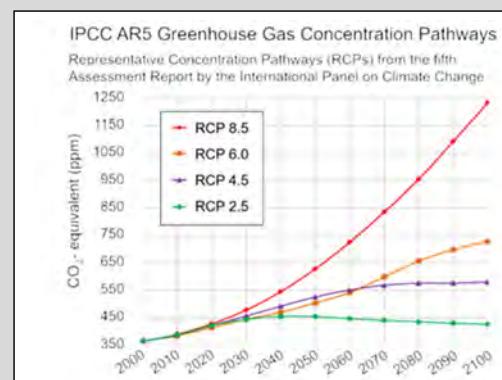
- RCP2.5: Concentrations peak in the early part of this century and then decline substantially. This is not considered plausible as an aggressive reduction in emissions would need to have occurred already.
- RCP4.5: Continued increase in concentrations until 2040 and then a decline with stabilization achieved by end of century.
- RCP6.0: Continued increase in concentrations until 2080 and then a decline after.
- RCP8.5: Aligns with our current trajectory but suggests significant increases in concentrations by end of century.

For climate impact assessments, results across multiple climate models are generally used to provide an indication of the scientific uncertainty when modeling the climate system. Results tied to multiple concentration scenarios provide an indication of how change in future society may influence future climate projections. Depending on the purpose of the impact assessment, multiple time periods may be used to assess how future change may evolve over the coming century. This is a requirement for an asset with a long-design life that needs to be resilient against today's and future conditions.

Peer-reviewed climate projections are publicly available that assess future change for locations in the U.S. The following climate datasets are often used in many transportation vulnerability and risk assessments:

- Localized Constructed Analogs (LOCA): Publicly available statistically downscaled GCM data developed by the Scripps Institute of Oceanography at the University of California, San Diego covering the continental United States. Downscaled results are provided at 1/16 degree spatial resolution for daily temperature and precipitation for RCP4.5 and RCP8.5 for more than 30 climate models from the World Climate Research Program (WCRP) Coupled Model Intercomparison Project (CMIP5) from 1950 to 2099. FHWA provides a CMIP processing tool that a user can run on their desktop, after downloading LOCA data, to produce several temperature and precipitation projections relevant to transportation practitioners. The 2nd version of this tool, that uses LOCA data, has not yet been published on the FHWA website at the time of publication but is expected to be released soon.
- Coordinated Regional Climate Downscaling Experiment (CORDEX): Publicly available regional downscaled GCM data is available through the North American Coordinated Regional Climate Downscaling Experiment (NA-CORDEX) covering the continental United States, portion of Alaska, and the Caribbean. For this effort, regional downscaling refers to a GCM that is used to drive a regional climate model (RCM). There is a growing number of GCM/RCM combination for RCP4.5 and RCP8.5. The spatial resolution is at 0.22 or 0.44 degrees. Because this effort draws on regional modeling, there are several climate variables including temperature and precipitation available at varying temporal scales from 1950 to 2100.

There are also processed climate projection data available through federal government, state, and academic portals. These provide helpful information and data. However, note that these portals are unlikely to provide tailored projections that represent specific thresholds and hazard metrics of interest when assessing impacts on your transportation system.



This figure shows the equivalent carbon dioxide (CO₂) concentrations in the atmosphere under a series of future scenarios. Source: IPCC AR5

- **Level 2:** We have achieved a Level 1 maturity. We have also interviewed our engineers to gain additional understanding and knowledge regarding design and failure thresholds. We have investigated how asset types were impacted during past events, including examining after-action reports.
- **Level 3:** We have achieved a Level 2 maturity. In addition, we have reviewed empirical research, engineering studies on asset failures, as well as other technical references. This information has been incorporated into our metrics and standard design procedures.

Factor 5.6 Have you collected geographic information system (GIS)-based transportation asset data necessary to perform an exposure analysis?

Transportation asset classes should be identified in as comprehensive a manner as possible. For example, the asset classes for a state DOT might include pavements, bridges, culverts, signage, guard rails, intelligent transportation system (ITS) technologies, and streetlights. In order to be useful for a system-wide assessment of hazards and threats, the database should include asset location, condition, and use (see text box for FHWA recommendations on asset data⁹). In addition, information should be collected that is relevant to assess susceptibility factors that may amplify the damage caused by a hazard or threat.

The distinction in maturity levels for this factor reflect the extent to which your agency has developed an asset database for the assets it is responsible for.

- Level 1: We have developed an asset data inventory for pavement and bridges that includes location, condition, and use. Assumptions have been made to fill in gaps as needed. We have developed written documentation describing how the data was collected and incorporated into our GIS systems.
- Level 2: We have achieved a Level 1 maturity. In addition, our GIS database includes location data and characteristics on the next most important asset types (such as culverts or other drainage treatments). The data are considered complete and are updated on a set schedule. The data attributes have also been screened to support linking hazards to the asset thresholds. All datasets are accurately georeferenced to elevation data and other relevant data sources.¹⁰

FHWA-Recommended Asset Data for Vulnerability Assessments

- Age of asset
- Design life
- Stage of design life
- Geographic location
- Current and historical performance and condition
- Elevation information
- Structural designs
- Occurrence/location of maintenance events
- Structural design (as built plans)

Source: FHWA (2017)

⁹ FHWA 2017. Note data on costs and consequences (such as replacement cost, level of use, evacuation routes) are addressed in Chapter 8.

¹⁰ For example, our roadway travel lanes are not depicted by a single georeferenced line for highways but with two lines to capture travel lanes.

- Level 3: We have achieved a Level 2 maturity. In addition, our GIS database includes auxiliary assets (e.g., signage, guard rails, ITS, lights, weigh stations, rest areas, geotechnical hazard mitigation measures, etc.).¹¹ The data are updated at least every two years.

Factor 5.7 Have you evaluated the current and future spatial extents of the natural hazards facing your agency?

Natural hazards may range from chronic risks (that is, occurring regularly over a long period), occur multiple times a year but not reoccurring every year, to rarely occurring.¹² Different frequencies of occurrence, magnitudes, and extents of exposure will likely be associated with different hazards. This factor develops a set of hazard data across the geographic area of interest. It can be challenging to portray accurately the likelihood of a hazard occurring based on historical data given the value can change depending on the years examined. This is particularly true for assessing the likelihood of extreme events that rarely occur. To ensure credible values, it is important to conduct sensitivity tests to reveal any outliers that may skew the data or conduct a Mann-Kendall Test¹³ to quantify if conditions have significantly changed. In some instances, changing conditions such as climate change or increasing sophistication of hackers will already be notable when comparing recent events to events experienced several years in the past

The future likelihood of whether a hazard might occur introduces a level of uncertainty in the estimation.¹⁴ A few methods are possible to consider future change, such as a trend analysis and processing data from causal models.

- **Trend analysis.** This method uses the observed change in the frequency or magnitude of specific hazards and threats that has occurred over a past time period and linearly extrapolates the trend into the future. This can be appropriate for hazards that have shown some evolution in frequency or magnitude but are not intricately linked to nonlinear drivers (e.g., climate change).
- **Future trends projected from causal models.** For most natural hazards (but not for such hazards as seismic events), a changing climate will influence the likelihood of future events occurring over the coming century. For future conditions, it is often important to assess the likelihood of an event occurring for plausible future scenarios relating to those factors contributing to the hazard. For example, in climate change projections, a plausible future scenario assumes global society will evolve along a given trajectory in energy use, technological advances, population growth, etc. Assuming a future scenario occurs, and given the credibility of the underlying causal relationships in the model, estimates of the likelihood of future events occurring can be made (see box below). This can then be done across a few different trajectories to provide a range of possible futures (see textbox entitled, *The Basics of Climate Projections*).

¹¹ These assets also include protective measures such as geotechnical assets including retainer walls, safety netting, guard pillars and so on (where guard pillars protect against vehicular terrorism and slope instability).

¹² The description of the hazard or threat provides the magnitude and duration of the event. Hence, there may be a series of hazard exposures assessed for a given hazard. For example, under coastal flooding, there may be a series of coastal flood exposures that are important to assess.

¹³ The Mann Kendall Trend Test is used to analyze data collected over time for consistently increasing or decreasing trends.

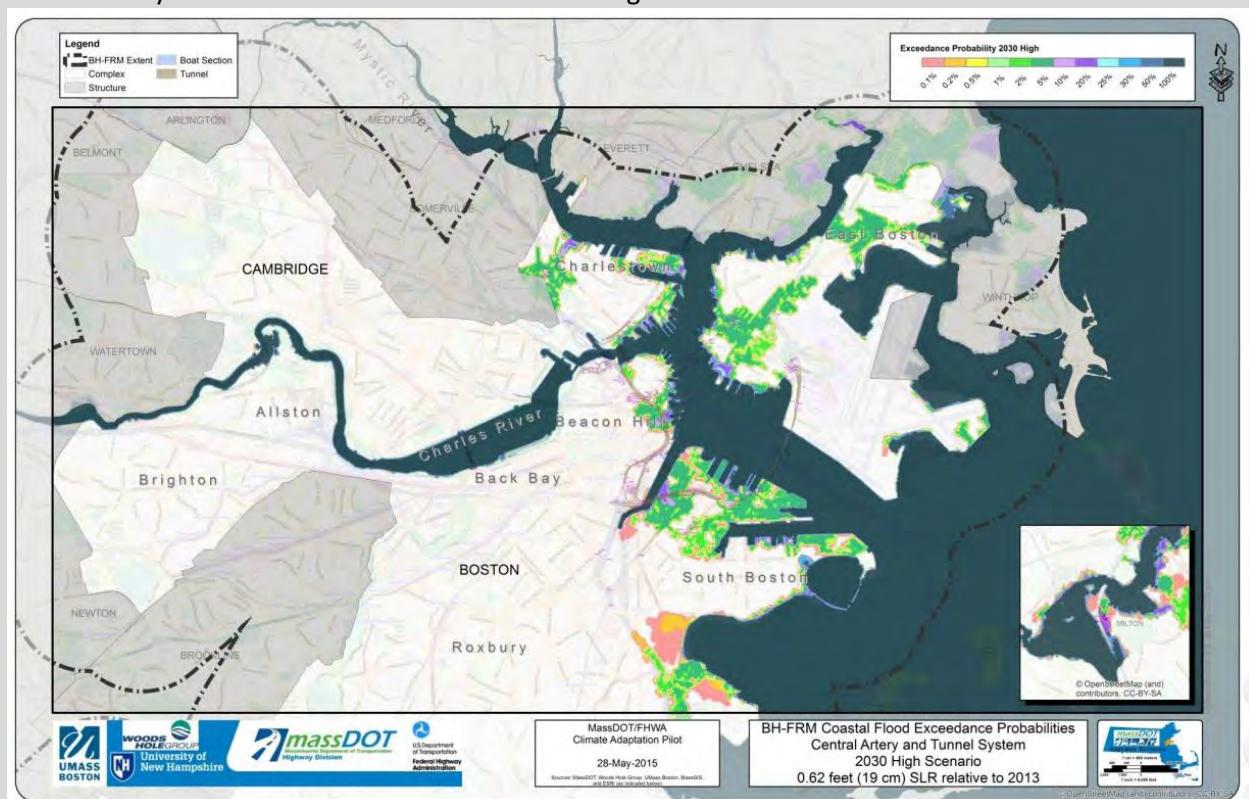
¹⁴ Generally, likelihood is considered as the probability of the event occurring in a given year (ranging from 0% (full confidence that the event will not happen) to 100% (full confidence that the event will happen)).

For hazards that can be characterized by spatial exposure, such as flooding and earthquakes, the minimum analysis for identifying potentially affected assets is to develop GIS hazard maps that portray future impacts under likely and the most extreme futures. If an asset is not affected at the most extreme level, then it is intuitively understood that the asset is not likely to be affected by less extreme future conditions. This is a conservative measure to ensure no potentially affected asset is dropped from future analyses.

For a more sophisticated approach, hazard stressors can be estimated for multiple future scenarios and presented visually in a way that captures the uncertainty in future projections. For example, likely damage areas from varying Richter scale earthquakes can give an indication of how extensive the damage might be. Climate change-related analyses are different than those for other hazards in that

Example: Probability of Coastal Flooding in 2030 Under a Future Sea Level Rise Scenario, Boston

Coastal flooding was defined at a depth greater than or equal to 2 inches (5 cm). The probability of exceeding this threshold is presented by color shading in geographic locations of the study area based on ADCIRC-SWAN modeling.



Source: Mass DOT-FHWA. 2015. MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery. Retrieved June 30, 2020 from

https://www.mass.gov/files/documents/2018/08/09/MassDOT_FHWA_Climate_Change_Vulnerability_1.pdf

much research and guidance has been developed on how future projections should be made.¹⁵

Along with these types of methods, it is important to identify and account for susceptibility factors that may amplify impacts. For example, assume a precipitation event that has a 1% chance of occurring in any given year is projected to occur with significantly more frequency in the future time period. Susceptibility factors may then include the timing of the event occurring (e.g., Is it more apt to happen at the close of the rainy season when soils are saturated or is it more apt to occur after significant drought conditions?), other environmental conditions that parallel the event (e.g., snowmelt in spring), and societal/environmental changes (e.g., more impervious surfaces increasing runoff).

The distinctions among the maturity levels reflect the degree to which you have examined the spatial extent of current and future natural hazards.

- Level 1: We have collected/developed GIS data showing the areas currently susceptible to all identified hazards.¹⁶ We have used available tools to project how hazards may change over the life span of our assets. For climate change, projections are based on worst-case emissions scenario using the ensemble average of GCMs.
- Level 2: We have collected/developed GIS data showing the areas currently susceptible to all identified hazards. We have used available tools to project how hazards may change over the life span of our assets. For climate change, projections are based on multiple scenarios to capture emissions uncertainty and provide median and extreme climate model projections to capture model uncertainty. When possible, we have estimated the probability of the hazards occurring.
- Level 3: We have achieved a Level 2 maturity. In addition, we have applied models to map those hazards that are not directly provided by models (e.g., the use of climate models for drought, surge, landslides, wildfires, etc.). When possible, we have estimated the probability of the modeled projections. We consider the interaction amongst hazards when estimating potential impacts (e.g., How likely is it that two hazards occurring sequentially or in tandem will exacerbate resulting impacts?) and used this information to identify which (if any) combinations of hazards and threats pose a significant concern. We have also considered human influences on the environment (e.g., levees and

¹⁵ There are different approaches in developing future climate scenarios for assessing which transportation assets are at risk. There may be a preference to: (1) identify climate simulations that represent specific future physical conditions (e.g., Global Climate Model (GCM)/Representative Concentration Path (RCP) combinations that suggest hot and dry summer conditions (some methods refer to these as “climate narratives” or “storylines”); (2) identify climate simulations that represent plausible futures at the median and extreme values of the stressor; and (3) average across the ensemble of GCMs for the median and uncertainty ranges for each stressor. With higher levels of agency maturity, your agency will become increasingly savvy as to which approach is most appropriate for the analyses. For example, if the analyses use hazard stressors independently then it may be appropriate to work with the median/extremes for each stressor. If the analyses use hazard stressors collectively, then it may be more acceptable to work with stressor values from estimates of future physical conditions. Given there are several GCMs available, some researchers feel more confident in using the ensemble averaging approach. However, it is important to recognize that averaging across climate model results for some climate stressors may lead to nonsensical results (e.g., climate models could suggest significant increases in a precipitation stressor as well as significant decreases; the average, though, suggests minimal change). Because of this, care should be used in evaluating the results to ensure confidence in using the ensemble average.

¹⁶ This entails using past conditions to assess the likelihood of the hazards and threats occurring (e.g., the likelihood of a winter storm occurring in a given year or the value of the precipitation event that has a 1% chance of occurring in any given year).

dams, changes in impervious surfaces, etc.) that can amplify/dampen the hazards.

Factor 5.8 Have you identified transportation assets exposed to natural hazards?

The previous factor focused on your agency's efforts to identify the extent of hazard exposure in your study area. It is next critical to identify which transportation assets might be exposed to hazards and threats. This exposure could result in damaged assets and/or system operational disruptions. This factor involves overlaying the hazard data with the asset information discussed in prior factors. Such overlays can be readily accomplished through GIS applications. The distinction among maturity levels is the level of comprehensiveness of the analysis in identifying exposed assets. As possible, it's also important to identify the associated uncertainty and confidence (see textbox entitled Confidence and Uncertainty in the Exposure Analysis).

- Level 1: We have identified assets that exceed specified thresholds of the observed/projected hazards and threats. This information is captured in a GIS database. For those hazards where future thresholds might be reached (e.g., when precipitation levels might create flood-critical flows), we have included the estimated length of time before such thresholds are likely reached (e.g., within the next decade, by mid-century, etc.). This is done by overlaying the time of exceedance with the design life of the asset.
- Level 2: We have achieved Level 1 maturity. In addition, we have included in the GIS database the degree to which the hazards exceed the critical thresholds. We have further indicated the levels of certainty and confidence of exposure. Our database also includes information on the past occurrence of hazards and threats over at least the past 20 years. We have developed metadata for all of this data in the GIS database.
- Level 3: We have achieved a Level 2 maturity. In addition, we have evaluated exposure from a systems perspective (not just asset-by-asset) across the transportation network.

Factor 5.9 Have you developed written documentation that describes the data, methodologies, and findings of the exposure analysis?

To ensure the tools, resources, data, decisions, and institutional knowledge applied in this step are captured, it is important to document the process along with the findings. It is also important to have written documentation on the methods and approaches used for this type of analysis given that the state-of-the-art and state-of-science are ever-evolving. A written document will also help to establish a baseline when methods and approaches are updated. The distinction among the levels of maturity are defined by the thoroughness, level of review, and availability of the documentation.

- Level 1: We have written documentation of the data used, our methodologies, and findings in the form of technical memoranda.
- Level 2: There is a single document that comprehensively describes all aspects of the exposure assessment. The working group has reviewed the document.
- Level 3: We have achieved a Level 2 maturity. In addition, we have produced a publicly available document that is graphically-rich and aimed at a broader non-technical audience.

Confidence and Uncertainty in the Exposure Analysis

When considering future projections, the Intergovernmental Panel on Climate Change's Fifth Assessment Report suggests the following two metrics when communicating the degree of certainty in findings (note that these terms are transferable to historic analyses as well):

- Confidence: Related to the validity of a finding, based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and the degree of agreement. Confidence is expressed qualitatively.
- Uncertainty: "The degree of certainty in each key finding of the assessment is based on the type, amount, quality, and consistency of evidence (e.g., data, mechanistic understanding, theory, models, expert judgment) and the degree of agreement. The summary terms to describe evidence are: limited, medium, or robust; and agreement: low, medium, or high..... The likelihood, or probability, of some well-defined outcome having occurred or occurring in the future can be described quantitatively through the following terms: virtually certain, 99–100% probability; extremely likely, 95–100%; very likely, 90–100%; likely, 66–100%; more likely than not, >50–100%; about as likely as not, 33–66%; unlikely, 0–33%; very unlikely, 0–10%; extremely unlikely, 0–5%; and exceptionally unlikely, 0–1%."

The findings of exposure should be weighed against the evidential support based on confidence in the findings and the associated uncertainty. Results can be presented with some measure of uncertainty or assigned a level of confidence. For example, using cartographic hashing when displaying the hazard layers on a map where there is significant agreement across models of the future change or described with terms such as "likely" representing 66 to 100% probability of the likelihood of the outcome.

When considering non-climate related conditions, the uncertainty is significantly low for events that occur frequently, increasing our confidence in expected exposure. When an event occurs with some regularity, then historical data can be used assuming there is no reason to believe amplification or dampening of events in the future. For rare events, expert judgment or modeling can provide information on future events and the associated uncertainty.

Table 14 shows the factors that are included in the self-assessment tool. The maturity levels for each factor are presented in the descriptions of each factor.

Recommended Actions to Maintain the Highest Level of Agency Resilience Capability

The highest level of capability for "Understanding the Hazards and Threats" focuses on continual improvement in agency capability and actions to understand and quantify which hazards and threats affect your assets. If your agency has reached Maturity Level 3, the steps that can be taken to maintain this level include:

- Periodically reassessing the effectiveness of your agency's working group. Adjust membership of the group based on the results of the analysis, adding members and expertise that will be necessary given projected future hazards.

- Periodically reassess the identification of hazards and threats that could impact your system. This includes engaging with emergency management staff as well as hazard/threat experts. Update the hazard and threat exposure layers as new information, methodologies, and data become available.
- Periodically review the asset data available and consider opportunities to expand the asset information that would fill in any gaps that exist for effectively assessing asset damage and/or ensure updates to existing information.
- Incorporate after-event information into a database to be used for future vulnerability and risk assessments. Use these data to continue to refine and calibrate your methods and approaches.
- Stay abreast of developments—especially in new data sources and analysis methods—that could be applied in the next update of your exposure analysis. This could include staff attendance at specialty conferences, workshops, peer exchanges, and staff training/professional development.

If you did not score a “27” in the assessment (a perfect score in Level 3 efforts), identify those factors that were rated lower and identify a strategy or action steps to improve these particular components of Step 5.

Table 14: Assessment Table for Step 5: Understand the Hazards and Threats

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
5.1 Have you established a working group for the system-wide assessment?	We have identified agency participants and formed an ad hoc working group to guide the hazard and threats analysis scope and milestones. Our working group is largely composed of internal unit representatives.	We have formed a formal working group to guide the hazard and threats analysis scope and milestones. The working group has identified key technical capabilities to support this self-assessment and enlisted representatives from other agencies to participate in the working group. The working group has (or will) prioritize the recommendations from the analysis.	We have achieved Level 2 maturity. In addition, the working group has formed subcommittees as needed to draw on external technical experts to support the technical assessment, including experts on climate science, environmental impacts, and cybersecurity specialists. The working group has also identified roles and responsibilities for implementing the findings, including establishing an on-going institutional responsibility for the working group.
5.2 Have you identified natural hazards that could impact your transportation system?	We have reviewed hazard mitigation plans and reached out to our agency's maintenance staff for their knowledge of past "hot spots" of exposure. We have also reviewed guidance documents on asset sensitivity to hazards such as that available on FHWA's website (USDOT's Sensitivity Matrix).	We have achieved a Level 1 maturity. In addition, we have reviewed after-action reports and analyzed maintenance response records to identify past events that resulted in disruptions to the transportation system.	We have achieved a Level 2 maturity. In addition, we have analyzed future climate changes that might affect the transportation system. This has included reviewing national/state/local hazard reports and reaching out to specialists (e.g., climate scientists) and other experts on individual stressors.
5.3 Have you identified physical or human-caused threats that may impact your agency?	We are aware of the types of physical threats that confront the agency and its employees including concerns about crime, terrorism, assault, and those relating to CBRNE (chemical, biological, radiological nuclear and explosives). This awareness lies primarily in the operations unit in my agency. We maintain a security awareness program.	We have achieved a Level 1 maturity. In addition, we have consulted with outside professionals in law enforcement, Department of Homeland Security (DHS), Transportation Security Administration (TSA), the transportation security industry, and public health agencies to identify specific threats to our agency's assets and operations.	We have achieved a Level 2 maturity. In addition, we participate in a working group(s)/coordinating committee(s) consisting of security, enforcement, transportation, public health, and other sector representatives whose focus is on protecting critical infrastructure and mission-critical operations. We actively participate in the development and updates of the State Hazard Mitigation Plan. We also participate in field exercises and drills that simulate physical attacks against transportation infrastructure.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
5.4 Have you identified cyber threats that may impact your agency?	We have reviewed resident information technology (IT) systems and the potential targeting against these systems. The history of attacks against each system has been documented.	We have achieved a Level 1 maturity. In addition, we have consulted with outside professionals in government and industry to identify all information system weaknesses and points of failure.	We have achieved a Level 2 maturity. In addition, we have considered how cyber threats may evolve in the future. This includes maintaining constant vigilance through daily assessments of the “Internet of Things” (IoT) and the cyber universe. We have engaged ‘white hat’ hackers to attack our IT systems to determine weaknesses.
5.5 Have you identified relevant hazard metrics by asset type?	We have reviewed design manuals to infer critical thresholds applicable to each asset type. We have used these resources to identify the hazard metrics and thresholds that, if exceeded, could damage our assets.	We have achieved a Level 1 maturity. We have also interviewed our engineers to gain additional understanding and knowledge regarding design and failure thresholds. We have investigated how assets types were impacted during past events, including examining after-action reports.	We have achieved a Level 2 maturity. In addition, we have reviewed empirical research, engineering studies on asset failures, as well as other technical references. This information has been incorporated into our metrics and standard design procedures.
5.6 Have you collected geographic information system (GIS)-based transportation asset data necessary to perform an exposure analysis?	We have developed an asset data inventory for pavement and bridges that includes location, condition, and use. Assumptions have been made to fill in gaps as needed. We have developed written documentation describing how the data was collected and incorporated into our GIS systems.	We have achieved a Level 1 maturity. In addition, our GIS database includes location data and characteristics on the next most important asset types (such as culverts or other drainage treatments). The data are considered complete and are updated on a set schedule. The data attributes have also been screened to support linking hazards to the asset thresholds. All datasets are accurately georeferenced to elevation data and other relevant data sources.	We have achieved a Level 2 maturity. In addition, our GIS database includes auxiliary assets (e.g., signage, guard rails, ITS, lights, weigh stations, rest areas, geotechnical hazard mitigation measures, etc.). The data are updated at least every two years.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
5.7 Have you evaluated the current and future spatial extents of the natural hazards facing your agency?	We have collected/developed GIS data showing the areas currently susceptible to all identified hazards. We have used available tools to project how hazards may change over the life span of our assets. For climate change, projections are based on the worst-case emissions scenario using the ensemble average of GCMs.	We have collected/developed GIS data showing the areas currently susceptible to all identified hazards. We have used available tools to project how hazards may change over the life span of our assets. For climate change, projections are based on multiple scenarios to capture emissions uncertainty and provide median and extreme climate model projections to capture model uncertainty. When possible, we have estimated the probability of the hazards occurring.	We have achieved a Level 2 maturity. In addition, we have applied models to map those hazards that are not directly provided by models (e.g., the use of climate models for drought, surge, landslides, wildfires, etc.). When possible, we have estimated the probability of the modeled projections. We consider the interaction amongst hazards when estimating potential impacts (e.g., How likely is it that two hazards occurring sequentially or in tandem will exacerbate resulting impacts?) and used this information to identify which (if any) combinations of hazards and threats pose a significant concern. We have also considered human influences on the environment (e.g., levees and dams, changes in impervious surfaces, etc.) that can amplify/dampen the hazards.
5.8 Have you identified transportation assets exposed to natural hazards?	We have identified assets that exceed specified thresholds of the observed/projected hazards and threats. This information is captured in a GIS database. For those hazards where future thresholds might be reached (e.g., when precipitation levels might create flood-critical flows), we have included the estimated length of time before such thresholds are likely reached (e.g., within the next decade, by mid-century, etc.). This is done by overlaying the time of exceedance with the design life of the asset.	We have achieved Level 1 maturity. In addition, we have included in the GIS database the degree to which the hazards exceed the critical thresholds. We have further indicated the levels of certainty and confidence of exposure. Our database also includes information on the past occurrence of hazards and threats over at least the past 20 years. We have developed metadata for all of this data in the GIS database.	We have achieved a Level 2 maturity. In addition, we have evaluated exposure from a systems perspective (not just asset-by-asset) across the transportation network.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
5.9 Have you developed written documentation that describes the data, methodologies, and findings of the exposure analysis?	We have written documentation of the data used, our methodologies, and findings in the form of technical memoranda.	There is a single document that comprehensively describes all aspects of the exposure assessment. The working group has reviewed the document.	We have achieved a Level 2 maturity. In addition, we have produced a publicly available document that is graphically-rich and aimed at a broader non-technical audience.
Score Range	Description of Agency Maturity in Assessing Current Practice		
0 to 12	Your agency is emerging into this area and has taken initial steps to begin to understand and document potential hazards and threats to your transportation system.		
13 to 23	Your agency has implemented several “understanding the hazards and threats” activities, capturing geospatial relationship between assets and hazards/threats.		
24 to 27	Your agency has reached significant maturity in understanding your hazards and threats. Major focus should be on maintaining and enhancing existing efforts when appropriate, and take advantage of enhancing and validating current practices whenever possible.		

Recommended Actions to Achieve Higher Levels of Resilience Capability

If you scored at the lowest level, you are just starting your evolution toward a more resilience-oriented agency. In such a case, the top managers of the agency should identify which of the factors in Table 14 were most lacking and determine priorities for better understandings hazards and threats. Table 15 is offered as a template to determine which actions your agency can take to improve your agency's resilience capabilities, who should be responsible, the timeframe for implementation, and the expected outcomes

Table 15: Actions to Achieve Higher Maturity for Step 5: Understand the Hazards and Threats

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Develop a full and complete asset inventory, including asset location, condition, and use. Over time, this asset inventory should include all assets for which your agency is responsible.			
	Collect and assess hazard and threat data and estimate the likelihood of the event occurring in the future (including noting the uncertainty in results as appropriate).			
	Collect maintenance records and other cost information for use in identifying likely hazards and the costs of responding.			
	Identify susceptibility factors that may worsen or reduce the system disruption caused by expected hazards.			
	Produce GIS mapping of hazard exposure across all assets in the transportation system for each hazard and threat.			
	Identify the assets as most exposed across hazards and threats.			
	Identify the mission-critical operations at most risk across hazards and threats.			
	Map system-scale disruptions for each hazard and threat.			
	Develop quantifiable hazard-to-impact relationships that are tailored to your geographic location and asset class.			
	Increase engagement and strengthen relationships internally with asset managers, engineers, emergency management, and GIS specialists.			
	Increase engagement and strengthen relationships externally with governmental and university climate science research centers, state climatologists, health professionals, cyber and terrorist experts, geotechnical experts, and sector experts.			
	Work with representatives from other sectors that affect and are affected by disruptions to respective networks. Identify potential points of vulnerability and collaboratively identify strategies for minimizing failure.			



Possible steps for “Implement Early Wins”

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Chapter 8: Understand the Impacts (Step 6)

This step evaluates the impacts of each hazard/threat on the transportation assets identified as being exposed in Step 5. Impacts may include the repair costs for fixing a damaged asset, user costs to detour around an exposed asset, effects on disadvantaged communities, and, costs associated with supply chain interruptions. Impacts can also include operational changes the



transportation agency needs to make to deal with the fallout of an incident (e.g., the need to redirect funding to repairs). Only those assets that have been identified in Step 5 as exposed to a potentially damaging hazard/threat are considered in this step. These are the assets that are to be carried through the vulnerability assessment process and eventually assigned a vulnerability score in Step 7.

The impact of a disruptive event, depending on its geographic scope, level of predictability, duration, and loss of lives and economic activity, can be classified as:

- Severe – disruptive events that can affect national or international transportation and rank very high in terms of economic loss incurred, and/or due to many lives that are lost. Such events include the 2011 Japan Earthquake, the 2002 West Coast port shutdown, the September 11, 2001 terrorist attacks, and the 2020 COVID-19 pandemic.
- High – disruptive events that can affect national or regional transportation and rank high on economic losses incurred, and/or due to lives that are lost. Events such as the 2001 Baltimore rail tunnel fire, the Midwest floods of 2015 and 2019, and the 2017 Atlanta I-85 bridge deck fire and collapse can be considered as high impact events.
- Low – disruptive events that can affect regional or local transportation and rank low to moderate on economic loss incurred, and/or due to injuries incurred. Events such as the 2013 I-5 Skagit River Bridge failure in Washington State fall in this category.

The interconnected and intermodal nature of the transportation system can also be an important characteristic of disruption. Significant disruptions to one part of a network or one sector of services can have a domino effect on other transportation system elements and services. For example, in the freight sector, this is particularly evident given the range of economic activities that place demands on the transportation system to provide essential raw materials and resources and to deliver finished products on just-in-time schedules along a supply chain extending across continents and oceans and affecting a vast multitude of stakeholders. In the case of human-caused, malicious disruptions, the targeting of transportation systems has the potential to result in profound long-term losses to the economy. More critically, such targeting can also compromise the lives and safety of people whose welfare and sustenance depends on the movement of vital goods or the provision of essential passenger transportation services.

On a smaller scale, but no less important to those affected, the loss of service for a critical bridge on a busy highway bypass--which might arise from an unexpected finding in a routine structural inspection--

could cause massive disruption along the surface streets of the community served by the bypass as well as to the people and goods that are attempting to move through the area.

This step considers the impacts of system disruptions along a range of possible cost: (1) those occurring to the owner of the asset(s) disrupted; (2) those using the system that now face additional delays or travel on detours; and (3) societal costs relating to environmental, equity, and socio-economic impacts.

Capability Factors and Levels of Maturity

Factor 6.1 Have you assessed the potential degree of physical damage to the exposed assets from each hazard?

This factor considers the degree to which an agency assesses the potential damage to exposed asset(s). This effort can range from having a qualitative understanding of damage based on staff knowledge to an empirically-based set of damage-cost relationships tailored to your system and assets. Ideally, each hazard/threat is considered

individually and then systematically reviewed to identify the various concerns with asset failure.

To understand either qualitatively or quantitatively how a hazard or threat might impact transportation assets, it is important to determine the cause-effect relationships with respect to potential damage.

Thresholds can be established for hazards/threats that relate to varying levels of asset damage and/or outage (i.e., loss of operation). Cause-effect relationships (also termed “impact functions”) may include: hazard/threat-to-outage relationships and hazard/threat-to-damage relationships. Note that these two relationships are not necessarily independent as the degree of asset damage can be intricately linked to the recovery time before an asset becomes usable. This factor considers hazard/threat-to-damage relationships, while the next considers hazard/threat-to-outage relationships. Although some assets might be damaged to varying

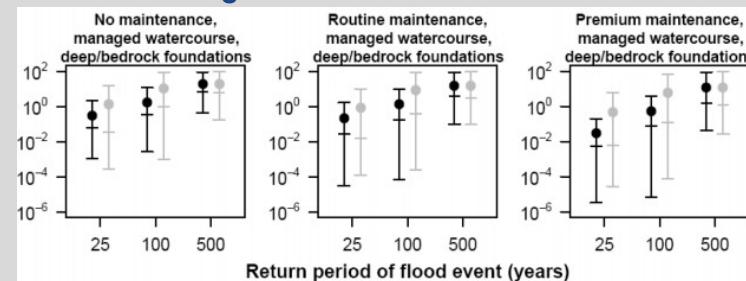
Example of Hazard/Threat-Damage Functions: Plain/Portland Concrete Road Flood Damage

Depth (m)	Damage (%)	Explanation
-0.05	0	Very slight damage
0	0	Presume there is no damage to the surface layer until water level is above paved elevation
1	0.05	Including slight damage due to water on asphalt surface
2	0.1	Higher degree due to floodwaters inundating paved surface
5	0.25	Upper boundary of road damage

* references made to elev'n of road surface; anything below which is assigned a (-)ve value and anything above the datum (+)

Source: Department of Civil and Engineering, University of Western Ontario. 2011. “The City of London: Vulnerability of Infrastructure to Climate Change.” Retrieved February 19, 2020 from https://www.london.ca/residents/Environment/Climate-Change/Documents/Final%20Report%20Vulnerability%20of%20City%20of%20London%20Climate%20Change%20August%202011_with%20Appendices_Doc%202011%202011.pdf

Example of Factoring in Maintenance Practices when Estimating Critical Thresholds



Source: 1. Lamb et al. 2016. Vulnerability of bridges to scour: insights from an international expert elicitation workshop. *Nat. Hazards Earth Syst. Sci. Discuss.*, doi:10.5194/nhess-2016-350.

These figures show fragility probability for bridges associated with flood event severity (%) [solid lines represent performance-weighted pooled expert judgements; light grey lines are unweighted pooled expert judgement. Whiskers indicate the 5th and 95th percentile uncertainty ranges around the mean (filled circle) and median (horizontal bar) expert estimates].

degrees if exposed, this is not the case for all cause-effect relationships. Some are, in essence, a binary relationship whereby if the asset is exposed to the hazard and/or threat it is anticipated to be damaged beyond repair (such as exposure to a terrorist attack with explosives or a very strong tornado). The hazard/threat-to-damage relationship would then be defined as 100% damage to the exposure of the hazard.

Overall, the preferred approach for a highest level of maturity is to create comprehensive and tailored relationships based on design manuals, past events, surveyed repair records by hazard and threat for each asset, empirical evidence, and staff expertise. This includes reviewing engineering studies that quantify the thresholds for hazard- or threat-related damage. If possible, tailored relationships developed for your asset types are ideal (see the text box for an example of flood damage to pavement). During the development of hazard/threat-to-damage relationships, it is also helpful to identify stressors that could amplify the damage or practices that may reduce damage (see text box for example of varying damage of flood events on bridges depending on the maintenance of the waterways).

To estimate the costs to repair damaged assets, a catalogue of recent replacement costs for each asset type and class is useful. For a simple, back-of-the-envelope approach, repair costs may be estimated as the total value of the asset multiplied by the predicted percent of damage and rehabilitation costs estimated as a percentage of the repair costs (e.g., rehabilitation costs are 68% of the repair costs).

Though ideally all hazards and threats are predictable, some hazards or threats are unpredictable and may have not occurred previously. Thus, it would be difficult to portray a quantifiable hazard/threat-to-damage relationship if there is not experience with such impacts. In these instances, tools such as tabletop exercises may serve to capture the potential impacts of the hazard or threat.

The distinction in the maturity levels for this factor are defined primarily as the level of effort your agency has taken to assess the potential degree of asset damage when exposed to each hazard. Note that this factor focuses on agency-costs associated with replacing a damaged asset. The broader user and societal costs are discussed in another factor. Note too that monetizing impacts is considered a desirable approach because the outputs (dollars) are easier to understand for decision-makers.

- Level 1: We have qualitatively assessed our potential degree of damage for different asset types (e.g., low, medium, and high) based on staff knowledge and professional judgement.
- Level 2: We have identified proxy indicators or surrogates that represent the potential for damage to the asset (e.g., condition ratings) and, if available, the associated costs (e.g., asset construction / replacement costs). We have surveyed repair records by hazard and threat for each of the asset classes available to estimate repair costs. If the record is not complete, unit construction costs are used for gaps.
- Level 3: We have established functional relationships between damage and costs by asset type (e.g., depth damage functions) and we have customized these relationships based on available data (e.g., asset size, type, materials, and condition; locational characteristics; etc.). We have a process to continually validate these relationships.

Factor 6.2 Have you estimated how long each asset will be unavailable due to an event?

To fully capture how a hazard/threat may impact an asset and its users, it is important to estimate how long an asset may be out of service during the event or after for repairs and/or clean up (referred to as the outage period). If the hazard/threat has occurred in the past, written records can provide a good indication of how long it will take for the asset to become operational. Resources such as emergency management and maintenance records should be reviewed. When using past records, it is important to relate damage and duration of asset operational loss to the degree of hazard exposure. With such data tailored relationships can be established between asset damage and repair time. These relationships should be assessed and monitored, revised, and updated over time. Once developed, validating these assumptions as events happen is important to ensure robust relationships and identify any additional factors that could affect the defined relationships.

When developing the hazard/threat-to-outage relationships, it is important to recognize a hazard or threat does not have to physically damage an asset to create a disruption. For example, a road closure might occur due to a flooding event but the road might be able to immediately reopen without damage once the flood waters recede. Relationships have been developed that indicate when a roadway is no longer passable given rising waters (see Figure 3).^{17 18}

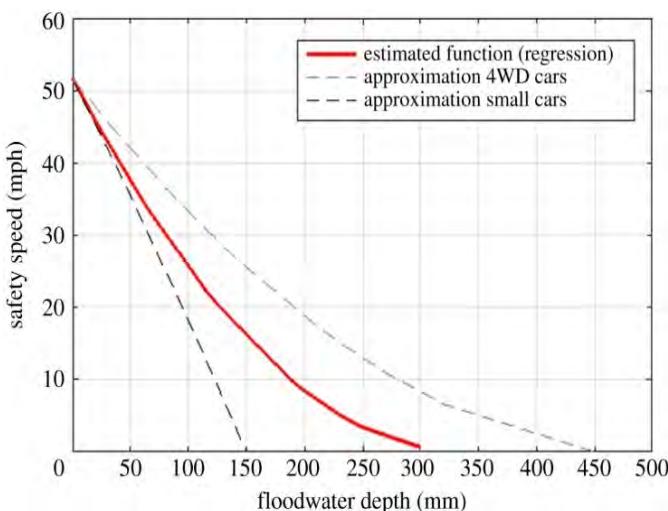


Figure 3: Depth-Disruption Function That Relates Vehicle Speed and Flood Depth on a Road

Source: Pregnolato et al. 2016. Assessing urban strategies for reducing the impacts of extreme weather on infrastructure networks. R Soc Open Sci. doi: 10.1098/rsos.160023

¹⁷ Pregnolato et al. 2016. Assessing urban strategies for reducing the impacts of extreme weather on infrastructure networks. R Soc Open Sci. doi: 10.1098/rsos.160023

¹⁸ Creating hazard/threat-to-outage relationships, such as based on Figure 3, can help one to identify which segments of the transportation network will likely be usable during an event. For example, assessment of roadway closures during a flood requires identifying those locations where flood depth might reach or surpass 11.8 inches (300 millimeters). To determine this flood level, it might be possible to map the frequency of flood depth reached on roadways in a region based on past events (e.g., Over the past 10 years, how often have roadways flooded to approximately this level?). A more mature analysis would construct a probabilistic flood map of locations that may reach or surpass 11.8 inches.

The distinction in maturity levels for this factor is related to the level of effort your agency has taken to estimate loss of asset operations due to the event.

- Level 1: We have qualitatively (e.g., low, medium, high) estimated, by asset type, the outage time for different hazards based on past experience.
- Level 2: We have developed quantitative estimates of outage time by asset type (e.g., 1 week, 2 weeks, 1 month, ...).
- Level 3: We have quantified the relationship between the type and degree of impact/damage and outage time (e.g., a depth-damage function with repair time factored in). We have a process to continually validate these relationships.

Factor 6.3 Have you identified interdependencies with other networks that interface with your system?

To be a truly resilient transportation system, it is important to identify how the assets in your system depend on other infrastructure and how these interdependencies may affect asset operation during various hazards/threats. This can range from a roadmap or conceptual diagram that outlines general entry points of dependencies for asset types (such as a swing bridge being dependent on electricity) to GIS mapping where assets with operational dependencies are identified. Discussions with organizations responsible for this other infrastructure are necessary to understand their vulnerabilities and how such vulnerabilities may ripple through to the dependent transportation assets. For example, a power surge may damage wiring or sensitive electronic equipment embedded in the internal workings of transportation assets. This understanding can then be geo-processed into a GIS map that identifies both dependent transportation assets and under what critical thresholds of hazard/threats operations they may be affected. The different levels of maturity in this factor are defined as the level of effort your agency has taken to identify interdependencies of your transportation system with other sectors.

- Level 1: We have identified general relationships that outline which assets within the transportation system are dependent on energy, water, communication and the like.
- Level 2: We have worked with the organizations whose infrastructure and services we are dependent on to determine their vulnerabilities to various hazards. We have taken that information and integrated it into our vulnerability assessment.
- Level 3: We have completed Level 2 and have quantified the likelihood of the loss of infrastructure and services under each of the hazards.

Factor 6.4 Have you estimated the socio-economic impact to affected communities of reduced services and loss of access?

A disrupted transportation system, whether it is a single asset or numerous assets, can create significant consequences to transportation users and to the communities that rely on a reliable, safe, and efficient transportation system. Hence, the costs to repair a damaged transportation asset are not the only costs associated with a system disruption. Disruption-related socio- economic costs to affected communities and populations focus on the consequences of disruption to the social, economic, and quality of life of such groups. Understanding socioeconomic losses requires an understanding of how the hazard/threat could impact the entire transportation system and the roles it plays in the day-to-day lives of people and

to the communities they live in. For example, closed roadways can affect usual travel flows, provision of emergency services, access to key community facilities, and the provision of goods and services.

In addition, closed roadways usually require detours to allow traffic to move around the bottleneck. The extra time and operating costs (e.g., the additional wear/tear on the vehicle) associated with this extra travel can be estimated monetarily and considered as additional costs associated with a disruption.

At its simplest, estimating socio-economic costs can be done qualitatively by estimating the level of impact on the traveling public. A higher level of sophistication, the use of indicators, can reflect detour length, traffic volumes, estimates of the number of users affected, and so on. At a still higher level of sophistication, the impact on the traveling public and on the community (e.g., loss of business sales) could be monetized. The distinction on maturity levels is the level to which you have quantified socio-economic costs associated with system disruptions.

- Level 1: We have qualitatively identified and estimated the degree of impact on the traveling public and on affected communities (e.g., high, medium, or low).
- Level 2: We have developed a set of socio-economic indicators to capture the impact (e.g., detour lengths, traffic volumes, amount of a community's population affected, number of key community facilities affected, and the like).
- Level 3: We have quantified the degree of costs of loss of service using economic modeling. We also use available social cost tools to assess the impacts of disrupted facilities on communities and populations.

Factor 6.5 Have you considered the impacts of asset loss to disadvantaged and/or underserved populations?

Disadvantaged and/or underserved populations could be more vulnerable to the loss of service and access than the rest of the population. For example, employees on hourly wages might not receive a paycheck if they are unable to reach their place of employment. There are also concerns that costs for staples such as groceries will increase during and after a disruption if transportation routes are unavailable. Finally, disadvantaged populations may be located in more vulnerable locations within the community, amplifying the potential damage that may occur to the transportation assets they rely on.

Many communities have developed GIS-based analysis tools based on census data that identifies the location of such communities. A social vulnerability index tool could be used that acts as a starting point in identifying vulnerable populations (CDC 2018; Georgetown Climate Center undated). Other efforts have tailored transportation-specific social vulnerability indices (e.g., identifying whether a household owns a car) for targeted analysis of populations likely to be affected. Cross-walking this data using a GIS-based tool can provide a high-level understanding of the potential hot spots within a community where disadvantaged and/or underserved populations might be most affected. The distinction in maturity levels for this factor is defined by the degree to which your agency considers the consequences of system disruption on disadvantaged and/or underserved populations.

- Level 1: We have identified transportation assets that are used by or relied on by disadvantaged populations. We use a qualitative rating (e.g., low, medium, high) in our assessment of the costs associated with system disruption.

- Level 2: We have developed a set indicator(s) that quantifies the degree to which transportation assets are used by or relied on by disadvantaged populations. These indicators reflect the importance of transportation services to the socio-economic well-being of these populations.
- Level 3: We have developed estimates of the monetary costs to disadvantaged communities that are associated with transportation disruption. This is based on a combination of empirical data and model simulations (e.g., estimated loss of hourly wages, monetized time lost due to longer travel time, and so on). These monetary costs are used when available, but if only a few such estimates are available, the analysis of the impacts on disadvantaged populations

Factor 6.6 Have you considered the impacts of asset loss to critical/lifeline routes?

This factor considers the impact of asset loss to pathways along transportation networks that are essential facilities, serve as lifeline routes, and/or are an essential travel route to isolated communities. Though the consequences of such loss can be difficult to quantify, there are methods that estimate the social cost of loss of a fire station, police station, hospital, emergency medical services, and so on.¹⁹ These costs can then be assigned to asset-specific losses under each hazard/threat scenario and then integrated into the costs associated with the impacts. The distinction in maturity focuses on the degree to which impacts to critical/lifeline routes are considered in your impact assessment.

- Level 1: We have identified which assets lie along emergency evacuation/recovery routes and routes to lifeline/essential services. We have assigned qualitative ratings (e.g., low, medium, and high) to potential impacts to such facilities.
- Level 2: We have developed numerical indicators that represent the access impacts to lifeline/essential facilities and evacuation/recovery routes. Such indicators reflect the important role that such facilities play in a community and the value of such service to human life and disaster recovery.
- Level 3: We have developed estimates of the degree of service loss (e.g., additional time for lifeline services) and have estimated the capacity constraints for alternative pathways for emergency evacuation/recovery routes. Monetary estimates are used where possible on the value of such service loss and we have integrated these costs into the impact functions (e.g., depth damage functions).

Factor 6.7 Have you considered the impacts of asset loss on freight movement?

Freight movement along highways and other truck routes is critical to the economic well-being of a region, state, or even the nation. Significant disruptions to freight movement can cascade into implications across the supply chain from manufacturing activities to the delivery of goods. This sensitivity of impacts on the supply chain is ever-increasing as distributors rely on just-in-time delivery. The impacts can be particularly significant in areas where manufacturing jobs are a large percentage of the region's employment. In these areas, loss of wages can be significant when materials do not arrive for processing.

¹⁹ FEMA (2016). Benefit-Cost Sustainment and Enhancements.

National Cooperative Freight Research Program (NCFRP) Report 50 identified the following characteristics of disruptions affecting freight movements (Meyer et al, 2019):

- The spatial or geographic scale of disruption will likely have a direct bearing on the magnitude and incidence of the disruptive impact.
- A disruption could affect the entire freight system of an area or affect a specific mode. For example, an anticipated increase in extreme storms and flooding due to sea level rise could have long-term effects in coastal areas. The Maryland DOT Freight Plan, for example, includes a sea level rise analysis to show where the freight network is most vulnerable to future flooding.²⁰
- The temporal nature of a disruption can have important economic consequences. Thus, network resiliency, in the form of rapid recovery of facilities and services, becomes an important consideration in assessing overall economic impact.
- The longer disruptions persist, the more geographically extensive they are, and the more breaks in the supply chain they lead to, the more extensive are likely to be the disruptive impacts.
- The economic impact of severe bottlenecks and disruptions could affect a wide range of supply chain participants, not just the ocean carriers, truckers, railroads, barge operators, and shippers that are using the network to transport the goods.
- Different types of disruption could have a range of direct and indirect economic impacts.
- Whether goods can be shipped economically via other modes depends on the value and nature of the cargo itself, as well as the availability of service and fuel
- Network redundancy is a very important characteristic of economic impact.
- Assessing disruptive effects has to take into account the nature of the methodologies being used and the questions being asked.
- The global goods movement supply chain is a multi-tiered system with various entities, stakeholders, networks, and modes involved, that span a huge physical space, and by their very nature are susceptible to natural and man-made disruptions.
- In case of a major event, such as a terrorist attack or an earthquake, standard mitigation measures, such as increasing safety stock, diversifying supply base and building redundancy into logistical systems, may or may not afford much protection from damage.
- Disruption resistance (security) and tolerance (resilience or recovery) are both important measures in disruption management. These measures have to be balanced with concerns regarding productivity, while promising to provide sufficient benefits to justify costs.

²⁰ Maryland DOT. 2017. Maryland Strategic Goods Movement Study. Baltimore, MD. Retrieved July 1, 2020 from http://www.mdot.maryland.gov/newMDOT/Freight/Documents/2018/Strategic_Goods_Movement_Plan_2017.pdf

The distinctions in maturity levels for this factor are defined as the degree to which your agency considers the impacts of asset loss on freight movement and the level to which freight industry representatives are involved in this process.

- Level 1: We have identified which facilities are essential freight routes and have assigned a subjective rating (e.g., low, medium, high) that is used in our impact analyses. The identification of these routes is based primarily on our agency's data on commercial vehicle flows.
- Level 2: We have developed indicators to identify facilities that are important for freight movement (e.g., based on truck volumes, routes accessing major economic areas, percentage of trucks, and the like). These indicators are used to show the relative importance of freight routes in the network.
- Level 3: We have estimated the monetary costs of disruption impacts to the freight sector. These costs are incorporated into economic models to estimate the economic costs of such disruptions.

Factor 6.8 Have you disseminated the results of the impact analysis?

To ensure the tools, resources, data, institutional knowledge, and decisions applied in Step 6 are captured, the findings and methodology should be documented. It is also important to have written documentation as a reference for future changes based on new science and tools. In addition, the documentation summarizes the estimated costs of system disruptions and expected costs of doing nothing. The major distinctions among the levels of maturity for this factor are the level of thoroughness, review, and availability of the documentation.

- Level 1: We have written documentation of the data used, our methodology, and priorities in a series of technical memoranda. In addition, the results of the analysis are summarized in the documentation.
- Level 2: There is a single document that comprehensively describes all aspects of this assessment and the resulting priorities for enhancing system resilience. The working group has reviewed the document, and it has been disseminated throughout our agency.
- Level 3: We have achieved a Level 2 maturity. In addition, we have also produced a publicly-available document on expected impacts and recommended strategies that is graphically-rich and aimed at a broader non-technical audience.

Table 16 shows the factors that are included in the self-assessment tool. The maturity levels for each factor are presented in the descriptions of each factor.

Table 16: Assessment Table for Step 6: Understand the Impacts

Maturity Factor	Level 1(1 point)	Level 2 (2 points)	Level 3 (3 points)
6.1 Have you assessed the potential degree of physical damage to the exposed assets from each hazard or threat?	We have qualitatively assessed our potential degree of damage for different asset types (e.g., low, medium, and high) based on staff knowledge and professional judgement.	We have identified proxy indicators or surrogates that represent the potential for damage to the asset (e.g., condition ratings) and, if available, the associated costs (e.g., asset construction / replacement costs). We have surveyed repair records by hazard and threat for each of the asset classes available to estimate repair costs. If the record is not complete, unit construction costs are used for gaps.	We have established functional relationships between damage and costs by asset type (e.g., depth damage functions) and we have customized these relationships based on available data (e.g., asset size, type, materials, and condition; locational characteristics; etc.). This is informed by our complete record of costs provided by maintenance and other departments in our agency. We have also identified the frequency of exposure at which the impact becomes cost and/or repair prohibitive. We have a process to continually validate these relationships.
6.2 Have you estimated how long each asset will be unavailable due to an event?	We have qualitatively (e.g., low, medium, high) estimated, by asset type, the outage time for different hazards based on past experience during similar hazard events.	We have developed quantitative estimates of outage time by asset type (e.g., 1 week, 2 weeks, 1 month,...).	We have quantified the relationship between the type and degree of impact/damage and outage time (e.g., a depth-damage function with repair time factored in). We have a process to continually validate these relationships.
6.3 Have you identified interdependencies with other networks that interface with your system?	We have identified general relationships that outline which assets within the transportation system are dependent on energy, water, communication and the like.	We have worked with the organizations whose infrastructure and services we are dependent on to determine their vulnerabilities to various hazards. We have taken that information and integrated it into our vulnerability assessment.	We have completed Level 2 and have quantified the likelihood of the loss of infrastructure and services under each of the hazards.
6.4 Have you estimated the socioeconomic costs on the affected communities in response to reduction of service?	We have qualitatively identified and estimated the degree of impact on the traveling public and on affected communities (e.g., high, medium low).	We have developed a set of socio-economic indicators to capture the impact (e.g., detour lengths, traffic volumes, amount of a community's population affected, number of key community facilities affected, and the like).	We have quantified the degree of costs of loss of service using economic modeling. We also use available social cost tools to assess the impacts of disrupted facilities on communities and populations.

Maturity Factor	Level 1(1 point)	Level 2 (2 points)	Level 3 (3 points)
6.5 Have you considered the impacts of asset loss within the system for disadvantaged and/or underserved populations?	We have identified transportation assets that are used by or relied on by disadvantaged populations. We use a qualitative rating (e.g., low, medium, high) in our assessment of the costs associated with system disruption.	We have developed a set indicator(s) that quantifies the degree to which transportation assets are used by or relied on by disadvantaged populations. These indicators reflect the importance of transportation services to the socio-economic well-being of these populations.	We have developed estimates of the monetary costs to disadvantaged communities that are associated with transportation disruption. These are based on a combination of empirical data and model simulations (e.g., estimated loss of hourly wages, monetized time lost due to longer travel time, and so on). These monetary costs are used when available, but if only a few such estimates are available, the analysis of the impacts on disadvantaged populations also includes indicators and/or qualitative measures to ensure all the potential impacts are represented in the analysis.
6.6 Have you considered the impacts of asset loss to critical/lifeline routes?	We have identified which assets lie along emergency evacuation/ recovery routes and routes to lifeline/essential services. We have assigned qualitative ratings (e.g., low, medium, and high) to potential impacts to such facilities.	We have developed numerical indicators that represent the access impacts to lifeline/essential facilities and evacuation/recovery routes. Such indicators reflect the important role that such facilities play in a community and the value of such service to human life and disaster recovery.	We have developed estimates of the degree of service loss (e.g., additional time for lifeline services) and have estimated the capacity constraints for alternative pathways for emergency evacuation/recovery routes. Monetary estimates are used where possible on the value of such service loss and we have integrated these costs into the impact functions (e.g., depth damage functions).
6.7 Have you considered the impacts of asset loss on freight movement?	We have identified which facilities are essential freight routes and have assigned a subjective rating (e.g., low, medium, high) that is used in our impact analyses. The identification of these routes is based primarily on our agency's data on commercial vehicle flows.	We have developed indicators to identify facilities that are important for freight movement (e.g., based on truck volumes, routes accessing major economic areas, percentage of trucks, and the like). These indicators are used to show the relative importance of freight routes in the network.	We have estimated the monetary costs of disruption impacts to the freight sector. These costs are incorporated into economic models to estimate the economic costs of such disruptions.

Maturity Factor	Level 1(1 point)	Level 2 (2 points)	Level 3 (3 points)
6.8 Have you disseminated the results of the impact analysis?	We have written documentation of the data used, our methodology, and priorities in a series of technical memoranda. In addition, the results of the analysis are summarized in the documentation.	There is a single document that comprehensively describes all aspects of this assessment and the resulting priorities for enhancing system resilience. The working group has reviewed the document, and it has been disseminated throughout our agency.	We have achieved a Level 2 maturity. In addition, we have also produced a publicly-available document on expected impacts and recommended strategies that is graphically-rich and aimed at a broader non-technical audience.
Score Range	Description of Agency Maturity in Understanding Impacts		
0 to 11	Your agency is emerging into this area and has taken initial steps to begin to understand the impacts to your transportation system and the community.		
12 to 20	Your agency has implemented several “understanding impact” activities and have a sense of which assets are both exposed to hazards/threat and, if harmed, could have a significant impact on the community.		
21 to 24	Your agency has reached significant maturity in understanding the impacts. Major focus should be on maintaining and enhancing existing efforts when appropriate, and take advantage of enhancing and validating current practices and findings whenever possible.		

Recommended Actions to Maintain the Highest Level of Agency Resilience Capability

The highest level of capability for "Understanding Impacts" focuses on continual improvement in agency capability and actions leading to a more resilient transportation system. If your agency has reached this level of agency capability, the steps that can be taken to maintain this level include:

- Periodically reassess the methodologies and results of the impacts when the assets are exposed to hazards and/or threats. This could be done in-house or by bringing in a third-party evaluator to conduct the evaluation.
- Continue to monitor system response after hazards and threats occur and gather data to enhance the impact functions developed as well as to evaluate whether modeled results are consistent with what was observed.
- Participate in meetings where socio-economic and/or other consequences of concern are discussed amongst stakeholders. Use this information to add to or revise the impacts modeled.
- Continue to monitor methodologies developed for capturing impacts across the spectrums of concern and consider ways to expand and/or revise the existing analyses to stay up-to-date.
- Work closely with partner agencies to refine impact assessments for both human-caused and natural disruptions.
- Adopt a leadership role in your state or community in fostering the efforts of others to understand the impacts and consequences of transportation system disruptions and, more generally, of community disruption.
- Participate in jointly identified impact analyses of the impacts associated with interdependent networks. Continue your efforts to work closely with those responsible for networks that are tied to the transportation network to identify their vulnerabilities.
- Provide training and professional development opportunities for the staff involved with impact analyses to be exposed to new developments and best practice.
- Continue to disseminate information to key constituencies and groups on the likely impacts of system disruptions to populations and communities and the types of strategies your agency has implemented to reduce the consequences of such impacts.

If you did not score a "24" in the assessment (a perfect score in Level 3 efforts), identify those factors that were rated lower and identify a strategy or action steps to improve these particular components of Step 6.

Recommended Actions to Achieve Higher Levels of Resilience Capability

If you scored at the lowest level, you are just starting your evolution toward a more resilience-oriented agency. In such a case, the top managers of the agency should identify which of the factors in Table 16 were most lacking and determine priorities for understanding the impacts of system disruptions.

Table 17 is offered as a template to determine which actions your agency can take to improve your agency's resilience capabilities, who should be responsible, the timeframe for the implementation and expected outcome.

Table 17: Actions to Achieve Higher Maturity for Step 6: Understand the Impacts

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Develop a catalog of impact functions for each asset type that may be exposed to the hazards and/or threats identified in Step 5.			
	Develop a menu of costs for each asset type identified as being potentially exposed to system disruptions.			
	Provide GIS mapping of entry points where other infrastructure systems that may impact transportation operations have been identified.			
	Develop conceptual diagrams to identify cross-sector interdependencies.			
	Increase engagement and strengthen relationships internally with planners, asset managers, engineers, emergency management, and GIS specialists to better understand potential impacts from system disruptions.			
	Collect damage and outage data after hazards/threat events for affected assets. Compare with and revise existing damage and outage data used in the analysis.			
	Collect economic data after hazards/threat events. Compare with and revise existing economic data used in impact analyses.			
	Develop transportation-specific vulnerability indices to identify populations that are more adversely affected by service and system outages.			
	Develop GIS layers of emergency evacuation routes and other layers that describe critical components of the transportation system.			
	Provide training and professional development opportunities to the staff responsible for impact analyses.			
	Prepare and disseminate information on system impacts to key stakeholders and to the general public.			



Possible steps for "Implement Early Wins"

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Chapter 9: Determine Vulnerability and Prioritize (Step 7)

This step brings together the exposure data (from Step 5) and the impacts data (from Step 6) to complete a systems-level vulnerability assessment. The vulnerability assessment assigns a vulnerability score to each exposed asset. These scores can be ranked to prioritize which assets should receive detailed facility-level assessments first (Step 8C). The results can also inform several other agency actions to enhance resilience (Steps 8A, 8B, and 8D).



There are three general approaches for conducting vulnerability analyses being used at the time of publications (note that there are many variations on these approaches and also hybrid approaches but for ease of understanding we boil it down to these three primary techniques):

Matrix approach: This approach develops a matrix (table) that is used to qualitatively assign a vulnerability score to each asset. Most often, this table is based on a qualitative definition of risk. Risk being the likelihood of the hazard/threat occurring multiplied by the consequences if the hazard/threat does occur, the rows in the table typically represent the likelihood of exposure and the columns the magnitude of the consequences, or vice-a-versa (see example in Figure 4). Depending on available data, the scoring of the likelihood of the hazard/threat and the associated consequences if the hazard/threat occurs can be based on qualitative (e.g., expert opinion) or quantitative information (e.g., empirically-based analysis); either way, each cell in the matrix represents a qualitative integration of this information (typically into some form of low, medium, or high vulnerability score). If the scoring is largely based on qualitative information, the results tend to be subjective and, therefore, may change depending on the resources and/or stakeholders engaged. In practice, a risk matrix approach will likely review GIS overlays of asset types with hazards to identify system-wide exposure, costs, and consequences over time for each hazard and threat. This information can inform general awareness of potential system impacts.

Indicators approach: This type of an approach identifies indicators, proxies, or criteria that, taken together, represent asset vulnerability. The approach essentially calculates a vulnerability index for transportation assets. For climate-related physical hazards, many state transportation agencies have used an indicators approach framing that considers whether the asset may be exposed ("exposure"), whether the asset is sensitive if it is exposed ("sensitivity"), and whether there are already available means to cope that reduce the potential consequences from the exposure ("adaptive capacity"). These indicators are then given scores based on the indicator value and combined to provide an overall vulnerability score. This approach can be scaled and applied asset-by-asset. A more general exposure-consequence framing can also be used with the indicators approach. Whichever framing is used, the indicators approach can be applied to assess multiple scenarios (e.g., "what-if" scenarios, future changes in climate, and so on). There are understood challenges with indicator approaches such as the selection in input criteria, standardization of data, determining the importance of criteria (weighting), integrating the relationships between them, and validating the results.

Another option, a variant of the indicators approach, is to consider multi-criteria analyses such as analytical hierarchy process (AHP) and the analytic network process (ANP). For example, one study applied a multi-criteria approach to assess transportation vulnerabilities by: (1) calculating how a disruption to a system of transportation assets and related economic assets in one sector of the economy impacts other sectors and the region as a whole due to the interdependencies; (2) applying hierarchical holographic modeling to capture the influence of multiple levels of disruption that reflect the impacts across sectors such as power, transportation, communication, supply chains, on the transportation network and operations. Through risk filtering, the stakeholders could then focus on those sources of risk that are most critical.

FHWA has developed a publicly available indicator-based tool, the Vulnerability Assessment Scoring Tool (VAST), for transportation practitioners interested in an indicators approach. VAST uses the more traditional index form of an indicators analysis as opposed to multi-criteria analysis. Challenges with vulnerability indices include them being (1) hard to interpret in terms of actual impacts, (2) the fact that they provide only a relative ranking across the assets compared, and (3) results can be hard to communicate and justify (e.g., Why is one asset's index-based vulnerability score a "71" while another is "54"?). In addition, which indicators are chosen can have a significant impact on the vulnerability results and, as such, should be used selectively and with purpose. For example, in some instances, asset condition does not always serve as a reasonable criterion for whether an asset will fail or be damaged if exposed to a hazard. Another drawback is that generally there is more confidence in estimating some indicator values over others; however, it is challenging to weight accurately the confidence to integrate this uncertainty into the results in a meaningful way.

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Severe
Almost certain	M	H	H	E	E
Likely	M	M	H	H	E
Possible	L	M	M	H	E
Unlikely	L	M	M	M	H
Rare	L	L	M	M	H

Note: Rows correspond to the likelihood of the hazard/threat occurring and the columns correspond to the degree of consequence if the hazard/threat occurs. Each row and column generally has a range of values (e.g., moderate financial consequences may be assigned to \$200,000-\$500,000).

Figure 4: Example of a Risk Matrix

Monetization approach: This approach, significantly more complex than the others, uses a quantitative risk-based framing to provide the most quantifiable and perhaps understandable vulnerability assessment results as they relate to transportation investment and system management strategies. For a given individual asset, the hazard/threat-to-damage curve is combined with the probability of hazard/threat occurring at the critical thresholds to produce damage curves as a function of the frequency of the hazard/threat occurring. The monetized consequences of the loss of service of the asset is folded into the hazard/threat-to-damage curves for a more comprehensive estimate of economic loss. If the hazard/threat is anticipated to change over time, particularly over the lifetime of the asset, an additional step is needed that projects the predicted damage costs over time. All assets are then ranked to identify which assets suggest significant damage without intervention. In addition, those consequences that cannot be monetized could be qualitatively applied to shift the rankings before finalizing the results. This approach provides dollar estimates in response to the loss of each of the assets over time, information that is more easily understood in support of prioritizing assets for more detailed study (and getting a high-level estimate of an agency's financial exposure to hazards/threats along the way).

It should be noted that approaches for assessing vulnerability, screening, and prioritizing as found in the Nation's seismic retrofitting program offer good examples of an approach similar to what is being suggested in Step 7 (see FHWA. "Seismic Retrofitting Manual for Highway Structures" Accessed September 23, 2020 at <https://www.fhwa.dot.gov/publications/research/infrastructure/bridge/06032/06032.pdf>).

A fully mature agency will have conducted sophisticated and well-vetted all-hazards and threat analyses that consider the interdependencies across other sectors, with the findings disseminated across the agency and the methodologies and approaches to vulnerability mainstreamed in agency practice.

Capability Factors and Levels of Maturity

Factor 7.1 Have you characterized the vulnerability of each asset to each hazard?

Vulnerability analyses can range from a basic understanding of which hazards and threats will likely cause system disruption (based on qualitative discussions in workshops) to comprehensive quantitative assessments. The level of analysis conducted informs an appropriate scale of decision-making. A basic understanding of asset vulnerability might prove useful in informing a transportation research plan and/or for growing agency awareness across stakeholders. A more comprehensive and quantitative analysis, however, is desirable in that it provides more useful and understandable information in support of informed decision-making.

This factor utilizes all the analyses conducted in Steps 5 and 6 to develop as comprehensive an understanding as possible of the vulnerability of each asset to each hazard. The levels are tied to the various vulnerability assessment approaches described above.

- Level 1: We have used the matrix approach to characterize the vulnerability of individual assets to each hazard/threat.
- Level 2: We have used the indicators approach to characterize the vulnerability of individual assets to each hazard/threat.
- Level 3: We have used the monetization approach to characterize the vulnerability of individual assets to each hazard/threat.

Vulnerability/Risk Assessments

The terminology of resilience, particularly when considering extreme weather/climate change, has in the past included usage of the terms “vulnerability” and “risk”, often interchangeably. The cross-pollination of these terms in the past has sometimes sewn confusion in the transportation field and created a disconnect when the perspective was expanded to include an all-hazards perspective, where a different structure was utilized - one where risk was the only guiding consideration (this is especially the case in the human threats assessment community). One of the primary factors which contributed to the past disconnect was the approach employed by the IPCC towards defining the implications of climate change on various systems (natural, human, etc.). In earlier documentation, the IPCC referred to vulnerability (not risk) as the final determining outcome, and the basis on which decisions were to be made. This structure has been carried into processes that are widely documented in past practices, including in the transportation profession. The term “vulnerability assessment”, in the context of climate change, has wide reaching recognition in the transportation profession and therefore it is recognized as an important structural element of this document.

In its latest release of information (AR5), the IPCC has adopted a framework which focuses assessments more toward a risk-based perspective, restructuring the elements and identifying vulnerability as one of the primary factors (with probability). Note, however, that this use of the term “vulnerability” is narrower than used before; more akin strictly to asset sensitivity to a hazard/threat (a use of the term common in the risk analysis community) than it is to the broader definition that has been used traditionally by IPCC and transportation climate vulnerability assessments. Moving forward, given the IPCC change in guidance and other considerations, risk-based climate assessments are anticipated to become more common and vulnerability-based framings less so. This will lead to a change in terminology and approach, particularly as more probabilistic and cost-based data is developed to facilitate risk-based analysis. This guidebook outlines both vulnerability-based and risk-based approaches to systems-level vulnerability analyses and identifies the methods by which assessments are generated for each. A full (quantitative) risk-based approach, whereby the probability of an event is multiplied by its likely impact costs, is presented as a Level 3 approach (referred to in this guidebook as the “monetization approach”). A qualitative risk-based approach is presented as a Level 1 approach (referred to in this guidebook as the “matrix approach”). The more traditional vulnerability based framing is presented as a Level 2 approach (referred to in this guidebook as the “indicators approach”).

Factor 7.2 Have you characterized the vulnerability of each asset for all potential hazards/threat and hazard/threat combinations?

This factor combines the findings of the prior factor to identify how the assets are vulnerable across all hazards and threats. An agency can develop its own transparent methodology to determine how best to compare identified vulnerabilities across hazards/threats for each asset.

In some regions, hazard combinations – that is hazards that could occur sequentially or in tandem – are a concern. In those instances, one can review the vulnerability scores across all hazard/assets combinations to identify which assets are most vulnerable to: (1) more than one hazard/threat; and (2) the degree to which the assets are vulnerable. This effort becomes subjective when using the matrix approach. An indicators approach provides an empirical means of combining indicator scores into an overall vulnerability score for the asset. A monetization approach is ideal as it naturally allows for the probability of the event and the corresponding impacts that have been monetized. That said, the joint probabilities of various hazard/threat combinations happening can be challenging to quantify.

The major distinction among the maturity levels for this factor is defined as the degree to which your agency characterizes the vulnerability of each asset for all potential hazards.

- Level 1: We have used the matrix approach to qualitatively consider all possible hazards and developed a final cross-hazard vulnerability score for each asset (e.g., low, medium, or high)
- Level 2: We have combined the indicator scores for each hazard to develop an all- hazards vulnerability score for each asset.
- Level 3: For each asset, we have summed the estimated “do-nothing” costs for each hazard to create an estimated lifecycle cost if no actions are taken.

Factor 7.3 Have you developed a prioritized list of vulnerable assets?

This factor considers the following to develop a prioritized list of vulnerable assets: (1) the results of the previous factor (i.e., identifying the vulnerability of each asset for all potential hazards and hazard combinations), (2) input from key stakeholders and the general public, and (3) your agency’s needs and mission. If all considerations are applied in the prioritization of vulnerable assets for a detailed assessment in Step 8C, then your agency has reached a Level 3 maturity. The major distinction among the different levels of maturity in this factor is degree to which resources have been applied to develop a list of vulnerable assets for detailed assessment.

- Level 1: We use vulnerability scores and agency policy considerations to develop a prioritized list of assets for more detailed assessments.
- Level 2: We have achieved Level 1 maturity. In addition, we have reviewed the vulnerability scores with staff responsible for the different assets and adjusted the priorities accordingly.
- Level 3: We have achieved a Level 2 maturity. In addition, we have cross-referenced the vulnerability scores to planned projects in our capital program.

Factor 7.4 Have you communicated the prioritization of assets to agency staff and key external constituencies?

Once an agency has a prioritized list of vulnerable assets, it is important that key agency staff and external constituencies understand how the list was developed and are given an opportunity to provide feedback on the prioritization. This is important to ensure the prioritized list is actionable and aligned with department considerations. In addition, this helps determine which agency departments are responsible for critical assets. The distinction in maturity levels in this factor reflect the degree to which agency staff and key external constituencies have been engaged in reviewing the prioritized list.

- Level 1: We have held an internal meeting on prioritization with relevant staff. We have identified agency points of contact who have reviewed the prioritization.
- Level 2: We have a formal working group that has reviewed the prioritization method and findings. The working group is charged with updating the methodology as appropriate. Key external groups have been briefed on the results of the prioritization assessment.
- Level 3: We have achieved a Level 2 maturity. In addition, we have also cross-walked the high priority assets with agency unit responsibilities. We have conducted workshop(s) and/or webinar(s) to discuss the prioritization methodology and preliminary findings with key external stakeholders. We have incorporated consensus feedback from these external stakeholders and transparently revised the prioritization. The results of the prioritization are part of our agency's resilience communications strategy in order to inform key constituencies and the public on how our agency is proactively implementing our resilience strategy.

Table 18 shows the factors that are included in the self-assessment tool. The maturity levels for each factor are presented in the descriptions of each factor.

Table 18: Assessment Table for Step 7: Determine Vulnerability and Prioritize

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
7.1 Have you characterized the vulnerability of each asset to each hazard?	We have used the matrix approach to characterize the vulnerability of individual assets to each hazard/threat.	We have used the indicators approach to characterize the vulnerability of individual assets to each hazard/threat.	We have used the monetization approach to characterize the vulnerability of individual assets to each hazard.
7.2 Have you characterized the vulnerability of each asset for all potential hazards/threats and hazard/threat combinations?	We have used the matrix approach to qualitatively consider the universe of hazards and developed a final cross-hazard vulnerability score for each asset (e.g., low, medium, or high)	We have combined the indicator scores from each hazard to develop an all-hazards vulnerability score for each asset.	For each asset, we have summed the estimated “do-nothing” costs for each hazard to create an estimated lifecycle cost if no actions are taken.
7.3 Have you developed a prioritized list of vulnerable assets?	We used the vulnerability scores and agency policy considerations to develop a prioritized list of assets for detailed assessments.	We have completed Level 1. In addition, we have reviewed the vulnerability scores with staff responsible for the assets and adjusted the priorities accordingly.	We have completed Level 2. In addition, we have cross-referenced the vulnerability scores to planned projects in our capital program.
7.4 Have you communicated the prioritization of assets to agency staff and key external constituencies?	We have held an internal meeting on prioritization with relevant staff. We have identified agency points of contact who have reviewed the prioritization.	We have a formal working group that has reviewed the prioritization method and findings. The working group is charged with updating the methodology as appropriate. Key external groups have been briefed on the results of the assessments.	We have achieved a Level 2 maturity. In addition, we have also cross-walked high priority assets with agency unit responsibilities. We have conducted workshop(s) and/or webinar(s) to discuss the prioritization methodology and preliminary findings with key external stakeholders. We have incorporated consensus feedback from these external stakeholders and transparently revised the prioritization. The results of the prioritization are part of our agency’s resilience communications strategy in order to inform key constituencies and the public on how our agency is proactively implementing our resilience strategy.

Score Range	Description of Agency Maturity in Determining Vulnerability and Prioritize
0 to 5	Your agency is emerging into this area and has taken initial steps to begin to identify which assets are vulnerable.
6 to 10	Your agency has implemented several “vulnerability and prioritization” activities and have a sense of which assets are responsible for the greatest risk to the transportation system.
11 to 12	Your agency has reached significant maturity in comprehensively prioritizing vulnerable assets drawing on expertise, agency mission and needs, and vulnerabilities. Major focus should be on maintaining and enhancing existing efforts when appropriate, and take advantage of enhancing and validating current practices and findings whenever possible.

Recommended Actions to Maintain the Highest Level of Agency Resilience Capability

The highest level of capability for "Determine Vulnerability and Prioritize" focuses on continual improvement in agency engagement, vulnerability analyses, and prioritization criteria to rank assets by their vulnerability. If your agency has reached Maturity Level 3 of agency capability, the steps that can be taken to maintain this level include:

- Update the prioritized list as new analyses from Step 5 and Step 6 occur.
- Periodically reassess the prioritized list of assets to ensure the ranking continues to correspond to agency needs and mission.
- As your agency units and personnel evolve, consider including new agency stakeholders to review the methodology and the prioritized list. Also continue to include external partners.
- Consider developing and periodically updating a plan of action to provide milestone and timeline of when specific vulnerable assets will be further analyzed.
- Update your agency's communications strategy and documentation with the results of the latest vulnerability assessment.

Recommended Actions to Achieve Higher Levels of Resilience Capability

If you scored at Maturity Levels 1 or 2, you are still in your evolution toward a more resilience-oriented agency. In such a case, the top managers of the agency should identify which of the factors in Table 18 were most lacking and determine priorities for implementing approaches for vulnerability assessments and prioritization.

Table 19 is offered as a template to determine which steps your agency can take to improve your agency's resilience capabilities, who should be responsible, the timeframe for implementation, and expected outcomes.

Table 19: Actions to Achieve a Higher Level of Maturity for Step 7: Determine Vulnerability and Prioritize

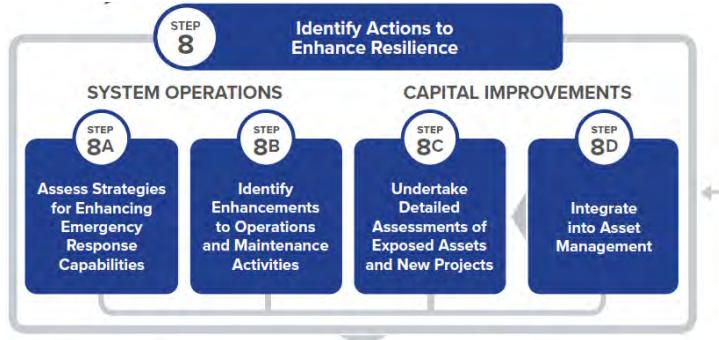
Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	For different asset types, develop methodologies for combining physical and socio-economic costs that may occur over the asset life span by scenario, time period, and hazard.			
	Monitor the process of using the information from Step 5 as input to Step 6. In addition, monitor how the results of Step 6 are used in subsequent steps.			
	Identify critical agency stakeholders and external partners who are crucial for supporting prioritization. Establish a means of collaborating with these groups in the assessment and prioritization processes.			
	Develop communication materials that describe the methodologies applied and the resulting rankings.			
	Map the prioritized assets to agency unit responsibilities			

Useful References

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Chapter 10: Identify Actions to Enhance Resilience (Step 8)

Step 8 represents one of the most important steps in the Framework. This step focuses on those actions—for improving system operations and for improving asset design and management—that collectively lead to a more resilient transportation system. Four sub-steps in Step 8 reflect these types of actions:



- Step 8A: Assess strategies for enhancing emergency response capabilities
- Step 8B: Identify enhancements to operations and maintenance activities
- Step 8C: Undertake detailed assessment of exposed assets and new projects
- Step 8D: Integrate into asset management

Three of these steps, those for emergency response, operations and maintenance, and resilience assessments of exposed and new projects, are considered to be the major resilience-related products of a transportation agency. Conducting a self-assessment of your agency's efforts in these three areas is thus considered an important ingredient for improving the current resilience-related efforts of your agency. The step on integrating resilience concepts into an agency's asset management program reflects the importance of asset management information for the types of decisions made by agency managers.

Four observations on these steps and how they fit into the Framework are important for understanding the logic of how Step 8 relates to the other steps in the tool.

1. The systems-level vulnerability analysis results from Step 7 should inform all sub-steps under Step 8.
2. The steps within Step 8 are interconnected. For example, some of the maintenance actions that are discussed in Step 8B should be integrated into the asset management system per Step 8D.
3. There are four paths for assets to reach Step 8C for a detailed facility-level assessment of adaptation options:
 - a. The first pathway is directly from Step 7, whereby the most vulnerable existing assets get studied for adaptation/mitigation options first. This pathway allows for immediate action meant primarily to address critical deficiencies related to resiliency. This special focus on resiliency and adaptation is warranted due to the safety issues such hazards/threats represent, their potentially existential threat to assets, and the sheer number of impacts that climate change will bring.
 - b. An alternate pathway to Step 8C is through your agency's asset management program. Here, vulnerability information should be combined with other factors related to asset performance and condition to identify capital improvement projects. Each of these capital improvement projects should receive a detailed assessment.

- c. All new capital projects (e.g., a new road alignment) and major upgrades to existing assets (due to capacity expansion, etc.) should also undergo detailed assessments.
 - d. Lastly, there is also a feedback loop from Step 10: *Monitor and Manage System Performance* to Step 8 as illustrated in Figure 1. This allows for assets that had previously been given detailed assessments and adapted to obtain a follow-up analysis if conditions change and the adaptation/mitigation measures are not performing as planned. Also, some adaptation options involve evolving an asset's design over time as conditions warrant (an adaptive management approach); this feedback indicates the need for that monitoring and revisiting of the design stage. This feedback loops should also influence other sub-steps in Step 8. For example, your agency's system monitoring program might indicate a higher-than-normal road closure trend due to flooding in a particular area which could feed into changes to your agency's operations and maintenance efforts in Step 8B.
4. As noted earlier, Step 8D is included in Step 8 because of the importance of asset management systems and programs in establishing priorities for system investment. The Step 8D self-assessment focuses on how to make the asset management process more inclusive of resilience factors when providing information to decision-makers on how budgets are to be allocated. However, asset management data collection efforts could also be an opportunity to provide more information on asset characteristics to enable more detailed systems-level vulnerability assessments in Steps 5 through 7 (hence the double-headed arrow from Step 8 to the "Revisit Analysis in the Future" flowline that leads back to Step 5 in Figure 1). The Step 8D self-assessment includes factors that reflect this potential for asset management to play such a role.
5. The results of the Step 8 tasks feed into the capital investment program and operating budgets for the different resilience-oriented units in your agency (Step 9). A major indication that your agency is becoming more sensitive to resilience concerns is the actual implementation of resilience projects and operating/maintenance strategies. Step 8 provides the information that will justify such expenditure as well as providing guidance on the types of project designs and operations strategies that will enhance system resilience.

The following chapters provide more detail on how each of the Step 8 sub-steps can contribute to your agency's resilience strategy.

Chapter 11: Assess Strategies for Enhancing Emergency Response Capabilities (Step 8A)

Emergency response staff in your agency are often the first to face the challenges of dealing with system disruptions. Whether this response is to a serious traffic crash that has closed a major highway or a larger disruption stemming from a widespread extreme weather event, your emergency response units are on the front line. Not only are your agency's emergency response capabilities important for returning the system or facility to normal operation as soon as possible, but the effectiveness of this response is often one of the critical dimensions of how key stakeholders and the general public perceive the performance of your agency. Some of the most challenging public relations efforts have involved responding to critiques and criticisms from the media and public on perceived incompetence in agency response to major system disruptions.

On the other hand, when a major disruption occurs and the agency is perceived as having responded quickly and efficiently and has expeditiously disseminated information to the traveling public, the agency's reputation can be enhanced. For example, the Georgia DOT's response to a 2017 bridge deck fire that closed a major interstate in Atlanta for just more than two months was widely applauded by the media, government officials, and transportation professionals.

One of the other important characteristics of emergency response (from the perspective of agency maturity) is the collaborative, multi-agency nature of such response. The number of agencies involved in an incident will depend on the nature of the incident. For example, a major crash that closes an interstate will likely involve many units within your agency (e.g., emergency response, maintenance, traffic operations, communications/public information, and, possibly, environmental and design units depending on the scale of the impacts and damage). In addition, such an incident will also likely involve law enforcement, the fire department, emergency medical services, towing companies, coroners and medical examiners, and hazardous materials and environmental inspectors (depending on the crash) along with news media.²¹ The participation in incident response becomes even more complex if there is suspicion of terrorist involvement. Homeland Security, a range of enforcement agencies, and other federal regulatory agencies can be added to the above listed agencies.

In addition to collaboration, several factors in this step examine your agency's preparedness for responding to cyberattacks. Some mission-critical factors in other steps are similar to those presented below. For example, Step 8B includes a factor relating to backing up key systems operations data whereas a factor in this step includes backing up all agency-critical data. These are related (the first could be subsumed in the second), however, backing up system operations data was considered so important for the systems operations function of a transportation agency that it was still included in that step. It is recognized that many agencies do not have direct responsibility for cybersecurity strategies and efforts; such responsibilities rest in other agencies having this mandate. In such a case, the cybersecurity related factors might be amended to address how well these departments are providing your agency protection against cyberattacks.

²¹ See Meyer, M. and O. Elrahman. 2019. *Transportation and Public Health, An Integrated Approach to Policy, Planning, and Implementation*. Chapter on Transportation System Safety and Public Health. Elsevier Publishing.

Capability Factors and Levels of Maturity

Factor 8A.1 Does your agency have effective internal and external processes for communicating and sharing emergency response information?

Major events, especially those causing severe and prolonged disruption, and those that are repetitive and routine require pre-established internal and external means of communication to ensure effective exchange of information. Such interfaces should occur at all levels within your agency as well as with other relevant agencies, with the public, and with community officials. The levels of maturity for this factor reflects the degree to which your agency has such communication capabilities and the level to which they are tested for reliable operation during an emergency.

- Level 1: We have established a communication process and protocol for internal DOT functions and with other relevant agencies in the event of a major system disruption. These include primarily email and telephone communications.
- Level 2: We have established multiple communication processes and protocols for internal DOT functions and with other relevant agencies in the event of a major system disruption. These include back-up processes in the event our primary communication system does not function. The process includes email and telephone communications as well as separate emergency communications systems used internally and between agencies. Detailed continuity of operations and security notification contact lists have been developed to account for loss of command and control capabilities.
- Level 3: We have achieved Maturity Level 2. In addition, we field test and conduct table top exercises of all communications systems and processes at a minimum of every other year. This includes verification and testing of back-up communication tools such as satellite phones.

Factor 8A.2 Does your agency have an “All-Hazards Plan” for responding to emergencies?

Your agency can anticipate the types of hazards that it will likely have to respond to based on the systems-level vulnerability analysis from Step 7. Responding to a wildfire along a roadside is very different than responding to motorists stranded from major flooding. Your agency’s emergency response capability should therefore be designed to handle a range of major types of incidents and disruptive events. This is called an “all-hazards” approach to emergency response. In essence, an all-hazards capability means that an agency is prepared for the full spectrum of incidents, disasters, or other major disruptions it could face. This factor focuses on the extent to which you have planned for, periodically reviewed, and examined collaboratively with partner agencies the need to respond to a variety of different hazards. The major distinction among the maturity levels reflect the levels of effort for doing so.

- Level 1: We have a written All-Hazards Plan that includes a detailed checklist(s) which allows a self-assessment of the effectiveness of our agency’s plan. The plan contains information about the agency’s policies, procedures, and countermeasures for all the hazards and threats likely to face the agency.
- Level 2: We have achieved a Level 1 maturity. In addition, the All Hazards Plan and checklist(s) are reviewed periodically by agency staff at a minimum of every three years. Revisions to the plan are communicated throughout the agency.

- Level 3: We have achieved a Level 2 maturity. However, reviews of the agency's All Hazards Plan and checklists occur in coordination with partner agencies. This review also occurs with operating and capital budget cycles to allow identified needs to be considered in budget decisions.

Factor 8A.3 Does your agency factor the information obtained from prior emergency incidents or events into its all-hazards response plans?

This factor reflects the good business practice of monitoring events and incidents your agency has faced so as to learn from that experience. With respect to emergency response for all possible hazards, this feedback is critical because no single incident will be exactly the same as prior events. In addition, given the number of different agencies involved in response to major disruptions it is often true that new personnel are involved in the efforts and thus can create new challenges or provide new perspectives on how to improve collaboration. The distinctions in the maturity levels for this factor represent the level to which your agency captures the experience of emergency response efforts and how this information is used.

- Level 1: We have mechanisms in place to capture and analyze important information about the effectiveness of joint emergency response efforts. We only examine those disruptions that relate to what we consider to be the most disruptive hazards and threats and those that have occurred very frequently in the past.
- Level 2: We have mechanisms in place to capture and analyze important information about the effectiveness of joint emergency response efforts. We have a formal template that is used by our agency emergency response staff to examine those aspects of the response that was effective and those where improvements could occur. We undertake this after-event assessment for all incidents and system disruptions. We use the information in updates of our All-Hazards Plan to inform estimates of likelihood of different hazards occurring in the future and to modify plan strategies to minimize impacts.
- Level 3: We have achieved a Level 2 maturity. In addition, the after-event information is tabulated and organized in such a way that it can inform the planning and design of new or reconstructed projects, including the consideration of the information in the project's lifecycle analysis. We meet periodically with partner agencies to review our after-event summaries and solicit their input on efforts that can be made to improve the effectiveness of joint efforts.

Factor 8A.4 Does your agency periodically field test critical emergency management technologies, equipment, and systems to ensure performance?

Making sure mission-critical equipment and coordination systems (such as communications equipment) are working efficiently and effectively in multiple types of hazard and threat scenarios is an important action for ensuring rapid response to disruptions. For example, one of the lessons learned from past disruptions (e.g., the 9/11 terrorist attacks and the 2017 multi-agency response to a major ice storm in Atlanta) was that incompatible communication systems amongst responders was one of the major constraints hindering a coordinated response. Such an issue could have been discovered beforehand by using simulated emergencies to determine where improvements could be made. This factor examines both the use of field tests as well as in-house testing of the performance of mission-critical equipment.

The major distinction among the levels of maturity for this factor reflects the degree to which mission critical equipment and technologies are tested on a periodic basis. Note that the first factor in this step has as part of Level 3 maturity the testing of communication systems, which could also be part of this factor. The difference between the two factors is that the first one focuses solely on communications systems while this factor examines whether all mission-critical equipment and systems are tested as a matter of agency standard operating procedure.

- Level 1: We maintain a list of mission critical emergency management technologies, equipment and systems. We monitor and test in place to detect proactively faults or performance deviations.
- Level 2: We have achieved Level 1 maturity. In addition, we conduct periodic readiness and deployment drills and assessments of mission-critical systems. Drill participants are those units in our agency that will participate in a response to an incident or major disruption.
- Level 3: We have achieved a Level 2 maturity. However, drill participants also include other partner agencies that will participate in a response to an incident or major disruption. The performance of the equipment and systems should be a particular focus of the after-drill evaluation. Internally, the results and information obtained through the monitoring and testing of mission-critical equipment and systems are considered in advance of procuring similar goods and services. Test results are used in support of establishing equipment or technology standards and specifications.

Factor 8A.5 Does your agency's emergency response/management and security staffs interact with other units in your agency (e.g., planning, design, construction, and operations) to provide input on resilience-related aspects of their efforts?

Transportation agency staff often approach a particular problem from the lens of their discipline or their business unit's mandate. Thus, construction staff will look at a project from the perspective of the schedule, phasing, equipment and materials needs and the level of oversight that might be necessary. Traffic operations staff might look at the same project from the perspective of traffic flow and safety. This factor relates to the participation of your agency's emergency response/management and security staff in agency discussions on preferred characteristics of resilience-oriented projects and strategies. For example, emergency response staff could suggest ways of providing emergency vehicle access to incident sites, how information is provided to the public, the traffic operations strategy for diverting traffic, the types and amount of materials to be stockpiled at remote sites, and the like. Security staff could advise on how to best protect structures against explosives, how visitor screening should occur in publicly-accessible buildings, or how to include enforcement and investigation staff in incidents where pre-meditate intent is suspected.

- Level 1: We include our emergency response/management and security staff in resilience discussions for only the most important projects that clearly relate to their responsibilities. This interaction usually occurs on an ad hoc basis at the discretion of the unit manager leading the development of a project or strategy.
- Level 2: We include our emergency response/management and security staff in resilience discussions for all projects that clearly relate to their responsibilities. This interaction has been formalized in our standard operating procedures. Recommendations from this staff have been

included in project designs and strategy formulations. For example, we have mitigated security threats to our most critical and vulnerable infrastructure by hardening, providing setbacks, or adopted other mitigation techniques.

- Level 3: We have achieved a Level 2 maturity. In addition, we have developed guidebooks and other guidance on the types of strategies that can be considered in project designs that enhance emergency response/management and security performance. Our staff participates in TRB, AASHTO, TSA, and/or DHS webinars or participate in quarterly calls to be up-to-date on the latest approaches for provide a secure, resilient infrastructure.

Factor 8A.6 Does your agency have a training and exercise program for the emergency response and management program?

Developing and maintaining a resilient emergency management capability requires expertise, due diligence, and a high level of staff training. Effective training is available in many forms and at varying levels of intensity and duration. It starts at the “awareness or introductory” level and extends to both on-line and classroom presentation of educational materials. However, the “gold star” standard for transportation organization training includes the conduct of both “discussion-based” and “operations-based” exercises. The Department of Homeland Security’s (DHS’s) Federal Emergency Management Agency (FEMA) provides a comprehensive “Drills and Exercise Program” (Homeland Security Exercise and Evaluation Program – HSEEP) that is widely used by industry and government agencies, including many transportation agencies. This factor examines the extent and level of training your agency staff participates in. The distinction among maturity levels reflects the frequency of such training.

- Level 1 – We have emergency management plans, procedures, and processes. This includes evacuation plans, a continuity of operation plan, a business continuity plan, and a security plan. We take steps to ensure agency staff are familiar with the contents of these plans.
- Level 2 – We have achieved a Level 1 maturity. In addition, we hold infrequent training drills, table top exercises, and full-scale exercises on these plans.
- Level 3 – We have achieved a Level 2 maturity except that we hold frequent training drills [e.g., yearly] table top exercises [every other year] and full-scale exercises [every five years] on these plans. We also monitor peer agencies, industry journals, and other sources for the latest emergency response technologies that could enhance our efforts.

Factor 8A.7 Do your agency’s budget and management support systems consider the staff surge, equipment, and communications system needs of your emergency response and management strategy?

An important, but often overlooked, aspect of emergency response and management, especially for large-scale disruptions is how your agency manages emergency response efforts relating to the mobilization and utilization of resources. How do you handle surges in resource needs, which typically exceed their existing capabilities? Have you analyzed past experiences to understand such needs? What standardized protocols are in place for ER incident management covering single minor events, multiple minor events, or single major events, cascading upwards in intensity or duration? The types of staff, equipment and maybe even communications equipment could vary depending on the type of emergency. A flood requires construction staff/contractors, engineers, environmental staff and

construction materials and equipment. A cyber emergency may require traditional and computer network security personnel, computer programmers and technicians, and related equipment. Communications (internal and external) during some types of security/hacking events may be quite different than during a natural disaster impacting parts or all of the system.

In most cases, the resources needed by the emergency response and management efforts are funded by the agency's budget. To what extent are such needs considered in budget requests? Another constraint faced by some agencies are the limitations placed on staff participation by job descriptions and other personnel requirements. This factor reflects the degree to which emergency response and management capacity needs are considered and supported by the budget and management support systems that provide information to the resource allocation decision. The distinction among the maturity levels is the degree to which such needs are considered.

- Level 1: The upgrade and purchase of updated equipment and communications systems for our emergency response unit occurs when the budget is available to do so. There is a good working relationship between the Emergency Management unit and other units that need to collaborate in order to implement an emergency response strategy (e.g., stockpiling needed replacement materials likely needed for system recovery). This working relationship primarily occurs on an ad hoc basis.
- Level 2: We have included periodic funding (e.g., every three years) for needed upgrades and purchase of emergency response equipment and communications systems. The Emergency Response unit and other units that need to collaborate in order to implement an emergency response strategy meet formally on a set schedule to coordinate budget requests. The focus of budget requests is only on those hazards and threats considered most important based on historical occurrences.
- Level 3: The budget of my agency includes annual funding for needed upgrades and purchase of emergency response equipment and communications systems. The Emergency Response unit and other units that need to collaborate in order to implement an emergency response strategy meet formally on a set schedule to coordinate budget requests. We include in our deliberations partner agencies to better understand how our budget investment reinforces their own budget allocations. We have made sure all agency staff are aware of what role, if any, they will have in a major disaster or system disruption.

Factor 8A.8 Does your agency have a “Continuity of Operations (COOP) Plan” / Disaster Recovery Plan in the event of major disruptions to the agency and/or in the chain of command?

System resiliency not only reflects the physical design and operational/maintenance strategies for protecting and minimizing disruption to assets, but also making sure that the agency decision-making processes and employee availability survive major disruptions as well. A COOP plan outlines the hierarchy of decision making in the event that agency key leadership is not available to make decisions. It also establishes protocols for how these decisions are to be made, who should be involved, and the records/paper trail that are necessary to describe the decision rationale post disruption. Employee safety is also a primary concern during an emergency affecting locations where employees are located. Agencies are required to establish emergency procedures and directions for such events. Maintaining the operational capability of the organization along with ensuring the safety of personnel are primary

goals during an emergency. The COOP plan should include contingency procedures for short-term emergency events, common events occurring periodically, as well as for more serious disruptions that happen infrequently.

In addition, the COOP plan should examine the scenario of a large number of mission-critical staff being unavailable due to epidemics/pandemics. Many transit agency pandemic plans, for example, discuss the challenge of providing lifeline transit service in the event that drivers are not available due to illness or taking care of family members. Similar challenges could occur for state DOTs, for example, in the staff available to run traffic management centers (TMCs). This factor focuses on the existence of a COOP and Disaster Recovery Plan (DRP). A DRP outlines a structured approach for how an organization can recover from a serious disruption, a term often used to describe recovery from a cyberattack. In this context, a DRP informs agency staff how to recover data loss and system functionality.

The major distinctions among the different levels of maturity reflect the degree to which the plans cover all units in the agency and the extent to which they are periodically tested.

- Level 1: We have a Continuity of Operations (COOP) Plan which includes the agency's essential functions, order of succession, delegation of authority, continuity facilities, continuity communications, vital records management, devolution of control and direction, and a reconstitution plan. This includes a Disaster Recovery Plan (DRP) with a documented process or set of procedures to recover and protect business IT infrastructure in the event of a disaster. There is limited capability in execution of essential operations and functions at alternate operating facilities. The COOP plan has not been updated in several years.
- Level 2: We have achieved Level 1 maturity. However, the COOP plan is periodically updated. The plan is regularly tested with in-field simulations of different types of emergencies. Partial execution of essential operations and functions capability is planned to occur at alternate operating facilities, with expected performance to include all critical business functions and some noncritical business functions being operational.
- Level 3: We have achieved a Level 2 maturity. However, the plan adopts an agency-wide perspective that includes decision-making and communication protocols for all units in the event of a major system disruption and/or loss of contact with agency senior management. The COOP plan is expected to be fully executed post disruption. The execution of essential operations and functions is capable at alternate operating facilities. All critical and noncritical business functions are operational. Any necessary emotional and medical support will be provided to employees.

Factor 8A.9 Does your agency conduct training, drills, and exercises on its COOP/Disaster Recovery Plans (including response procedures and decision-making processes)?

Similar to the above factor on testing the effectiveness of emergency response and management capability, this factor tests the effectiveness of the COOP and Disaster Recovery Plans. In particular, the focus of such tests examines the ability of your agency to function and provide disaster response in the event of loss of command and control capability. This can occur by not allowing communications with top agency leadership and conducting exercises on how your agency responds to a simulated disaster. To what extent has decision-making authority been granted to lower level managers to respond to the disaster without approval of top management? What backup information is needed when such decisions are made? How long does it take for front-line staff to realize they are cut off from top agency

management and how do they respond? How does your agency respond to requests from other agencies for help or support when top leadership is not available to approve such requests? The major distinction among the levels of maturity for this factor reflects the degree to which you test and evaluate your agency's COOP and Disaster Recovery Plan.

- Level 1: We provide limited training to agency emergency response and management staff on the COOP/Disaster Recovery Plan, procedures, and processes. These are primarily table top exercises using pre-determined hazard and threat scenarios. No field drills or operations-based exercises are conducted.
- Level 2: We provide periodic training to all agency staff on the COOP/Disaster Recovery Plan. This includes discussion-based exercises on continuity of operations/disaster recovery including workshops and tabletop exercises. We sometimes include COOP/Disaster Recovery Plan contingencies in field exercises undertaken for emergency response and management training.
- Level 3: We have achieved a Level 2 maturity. We conduct training and field drills specifically on the requirements of the COOP/Disaster Recovery Plan. If the capability exists to take over agency command and control responsibilities from alternate sites, such a scenario is tested by allowing alternate sites to "run" the agency for one day. We include in the test of the COOP a third party who introduces "new" disruptions that were not anticipated.

Factor 8A.10 Does the agency have a plan to address emergencies associated with Industrial Control Systems (ICS) and Information Technology (IT) system cyber threats?

State transportation agencies, like other complex public and private organizations, increasingly rely on information technology (IT) systems and operational technology (OT) assets to fulfill their public mission. In addition to the use of IT for administrative functions, the real-time use of technology to operate and manage transportation facilities and services presents particularly acute challenges. There have been several well-noted examples of cyberattacks against transportation agencies that have caused significant disruption to agency operations.

- Level 1: We have written information and information systems plan in place to assure the confidentiality, integrity, and availability of all critical information. The plan complies with applicable information security and data privacy laws and regulations.
- Level 2: We conduct continuous and on-going assessments of our agency's information and information systems protection plans. There is a communications strategy in place to maintain situational awareness of threats and vulnerabilities.
- Level 3: We have achieved a Level 2 maturity. In addition, we review our agency's information and information systems protection plan routinely in coordination with the agency's operating and capital budget cycles.

Factor 8A.11 Has your agency identified cybersecurity user categories for employees and contractors and developed and implemented policies and guidelines for these categories (e.g., policies regarding mobile devices) to ensure the protection of the agency against information system external and internal threats?

One of the lessons from cyberattacks against all types of agencies is that hackers often gain access through individual computers or other connected devices. A major defense against such attacks is to create firewalls so that entry cannot occur. However, another important strategy is to make sure that employee IT and internet access is clearly delineated and understood. This is also applicable for contractors working on DOT premises. This factor focuses on how your agency has identified the extent to which employees and contractors will have access to your agency's internet and digital capabilities. This can be done by establishing different levels of access, use of protected passwords, and other means of controlling use to protect against cyberattacks. The distinctions among the different maturity levels for this factor reflect the degree to which cybersecurity roles and use characteristics have been defined for employees and screening procedures have been established for vendors.

- Level 1: We have identified a few cybersecurity roles and user categories for employees and contractors. We have begun to develop employee and contractor policies and guidelines (e.g., policies regarding mobile devices) but have not fully implemented them.
- Level 2: We have identified some cybersecurity roles and user categories for employees and contractors. We have developed a full range of employee and contractor cybersecurity policies and guidelines (e.g., policies regarding mobile devices). We screen vendors on an ad hoc basis.
- Level 3: We have identified all cybersecurity roles and user categories for employees and contractors. We have developed and implemented a full range of employee and contractor policies and guidelines (e.g., policies regarding mobile devices). We have developed and implemented a screening procedure for vendors.

Factor 8A.12 Does your agency use basic cybersecurity techniques and cyber hygiene practices?

Best practice in cybersecurity relies on some basic approaches and strategies for protecting IT systems against cyberattacks (e.g., the use of firewalls). This factor focuses on the extent to which such techniques and practices have been integrated into your agency's day-to-day actions. The distinction among the maturity levels for this factor reflects the degree to which your agency uses such basic techniques and practices.

- Level 1: We use a few basic cybersecurity techniques and cyber hygiene practices on an ad hoc basis.
- Level 2: We have achieved a Level 1 maturity. However, we use more advanced techniques and practices for the most important command and control functions in our agency.
- Level 3: We use the full range of cybersecurity techniques and cyber hygiene practices across my agency.

Factor 8A.13 Has your agency developed and tested a cyber-incident response and recovery plan with the participation of key stakeholders?

Organizations Participating in Response to Colorado DOT Cyberattack

- Colorado Department of Transportation
- Colorado Governor's Office of Information Technology
- Colorado Division of Homeland Security and Emergency Management
- Colorado Army National Guard
- Colorado Bureau of Investigation
- Federal Bureau of Investigation
- Department of Homeland Security-Cyber
- Department of Homeland Security-Infrastructure Protection
- Department of Homeland Security-Hunt and Incident Response Team
- Federal Emergency Management Agency
- Federal Emergency Management Agency-MERS
- Private cybersecurity contractors

Transportation agency officials whose agencies have experienced cyberattacks often express surprise that such an attack against their agency was successful. Often these same officials are surprised at how involved and fast the response to such attacks must be. The text box, for example, lists the different organizations that became part of the response to a cyberattack against the Colorado DOT (CDOT). CDOT was one of the agencies whose responsibility of cybersecurity rested in another agency. This attack seriously affected CDOT's internal administrative operations, including the ability to issue paychecks to its employees. The attack entered through a CDOT website that had been left on the web even though it was no longer used.

This factor focuses on the extent to which your agency (or in partnership with the agency responsible for cybersecurity) has developed and tested a cyber-incident response and recovery plan. The major distinction among the maturity levels for this factor reflects the degree to which a plan has been developed, who has been involved in plan development, and the level to which the plan is tested, especially as new cyber threats occur.

- Level 1: We have developed a cyber-incident response and recovery plan in collaboration with a few key stakeholders. The plan is only partially implemented.
- Level 2: We have developed and implemented a cyber-incident response and recovery plan in collaboration with all key internal and external stakeholders.
- Level 3: We achieved a Level 2 maturity. In addition, we test the plan by hiring hackers to attack our systems (so-called white hat hackers). The results of such attacks are used in updates of our plan. In addition, our IT unit communicates with and participates in workshops on the latest protection and recovery strategies for cyberattacks.

Factor 8A.14 Does your agency regularly back up agency critical data accessible in an accessible secondary digital location?

Transportation agencies produce and use a lot of data on transportation system performance, user data (where their responsibilities include issuing driver licenses or road use permits), historical data on project designs and program results, financial data, and employee information. Loss or the corruption of such data could create serious problems for day-to-day operations of a transportation agency. One of the ways of protecting against such loss is to back up the data considered most important to your agency. This back-up could occur within your own IT network (e.g., in a dedicated cloud zone) or through a remote site not connected to your IT systems. The backup could occur automatically, on some time

period, or at the discretion of an agency manager. The distinction among the maturity levels for this factor reflect the frequency of data backups and the degree to which the backed up data are protected against attacks.

- Level 1: We back up some mission-critical data as part of our existing IT standard operating procedures. This backup is located in our existing database storage. The backup occurs at the discretion of agency managers.
- Level 2: We back up all data considered important to the day-to-day operations of our agency. The backup procedure is automatic and the data are stored in a temporary storage site in our existing IT system. Archived data are deleted after some period of time once they are no longer usefulness to the agency. As-built project plans have been digitized and protected for only a subset of our assets.
- Level 3: We have achieved Maturity Level 2. In addition, we store backed up data digitally in the cloud or at remote sites with firewalls and other cyber defenses in place that will not allow attacks on our agency's primary IT systems to reach the remote sites. As-built project plans have been digitized and protected for all our assets.

Factor 8A.15 Has your agency established a cybersecurity awareness training program?

Providing information on the basics of cyber security to employees and contractors is an important part of an agency's cyber protection strategy. This factor reflects the level to which your agency has provided such training. The major distinction among the maturity levels relates to the degree to which this training is provided.

- Level 1: We have developed a cybersecurity awareness training program. All new employees must take the training. A contractor cybersecurity awareness program has also been developed but only a subset of our contractors have completed the training. Materials to reinforce awareness are distributed on an ad hoc basis.
- Level 2: We have achieved Maturity Level 1. In addition, the training is required for all employees, not just new employees. Refresher training providing updated content is provided on at least an annual basis.
- Level 3: We have achieved Maturity Level 3. In addition, all contractors have taken the training. Materials to reinforce awareness are distributed periodically. An emphasis on cybersecurity is incorporated into our internal and external communications strategy.

Table 20 shows the factors that are included in the self-assessment tool. The maturity levels for each factor are presented in the descriptions of each factor

Table 20: Assessment Table for Step 8A: Assess Strategies for Enhancing Emergency Response Capabilities

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
8A.1 Does the agency have effective internal and external processes for communicating and sharing emergency response information?	We have established a communication process and protocol for internal DOT functions and with other relevant agencies in the event of a major system disruption. These include primarily email and telephone communications.	We have established multiple communication processes and protocols for internal DOT functions and with other relevant agencies in the event of a major system disruption. These include back-up processes in the event our primary communication system does not function. The process includes email and telephone communications as well as separate emergency communications systems used internally and between agencies. Detailed continuity of operations and security notification contact lists have been developed to account for loss of command and control capabilities.	We have achieved Maturity Level 2. In addition, we field test and conduct table top exercises of all communications systems and processes at a minimum of every other year. This includes verification and testing of back-up communication tools such as satellite phones.
8A.2 Do you have an “All-Hazards Plan” for responding to emergencies?	We have a written All-Hazards Plan that includes a detailed checklist(s) which allows a self-assessment of the effectiveness of our agency’s plan. The plan contains information about the agency’s policies, procedures, and countermeasures for all the hazards and threats likely to face the agency.	We have achieved a Level 1 maturity. In addition, the All Hazards Plan and checklist(s) are reviewed periodically by agency staff at a minimum of every three years. Revisions to the plan are communicated throughout the agency.	We have achieved a Level 2 maturity. However, reviews of the agency’s All Hazards Plan and checklists occur in coordination with partner agencies. This review also occurs with operating and capital budget cycles to allow identified needs to be considered in budget decisions.
8A.3 Does your agency factor the information obtained from prior emergency incidents or events into its all-hazards response plans?	We have mechanisms in place to capture and analyze important information about the effectiveness of joint emergency response efforts. We only examine those disruptions that relate to what we consider to be the most disruptive hazards and threats and those that have occurred very frequently in the past.	We have mechanisms in place to capture and analyze important information about the effectiveness of joint emergency response efforts. We have a formal template that is used by our agency emergency response staff to examine those aspects of the response that was effective and those where improvements could occur. We undertake this after-event assessment for all incidents and system disruptions. We use the information in updates of our All-Hazards Plan to inform estimates of likelihood of different hazards occurring in the future and to modify plan strategies to minimize impacts.	We have achieved a Level 2 maturity. In addition, the after-event information is tabulated and organized in such a way that it can inform the planning and design of new or reconstructed projects, including the consideration of the information in the project’s lifecycle analysis. We meet periodically with partner agencies to review our after-event summaries and solicit their input on efforts that can be made to improve the effectiveness of joint efforts.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
8A.4 Does your agency periodically field test critical emergency management technologies, equipment, and systems to ensure performance?	We maintain a list of mission critical emergency management technologies, equipment and systems. We monitor and test in place to detect proactively faults or performance deviations.	We have achieved Level 1 maturity. In addition, we conduct periodic readiness and deployment drills and assessments of mission-critical systems. Drill participants are those units in our agency that will participate in a response to an incident or major disruption.	We have achieved a Level 2 maturity. However, drill participants also include other partner agencies that will participate in a response to an incident or major disruption. The performance of the equipment and systems should be a particular focus of the after-drill evaluation. Internally, the results and information obtained through the monitoring and testing of mission-critical equipment and systems are considered in advance of procuring similar goods and services. Test results are used in support of establishing equipment or technology standards and specifications.
8A.5 Does your agency's emergency response/management and security staffs interact with other units in your agency (e.g., planning, design, construction, and operations) to provide input on resilience-related aspects of their efforts?	We include our emergency response/management and security staff in resilience discussions for only the most important projects that clearly relate to their responsibilities. This interaction usually occurs on an ad hoc basis at the discretion of the unit manager leading the development of a project or strategy.	We include our emergency response/management and security staff in resilience discussions for all projects that clearly relate to their responsibilities. This interaction has been formalized in our standard operating procedures. Recommendations from this staff have been included in project designs and strategy formulations. For example, we have mitigated security threats to our most critical and vulnerable infrastructure by hardening, providing setbacks, or adopted other mitigation techniques.	We have achieved a Level 2 maturity. In addition, we have developed guidebooks and other guidance on the types of strategies that can be considered in project designs that enhance emergency response/management and security performance. Our staff participates in TRB, AASHTO, TSA, and/or DHS webinars or participate in quarterly calls to be up-to-date on the latest approaches for provide a secure, resilient infrastructure.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
8A.6 Does your agency have a training and exercise program for the emergency response and management program?	We have emergency management plans, procedures, and processes. This includes evacuation plans, a continuity of operation plan, a business continuity plan, and a security plan. We take steps to ensure agency staff are familiar with the contents of these plans.	We have achieved a Level 1 maturity. In addition, we hold infrequent training drills, table top exercises, and full-scale exercises on these plans.	We have achieved a Level 2 maturity except that we hold frequent training drills [e.g., yearly] table top exercises [every other year] and full-scale exercises [every five years] on these plans. We also monitor peer agencies, industry journals, and other sources for the latest emergency response technologies that could enhance our efforts.
8A.7 Do your agency's budget and management support systems consider the staff surge, equipment, and communications system needs of your emergency response and management strategy?	The upgrade and purchase of updated equipment and communications systems for our emergency response unit occurs when the budget is available to do so. There is a good working relationship between the Emergency Management unit and other units that need to collaborate in order to implement an emergency response strategy (e.g., stockpiling needed replacement materials likely needed for system recovery). This working relationship primarily occurs on an ad hoc basis.	We have included periodic funding (e.g., every three years) for needed upgrades and purchase of emergency response equipment and communications systems. The Emergency Response unit and other units that need to collaborate in order to implement an emergency response strategy meet formally on a set schedule to coordinate budget requests. The focus of budget requests is only on those hazards and threats considered most important based on historical occurrences.	The budget of my agency includes annual funding for needed upgrades and purchase of emergency response equipment and communications systems. The Emergency Response unit and other units that need to collaborate in order to implement an emergency response strategy meet formally on a set schedule to coordinate budget requests. We include in our deliberations partner agencies to better understand how our budget investment reinforces their own budget allocations. We have made sure all agency staff are aware of what role, if any, they will have in a major disaster or system disruption.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
8A.8 Does your agency have a “Continuity of Operations Plan” (COOP)/ Disaster Recovery Plan in the event of major disruptions to the agency and/or in the chain of command?	We have a Continuity of Operations Plan (COOP) which includes the agency’s essential functions, order of succession, delegation of authority, continuity facilities, continuity communications, vital records management, devolution of control and direction, and a reconstitution plan. This includes a Disaster Recovery Plan (DRP) with a documented process or set of procedures to recover and protect business IT infrastructure in the event of a disaster. There is limited capability in execution of essential operations and functions at alternate operating facilities. The COOP has not been updated in several years.	We have achieved Level 1 maturity. However, the COOP is periodically updated. The plan is regularly tested with in-field simulations of different types of emergencies. Partial execution of essential operations and functions capability is planned to occur at alternate operating facilities, with expected performance to include all critical business functions and some noncritical business functions being operational.	We have achieved a Level 2 maturity. However, the plan adopts an agency- wide perspective that includes decision-making and communication protocols for all units in the event of a major system disruption and/or loss of contact with agency senior management. The COOP is expected to be fully executed post disruption. The execution of essential operations and functions is capable at alternate operating facilities. All critical and noncritical business functions are operational. Any necessary emotional and medical support will be provided to employees.
8A.9 Does your agency conduct training, drills, and exercises on its COOP/Disaster Recovery Plans (including response procedures and decision- making processes)?	We provide limited training to agency emergency response and management staff on the COOP/Disaster Recovery Plan, procedures, and processes. These are primarily table top exercises using pre-determined hazard and threat scenarios. No field drills or operations-based exercises are conducted.	We provide periodic training to all agency staff on the COOP/Disaster Recovery Plan. This includes discussion-based exercises on continuity of operations/disaster recovery including workshops and tabletop exercises. We sometimes include COOP/Disaster Recovery Plan contingencies in field exercises undertaken for emergency response and management training.	We have achieved a Level 2 maturity. We conduct training and field drills specifically on the requirements of the COOP/Disaster Recovery Plan. If the capability exists to take over agency command and control responsibilities from alternate sites, such a scenario is tested by allowing alternate sites to “run” the agency for one day. We include in the test of the COOP a third party who introduces “new” disruptions that were not anticipated.
8A.10 Does the agency have a plan in place to address emergencies associated with Industrial Control Systems (ICS) and Information Technology (IT) system cyber threats?	We have written information and information systems plan in place to assure the confidentiality, integrity, and availability of all critical information. The plan complies with applicable information security and data privacy laws and regulations.	We conduct continuous and on-going assessments of our agency’s information and information systems protection plans. There is a communications strategy in place to maintain situational awareness of threats and vulnerabilities.	We have achieved a Level 2 maturity. In addition, we review our agency’s information and information systems protection plan routinely in coordination with the agency’s operating and capital budget cycles.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
8A.11 Has your agency identified cybersecurity user categories for employees and contractors and developed and implemented policies and guidelines for these categories (e.g., policies regarding mobile devices) to ensure the protection of the agency against information system external and internal threats?	We have identified a few cybersecurity roles and user categories for employees and contractors. We have begun to develop employee and contractor policies and guidelines (e.g., policies regarding mobile devices) but have not fully implemented them.	We have identified some cybersecurity roles and user categories for employees and contractors. We have developed a full range of employee and contractor cybersecurity policies and guidelines (e.g., policies regarding mobile devices). We screen vendors on an ad hoc basis.	We have identified all cybersecurity roles and user categories for employees and contractors. We have developed and implemented a full range of employee and contractor policies and guidelines (e.g., policies regarding mobile devices). We have developed and implemented a screening procedure for vendors.
8A.12 Does your agency use basic cybersecurity techniques and cyber hygiene practices?	We use a few basic cybersecurity techniques and cyber hygiene practices on an ad hoc basis.	We have achieved a Level 1 maturity. However, we use more advanced techniques and practices for the most important command and control functions in our agency.	We use the full range of cybersecurity techniques and cyber hygiene practices across my agency.
8A.13 Has your agency developed and tested a cyber-incident response and recovery plan with the participation of key stakeholders?	We have developed a cyber-incident response and recovery plan in collaboration with a few key stakeholders. The plan is only partially implemented.	We have developed and implemented a cyber-incident response and recovery plan in collaboration with all key internal and external stakeholders.	We achieved a Level 2 maturity. In addition, we test the plan by hiring hackers to attack our systems (so-called white hat hackers). The results of such attacks are used in updates of our plan. In addition, our IT unit communicates with and participates in workshops on the latest protection and recovery strategies for cyberattacks.
8A.14 Does your agency regularly back up agency critical data in an accessible secondary digital location?	We back up some mission-critical data as part of our existing IT standard operating procedures. This backup is located in our existing database storage. The backup occurs at the discretion of agency managers.	We back up all data considered important to the day-to-day operations of our agency. The backup procedure is automatic and the data are stored in a temporary storage site in our existing IT system. Archived data are deleted after some period of time once they are no longer usefulness to the agency. As-built project plans have been digitized and protected for only a subset of our assets.	We have achieved Maturity Level 2. In addition, we store backed up data digitally in the cloud or at remote sites with firewalls and other cyber defenses in place that will not allow attacks on our agency's primary IT systems to reach the remote sites. As-built project plans have been digitized and protected for all our assets.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
8A.15 Has your agency established a cybersecurity awareness training program?	We have developed a cybersecurity awareness training program. All new employees must take the training. A contractor cybersecurity awareness program has also been developed but only a subset of our contractors have completed the training. Materials to reinforce awareness are distributed on an ad hoc basis.	We have achieved Maturity Level 1. In addition, the training is required for all employees, not just new employees. Refresher training providing updated content is provided on at least an annual basis.	We have achieved Maturity Level 3. In addition, all contractors have taken the training. Materials to reinforce awareness are distributed periodically. An emphasis on cybersecurity is incorporated into our internal and external communications strategy.
Score Range	Description of Agency Maturity for Enhancing Emergency Response and Agency Preparedness Capabilities		
0 to 20	Your agency is emerging into this area and has taken initial steps to grow awareness and understanding of enhancing emergency response and agency preparedness capabilities.		
21 to 39	Your agency has implemented several emergency response and agency preparedness strategies, not so much as part of an agency-wide strategy but rather at the initiative of agency staff.		
40 to 45	Your agency has reached significant maturity in identifying and implementing an emergency response and agency preparedness strategy. Major focus should be on maintaining and enhancing existing efforts when appropriate, and take advantage of new opportunities as they become available.		

Recommended Actions to Maintain the Highest Level of Agency Resilience Capability

The highest level of capability for Enhancing Emergency Response and Agency Preparedness Capabilities focuses on organizational cognizance and performance across five mission areas of emergency management – prevention, protection, mitigation, response and recovery as well as on your agency's positioning to recover against a disruption to its command and control structure, including an attack against your IT systems. If your agency has reached Maturity Level 3 of agency capability, the steps that can be taken to maintain this level include:

- Make sure your all-hazards plan is updated on a regular basis with the most up-to-date hazard projections and threat assessments. Engage outside experts on individual hazards and threats to assess the likely effectiveness of your response.
- Regularly update redundant emergency contact information for all key personnel and points of contact.
- Regularly assess for quality the data and information collected from prior incidents and disruptions that are archived for use in updating the all-hazards plan (and used also in other functions in the agency).
- Using the established coordination mechanism for your agency's resilience strategy and efforts, assess the level and quality of interaction between your emergency response/management and security staff and the staff of other units. Make improvements where necessary.
- Continue to assess the effectiveness of the communications systems with partner agencies as they support emergency response efforts. Test these systems against all types of hazards and threats that your agency might face.
- Conduct annual assessments of interagency emergency response drills and exercises in collaboration with federal, state, and regional partners.
- Conduct and review drills and exercises of your agency's COOP and Disaster Recovery Plan.
- Establish (if not already) a redundant secondary COOP site that can be activated in the event of a disruption in agency command and control structures.
- Update (or develop if not available) real-time monitoring systems, sensors, mobile devices, video and Internet of Things (IoT) devices that can be used during emergencies to send automated notifications to response teams.
- Conduct white hat hacker attacks against your agency's IT systems to identify access points.
- Continue to update employee and contractor training on cybersecurity as new threats occur.
- Continue to include information on your agency's emergency response/management and disaster recovery efforts in the resilience communications strategy.

Recommended Actions to Achieve Higher Levels of Resilience Capability

If you scored at the lowest level, you are just starting your evolution toward a more resilience-oriented agency. In such a case, the top managers of the agency should identify which of the factors in Table 20 were most lacking and determine priorities for enhancing emergency response and agency preparedness capabilities. Table 21 is offered as a template to determine which steps your agency can take to improve your agency's resilience capabilities, who should be responsible, the timeframe for the implementation and expected outcomes.

Table 21: Actions to Achieve Higher Maturity for Step 8A: Enhancing Emergency Response and Agency Preparedness Capabilities

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Develop a 24/7 threat and hazard warning system			
	Create or modernize your agency's emergency notification system			
	Implement a multi-year exercise program that includes the conduct of emergency management drills, functional, and full scale exercises.			
	Assess the effectiveness of the multi-agency communications systems and protocols used during emergency response/management actions. Include in this assessment the effectiveness of the technologies and equipment used in the response.			
	If not already done, develop an all hazards response plan and establish an update schedule.			
	Develop and periodically update a strategy and mechanism for emergency management and security staff to provide input into the decisions of other agency units.			
	Develop and periodically update a strategy and mechanism for data and information obtained from prior disruptions to be incorporated into agency decisions.			
	Monitor the allocation over time of agency budget resources to the emergency response/management and disaster recovery capacity. Determine if such allocations are adequate to prepare your agency for dealing with major disruptions.			
	Publish an agency-wide COOP plan that identifies types of critical incidents or events, emergency activation criteria, and procedural guidelines to ensure safe internal and external operations.			
	Test the COOP plan on a periodic basis. Include in this test unexpected variations of likely hazards and threats (e.g., two major disruptions occurring at the same time).			
	If not already done, locate a COOP secondary site at a traffic management center (TMC), Fusion Center, or Statewide Emergency Management Operations Center			
	Establish a common set of cross-disciplinary criteria for prevention, preparedness, mitigation, disaster management, emergency management, environmental management, and business continuity of operations.			
	Publish a training calendar and schedule for emergency management introductory level training for all agency personnel.			
	Develop, update, and test physical and cybersecurity plans. The plans should be coordinated with the other agencies who have primary responsibility for the provision of security services.			
	Publish a training calendar and schedule for cybersecurity awareness for agency personnel and contractors.			
	Create and support opportunities for agency staff involved in emergency response/management, disaster recovery, and cybersecurity efforts to interact with peers in other agencies and in professional organizations' meetings.			



Possible steps for “Implement Early Wins”

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Chapter 12: Identify Enhancements to Operations and Maintenance Activities (Step 8B)

An agency's operations and maintenance units are often the ones first affected by system disruptions. This typically involves responding to maintain some level of traffic flow and cleaning up an incident site. It is the responsibility of the maintenance unit to replace many of the ancillary assets (e.g., traffic signs, signals, and guard rails) that have failed from the disruption and to remove debris that often accompanies extreme weather events. It is the responsibility of the operations unit to reroute traffic around blocked roads and manage evacuation routes in anticipation of or response to major disasters. As noted in an FHWA report,

Many TSMO [transportation systems management and operations] and maintenance adaptations will be the "low-hanging fruit" to prepare DOTs for extreme weather events, in contrast to necessary changes to infrastructure design. For example, many of the technology elements used to support safety, congestion mitigation, and traveler information objectives are already in place. To adapt to extreme weather events, agencies need to consider how these existing capabilities that already help to improve operations and reliability need to evolve to meet the new and emerging requirements of a changing climate.²²

In the same document, FHWA identified the following potential impacts to TSMO and maintenance programs from extreme weather events and longer-term climate change:

- Increased frequencies of extreme events require additional personnel to monitor, control, report, and respond to events.
- Changes in long-term climate trends may change seasonal work requirements (e.g., changes in winter weather seasons, construction timing, or landscaping timing) and additional or unique staff expertise to monitor and respond to new types of climate events.
- Increases in temperature can increase annual pavement maintenance costs, and changes in freeze/thaw cycles can increase potholes.
- Objectives and performance measures relating to emergency response or return to level of service may be affected by the frequency and severity of extreme events.
- Bridges with joints and moveable parts are more susceptible to damage due to their sensitivity to temperature and water infiltration. As a result, affected bridges may need to be closed and traffic may need to be re-routed.

In today's world where digital and electronic surveillance and command and control centers serve as the foundation of modern TSMO strategies, traffic operations also become a likely target for cyberattacks. As noted by Fok et al.:

²² Federal Highway Administration (FHWA). 2015. "Transportation System Resilience to Extreme Weather and Climate Change – Executives; Adaptation to Climate Change in Transportation Systems Management, Operations, and Maintenance" Report FHWA-HOP-15-024. Retrieved June 30, 2020 from <https://ops.fhwa.dot.gov/publications/fhwahop15026/index.htm>

“Transportation systems are not only becoming more connected, but also more dependent on communications and information technologies. These technological advances improve the efficiency and functionality of transportation systems, but they also increase potential vulnerabilities to transportation safety. In response, transportation agencies across the country are rising to the challenge to learn more about cybersecurity issues and develop and implement solid cybersecurity programs.²³

Indeed, all forms of digital and web-based operations data use are potential targets for cyberattacks

Capability Factors and Levels of Maturity

Factor 8B.1 Has your agency assessed current operations & maintenance (O&M) strategies based on the potential vulnerabilities identified in Step 7?

Step 7 identified the types of vulnerabilities facing your transportation system. This factor reflects the extent to which O&M actions are part of the strategies identified to reduce these vulnerabilities. The major distinctions among the three levels of maturity levels reflect the breadth of assessment of such O&M strategies and the degree to which the implementation of such strategies has been considered in the assessment.

- Level 1: We have identified O&M-related vulnerability areas. The assessment identified the likely costs of implementing O&M strategies and qualitatively analyzed likely impacts.
- Level 2: We have achieved a Level 1 maturity. In addition, the assessment has examined the potential impacts of different O&M options along with an assessment of implementation needs (e.g., staffing/training, equipment, and other budgetary requirements).
- Level 3: We have achieved a Level 2 maturity, plus the assessment included the use of benefit/cost analysis to determine the most appropriate O&M actions. Our agency has already implemented some of the O&M strategies identified in this assessment.

Factor 8B.2 Does your agency provide O&M staff opportunities to report resilience-oriented problems and potential corrective actions?

The front-line O&M staff are often the agency staff most familiar with the “on-the-ground” consequences of system disruptions, what it takes to recover in the short-term from such disruptions, and in understanding what might be needed in the longer term. This staff is also often responsible for the collection of data on system performance and asset condition. This factor focuses on the type of information collected by O&M staff as part of an agency’s data collection program, and the extent to which resilience-oriented problems are included in such efforts. The major distinctions among the three maturity levels relate to the degree of formality of including resilience-related data in O&M data collection and of how that data are used to identify O&M strategies to enhance system resilience.

²³ Fok, E., R. Murphy, E. Phomsavath, and J. Walker. 2015. “Taming Cyber Risks,” Public Roads. FHWA-HRT-15-006 Issue No: Vol. 79 No. 2, September/October. Retrieved July 1, 2020 from <https://www.fhwa.dot.gov/publications/publicroads/15sepoct/01.cfm>

- Level 1: We encourage O&M staff to provide information on resilience-related problems to their managers (e.g., noticeable erosion near culverts or retaining walls). There are no formal requirements for doing so.
- Level 2: We have a formal report template to report resilience-related problems to O&M managers. At their discretion, these managers can forward the information to other units in our agency for their use.
- Level 3: We have achieved Level 2 maturity. In addition, a formal reporting system is used to proactively request O&M staff to identify actions to enhance transportation system resilience. Our O&M staff provide after-event reports on the nature of disruptions, the type of response undertaken, and costs. Our maintenance-oriented asset inspection program includes information categories for potential system resilience problems at defined asset locations.

Factor 8B.3 Has your agency examined changes in vegetation control practices to keep pace with changes in climate (e.g., increased trimming frequency or planting more drought- or heat-tolerant species)?

This factor focuses on a very specific consequence of a changing climate---the needs and challenges to vegetation management and control strategies relating to changing climate conditions. For example, in some states where drought or prolonged higher temperatures are already occurring, some agencies are relying more on drought-resistant vegetation in rights-of-way. The major distinctions among the maturity levels for this factor is the depth of the assessment of changing climate conditions on vegetation management and the degree to which specific recommendations have been made in agency practices.

- Level 1: We have studied the major climate changes that have occurred in recent years (e.g., prolonged higher temperatures) that might affect our vegetation control practices). This has occurred only in selected geographic regions that have been affected the most and with little to no emphasis on future changes.
- Level 2: We have achieved a Level 1 maturity. However, the assessment was done statewide and for all types of potential climate change-related environmental stresses that occur in future years. The focus of recommendations has primarily been on the changes in vegetation types.
- Level 3: We have achieved a Level 2 maturity. In addition, changes in agency vegetation control strategies have been recommended for different timeframes (e.g., short-, medium-, and long-term time horizons). The assessment has also included specific recommendations on a range of changes in agency vegetation practices.

Factor 8B.4 Has your agency coordinated the collection of asset condition data as part of its asset management program with on-going maintenance activities in order to identify the total costs of recurring asset failure?

Lifecycle costing (for individual assets) and lifecycle planning (LCP) used in developing the Transportation Asset Management Plan (TAMP) are some of the mainstays in many transportation agencies of asset management and of other investment decision-making support. One of the requirements of such costing is that the costs of different asset conditions and repairs/replacements are known in sufficient detail to undertake a lifecycle cost analysis for individual assets, and for classes and sub-categories of

assets, which may face different hazards and risks over time. Maintenance staff often collect data on repairs and minor replacements, which could provide an important archival database on the potential costs associated with future asset failures. This information can also help inform future systems-level vulnerability analyses. This factor reflects the extent to which the maintenance and asset management programs in your agency have coordinated their cost data collection efforts to identify the total costs for recurring asset failure. The major distinction among the three maturity levels is the degree to which this coordination is formalized in your agency. (Note that a similar factor is part of Step 8D: *Integrate into Asset Management*.)

- Level 1: Our maintenance unit collects data on asset condition during its normal data collection activities. This information is primarily used at the district level and not related to asset management.
- Level 2: Our maintenance unit collects condition data on assets as part of its formal asset inspection process. If significant maintenance activities have occurred at a specific location, the maintenance requirements and costs in response are forwarded to the asset management program.
- Level 3: Our maintenance unit collects asset condition data as part of its asset inspection process and provides this data to the asset management program. Recurring failures at one location or of a particular asset (e.g., a culvert) are incorporated into the extent, type, and cost of investment that occurs at that location. Asset management systems or maintenance management systems (MMS) have been configured to issue alerts when vulnerable assets are due for maintenance, repair, or replacement.

Factor 8B.5 Does your agency have contingency plans in the event your traffic management centers are disrupted (e.g., alternative ways of providing traveler information when there is a disruption of the electrical grid)?

Many transportation agencies have developed traffic management centers (TMCs) that provide important system command and control capabilities to agency staff. These centers range in sophistication from simple monitoring of system conditions to real-time control of traffic control devices. Increasingly, these centers are becoming more dependent on internet capability as well as almost completely dependent on the electrical power grid. This factor reflects the extent to which your agency has developed contingency plans in the event a TMC is disrupted either by loss of power or by cyberattacks. The major distinctions among the maturity levels reflect the extent of disruption types that are part of the contingency plan and the degree to which the plan is periodically tested.

- Level 1: We have developed TMC contingency plans for one type of system disruption (e.g. power loss). We have not done a comprehensive examination of all types of management center failures to determine contingencies.
- Level 2: We have a contingency plan in place for all types of possible types of system disruptions. Traffic management center operators understand what needs to be done for each type of disruption.

- Level 3: We have achieved a Level 2 maturity. In addition, we field test the plans (conducting “what if” scenario analyses) with relevant partner agencies. Redundant systems or other means of conveying information are in place.

Factor 8B.6 Has your agency developed field exercises and training exercises for O&M staff on the roles they play in overall system resilience?

Staff training and professional development opportunities are an important part of an agency’s resilience strategy. This is especially the case for the O&M staff who have critical response and recovery responsibilities during and after system disruptions. As noted earlier, such staff also have important roles in data collection and in identifying potential resilience strategies to minimize the vulnerability of assets. One of the common approaches to training and professional development for O&M staff is to conduct field exercises or drills that simulate “real-world” situations, usually with a post-drill assessment of how the agency response can be improved. This factor examines the extent to which such field and training exercises occur in your agency. The major distinctions among the maturity levels reflect the breadth of resilience-related O&M training as well as the level to which partner agencies are part of the field exercises.

- Level 1: We include an overview of the system resilience role of operations and maintenance in training materials for the respective functional units. The responsibility for structuring this training is at the unit level.
- Level 2: We conduct periodic training for our O&M staff on how to better conduct their activities in achieving agency resilience goals. Part of this training includes a focus on system resilience and how the O&M staff can contribute to a more reliable and resilient transportation system. We conduct in-house field exercises that simulate the deployment of O&M resources in response to different types of incidents and disruptions.
- Level 3: We have achieved a Level 2 maturity. In addition, we participate in training and field exercises with partner agencies to test and assess our operational response to system disruptions.

Factor 8B.7 Has your agency implemented a cybersecurity protection plan for critical traffic management center and operations assets?

Cybersecurity has become increasingly important to today’s transportation agency. There have been many examples where transportation agencies or a jurisdiction (e.g., city or county) have been attacked by cyber hackers. Several agencies (e.g., Federal Emergency Management Agency (FEMA), Department of Homeland Security (DHS), and the National Institute of Standards and Technology NIST)) have developed guidelines for how agencies can protect themselves against such attacks. This factor emphasizes the degree to which your agency has developed a cybersecurity protection plan for critical traffic operations assets. The major distinction among the maturity levels reflects the degree to which a plan has been implemented in your agency. It is recognized that in some cases the responsibility for cybersecurity does not rest in the transportation agency. In such cases, this factor can be redefined to be more specific to the institutional circumstances of your agency.

- Level 1: We have identified command and control facilities and processes that are vulnerable to potential cyberattack but have not yet put in place protection measures.

- Level 2: We have identified the points of susceptibility of our critical command and control facilities and processes and have taken steps to protect them against a cyberattack.
- Level 3: We have a cybersecurity protection plan for all our critical command and control facilities and processes. System back-ups are in place if these facilities are compromised. The plan is updated every two years. We have also put in place redundant systems to make sure critical operations will continue after a cyberattack.

Factor 8B.8 Has a document describing your O&M-related resilience strategy been developed?

Formally documenting resilience strategies for all components of your agency's resilience efforts is considered an important action to not only inform your own staff of what the agency is doing, but also to provide information to other stakeholders on the agency's resilience strategy. Given that O&M staff are part of the first response to system disruptions, their performance will likely have an important influence on public perceptions of your agency's competence in system management. Thus, it is important that your agency describe the steps it is taking to make sure this response is timely and effective. This factor focuses on whether your agency has produced such materials. The distinctions among the three maturity levels reflects the degree to which such information is available, the breadth of coverage, and the frequency of updating this information.

- Level 1: We have Information on our O&M resiliency actions but it is scattered across multiple, internally-focused documents. This information is not regularly updated.
- Level 2: We have produced a single document that contains sections on each of our O&M resilience responsibilities and efforts. The document is not regularly updated.
- Level 3: We have a formal, publicly-available document that comprehensively describes all aspects of the O&M resilience strategy and efforts. Updates to the document are made on a regular basis.

Table 22 summarizes the factors that are included in the self-assessment tool for Step 8B. The maturity levels for each factor are presented in the descriptions of each factor. The total score for this step is found by summing the number of points given for each factor.

Table 22: Assessment Table for Step 8B: Identify Enhancements to Operations and Maintenance Activities

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3,points)
8B.1 Has your agency assessed current operations & maintenance (O&M) strategies based on potential vulnerabilities identified in Step 7?	We have identified O&M-related vulnerability areas. The assessment identified the likely costs of implementing O&M strategies and qualitatively analyzed likely impacts.	We have achieved a Level 1 maturity. In addition, the assessment has examined the potential impacts of different O&M options along with an assessment of implementation needs (e.g., staffing/training, equipment, and other budgetary requirements).	We have achieved a Level 2 maturity, plus the assessment included the use of benefit/cost analysis to determine the most appropriate O&M actions. Our agency has already implemented some of the O&M strategies identified in this assessment.
8B.2 Does your agency provide O&M staff opportunities to report resilience-oriented problems and potential corrective actions?	We encourage O&M staff to provide information on resilience-related problems to their managers (e.g., noticeable erosion near culverts or retaining walls). There are no formal requirements for doing so.	We have a formal report template to report resilience-related problems to O&M managers. At their discretion, these managers can forward the information to other units in our agency for their use.	We have achieved Level 2 maturity. In addition, a formal reporting system is used to proactively request O&M staff to identify actions to enhance transportation system resilience. Our O&M staff provide after-event reports on the nature of disruptions, the type of response undertaken, and costs. Our maintenance-oriented asset inspection program includes information categories for potential system resilience problems at defined asset locations.
8B.3 Has your agency examined changes vegetation control practices to keep pace with changes in climate (e.g., increase trimming frequency or planting more drought- or heat-tolerant species)?	We have studied the major climate changes that have occurred in recent years (e.g., prolonged higher temperatures) that might affect our vegetation control practices. This has occurred only in selected geographic regions that have been affected the most and with little to no emphasis on future changes.	We have achieved a Level 1 maturity. However, the assessment was done statewide and for all types of potential climate change-related environmental stresses that occur in future years. The focus of recommendations has primarily been on the changes in vegetation types.	We have achieved a Level 2 maturity. In addition, changes in agency vegetation control strategies have been recommended for different timeframes (e.g., short-, medium-, and long-term time horizons). The assessment has also included specific recommendations on a range of changes in agency vegetation practices.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3,points)
8B.4 Has your agency coordinated the collection of asset condition data as part of its asset management program with on-going maintenance activities in order to identify the total costs of recurring asset failure?	Our maintenance unit collects data on asset condition during its normal data collection activities. This information is primarily used at the district level and not related to asset management.	Our maintenance unit collects condition data on assets as part of its formal asset inspection process. If significant maintenance activities have occurred at a specific location, the maintenance requirements and costs in response are forwarded to the asset management program.	Our maintenance unit collects asset condition data as part of its asset inspection process and provides this data to the asset management program. Recurring failures at one location or of a particular asset (e.g., a culvert) are incorporated into the extent, type, and cost of investment that occurs at that location. Asset management systems or maintenance management systems (MMS) have been configured to issue alerts when vulnerable assets are due for maintenance, repair, or replacement.
8B.5 Does your agency have contingency plans in the event your traffic management centers are disrupted (e.g., alternative ways of providing traveler information when there is a disruption of the electrical grid)?	We have developed TMC contingency plans for one type of system disruption (e.g. power loss). We have not done a comprehensive examination of all types of management center failures to determine contingencies.	We have a contingency plan in place for all types of possible types of system disruptions. Traffic management center operators understand what needs to be done for each type of disruption.	We have achieved a Level 2 maturity. In addition, we field test the plans (conducting “what if” scenario analyses) with relevant partner agencies. Redundant systems or other means of conveying information are in place.
8B.6 Has your agency developed field exercises and training exercises for O&M staff on the roles they play in overall system resilience?	We include an overview of the system resilience role of operations and maintenance in training materials for the respective functional units. The responsibility for structuring this training is at the unit level.	We conduct periodic training for our O&M staff on how to better conduct their activities in achieving agency resilience goals. Part of this training includes a focus on system resilience and how the O&M staff can contribute to a more reliable and resilient transportation system. We conduct in-house field exercises that simulate the deployment of O&M resources in response to different types of incidents and disruptions.	We have achieved a Level 2 maturity. In addition, we participate in training and field exercises with partner agencies to test and assess our operational response to system disruptions.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3,points)
8B.7 Has your agency implemented a cybersecurity protection plan for critical traffic management center and operations assets?	We have identified command and control facilities and processes that are vulnerable to potential cyberattack but have not yet put in place protection measures.	We have identified the points of susceptibility of our critical command and control facilities and processes and have taken steps to protect them against a cyberattack.	We have a cybersecurity protection plan for all our critical command and control facilities and processes. System back-ups are in place if these facilities are compromised. The plan is updated every two years. We have also put in place redundant systems to make sure critical operations will continue after a cyberattack.
8B.8 Has a document describing your O&M-related resilience strategy been developed?	We have information on our O&M resiliency actions but it is scattered across multiple, internally-focused documents. This information is not regularly updated.	We have produced a single document that contains sections on each of our O&M resilience responsibilities and efforts. The document is not regularly updated.	We have a formal, publicly-available document that comprehensively describes all aspects of the O&M resilience strategy and efforts. Updates to the document are made on a regular basis.
Score Range	Description of Agency Maturity in Enhancing Operations and Maintenance Activities		
0 to 11	Your agency is emerging into this area and has taken initial steps to enhance operations and maintenance activities. However, much more can be done.		
12 to 20	Your agency has implemented several “enhanced operations and maintenance activities,” not so much as part of an agency-wide strategy but primarily at the unit level. There are still important actions that can be taken to reach the next level of maturity.		
21 to 24	Your agency has reached significant maturity in enhancing operations and maintenance activities. Major focus should be on maintaining and enhancing existing efforts when appropriate and take advantage of new opportunities as they become available.		

Recommended Actions to Maintain the Highest Level of Agency Resilience Capability

The highest level of capability for “Identify Enhancements to Operations and Maintenance Activities” focuses on continual improvement in agency capability and actions leading to a more resilient transportation system. If your agency has reached Level 3 maturity, the steps that can be taken to maintain this level include:

- Continue to monitor the resilience of the transportation system and consider changes in system performance and asset condition when making changes in the agency’s operations and maintenance capabilities.
- Periodically reassess TSMO or maintenance program goals and operations objectives to reflect the latest experience with system disruptions.
- Continue to review (and archive) traffic incident reports, maintenance records, after- action reports, emergency reimbursement forms, and other sources to determine how system disruptions have affected performance and agency costs over time.
- Continue to examine your agency response to system disruptions from the perspective of internal actions and procedures. For example, does your agency need to revamp work order codes for system disruptions or use other methods to improve tracking of labor, equipment, and materials costs over time.
- Update staff professional development and training opportunities to include the latest thinking and concepts in system resilience as it relates to operations and maintenance. This includes cross-training of agency staff (including across operations, maintenance, and emergency management).
- Periodically reassess stand-by support contracts for system disruptions to make sure such contracts are providing the needed capability and resources for the types of disruptions being faced.
- Establish transition plans for retiring staff to maintain institutional knowledge as it relates to operations and maintenance resilience-related actions.
- Maintain situational awareness of rapidly changing cyber and physical security exposures that impact agency resilience and capabilities. This includes monitoring developments in technology risks and cyberattacks as they related to your agency’s IT-related functions.

If you did not score a “24” in the assessment (a perfect score for Level 3 efforts), identify those factors that were rated lower and identify a strategy or actions to improve these particular components of Step 8B.

Recommended Actions to Achieve Higher Levels of Agency Capability

If you scored at Level 1 or 2, you can take steps to continue your evolution toward a more resilience-oriented agency as it relates to enhancements to operations and maintenance activities. In such cases, agency managers should identify which of the factors in Table 22 were most deficient and determine priorities for improving your agency’s organizational resilience capabilities in operations and maintenance activities.

Table 23 is offered as a template to determine which steps your agency can take to improve your agency’s resilience capabilities in operations and maintenance, who should be responsible, the timeframe for implementation, and expected outcomes.

Table 23: Actions to Achieve Higher Maturity for Step 8B: Identify Enhancements to Operations and Maintenance Activities

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Assess your agency's O&M strategies with respect to the vulnerabilities identified in Step 7. Emphasize the implementation requirements for additional actions that are deemed necessary.			
	Examine how O&M data collection efforts can be modified to collect resilience-related data that can be used for systems-level vulnerability analyses and asset management, in addition to O&M planning.			
	Examine how O&M data can be used to inform lifecycle costing analyses in the asset management program or in other investment evaluation efforts in your agency.			
	Investigate the extent to which your agency's vegetation management and control program reflects the likely changes in climate that your jurisdiction will face over time.			
	Update your agency's continuity of operations plan as it reflects system operations management and control to reflect the types of vulnerabilities and risks that resulted from Step 7.			
	Re-examine (or develop) contingency plans for traffic management centers or other critical assets relating to transportation system management and operations. The contingency plans should reflect the types of disruptions that could occur and the key functions of the centers that might be lost.			
	Reassess (or develop) multi-agency training and field exercises that reflect the likely circumstances that will be faced in a serious disruption event.			
	Examine your agency's (or jurisdiction's) cybersecurity plan from the perspective of vulnerabilities to O&M functions. Investigate the extent to which redundant systems are in place and protected against an initial attack.			
	Examine (or develop) a strategy for backing up critical operations data relating to the functions of traffic management centers. To what extent are these backup capabilities tested to assure uninterrupted traffic operations command and control actions during and following a disruption.			
	Document the O&M resilience efforts of your agency.			



Possible steps for “Implement Early Wins”

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Chapter 13: Undertake Detailed Assessments of Exposed Assets and New Projects (Step 8C)

Step 7 identified and prioritized existing assets that are potentially vulnerable to hazards and threats. Step 8C involves more detailed assessments of these assets, one-by-one (or collectively if several vulnerable assets are clustered together such that it might make sense to look for more holistic solutions). The order these detailed assessments get done in should be based on their vulnerability as reflected in their Step 7 prioritization. Step 8C also involves detailed assessments for all new facilities in the asset management and capital improvements program.

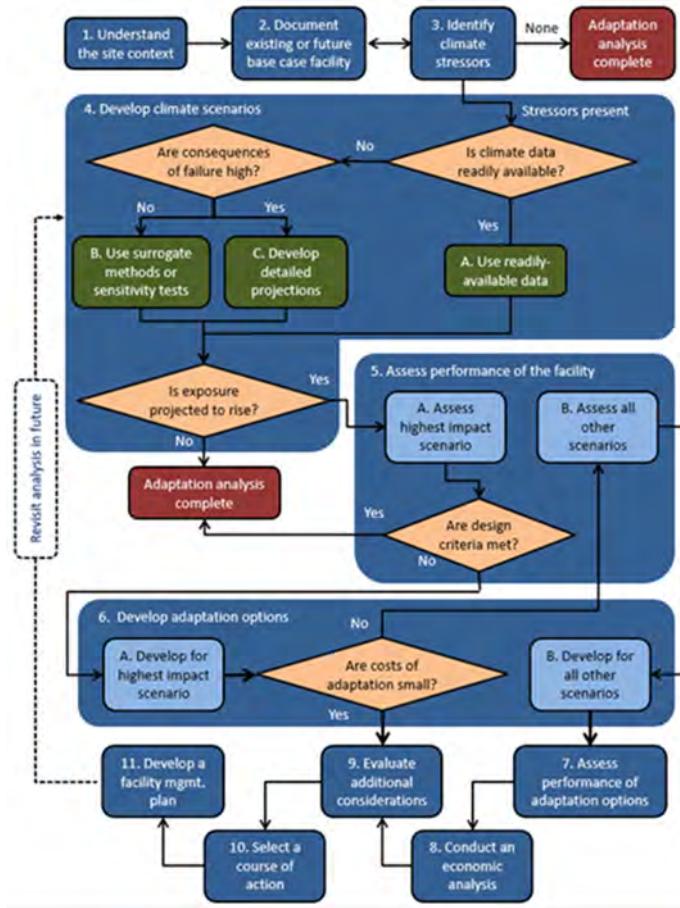
The self-assessment factors for Step 8C reflect a technical approach for conducting detailed assessments that leads to cost effective means of reducing damage and/or minimizing outage caused by hazards and/or threats. This technical approach was developed by FHWA for facility level pilot studies they conducted and is called the Adaptation Decision-making Assessment Process (ADAP). An overview of ADAP can be found in the text box along with references to a more detailed description of it. ADAP helps you consider whether your agency would benefit by integrating adaptation/mitigation measures now or later on during the lifecycle of the asset (in effect, examining the investment tradeoffs of reducing damage and consequences given the uncertainties of future disruptions actually occurring). It also helps determine what the most cost-effective adaptation/mitigation measure might be across the range of possible future scenarios.

The following section describes the capability factors and levels of maturity for this step. Note that the detailed assessments are discussed in terms of being part of the project development process, regardless of whether the detailed assessment is for a new asset or an existing asset. This language is used even for existing assets because the detailed assessments of the exposed assets are very likely to lead to new capital projects that can be programmed into the capital improvement program in Step 9.

Capability Factors and Levels of Maturity

Factor 8C.1 When projects are being developed, does your agency require the consideration of resilience concerns?

Ideally, an assessment of natural hazards and human threats will occur for each project and adaptation/mitigation measures will be undertaken where necessary. This assessment should consider the assets entire lifecycle and the hazards/threats it may experience over this time. Because of the long design-lives of many transportation assets, the need to take climate changes into account is important. Even for assets with a relatively short design life like pavement, the pavement composition chosen for today's conditions may underperform over the next 30+years of pavement's life if prolonged extreme heat events increase in frequency, magnitude, and duration due to climate change. The chances of adverse change are greater for longer-lived assets like bridges. By assessing the potential risks posed to an asset or project associated with future hazards, the analysis can identify alternatives that are more cost-effective over the lifecycle of the project. The consideration of hazards and threats over the lifecycle of an asset should also include an examination of any physical security, crime prevention, personal safety, and fire and life safety concerns, where appropriate.



Federal Highway Administration's (FHWA) Adaptation Decision-making Assessment Process (ADAP)

ADAP was developed to assess climate change-related risks and response options for transportation assets (see Figure 4). This process was borne from the FHWA Gulf Coast 2 project and refined through the Transportation Engineering Approaches to Climate Resiliency (TEACR) study that evaluated, with a series of case studies, how climate change impacts can be integrated into the design of transportation projects. The framework can be adapted to assess other forms of physical risk to an asset, not just climate change impacts. For a more detailed description of ADAP see https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm. Many of the factors described in Step 8C are also detailed in ADAP.

The major distinctions in different maturity levels for this factor are related to the level to which more detailed assessments include a range of hazards and threats and the extent to which different subject matter experts are included in the analysis process. An agency at a Level 3 maturity will include a long-term, risk-based perspective in detailed project-level analyses.

- Level 1: We consider natural hazards and climate change on an ad hoc basis. The extent of consideration of physical security, crime prevention, and personal safety is dependent on the type of project. Major projects usually include a review by security personnel and projects are developed in accordance with fire and life safety codes. Major projects usually include a review by emergency management personnel.
- Level 2: We require the consideration of natural hazards and climate change in all our project analyses. With respect to human-caused threats, crime prevention through environmental design (CPTED) principles are considered during the project development process. Emergency management aspects of projects are also considered.
- Level 3: We have achieved a Level 2 maturity. In addition, we have adopted a process scenarios-based risk assessment process like ADAP (see box) for our project development process. Where appropriate, all projects are examined for security concerns in the context of resilient and continuous operations, future growth, and potential countermeasures. Agency projects are built with emergency management's fire and life safety concerns as critical core components. Project sign-offs are required for security and emergency management compliance.

Factor 8C.2 When projects are being developed, do you utilize projected data on the future frequency, magnitude, and scope of natural hazards?

Traditionally, assets have been designed based on statistical analyses of observed natural hazard data. For example, a culvert designer might use NOAA Atlas 14 precipitation depths, based on statistical analyses of observed rainfall data, to size his/her culvert. However, the growing understanding of climate change is upending the basic assumption that the future will be like the past. This is leading many to question the practice of using statistical analyses of past conditions as good indicators of the conditions that assets will be subject to in the future. Moving forward, projections of future conditions will need to be used to supplement and, in some cases, replace historically-focused design inputs. For many natural hazards, models and tools are now available to help you project future conditions given the expected changes in underlying causal factors (e.g., climate change). These models and tools should be used to project potential impacts to assets over their lifetime as part of the standard practice when developing projects. The major distinction among the different maturity levels in this factor reflect the degree to which future-oriented projected data on the frequency, magnitude, and scope of hazards and threats are used as input into project analyses.

- Level 1: We consider only historical data on natural hazards in the design process. This includes special consideration of DOT records on past extreme weather events impacts in the vicinity of the asset. Such data have been tabulated and summarized so that designers have available information at their fingertips to supplement the standard sources of climate data.
- Level 2: We consider both historical and projected data of natural hazards (including climate change projections) when developing all projects.
- Level 3: We have achieved a Level 2 maturity. In addition, we consider the interactions amongst hazards and how such interactions could affect our assets. This consideration also includes the amplifying or dampening effects of other environmental factors (e.g., land use change in a drainage area). We have codified this data and information into our standard environmental and design practices.

Factor 8C.3 When you develop projects, does your agency formally account for the uncertainty in natural hazard likelihood?

This factor considers the degree to which your agency incorporates uncertainty into project analyses. Uncertainty exists for estimating the likelihood of recurrence of events today using historical data and becomes even greater when considering future climate changes. Uncertainty associated with such events occurring could have a strong influence on whether decision-makers would be willing to invest in recommended resilience strategies.

Ideally, the likelihood of an event occurring can be represented by probabilities, which can then be used to determine the level of risk associated with potential disruptions. However, coming up with such probabilities can be challenging.

One approach recommended by several federal agencies is to use hazard and threat scenarios in the analysis. A scenario simulates one or more possible conditions to which the asset might be exposed. It is preferable to consider a range of plausible scenarios when evaluating the future performance of an asset rather than relying on just a single scenario. Many sources of historical data on natural hazards quantify uncertainty in a way that could be used for a scenarios-based analysis. For example, NOAA Atlas 14 rainfall projections provide a confidence interval around their central projection: the outer bounds of these confidence limits along with the central projection can be used in a scenarios framework like ADAP to perform a sensitivity test on the proposed design and determine if enhanced design measures are cost-effective. For future oriented projections, the RCPs discussed in relation to Step 5 represent scenarios used to capture the plausible range of future greenhouse gas emissions. Climate metrics pertinent to the design task at hand can be calculated under each of the RCPs and used to define a range of plausible scenarios on future conditions that the asset may be exposed to.

The major distinction for the different maturity levels on this factor relate to the extent to which your agency's project analyses incorporate some accounting for the uncertainty of the likelihood and magnitude of natural hazard impacts.

- Level 1: We consider only historical data on natural hazards when developing projects. We routinely do scenarios-based sensitivity tests of our designs using the published uncertainty ranges of the input data.
- Level 2: We use future climate projections for natural hazards when developing projects. However, we do not use scenarios to perform sensitivity testing of the design to understand uncertainty. Instead we use a pre-determined climate scenario (RCP or SLR amount) for our work.
- Level 3: As standard practice for project design, we utilize a scenarios-based approach such as ADAP to better understand the range of uncertainty in the natural hazards that might affect our projects (and its implications). At least two future-oriented climate scenarios are evaluated in each case.

Factor 8C.4 When you develop projects, how are adaptation options determined?

For situations where the detailed assessment has confirmed that either the existing asset or (for new assets) the standard design option (a traditional design based on historical data on natural hazards) is

exposed to current/future natural hazards, adaptation options need to be developed. This factor considers how your agency develops adaptation options for its projects. On most projects, several different adaptation strategies are possible. In general, the more alternatives explored and tested the better, as this increases the chance that the best solution will be chosen. Typically, adaptation options are tied to the various natural hazard scenarios discussed in prior factors with each option offering protection under that scenario. An exception is a novel approach to adaptation that is meant to address the uncertainties in future climate changes; adaptive (or flexible) design. An adaptive design approach allows for integrating adaptation project characteristics over time as the likelihood of impacts becomes more certain (i.e., uncertainty over the future decreases). The distinction amongst the maturity levels in this factor reflect the level of effort expended in developing different adaptive design options for evaluation.

- Level 1: As standard practice, we develop one adaptation option for each natural hazard/climate scenario evaluated. Each adaptation option is designed to meet design standards under its corresponding scenario.
- Level 2: As standard practice, we develop more than one adaptation option for each natural hazard/climate scenario evaluated. Each adaptation option for a given scenario represents a different strategy for meeting design standards under that scenario.
- Level 3: We have achieved a Level 2 maturity. In addition, as a matter of practice we always consider an adaptive management approach in our development of adaptation options. Our design guides/manuals have been modified to allow this approach as part of standard design practice.

Factor 8C.5 When you develop projects, do you use resiliency-driven economic analysis to determine the most cost effective project design?

Given that most decision-makers want to know what system or other benefits are going to accrue for the dollars being expended, some form of economic analysis is often used to show the relative monetary value of choosing one option over another. For evaluating adaptation measures, this takes the form of a benefit-cost analysis (BCA). BCA is used to quantify and compare societal benefits and costs associated with a project (where such benefits and costs can be monetized). The primary purpose of a BCA is to identify the benefits that will accrue with project investment as compared to the costs incurred, in some sense this can be considered a return on investment analysis. With respect to BCAs for detailed facility-level assessment, benefits are defined as the costs avoided from natural hazard impacts (relative to leaving the existing asset in place as-is or, for new assets, a standard design based on historical climate data) whereas costs are the incremental costs to construct and maintain the adaptation option. BCA helps you consider the relationships between costs and benefits for different adaptation options.

Many BCAs only include the agency costs avoided (e.g., from reducing damage to an asset) when determining the benefit of an adaptation. However, there are additional consequences and user costs when an asset or facility is out of service that can also be included as avoided costs (benefits). For example, if a highway segment is damaged and closed for repairs, the resulting congestion and/or detour routing may lead to lost time for drivers and passengers (these are called user-costs). Costs to the broader society (beyond just the direct costs to systems users) can also be included (e.g., the costs

to business if an asset providing access to them is taken out of service). All the costs can be calculated for the base case and each alternative and then integrated into lifecycle costs by natural hazard scenario. The distinction among the different levels of maturity for this factor reflect the degree to which project-level economic analysis methods are used to determine which adaptation options or strategies are most cost effective:

- Level 1: We conduct a resiliency-driven BCA that considers just lifecycle agency costs due to natural hazards on all projects.
- Level 2: We conduct a resiliency-driven BCA that considers lifecycle agency and user costs due to natural hazards on all projects.
- Level 3: We conduct a resiliency-driven BCA that considers lifecycle agency, user, and (whenever appropriate) broader societal costs due to natural hazards on all projects.

Factor 8C.6 Does your value engineering process consider resilience measures as a valid cost?

Agencies will generally have a value engineering assessment process that reviews project designs to determine where cost reductions could occur while still meeting the functional goals of the project. Experience from some transportation agencies suggests that the value engineering assessment often results in the removal of adaptation/mitigation measures because they are considered “extra” costs. Recommending a least-cost alternative during the value engineering process typically only involves consideration of up-front costs, not lifecycle costs. This may lead to a final design with resilience-specific fatal flaws, increasing the possibility of significant damage to the asset and/or lead to significant consequences to the agency, transportation users, and surrounding communities. In other words, the costs incurred over the long run may very well outweigh any up-front cost savings identified through value engineering. This factor focuses on how your agency’s value engineering process considers resilience-related project characteristics. The major distinction among the different levels of maturity for this factor reflects the extent to which resilience characteristics are considered as part of your value engineering process.

- Level 1: We consider additional expenditures for resilience enhancements on a case-by-case basis. The justification for such a consideration is based on the engineering judgment of the designers included on the project. There is no guidance as to how such costs should be considered in the value engineering assessment. This has resulted in some resilience enhancements being removed during the value engineering process.
- Level 2: We consider additional expenditures for resilience enhancements as valid expenditures for all projects subject to value engineering. The justification for such a consideration is based on the economic analysis results conducted during the detailed assessment process. This has resulted in most resilience enhancements being included post-value engineering.
- Level 3: We have achieved a Level 2 maturity. In addition, we have developed a resilience “test” that is applied to ensure cost saving recommendations do not have broader implications for facility and societal risk. The consideration of resilience concerns in value engineering has been codified in value engineering guidance.

Factor 8C.7 Do you consider resilience in facility management plans?

A facility management plan strategically outlines how an asset will be used and managed over its lifetime. The term “facility management” includes both transportation facilities as well as buildings and other structures that are part of an agency providing its services. A facility management plan provides the means to continue monitoring asset performance to ensure it meets expectations. Further, the plan may lay out adaptive management processes for integrating resilience strategies over time. The distinction among the different levels of maturity for this factor reflects the degree to which resilience concerns are included in your facility management plans.

- Level 1: We incorporate resilience concerns into the facility management plans for only a small number of the most important assets of the transportation system and for other facilities considered essential to managing the system.
- Level 2: We incorporate resilience concerns into the facility management plans for all assets of the transportation system for which facility management plans are developed and for other facilities considered essential to managing the system.
- Level 3: We have achieved a Level 2 maturity. In addition, our facility management plans are monitored and periodically revisited to address changing conditions. The results of this reassessment are incorporated into our agency’s project development process to inform future adaptive management designs.

Factor 8C.8 Do you document how resilience concerns were addressed for each project?

This factor focuses on documenting the tools, resources, data, decisions, and institutional knowledge applied in this step for each project undertaken. The process and justifications for recommended actions should also be documented. Documentation on the methods and approaches also provides a benchmark for future reference in a rapidly evolving field such as resilience. The distinction amongst the different levels of maturity for this factor reflect the level to which you document the resilience considerations and results for each project coming out of project development.

- Level 1: We document the process followed and the justification for recommended actions, but only for the most important projects. We do not have a formal process for consistent documentation.
- Level 2: We document the process followed and the justification for recommended actions for all projects. We do not have a formal process for consistent documentation; the document reflects the factors the designers considered as part of the design process.
- Level 3: We document the process followed and the justification for recommended actions for all projects. We have a formal process for consistent documentation (using the ADAP steps or something similar as an outline) that has been included in the standard operating procedures of my agency.

Table 24 summarizes the factors that are included in the self-assessment tool for Step 8C. The maturity levels for each factor are presented in the descriptions of each factor. The total score for this step is found by summing the number of points given for each factor.

Table 24: Assessment Table for Step 8C: Undertake Detailed Assessments of Exposed Assets and New Projects

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
8C.1 When projects are being developed, does your agency require the consideration of resilience concerns?	We consider natural hazards and climate change on an ad hoc basis. The extent of consideration of physical security, crime prevention, and personal safety is dependent on the type of project. Major projects usually include a review by security personnel and projects are developed in accordance with fire and life safety codes. Major projects usually include a review by emergency management personnel.	We require the consideration of natural hazards and climate change in all our project analyses. With respect to human-caused threats, crime prevention through environmental design (CPTED) principles are considered during the project development process. Emergency management aspects of projects are also considered.	We have achieved a Level 2 maturity. In addition, we have adopted a process scenarios-based risk assessment process like ADAP (see box) for our project development process. Where appropriate, all projects are examined for security concerns in the context of resilient and continuous operations, future growth, and potential countermeasures. Agency projects are built with emergency management's fire and life safety concerns as critical core components. Project sign-offs are required for security and emergency management compliance.
8C.2 When projects are being developed, do you utilize projected data on the future frequency, magnitude, and scope of natural hazards?	We consider only historical data on natural hazards in the design process. This includes special consideration of DOT records on past extreme weather events impacts in the vicinity of the asset. Such data have been tabulated and summarized so that designers have available information at their fingertips to supplement the standard sources of climate data.	We consider both historical and projected data of natural hazards (including climate change projections) when developing all projects.	We have achieved a Level 2 maturity. In addition, we consider the interactions amongst hazards and how such interactions could affect our assets. This consideration also includes the amplifying or dampening effects of other environmental factors (e.g., land use change in a drainage area). We have codified this data and information into our standard environmental and design practices.
8C.3 When you develop projects, does your agency formally account for the uncertainty in natural hazard likelihood?	We consider only historical data on natural hazards when developing projects. We routinely do scenarios-based sensitivity tests of our designs using the published uncertainty ranges of the input data.	We use future climate projections for natural hazards when developing projects. However, we do not use scenarios to perform sensitivity testing of the design to understand uncertainty. Instead we use a pre-determined climate scenario (RCP or SLR amount) for our work.	As standard practice for project design, we utilize a scenarios-based approach such as ADAP to better understand the range of uncertainty in the natural hazards that might affect our projects (and its implications). At least two future-oriented climate scenarios are evaluated in each case.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
8C.4 When you develop projects, how are adaptation options determined?	As standard practice, we develop one adaptation option for each natural hazard/climate scenario evaluated. Each adaptation option is designed to meet design standards under its corresponding scenario.	As standard practice, we develop more than one adaptation option for each natural hazard/climate scenario evaluated. Each adaptation option for a given scenario represents a different strategy for meeting design standards under that scenario.	We have achieved a Level 2 maturity. In addition, as a matter of practice we always consider an adaptive management approach in our development of adaptation options. Our design guides/manuals have been modified to allow this approach as part of standard design practice.
8C.5 When you develop projects, do you use resiliency-driven economic analysis to determine the most cost-effective project design?	We conduct a resiliency-driven BCA that considers lifecycle agency costs due to natural hazards on all projects.	We conduct a resiliency-driven BCA that considers lifecycle agency and user costs due to natural hazards on all projects.	We conduct a resiliency-driven BCA that considers lifecycle agency, user, and (whenever appropriate) broader societal costs due to natural hazards on all projects.
8C.6 Does your value engineering process consider resilience measures as a valid cost?	We consider additional expenditures for resilience enhancements on a case-by-case basis. The justification for such a consideration is based on the engineering judgment of the designers included on the project. There is no guidance as to how such costs should be considered in the value engineering assessment. This has resulted in some resilience enhancements being removed during the value engineering process.	We consider additional expenditures for resilience enhancements as valid expenditures for all projects subject to value engineering. The justification for such a consideration is based on the economic analysis results conducted during the detailed assessment. This has resulted in most resilience enhancements being included post-value engineering.	We have achieved a Level 2 maturity. In addition, we have developed a resilience “test” that is applied to ensure cost saving recommendations do not have broader implications for facility and societal risk. The consideration of resilience concerns in value engineering has been codified in value engineering guidance.
8C.7 Do you consider resilience in facility management plans?	We incorporate resilience concerns into the facility management plans for only a small number of the most important assets of the transportation system and for other facilities considered essential to managing the system.	We incorporate resilience concerns into the facility management plans for all assets of the transportation system for which facility management plans are developed and for other facilities considered essential to managing the system.	We have achieved a Level 2 maturity. In addition, our facility management plans are monitored and periodically revisited to address changing conditions. The results of this reassessment are incorporated into our agency’s project development process to inform future adaptive management designs.

Maturity Factor	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
8C.8 Do you document how resilience concerns were addressed for each project?	We document the process followed and the justification for recommended actions, but only for the most important projects. We do not have a formal process for consistent documentation.	We document the process followed and the justification for recommended actions for all projects. We do not have a formal process for consistent documentation; the document reflects the factors the designers considered as part of the design process.	We document the process followed and the justification for recommended actions for all projects. We have a formal process for consistent documentation (using the ADAP steps or something similar as an outline) that has been included in the standard operating procedures of my agency.
Score Range	Description of Agency Maturity in Enhancing Operations and Maintenance Activities		
0 to 11	Your agency is emerging into this area and has taken initial steps to begin to undertake detailed assessment of exposed assets and new projects.		
12 to 20	Your agency has conducted assessments that provide an indication of resilience options and measures that are cost-effective and provide the least consequences for individual hazards and threats.		
21 to 24	Your agency has reached significant maturity in undertaking detailed assessment of exposed assets and new projects. Major focus should be on maintaining and enhancing existing efforts when appropriate, and take advantage of enhancing and validating current practices and findings whenever possible.		

Recommended Actions to Maintain the Highest Level of Agency Resilience Capability

The highest level of capability for "Undertaking detailed assessments of exposed assets and new projects" focuses on continual improvement in agency capability and actions leading to a more resilient transportation system. If your agency has reached a Level 3 maturity, the steps that can be taken to maintain this level include:

- Periodically reassessing the project analysis process to assure it is considering all of the possible hazards and threats facing your transportation agency. Update your process where necessary.
- Continue to monitor asset performance. Collect data on asset failures to understand what went wrong and how this can be rectified in the future. This could be done in-house or by bringing in a third-party evaluator to conduct the evaluation.
- Keep abreast of the latest science and best practice for projecting future climate stressors and on approaches for considering and reporting on levels of uncertainty in future projections. Consider ways to expand and/or revise the existing analyses to stay up-to-date.
- Monitor and conduct assessments on the effectiveness of adaptation/mitigation strategies and/or enhanced operational measures in the face of different hazards and threats. Feed the results of these assessments back into your agency's design guidance.
- In concert with the above actions, examine the original economic analysis tools used and the results to verify that the assumptions used and the results were close to actual outcomes.
- Monitor your value engineering outcomes to ensure resilience actions continue to be considered accepted costs in the project design.
- Periodically hold meetings with project development staff to identify any suggestions for improving how resilience concerns are considered in project development.
- Update your agency's documentation on its resilience program to highlight successful application of resilience strategies and actions.
- Provide training and professional development opportunities to your agency's staff to learn about the latest approaches to adaptive design approaches.
- Where necessary, work closely with key leaders in the legislative and executive branch of your governmental system to codify changes in procedures, institutional relationships, and other actions necessary to enable the steps necessary to mainstream adaptive design into your agency's standard operating procedures.

If you did not score a 24 in the self-assessment (a perfect score in Level 3 efforts), identify those factors that were rated lower and identify a strategy or actions to improve the particular components of Step 8C.

Recommended Actions to Achieve Higher Levels of Resilience Capability

If you scored at maturity level 1 or 2, you are still evolving toward a more resilience-oriented agency. In such a case, the top managers of your agency should identify which of the factors in Table 24 were most lacking and determine priorities for undertaking detailed assessments of exposed assets and new

projects. Table 25 is offered as a template to determine which actions your agency can take to improve your agency's resilience capabilities, who should be responsible, the timeframe for implementation, and expected outcomes.

Table 25: Actions to Achieve a Higher Maturity for Step 8C: Undertaking Detailed Assessments of Exposed Assets and New Projects

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Examine your current project development process from the perspective of where and how resilience concerns are incorporated into the process. To what extent would standard operating procedures have to be changed to provide a more flexible approach?			
	Monitor and record stressor/hazard/threat impacts on assets and related costs as they occur. Feed this information back into the project development process so that agency staff have the most up-to-date information on the likely benefits of adaptive designs.			
	Identify staff who are capable and interested in integrating resilience into asset-specific analyses. If necessary, provide additional training to these staff members.			
	Where appropriate, conduct pilot studies of the application of an adaptive design process to illustrate key steps and what a resilience-sensitive project will look like.			
	Develop a menu of general adaptation and mitigation options and crosswalk these against hazards/threats and asset types to streamline choices.			
	Work with partner agencies (e.g., resource agencies) to explain the approach your agency is taking toward adaptive design and identify any changes to existing agreements and interactions that might be necessary to implement desired changes.			
	Monitor any activities or strategies already being implemented that may serve as future adaptation options/measures.			
	Develop an internal communications strategy to convey to agency staff what is occurring with respect to resilience-oriented project development and how they can contribute.			
	Internally discuss and identify a funding stream to support detailed assessments that result in more resilience-oriented project development.			
	Incorporate your resilience-oriented project development approach into your agency's external communications strategy and plan. Meet with external partners (e.g., regional agencies, cities, and towns) to explain the approach.			



Possible steps for “Implement Early Wins”

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Chapter 14: Integrate into Asset Management (Step 8D)

AASHTO defines Transportation Asset Management (TAM) as a, “strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their life cycle.”²⁴ In response to federal legislation that emphasized performance-based program management, the FHWA further defined a risk-based asset management process as an application of performance management principles with a long-term focus to manage the performance of infrastructure assets, the resources allocated to operate a transportation system, and the investments made to achieve the agency’s long-term goals and objectives.

Importantly, TAM principles, data, and tools are to link to agency decisions and resource allocation in the following ways:

- Inform agency resource allocation with respect to the degree to which policy objectives might be achieved.
- Identify asset and system performance and condition targets.
- Assess and evaluate tradeoffs among the targets at the appropriate stages of decision making.
- Promote the feedback information loop such that the impacts of resource allocation over time quantifies the level of target achievement.

The Transportation Asset Management Plan (TAMP), TAM process, and asset management processes are important elements of an agency’s resilience program. In the context of this guide, Step 8D has many potential roles. First, given the federally-required risk orientation of the TAM process, the results of the vulnerability assessment (Steps 5 to 7), specifically the final vulnerability scores for each asset, can feed directly into the updates of the TAMP. There needs to be a strong linkage between these steps and Step 8D.

Second, a TAM system, such as a pavement management system or bridge management system, can be used during and after an incident/event to inform post incident inspections of those assets that might be potentially damaged because of previously noted poor asset condition. Such assets could include not only those directly affected by an incident or event, but also nearby assets that could also be affected. For example, the collapse of a culvert could cause additional damage as water flow now bypasses the culvert to arrive with potentially greater flow and force downstream. Similarly, the results of the inspections of damaged assets should be included in the agency’s asset management system so that appropriate longer-term action can be taken.

²⁴ AASHTO. 2013. Transportation Asset Management Guide. Washington DC. Retrieved July 1, 2020 from <https://www.fhwa.dot.gov/asset/pubs/hif13047.pdf>

Capability Factors and Levels of Maturity

Factor 8D.1 What assets and asset attributes are included in your asset management process that relate to system resilience?

The TAM process and database should include those assets and asset attributes required by federal law (e.g., bridge and pavements) and others desired by your agency (e.g., culverts and highway appurtenances). Performance and condition metrics and targets are included in the TAMP relating to the primary policy goals of your agency. This factor focuses on the level of attention your agency has given to identifying and implementing asset management actions to improve the agency's capabilities in mainstreaming transportation system resilience into agency decision-making.

- Level 1: In addition to the federally-required TAMP data on bridges and pavements, we have added locational and condition data for other asset types such as culverts and other drainage treatments on a subset of the highway network considered to be most critical. In addition, we have added facility attribute data (e.g., first floor elevations and location of HVAC equipment) for our most critical buildings.
- Level 2: We have achieved Level 1 maturity. In addition, we have added other asset types (e.g., geotechnical assets such as retaining walls) to the database along with attribute information that characterizes location and condition. For bridge data we have added attribute data on bridge low chord elevation and deck thickness. Bridge, road, and culvert attribute data reflecting system disruption characteristics are available on all of our assets and facilities. Unit cost estimates based on historical data are available that will assist with estimating replacement costs.
- Level 3: We have achieved Level 2 maturity. In addition to the assets in the Level 2 database, we have complete inventories of traffic control devices, signs, and guardrails that allow for faster replacement immediately after a major disruption. Good unit-cost data are available that will assist with estimating replacement costs. This cost data is updated at least every two years. In addition, the collection and updates of these attributes to these asset classes occur routinely and is used as part of a programmatic acceptance of data use.

Factor 8D.2 Have you integrated vulnerability scores from Step 7 into your asset management plan (TAMP) and TAM process?

This factor focuses on the interrelationship between the systems-level vulnerability analysis and the TAMP and TAM process. As noted earlier, federal law and guidelines require transportation agencies to integrate risk management into their asset management plans relating to the National Highway System. A risk-based TAMP was to contain, (1) a summary listing of the pavement and bridge assets on the NHS including a description of the condition of those assets; (2) asset management objectives and measures; (3) performance gap identification; (3) lifecycle cost and risk management analysis; (5) a financial plan; and (6) investment strategies. With respect to the risk management analysis, the TAMP is intended to set the context for risk management, define key programmatic risks associated with the implementation of the TAMP (e.g., cost escalations, budget cuts and environmental delays), define system risks that could adversely affect the NHS (e.g., asset failure and external events such as floods, earthquakes, and hurricanes), provide a map showing the NHS assets most at risk, and (4) include a risk register that

provides the following for each programmatic risk – likelihood of occurrence, consequences of occurrence, and mitigation activities.²⁵

A systems-level vulnerability analysis could provide important input into the risk assessment component of the TAMP. The distinctions among the different levels of maturity reflect the degree to which this relationship exists and the types of information provided as part of Step 7.

- Level 1: We have not used the results from our vulnerability assessment in our asset management process. Our TAMP presents the most important types of hazards and threats that have occurred in the past.
- Level 2: We have used the results from our vulnerability assessment in our asset management process. Our TAMP summarizes all the types of natural disruptions that have occurred in the past on our transportation system. It also summarizes likely future causes of disruptions. Estimated costs to our agency of such disruptions are also reported.
- Level 3: We have used the results from our vulnerability assessment in our asset management process. Our TAMP summarizes all the types of human-caused and natural disruptions that have occurred in the past on our transportation system. It also summarizes likely future causes of disruptions. Estimated costs to our agency, system users, and societal costs are also reported.

Factor 8D.3 Does your TAMP use asset condition and performance measures/targets relating to natural and human-caused disruptions?

TAM systems are to be based on performance and condition measures that provide the foundation for monitoring over time. Typical measures report on such things as the physical condition of bridges and pavements. This factor examines the degree to which the TAM process considers the types of assets that will likely be exposed to disruptions and the existence of asset levels of service related to system resilience.

- Level 1: Our TAMP identifies the types of assets or network segments that will likely be exposed to natural hazard disruptions. We have established condition targets for assets considered to be exposed.
- Level 2: Our TAMP identifies the types of assets or network segments that will likely be exposed to natural hazard and human-caused disruptions. We have established condition targets for assets considered to be exposed.
- Level 3: Our TAMP identifies the types of assets or network segments that will be exposed to natural and human-caused disruptions. Short- and long-term condition targets for resiliency have been established for asset or asset categories that are exposed. Desired levels of service relating to redundancy, evacuation, and recovery have also been identified.

²⁵ FHWA. 2013. Generic Work Plan for Developing a TAMP. Washington DC. Retrieved July 1, 2020 from <https://www.fhwa.dot.gov/asset/tamp/workplan.pdf>

Factor 8D.4 Does your risk-based performance gap assessment for your TAMP include risks associated with system resilience?

Part of the TAMP development process includes identifying the gaps between desired system performance and the actual performance of the system. This includes identifying the types of risks that might cause disruption to system performance. This factor emphasizes the inclusion of risks relating to system resilience in the determination of performance gaps. An important consideration is not only whether asset risks are identified but also whether the information is used in decisions on investments. This consideration is further discussed in Factor 8D.8, which focuses on the TAMP financial plan. The major distinctions among the three maturity levels are the time horizons for risks considered in this assessment and the level to which all types of resilience risks are considered. For example, Level 3 maturity includes the consideration of all the relevant system risks (including climate change impacts) on system performance.

- Level 1: We consider a short-term asset management planning horizon in our performance gap analysis as it relates to hazards and their impact on system performance. The existing performance gaps for the most important current types of hazards are described in the TAMP.
- Level 2: We consider a short-term asset management planning horizon in our performance gap analysis as it relates to potential disruptions and their impact on system performance. The existing performance gaps for all current types of hazards are described in the TAMP. In addition, a longer-term planning horizon has been used to determine expected performance gaps with respect to some of the most important future hazards.
- Level 3: We include both short- and long-term asset management planning horizons in our performance gap analysis as they relate to hazards and their impact on system performance. The longer-term planning horizon includes potential climate change-related disruptions and their impact on system performance. The existing and future performance gaps for all types of hazards are described in the TAMP and used in allocating investment funds.

Factor 8D.5 Does your TAMP and TAM process use lifecycle costs that reflect potential system disruptions?

Asset management best practice includes the use of lifecycle costs over the expected useful life of an asset. Such costs include all sources of potential costs, including in this case the potential costs associated with system disruptions. The major distinction among the three maturity levels for this factor is the extent to which different types of costs—agency, user, and societal—are considered in the lifecycle cost assessment.

- Level 1: Our TAMP and asset management process use lifecycle costs that consider the possibility of system disruptions. The costs considered are agency costs.
- Level 2: Our TAMP and asset management process use lifecycle costs that consider the possibility of system disruptions. The costs considered are both agency and user costs.
- Level 3: Our TAMP and asset management process use lifecycle costs that consider the possibility of system disruptions. The costs considered are agency, user, and societal costs.

Factor 8D.6 Does your TAMP risk management analysis include risks associated with natural hazards?

This factor relates to the use of vulnerability data produced in Step 7. In essence, this factor assesses the linkage between the information produced as part of the agency's vulnerability assessment and how this information is used in other functional area responsibilities, in this case, asset management. The types of actions/strategies that can be considered in preparation of the risk management analysis are discussed in the TAMP with input from Steps 8A, 8B, and 8C as appropriate. Two key distinctions are reflected in the different maturity levels: (1) the breadth of consideration of likely hazards and (2) the entity(-ies) most affected. For example, a Level 1 maturity examines the "most likely" hazards and risks directly affecting the agency. In comparison, Level 3 focuses on all possible hazards, and the risks directly affecting the agency, system users, and society in general.

- Level 1: Our risk management analysis focuses on the most likely hazards currently faced in our agency's area of responsibility as identified in Step 5. Risks are defined solely as those directly impacting my agency.
- Level 2: Our risk management analysis focuses on all of the hazards identified in Step 5. In addition, expected risks associated with some of the most important future hazards including hazards affected by climate change are considered. Risks consider impacts to our agency and those relating to the users of the transportation system.
- Level 3: Our risk management analysis focuses on all the hazards identified in Step 5. In addition, expected risks associated with all the future hazards (including all hazards affected by climate change) are considered. Risks consider impacts to our agency, those relating to the users of the transportation system, and to society in general.

Factor 8D.7 Is your TAM process linked to your agency's maintenance program such that it considers the trade-offs between today's capital investment and tomorrow's operations/maintenance costs?

One of the key trade-offs inherent in asset management is the use of dollars today to invest in asset improvement versus investing in periodic maintenance and restoration costs over time to bring the asset up to some targeted performance/condition threshold. This is especially true for resilience-related investments where investment today to protect an asset against future disruptions results in foregone future operations and maintenance costs for repairing the asset. The main distinctions among the maturity levels in this factor relate to how formal this trade-off analysis is and the degree to which such trade-off analysis informs or guides maintenance practices.

- Level 1: Our TAM process considers the trade-offs between investing in today's capital program to reduce future operations and maintenance costs. This is done on an ad hoc basis and usually for only the most-costly projects.
- Level 2: Our TAM process considers the trade-offs between investing in today's capital program to reduce future disruption-related operations and maintenance costs. A formal process has been established for doing so, and it is applied for a defined subset of projects in the program (e.g., all bridges or culverts).

- Level 3: Our TAM process considers the trade-offs between investing in today's capital program for all projects to reduce future operations and maintenance costs. A formal process has been established for doing so, and it is applied for all projects in the program. In addition, the asset management program guides sound maintenance practices within an asset management regime because well maintained assets are better able to withstand disruption-related stresses. Maintenance management systems produce real time data that informs the TAM process.

Factor 8D.8 Does your TAMP financial plan include a strategy for funding needed improvements to reduce system risks, whether as part of normal capital investment or as a stand-alone funding initiative and improve/enhance system resilience?

A TAMP financial plan, especially when facing a constrained resource environment, is an important tool for identifying the most cost-effective investments to the existing transportation network. In most cases, such financial plans not only describe the overall funding necessary to keep the condition and performance of the transportation system at some threshold level, but they also identify the distribution of funding among different program categories, each often having very specific requirements for the use of the funding. The major distinctions among the maturity levels for this factor are the degree to which funding is allocated to reduce known and future risks and the degree to which specific resilience-oriented financial strategies have been incorporated into financial planning and budgeting.

- Level 1: Our TAMP financial plan includes a strategy for funding needed improvements to reduce system vulnerabilities for current climate conditions, whether as part of normal capital investment or as a stand-alone funding initiative.
- Level 2: Our TAMP financial plan includes a strategy for funding needed improvements to reduce system vulnerabilities for current and future climate conditions, whether as part of normal capital investment or as a stand-alone funding initiative.
- Level 3: We have achieved Level 2. In addition, adaptation strategies are incorporated into our agency's short- and long- range financial plans and O&M budgeting processes. Maintenance management systems produce real time data that informs the TAMP process.

Factor 8D.9 Has your agency considered changes to the asset management process itself so as to enhance the consideration of resilience?

TAM best practice includes a reassessment of how asset management decisions are made and the effectiveness of data analysis in supporting these decisions. This reassessment should include all aspects of the TAM process, including, in this case, improvements to reinforce the consideration of resilience in decision-making processes. The major distinction among the three levels of maturity in this factor reflects the degree to which such a consideration is formalized in the assessment.

- Level 1: As part of the asset management enhancement process, we consider changes that will result in a more effective way of considering system disruptions. This is done on an ad hoc basis, and usually relies on the initiative of individual managers.
- Level 2: As part of the asset management enhancement process, we formally identify priority changes that will result in a more effective way of considering system disruptions. This

consideration has been formalized in the standard operating procedures that guide our enhancement process.

- Level 3: We have achieved a Level 2 maturity. In addition, funding has been set aside to implement these enhancements.

Factor 8D.10 Has your agency provided training or professional development opportunities to the asset management staff that include how to better consider system resilience in the asset management process?

This factor examines the degree to which asset management staff are trained or have access to professional development opportunities as they relate to enhanced consideration of system resilience in asset management. The major distinction among the three maturity levels in this factor is the degree to which the staff are exposed to both past and future risks as part of training. For example, a Level 3 maturity might include training on how to project future climatic conditions (or at least understand how such projections are done), how to participate in and understand vulnerability assessments, the range of potential system impacts and consequences, and the types of strategies a transportation agency might consider to reduce risks.

- Level 1: We provide asset management staff with examples from other states or jurisdictions that illustrate best practice risk-based asset management examples.
- Level 2: We have included topics relating to risk management into existing courses. This material examines risk management approaches for past and some future risks.
- Level 3: Our training program includes courses dedicated to risk management and how it can be applied to system resilience. Past and all future risks, including climate change, are included in the material.

Table 26 summarizes the factors that are included in the self-assessment tool for Step 8D. The maturity levels for each factor are presented in the descriptions of each factor. The total score for this step is found by summing the number of points given for each factor.

Table 26: Assessment Table for Step 8C: Integrate into Asset Management

Maturity Characteristic	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
8D.1 What assets and asset attributes are included in your asset management process that relates to system resilience?	In addition to the federally-required TAMP data on bridges and pavements, we have added locational and condition data for other asset types such as culverts and other drainage treatments on a subset of the highway network considered to be most critical. In addition, we have added facility attribute data (e.g., first floor elevations and location of HVAC equipment) for our most critical buildings.	We have achieved Level 1 maturity. In addition, we have added other asset types (e.g., geotechnical assets such as retaining walls) to the database along with attribute information that characterizes location and condition. For bridge data we have added attribute data on bridge low chord elevation and deck thickness. Bridge, road, and culvert attribute data reflecting system disruption characteristics are available on all of our assets and facilities. Unit cost estimates based on historical data are available that will assist with estimating replacement costs.	We have achieved Level 2 maturity. In addition to the assets in the Level 2 database, we have complete inventories of traffic control devices, signs, and guardrails that allow for faster replacement immediately after a major disruption. Good unit-cost data are available that will assist with estimating replacement costs. This cost data is updated at least every two years. In addition, the collection and updates of these attributes to these asset classes occur routinely and is used as part of a programmatic acceptance of data use.
8D.2 Have you integrated vulnerability scores from Step 7 into your asset management plan (TAMP) and TAM process?	We have not used the results from our vulnerability assessment in our asset management process. Our TAMP presents the most important types of hazards and threats that have occurred in the past.	We have used the results from our vulnerability assessment in our asset management process. Our TAMP summarizes all the types of natural disruptions that have occurred in the past on our transportation system. It also summarizes likely future causes of disruptions. Estimated costs to our agency of such disruptions are also reported.	We have used the results from our vulnerability assessment in our asset management process. Our TAMP summarizes all the types of human-caused and natural disruptions that have occurred in the past on our transportation system. It also summarizes likely future causes of disruptions. Estimated costs to our agency, system users, and societal costs are also reported.
8D.3 Does your TAM process use asset condition and performance measures relating to natural and human-caused disruptions?	Our TAMP identifies the types of assets or network segments that will likely be exposed to natural hazard disruptions. We have established condition targets for assets considered to be exposed.	Our TAMP identifies the types of assets or network segments that will likely be exposed to natural hazard and human-caused disruptions. We have established condition targets for assets considered to be exposed.	Our TAMP identifies the types of assets or network segments that will be exposed to natural and human-caused disruptions. Short- and long-term condition targets for resiliency have been established for asset or asset categories that are exposed. Desired levels of service relating to redundancy, evacuation, and recovery have also been identified.

Maturity Characteristic	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
8D.4 Does your risk-based performance gap assessment for your TAMP include risks associated with system resilience?	We consider a short-term asset management planning horizon in our performance gap analysis as it relates to hazards and their impact on system performance. The existing performance gaps for the most important current types of hazards are described in the TAMP.	We consider a short-term asset management planning horizon in our performance gap analysis as it relates to potential disruptions and their impact on system performance. The existing performance gaps for all current types of hazards are described in the TAMP. In addition, a longer-term planning horizon has been used to determine expected performance gaps with respect to some of the most important future hazards.	We include both short- and long-term asset management planning horizons in our performance gap analysis as they relate to hazards and their impact on system performance. The longer-term planning horizon includes potential climate change-related disruptions and their impact on system performance. The existing and future performance gaps for all types of hazards are described in the TAMP and used in allocating investment funds.
8D.5 Does your TAMP and TAM process use lifecycle costs that reflect potential system disruptions?	Our TAMP and asset management process use lifecycle costs that consider the possibility of system disruptions. The costs considered are agency costs.	Our TAMP and asset management process use lifecycle costs that consider the possibility of system disruptions. The costs considered are both agency and user costs.	Our TAMP and asset management process use lifecycle costs that consider the possibility of system disruptions. The costs considered are agency, user, and societal costs.
8D.6 Does your TAMP risk management analysis include risks associated with natural hazards?	Our risk management analysis focuses on the most likely hazards currently faced in our state and identified in Step 5. Risks are defined solely as those directly impacting our agency.	Our risk management analysis focuses on all the hazards identified in Step 5. In addition, expected risks associated with some of the most important future hazards including hazards affected by climate change are considered. Risks consider impacts to our agency and those relating to the users of the transportation system.	Our risk management analysis focuses on all the hazards identified in Step 5. In addition, expected risks associated with all the future hazards (including all hazards affected by climate change) are considered. Risks consider impacts to our agency, those relating to the users of the transportation system, and society in general.
8D.7 Is your TAM process linked to your agency's maintenance program such that it considers the trade-offs between today's capital investment and tomorrow's operations/maintenance costs?	Our TAM process considers the trade-offs between investing in today's capital program to reduce future operations and maintenance costs. This is done on an ad hoc basis and usually for only the most-costly projects.	Our TAM process considers the trade-offs between investing in today's capital program to reduce future disruption-related operations and maintenance costs. A formal process has been established for doing so, and it is applied for a defined subset of projects in the program (e.g., all bridges or culverts).	Our TAM process considers the trade-offs between investing in today's capital program for all projects to reduce future operations and maintenance costs. A formal process has been established for doing so, and it is applied for all projects in the program. In addition, the asset management program guides sound maintenance practices within an asset management regime because well maintained assets are better able to withstand disruption-related stresses. Maintenance management systems produce real time data that informs the TAM process.

Maturity Characteristic	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
8D.8 Does your TAMP financial plan include a strategy for funding needed improvements to reduce system risks, whether as part of normal capital investment or as a stand-alone funding initiative, and improve/enhance system resilience?	Our TAMP financial plan includes a strategy for funding needed improvements to reduce system vulnerabilities for current climate conditions, whether as part of normal capital investment or as a stand-alone funding initiative.	Our TAMP financial plan includes a strategy for funding needed improvements to reduce system vulnerabilities for current and future climate conditions, whether as part of normal capital investment or as a stand-alone funding initiative.	We have achieved Level 2 maturity. In addition, adaptation strategies are incorporated into our agency's short- and long- range financial plans and O&M budgeting processes. Maintenance management systems produce real time data that informs the TAMP process.
8D.9 Has your agency considered changes to the asset management process itself so as to enhance the consideration of resilience?	As part of the asset management enhancement process, we consider changes that will result in a more effective way of considering system disruptions. This is done on an ad hoc basis, and usually relies on the initiative of individual managers.	As part of the asset management enhancement process, we formally identify priority changes that will result in a more effective way of considering system disruptions. This consideration has been formalized in the standard operating procedures that guide our enhancement process.	We have achieved a Level 2 maturity. In addition, funding has been set aside to implement these enhancements.
8D.10 Has your agency provided training or professional development opportunities to the asset management staff that include how to better consider system resilience in the asset management process?	We provide asset management staff with examples from other states or jurisdictions that illustrate best practice risk-based asset management examples.	We have included topics relating to risk management into existing courses. This material examines risk management approaches for past and some future risks.	Our training program includes courses dedicated to risk management and how it can be applied to system resilience. Past and all future risks, including climate change, are included in the material.
Score Range	Description of Agency Maturity in Integrating into Asset Management		
0 to 13	Your agency is emerging into this area and has taken initial steps to grow awareness and understanding of the types of efforts it can take to integrate resilience concepts into asset management. Additional actions are warranted.		
14 to 26	Your agency has implemented several "asset management integration" strategies, not so much as part of an agency-wide strategy but rather at the initiative of agency staff. More actions are warranted.		
27 to 30	Your agency has reached significant maturity in integrating resilience concepts into asset management. Major focus should be on maintaining and enhancing existing efforts where appropriate, and take advantage of new opportunities as they become available.		

Recommended Actions to Maintain the Highest Level of Agency Resilience Capability

The highest level of capability for "Integrate into Asset Management" focuses on continual improvement in agency capability and actions leading to a more resilient transportation system. If your agency has reached a Level 3 maturity, the steps that can be taken to maintain this level include:

- Periodically reassess the capability of your agency's asset management unit with respect to its role in transportation system resilience. This could be done in-house or by bringing in a third-party evaluator to conduct the assessment.
- Continue to monitor the resilience of the transportation system and consider changes in the performance and asset condition when making changes in the agency to enhance your current asset management capability.
- Monitor the use of recurring emergency/disaster funding to respond to system disruptions and determine how much of such funding is used by your agency and for what purposes. Use this information to determine if some targeted resilience-oriented funding should be used to preempt future similar disruptions on critical parts of the transportation system.
- Periodically assess your agency's asset management data collection procedures and processes to identify where additional resilience-related data could be collected cost-effectively.
- Update staff professional development and training opportunities to include the latest thinking and concepts in system resilience as it relates to asset management.
- Maintain situational awareness of rapidly changing cyber and physical security exposures that impact agency resilience and capabilities. This includes monitoring developments in technology risks and cyberattacks as they relate to your agency's IT-related functions.

If you did not score a "30" in the assessment (a perfect score in Level 3 efforts), identify those factors that were rated lower and identify a strategy or action steps to improve these particular components of Step 8D.

Recommended Actions to Achieve Higher Levels of Resilience Capability

If you scored at Level 1 or 2, you can take steps to continue your evolution toward a more resilience-oriented agency as it relates to asset management. In such cases, agency managers should identify which of the factors in Table 26 were most deficient and determine priorities for improving your agency's organizational resilience capabilities in asset management.

Table 27 is offered as a template to determine which steps your agency can take to improve your agency's resilience capabilities in asset management, who should be responsible, the timeframe for the implementation, and expected outcomes.

Table 27: Actions to Achieve a Higher Maturity for Step 8D: "Integrate into Asset Management"

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Ensure that you have included in your resilience and asset management program assets and asset types that might be most vulnerable to future disruptions.			
	Ensure that the results of Steps 5 to 7 (and Steps 8A to 8C, where appropriate) are fed into the asset management process.			
	Investigate the extent to which resilience-oriented condition and performance measures relating to natural and human-caused disruptions are included in the TAMP and asset management process. Add as appropriate.			
	When your agency conducts future performance gap assessment as part of the TAMP update processes, ensure that system resilience concerns are part of the risks considered in the assessment.			
	Utilize lifecycle costs from Step 6 to determine which types of costs will be considered as part of the lifecycle analysis.			
	Ensure that all past and future hazards that could potentially disrupt system performance are part of the risk assessment.			
	Examine and improve the linkage between asset management and maintenance practices in your agency. Consider how tradeoffs in related costs can be considered in agency decision-making.			
	Develop a funding strategy for resilience-enhancing investments in your agency's TAMP financial plan.			
	Ensure during your agency reassessment of the TAMP process that resilience concerns and factors are incorporated moreeffectively into decision-making.			
	Develop training and professional development opportunities for your agency's asset management staff to enhance the consideration of resilience in asset management practices.			



Possible steps for “Implement Early Wins”

Useful References

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Chapter 15: Program and Implement Resilience Measures (Step 9)

The ultimate products of applying the Framework (and, in particular, of the analyses and efforts in Step 8) are projects, actions, and strategies



Program and Implement Resilience Measures

aimed at improving your agency's resiliency. Step 9 consists of programming and implementing resilience-related projects. Many different factors will influence the degree to which resilience projects are implemented as part of your agency's resilience program. Such things as eligibility criteria for categorical funding programs, the adopted priority criteria used to allocate funding, the degree to which funding sources (e.g., state legislatures) understand the need for resilience investments, and the willingness of partner agencies to collaborate in supporting mutually beneficial resilience-supporting efforts.

Governmental transportation programs are often limited by constitutional/legal requirements on how different funding sources can be used to further an agency's goals. Thus, this step reflects the level of support your agency has obtained. This speaks to the importance of making the business case for resilience, a theme reflected in the factors below.

Capability Factors and Levels of Maturity

Factor 9.1 Has your agency made the business case for investing in resilience-oriented projects and strategies?

Programming and implementing resilience projects and actions depend on the budgetary and funding support of different enabling agencies. For state transportation agencies, the source of funds primarily comes from the state government, dedicated trust funds, and/or the federal government. Often, convincing decision makers to invest in any transportation program depends on a perceived return on investment, either benefits measured in dollars or those that are considered public benefits (and not easily monetized). A successful resilience program will require funds that can be used for capital investments aimed at a more resilient transportation system as well as budget allocations to agency units that are on the front-line of implementing this program, such as operations, maintenance, and emergency response. This factor focuses on your agency's efforts to make the business case for resilience-oriented investments and/or budget allocations. The major distinctions among the different maturity levels of this factor reflect the level of sophistication in making this case, e.g., in assigning monetary values to expected benefits, and the degree to which resilience-oriented projects have been implemented.

- Level 1: We rely on a subjective assessment of the need for additional investment in resilience projects and strategies when justifying additional funding.
- Level 2: We have developed written materials based on historical evidence relating to the benefits associated with resilience investments. This written material is used in our efforts to justify additional budget requests.
- Level 3: We have developed written materials based on economic analysis of the benefits of providing funding of resilience actions. This business case explicitly recognizes resilience co-

benefits with other project goals. This information has resulted in additional funds being provided for resilience actions.

Factor 9.2 Has your agency/jurisdiction established a resilience project funding category or targeted funds to projects whose primary aim is to enhance system resilience?

This factor represents your agency's commitment to a resilience program by creating a stand-alone funding category for resilience project or by using existing funds to target resilience-related project components. Except for federal emergency relief (ER) funds and funding programs aimed at seismic protection, there are few examples of dedicated funding aimed at enhancing system resilience. In most cases, developing a dedicated funding program requires enabling legislation and thus the need for your agency to make the business case for such investments (see previous factor). The major distinction among the maturity levels reflects the degree to which resilience funding has been set aside and institutionalized in your agency.

- Level 1: We consider system resilience as part of the project selection process and will often spend an incremental amount of funds to support resilience efforts. However, there is no dedicated resilience project funding source.
- Level 2: We have set aside funds from existing funding sources to support resilience projects. There are many examples where such funds have been used for this purpose.
- Level 3: We have a dedicated funding source for resilience projects. We have adopted written guidance on the criteria for project eligibility.

Factor 9.3 To what degree are project resilience-oriented considerations included in the capital program prioritization process?

Prioritization criteria are often used in identifying the most desired projects in a capital investment program. These criteria relate to adopted agency goals and mandates and are subject to scrutiny and periodic review. In many ways, such criteria are a good indication of what an agency considers most important when allocating its limited funding. This factor focuses on the extent to which resilience-oriented considerations are part of the capital program prioritization process. This could be either with explicit resilience criteria or with the use of surrogate criteria that would serve many goals, one of which would be to enhance system resilience. The major distinctions among the maturity levels in this factor reflect the level of formal inclusion of resilience criteria in the prioritization process and the level of monetization incorporated into these criteria.

- Level 1: Our capital programming prioritization process uses resilience information from Step 8 on an ad hoc basis. There are no formal resilience-related prioritization criteria.
- Level 2: Our capital programming prioritization process uses resilience-oriented prioritization criteria for some of our capital investment program areas but not for every program in the agency. The set of criteria does not include economic or BCA monetary assessments of resilience project benefits.
- Level 3: We have achieved a Level 2 maturity. In addition, formal resilience-oriented prioritization criteria are used for all of our capital investment decisions where project priorities need to be established. In addition, economic or BCA monetary assessments of resilience project

benefits are considered as part of the prioritization process. Resilience co-benefits with other project goals are explicitly included in the prioritization.

Factor 9.4 To what degree are project resilience-oriented considerations included in non-capital program prioritization processes (e.g., operations and maintenance program priorities)?

Similar in concept to the above factor, this factor focuses on the extent to which resilience considerations are incorporated into budget allocations for your agency units that have an important resilience role and which are dependent on the agency's budget for implementing and maintaining program activities. This factor links back to Step 8 and examines the extent to which Step 8 activities are used in establishing non-capital program priorities. The major distinctions among the levels of maturity reflect the degree of formality in using resilience information in budgetary decisions and the level of economic analysis that accompanies the use of such information.

- Level 1: Our non-capital programming prioritization processes use resilience information from Step 8 on an ad hoc basis. There are no formal resilience-related prioritization criteria.
- Level 2: Our non-capital programming prioritization processes use resilience-oriented prioritization criteria for some of our program areas but not for every program in the agency. The set of criteria does not include economic or BCA monetary assessments of resilience project or strategy benefits.
- Level 3: We have achieved a Level 2 maturity level. In addition, formal resilience-oriented prioritization criteria are used for all of our non-capital investment decisions where project or strategy priorities need to be established. In addition, economic or BCA monetary assessments of resilience benefits are considered as part of the prioritization process. Resilience co-benefits with other project goals are explicitly included in the prioritization.

Factor 9.5 Has your agency implemented projects where incremental increases in project costs were allowed in order to increase system resilience?

One strategy used by some transportation agencies to fund resilience-oriented project components is to piggy back resilience funding on the capital budget of a project that is often being undertaken for other purposes. This approach has been used to include seismic protection into structures and other projects that were considered particularly vulnerable. Although such additional costs might be considered scope creep (and are often viewed negatively as part of the value engineering process), this factor recognizes that using incremental costs for key projects is one of the most direct ways of making some investment in system resilience. The major distinction among the maturity levels for this factor is the degree of formality in considering such costs.

- Level 1: We have used incremental funding to enhance resilience in a few cases with the initiative to do so coming from individual engineers or unit leaders.
- Level 2: We have used incremental funding to enhance resilience in a few cases. We have done so for targeted programs such as bridge rehabilitation projects where incremental costs provide a greater level of protection against hazards (e.g., seismic or flooding). However, this approach is not widespread in the agency.

- Level 3: We actively seek changes in project scopes where incremental increases in project costs are allowed because of expected additional system resilience benefits. Guidance has been developed to provide directions for doing so.

Factor 9.6 Has your agency participated with partner agencies in jointly sponsoring projects that will enhance overall system resilience?

As has been noted elsewhere in this guide, resilience programs and actions often include the participation of numerous agencies each having different mandates and goals. Such coordinated and collaborative actions are necessary to ensure successful implementation of many resilience efforts. This factor recognizes the multi-agency, multi-participant nature of many resilience efforts. The major distinctions among the maturity levels reflect the degree of formality of this interaction and the extent to which such interaction includes jointly funding strategies aimed at improving system resilience.

- Level 1: We meet on an ad hoc basis with some of the agencies involved with providing a resilient transportation system (e.g., emergency responders) to identify mutually beneficial projects. Results of these discussions are considered in budget decisions.
- Level 2: We formally meet with some of the agencies involved with providing a resilient transportation system to identify mutually beneficial projects/strategies. We have identified projects/actions that will enhance our collaborative efforts and by mutual agreement, these projects receive priority in each agency's budget process,
- Level 3: We have achieved a Level 2 maturity. In addition, we have jointly funded projects/strategies aimed at improving system resilience and that benefit each partner. Jointly defined projects receive funding priority in our programs.

Factor 9.7 If your agency uses public/private/partnership (P3) agreements, to what extent are resilience-oriented performance criteria incorporated into the contractual requirements of the investor/bidder responsibilities?

Some transportation agencies use P3 agreements for especially-costly projects or programs. Such agreements establish the respective roles of government agencies and private investors in a project or program that receives private investment. In essence, the purpose of a P3 agreement is to promote private investment in a project or program in exchange for the investor obtaining a financial return on the initial investment over a specified time frame. At some point in the project life, the asset which, during the term of the agreement is the responsibility of the investor, is turned back to the government. This factor reflects the degree to which resilience considerations are part of the contractual requirements of the investor. The major distinction in the maturity levels reflects the level of formality in including resilience provisions in the contract documents.

- Level 1: We have noted facility resilience (in light of future disruption uncertainty) as a desired facility characteristic in the project scope. However, such characteristics are not linked to performance criteria that applicants must respond to such as the length of time for recovering from asset failures.
- Level 2: We have explicitly incorporated resilience criteria (e.g., guaranteed facility performance in light of future disruption potential) into the P3 agreement. We have also included adaptive

design criteria as part of the design process. Only a limited number of potential hazards and threats are identified in the project scope.

- Level 3: We have achieved Level 2 maturity. However, all possible potential hazards and threats are considered. It is expected that the applicant will conduct a detailed assessment of these hazards and threats using a process like ADAP and will include the monetary value of any risks in the fee/payment structure.

Factor 9.8 Does your agency periodically monitor funding allocations to determine how many projects are being funded that have been defined from Step 8 has having system resilience benefits?

This factor reflects the degree to which your agency's implemented resilience program is actually having an impact on your agency's resilience efforts. The intent is to monitor resilience- related funding over time to identify trends in such funding and to determine the level of success in implementing projects and actions resulting from Step 8 activities. The major distinctions among the levels of maturity reflect the level of analysis and the formality of reporting such funding allocations.

- Level 1: We monitor the allocation of project funding only as it relates to targeted resilience policy and program priorities established by agency leadership. The allocation is reported periodically to agency leadership.
- Level 2: We monitor the funding allocation of project funding for all resilience projects and strategies undertaken by our agency. The results of this monitoring are reported as part of the agency's annual performance management process.
- Level 3: We have achieved a Level 2 maturity. In addition, we provide more detailed analysis on the benefits and costs associated with investing in resilience actions (e.g., the incremental costs of providing resilience benefits as part of projects undertaken primarily for other reasons).

Table 28 summarizes the factors that are included in the self-assessment tool for Step 9. The maturity levels for each factor are presented in the descriptions of each factor. The total score for this step is found by summing the number of points given for each factor.

Table 28: Assessment Table for Step 9: Program and Implement Resilience Measures

Maturity Characteristic	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
9.1 Has your agency made the business case for investing in resilience-oriented projects and strategies?	We rely on a subjective assessment of the need for additional investment in resilience projects and strategies when justifying additional funding.	We have developed written materials based on historical evidence relating to the benefits associated with resilience investments. This written material is used in our efforts to justify additional budget requests.	We have developed written materials based on economic analysis of the benefits of providing funding of resilience actions. This business case explicitly recognizes resilience co-benefits with other project goals. This information has resulted in additional funds being provided for resilience actions.
9.2 Has your agency/jurisdiction established a resilience project funding category or have you targeted funds to projects whose primary aim is to enhance system resilience?	We consider system resilience as part of the project selection process and will often spend an incremental amount of funds to support resilience efforts. However, there is no dedicated resilience project funding source	We have set aside funds from existing funding sources to support resilience projects. There are many examples where such funds have been used for this purpose.	We have a dedicated funding source for resilience projects. We have adopted written guidance on the criteria for project eligibility.
9.3 To what degree are project resilience-oriented considerations included in the capital program prioritization process?	Our capital programming prioritization process uses resilience information from Step 8 on an ad hoc basis. There are no formal resilience-related prioritization criteria.	Our capital programming prioritization process uses resilience-oriented prioritization criteria for some of our capital investment program areas but not for every program in the agency. The set of criteria does not include economic or BCA monetary assessments of resilience project benefits.	We have achieved a Level 2 maturity plus formal resilience-oriented prioritization criteria are used for all of our capital investment decisions where project priorities need to be established. In addition, economic or BCA monetary assessments of resilience project benefits are considered as part of the prioritization process. Resilience co-benefits with other project goals are explicitly included in the prioritization.

Maturity Characteristic	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
9.4 To what degree are project resilience-oriented considerations included in non-capital program prioritization processes (e.g., operations and maintenance program priorities)?	Our non-capital programming prioritization processes use resilience information from Step 8 on an ad hoc basis. There are no formal resilience-related prioritization criteria.	Our non-capital programming prioritization processes use resilience-oriented prioritization criteria for some of our program areas but not for every program in the agency. The set of criteria does not include economic or BCA monetary assessments of resilience project or strategy benefits.	We have achieved a Level 2 maturity. In addition, formal resilience-oriented prioritization criteria are used for all of our non-capital investment decisions where project or strategy priorities need to be established. In addition, economic or BCA monetary assessments of resilience benefits are considered as part of the prioritization process. Resilience co-benefits with other project goals are explicitly included in the prioritization.
9.5 Has your agency implemented projects where incremental increases in project costs were allowed to increase system resilience?	We have used incremental funding to enhance resilience in a few cases with the initiative to do so coming from individual engineers or unit leaders.	We have used incremental funding to enhance resilience in a few cases. We have done so for targeted programs such as bridge rehabilitation projects where incremental costs provide a greater level of protection against hazards (e.g., seismic or flooding). However, this approach is not widespread in the agency.	We actively seek changes in project scopes where incremental increases in project costs are allowed because of expected additional system resilience benefits. Guidance has been developed to provide directions for doing so.
9.6 Has your agency participated with partner agencies in jointly sponsoring projects that will enhance overall system resilience?	We meet on an ad hoc basis with some of the agencies involved with providing a resilient transportation system (e.g., emergency responders) to identify mutually beneficial projects. Results of these discussions are considered in budget decisions.	We formally meet with some of the agencies involved with providing a resilient transportation system to identify mutually beneficial projects/strategies. We have identified projects/actions that will enhance our collaborative efforts and by mutual agreement, these projects receive priority in each agency's budget process.	We have achieved a Level 2 maturity. In addition, we have jointly funded projects/strategies aimed at improving system resilience and that benefit each partner. Jointly defined projects receive funding priority in our programs.

Maturity Characteristic	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
9.7 If your agency uses public/private/partnership (P3) agreements, to what extent are resilience-oriented performance criteria incorporated into the contractual requirements of the investor/bidder responsibilities?	We have noted facility resilience (in light of future disruption uncertainty) as a desired facility characteristic in the project scope. However, such characteristics are not linked to performance criteria that applicants must respond to such as the length of time for recovering from asset failures.	We have explicitly incorporated resilience criteria (e.g., guaranteed facility performance in light of future disruption potential) into the P3 agreement. We have also included adaptive design criteria as part of the design process. Only a limited number of potential hazards and threats are identified in the project scope.	We have achieved Level 2 maturity. However, all possible potential hazards and threats are considered. It is expected that the applicant will conduct a detailed assessment of these hazards and threats using a process like ADAP and will include the monetary value of any risks in the fee/payment structure.
9.8 Does your agency periodically monitor funding allocations to determine how many projects are being funded that have been defined from Step 8 has having system resilience benefits?	We monitor the allocation of project funding only as it relates to targeted resilience policy and program priorities established by agency leadership. The allocation is reported periodically to agency leadership.	We monitor the funding allocation of project funding for all resilience projects and strategies undertaken by our agency. The results of this monitoring are reported as part of the agency's annual performance management process.	We have achieved a Level 2 maturity plus we provide more detailed analysis on the benefits and costs associated with investing in resilience actions (e.g., the incremental costs of providing resilience benefits as part of projects undertaken primarily for other reasons).
Score Range	Description of Agency Maturity in Programming and Implementing Resilience Measures		
0 to 11	Your agency is emerging into this area and has taken initial steps to grow awareness and understanding of the types of efforts it can take to program/prioritize resilience projects and strategies. Additional action is warranted.		
13 to 20	Your agency has implemented several “programming/prioritizing” strategies, not so much as part of an agency-wide strategy but rather at the initiative of agency staff.		
21 to 24	Your agency has reached significant maturity in programming/prioritizing resilience projects/strategies. Major focus should be on maintaining and enhancing existing efforts where appropriate, and take advantage of new opportunities as they become available.		

Recommended Actions to Maintain the Highest Level of Agency Resilience Capability

The highest level of capability for “Program and Implement Resilience Measures” focuses on continual improvement in agency capability and actions leading to a more resilient transportation system. If your agency has reached a Level 3 maturity, the steps that can be taken to maintain this level include:

- Continue to update the business case for resilience with the most recent benefit-cost data collected by your agency. Update written materials accordingly.
- Monitor the allocation of resilience-related funding to determine trends over time and to determine the types of resilience projects implemented. Link to the benefits calculation in the previous bullet.
- Periodically reassess the resilience-oriented prioritization criteria used by your agency in developing capital programs to determine how these criteria are influencing capital program development. Update monetary costs in the economic analysis associated with relevant criteria.
- Similar to the previous bullet, periodically review how resilience-oriented prioritization criteria are used by your agency in developing non-capital investment priorities. Assess the extent to which they have influenced budget allocation to resilience-oriented functions in your agency. Update monetary costs in the economic analysis associated with the relevant criteria in the budget analysis.
- Monitor the effectiveness of incremental project scope changes aimed at enhancing system resilience. Over the long-term, determine the benefit/cost relationship for such incremental investments.
- Continue to nurture the collaborative relationships established with partner organizations. Re-energize these relationships if necessary. Hold interagency meetings with the leaders of all partner agencies to identify enhancements in these relationships, if needed.
- If your agency used P3 agreements, monitor the effectiveness of the resilience-related requirements in contract documents. Modify related language for future P3 agreements to account for any deficiencies in existing agreements.

If you did not score a “24” in the assessment (a perfect score in Level 3 efforts), identify those factors that were rated lower and identify a strategy or action steps to improve these particular components of Step 9.

Recommended Actions to Achieve Higher Levels of Resilience Capability

If you scored at Level 1 or 2, you can take steps to continue your evolution toward a more resilience-oriented agency as it relates to enhancements to program and implement resilience activities. In such cases, agency managers should identify which of the factors in Table 28 were most deficient and determine priorities for improving your agency’s organizational resilience capabilities in programming and implementing resilience measures.

Table 29 is offered as a template to determine which steps your agency can take to improve your agency’s resilience capabilities in programming and implementing resilience measures, who should be responsible, the timeframe for the implementation, and expected outcomes.

Table 29: Actions to Achieve Higher Maturity for Step 9: Program and Implement Resilience Measures

Let's do this (check)	Action	Responsibility?	Timeline?	Expected outcomes?
	If you have not done so, develop a business case for resilience investments that can be used to justify more such investments. If such a business case has been developed, update periodically as new information on benefits and costs become available.			
	Develop and implement a strategy for securing dedicated funding for resilience actions and project design components. This could be a stand-alone funding program or incremental additions to existing funding programs that allow resilience-related investments.			
	Develop and implement a set of prioritization criteria that will result in more investment in resilience projects and strategies. Periodically assess the influence of these criteria in supporting resilience projects. Adjust over time as needed.			
	Hold meetings with agency leaders and staff, especially those who often speak in public forums, to make sure they understand the meaning, implications, and benefits associated with your agency's resilience program (as reflected in reported performance measures).			
	Continue to investigate the most appropriate strategy for monetizing resilience benefits. Monitor the literature and examine best practice from other transportation agencies in how this can be done most convincingly.			

 Possible steps for “Implement Early Wins”

Useful References

1. Federal Highway Administration (FHWA). 2020. Put in the forthcoming Resilience and Transportation Planning Guidebook once published.
2. FHWA. 2019. “Performance-Based Planning and Programming.” Website. Retrieved June 30, 2020 from https://ops.fhwa.dot.gov/plan4ops/performance_based.htm
3. Federal Highway Administration (FHWA). 2015. “Transportation System Resilience to Extreme Weather and Climate Change – Executives; Adaptation to Climate Change in Transportation Systems Management, Operations, and Maintenance” Report FHWA-HOP-15-024. Retrieved June 30, 2020 from <https://ops.fhwa.dot.gov/publications/fhwahop15026/index.htm>
4. Transportation Research Board (TRB). 2017. “Transportation Systems Resilience Preparation, Recovery, and Adaptation.” Transportation Research Circular E-226. Nov.

Washington DC. Retrieved June 30, 2020 from
<http://onlinepubs.trb.org/onlinepubs/circulars/ec226.pdf>

5. Weilant, S., A. Strong, B. Miller. 2019. "Incorporating Resilience into Transportation Planning and Assessment." RR-3038-TRB. RAND Corporation. Retrieved June 30, 2020 from DOI: <https://doi.org/10.7249/RR3038>

Chapter 16: Monitor and Manage System Performance (Step 10)

The 2012 "Moving Ahead for Progress in the 21st Century Act" (MAP-21) legislation called for statewide and metropolitan planning processes to incorporate a more comprehensive, performance-based approach to decision-making. According to the FHWA, performance-based planning and programming:

"Applies performance management principles to transportation system policy and investment decisions, providing a link between management and long-range decisions about policies and investments that an agency makes in its transportation system. Performance-based planning and programming is a system-level, data-driven process to identify strategies and investments. Long-range planning helps to define key goals and objectives and to analyze and evaluate strategies and scenarios for meeting goals. Connecting performance measures to goals and objectives through target setting provides a basis for understanding and sharing information with stakeholders and the public."²⁶

Such an objectives-driven, performance-based approach to decision-making has also been applied to other functional areas of a transportation agency such as traffic safety, asset management, freight, and others. With respect to system resilience, performance metrics relating to an agency's efforts to enhance system resilience would be a logical addition to such metrics. Indeed, the FHWA *Guidebook on Transportation System Resilience to Extreme Weather and Climate Change, Adaptation to Climate Change in Transportation Systems Management, Operations, and Maintenance* recommends that identifying operations performance metrics for system resilience is one of the steps that should be taken by O&M managers.²⁷

Step 10 emphasizes two aspects of performance monitoring and management: (1) the performance (e.g., effectiveness) of agency actions in achieving a more resilient transportation system and (2) the monitoring of transportation system resilience to assess the extent to which agency actions are making a difference. This step also examines how well performance monitoring information feeds back into Task 8 actions and future systems-level vulnerability assessment work in Step 5 (hence the arrow shown to these steps from Step 10 in Figure 1). In a simple sense, Step 10 can be viewed as a feedback loop in the overall decision-making and program management structure for an agency. It provides information to decision-makers on the current state of transportation system performance which can be used to identify areas of opportunity for further actions to enhance system resilience.



²⁶ FHWA. 2019. "Performance-Based Planning and Programming." Website. Retrieved June 30, 2020 from https://ops.fhwa.dot.gov/plan4ops/performance_based.htm

²⁷ FHWA. 2015. "Transportation System Resilience to Extreme Weather and Climate Change – Executives; Adaptation to Climate Change in Transportation Systems Management, Operations, and Maintenance" Report FHWA-HOP-15-024. Retrieved June 30, 2020 from <https://ops.fhwa.dot.gov/publications/fhwahop15026/index.htm>

Capability Factors and Levels of Maturity

Factor 10.1 Have you identified, and are you using, resilience metrics to monitor transportation system performance and your agency's contribution to system resilience?

This factor reflects a fundamental component of a performance-based approach to system resilience; the existence of resilience metrics that both monitor system performance and keep track of an agency's programmatic contribution to this outcome. Examples of the first performance category include such outcome topics as average system delay or user cost per type of disruption, number of road closures due to system disruption, number of successful cyberattacks against an agency's IT capability, and number of debris-ridden culverts. Examples of the second category of output performance metrics include such topics as number of culverts cleaned per year, average agency response time to major incidents, amount of funding targeting resilience-enhancing projects, and the number of agency staff trained in system resilience courses. The major distinctions among the maturity levels in this factor consist of the level of comprehensiveness associated with the number of identified performance metrics and how the resulting information is used in agency decision making.

- Level 1: We have examined and expect to use (but are not currently doing so) resilience metrics that are most relevant to the types of decisions our agency makes relating to system resilience.
- Level 2: We have identified and are using system and agency resilience metrics in several of our agency's units. These metrics are both outcome-oriented (that is, focused on transportation system resilience) and output-oriented (that is, focused on internal agency activities and actions leading to a more resilient transportation system). The performance measures are used primarily to guide management decisions in these units.
- Level 3: We have a comprehensive set of resilience metrics relating to our agency's entire resilience program and strategy.

Factor 10.2 Are the results of resilience performance monitoring reported on a periodic basis to agency leadership?

Reporting performance information can occur for many reasons, one of the most important being to influence decision-making within an agency. The key concept in this factor is to focus on the extent to which resilience performance information is reported to the agency leaders. This idea is similar in concept to many state DOTs having the number of traffic crashes and fatalities reported to top management weekly or monthly (given its importance to the agency and to the public). The rationale for this factor is that what is reported to top management reflects what is important to the agency. The major distinctions among the maturity levels in this factor reflect the extent to which resilience performance monitoring is agency-wide versus unit-specific and the degree to which this information is used for decision making.

- Level 1: Individual unit leads in our agency receive reports relating to their resilience- oriented functional responsibilities. This information is used to enhance the unit's efforts at improving that component of our system resilience program.
- Level 2: Agency leaders and relevant unit managers are presented the results of agency- wide resilience monitoring as part of our normal system performance monitoring. This information is

used by agency leaders to allocate resources to improve the resilience component of our transportation capital program and operating budgets.

- Level 3: We have achieved Level 2 maturity. In addition, agency leaders receive “after event” reports in order to identify how the agency can improve its resilience efforts. These reports are linked to agency performance measures relating to emergency response and incident/event recovery efforts.

Factor 10.3 Has the monitoring of system resilience led to changes in agency processes or outputs in order to achieve better system resilience?

This factor represents the bottom-line in the use of performance measures; has anything changed based on the information provided? Thus, the different levels of maturity reflect the degree to which changes have actually occurred to enhance agency resilience actions based on the information provided.

- Level 1: The performance measure information is used to monitor trends and acts as an “early warning” system when system performance is starting to deteriorate. This information often leads to resilience-oriented actions implemented by unit managers, although there is no monitoring of how this information is used.
- Level 2: The information is used by our resilience-related units to improve their efforts. There are many examples of where such efforts have occurred because of the information produced from performance measures.
- Level 3: We systematically examine the trends in system resilience performance and use this information to identify where organizational and programmatic changes should occur. There is also a systematic and comprehensive monitoring of steps taken by agency units that feeds into an agency-wide perspective on resilience-related actions. There are many examples where organizational change has occurred due to information provided from the performance monitoring system.

Factor 10.4 Is your resilience monitoring internally consistent amongst agency units?

One of the early experiences with the use of performance measures was that different units in an agency developed their own metrics, often inconsistent with the measures being used by other units or with overall agency objectives. The major distinctions among the maturity levels in this factor examine the degree to which resilience measures used throughout the agency are consistent with one another and the extent to which they reflect and contribute to overall agency resilience goals and objectives.

- Level 1: We have developed unit-specific, resilience-oriented performance metrics, but have not looked at resilience measurement organization-wide to assure consistency and compatibility among all the units.
- Level 2: We have developed performance metrics with specific consideration of similar and/or linked responsibilities in other resilience-oriented units (e.g., traffic operations and emergency response).
- Level 3: Our agency’s resilience monitoring program was developed collaboratively amongst all units with internal consistency and interconnection in mind. Each unit’s performance measures are linked directly to an agency-wide resilience performance metric.

Factor 10.5 Do you monitor the performance metrics of other agencies and partners who have a role in enhancing system resilience (e.g., enforcement or emergency response providers) to determine how your agency's actions affect their overall performance?

Transportation agency resilience programs and activities are often conducted in collaboration with other agencies (e.g., emergency response and disaster recovery efforts). This factor reflects the extent to which collaboration occurs with your agency's partners in defining and monitoring the performance and effectiveness of jointly-conducted resilience efforts. This factor represents a very proactive, multi-organization effort at enhancing system resilience. The major distinction among the maturity levels reflects the level to which partner agencies are brought into your agency's resilience efforts to improve system resilience performance.

- Level 1: We informally monitor what partner agencies are reporting as their key performance metrics as they relate to system resilience. We consider this information to make our collaborative efforts more effective.
- Level 2: Certain units in our agency monitor the performance metrics of their partner agency units and collaborate closely with key partners to determine if our agency can implement actions to improve overall system resilience and benefit all those involved. Our collaborative efforts are linked closely to the unit's resilience performance metrics.
- Level 3: We monitor the performance metrics of our key partners and use this information to determine jointly and periodically what actions can be taken to improve system resilience performance. These efforts to improve system resilience are linked closely to our agency's system resilience performance measures.

Factor 10.6 Have you used resilience metrics in communicating to key policy leaders and other decision-makers outside of your agency?

Besides monitoring an agency's effectiveness in affecting the performance and condition of the transportation system, performance measures can be used to communicate to key individuals on what your agency is doing and why it is important. Many transportation agencies, for example, have developed annual "state-of-transportation" reports for widespread dissemination on the trends in transportation system performance. This factor focuses on how resilience performance measures are used as part of an agency's communications strategy. The major distinctions among maturity levels are the degree to which resilience performance measures are used as part of this communications strategy and how this information is used as part of budget justification.

- Level 1: We provide resilience information from our agency's performance measures when requested by key decision-makers and stakeholders.
- Level 2: The resilience metrics are part of an overall agency communications strategy for informing key government leaders on what our agency has been doing to improve the resilience of the transportation system. The information is sent to these leaders and constituency groups as part of a periodic outreach effort.
- Level 3: We have achieved Level 2 maturity. In addition, the resilience performance measures are used to showcase our agency's contribution to a resilient transportation system to the general public.

Factor 10.7 Have you developed and reported on performance metrics relating to incident/event response?

Traffic crashes and other incidents are some of the most visible and most frequent disruptions to a transportation system. They not only disrupt travel in key mobility corridors but they also directly influence the public's perception of a transportation agency's competence in managing the system. The creation and on-going evolution of traffic management centers is an example of how transportation agencies have been more active in improving their response and recovery efforts associated with such incidents. The major distinction among the maturity levels is the degree to which such information is provided to different groups.

- Level 1: We have developed incident/event performance metrics primarily for internal purposes. The information is provided to key decision-makers and stakeholders when requested.
- Level 2: The incident/event performance metrics are part of an overall agency communications strategy for handling incidents and disruptive events. The information is provided to the media as part of an incident/disruptive event communications effort.
- Level 3: We have achieved Level 2 maturity. In addition, the incident/disruptive event performance information is regularly provided to key governmental leaders and constituency groups as part of our agency's resilience outreach efforts.

Factor 10.8 Have you assigned monetary estimates to the benefits of showing positive resilience outcomes?

Estimating the monetary value of the benefits of a transportation program is one of the major ways of attracting decision-maker attention on transportation program effectiveness. This factor focuses on the extent to which such benefits have been assigned monetary values. The major distinctions among the maturity levels include the degree to which monetary benefits have been defined and the extent to which they are used in supporting agency resilience programs.

- Level 1: We have considered (or are considering) the use of monetary benefits and expect to adopt them as part of the agency's performance measurement strategy.
- Level 2: Some of our agency's units use widely accepted BCA analysis to illustrate the benefits of resilience actions (e.g., monetary benefits of responding to incidents quickly).
- Level 3: We have developed monetary measures on a wide range of parameters relating to system resilience (e.g., economic impacts, user costs, freight impacts, and the like). Our agency regularly reports on what the expected monetary benefits are for agency-wide actions to improve system resilience.

Table 30 summarizes the factors that are included in the self-assessment tool for Step 10. The maturity levels for each factor are presented in the descriptions of each factor. The total score for this step is found by summing the number of points given for each factor.

Table 30: Assessment Table for Step 10: Monitor and Manage System Performance

Maturity Characteristic	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
10.1 Have you identified, and are you using, resilience metrics to monitor transportation system performance and your agency's contribution to system resilience?	We have examined and expect to use (but are not currently doing so) resilience metrics that are most relevant to the types of decisions our agency makes relating to system resilience.	We have identified and are using system and agency resilience metrics in several of our agency's units. These metrics are both outcome-oriented (that is, focused on transportation system resilience) and output-oriented (that is, focused on internal agency activities and actions leading to a more resilient transportation system). The performance measures are used primarily to guide management decisions in these units.	We have a comprehensive set of resilience metrics relating to our agency's entire resilience program and strategy.
10.2 Are the results of resilience performance monitoring reported on a periodic basis to agency leadership?	Individual unit leads in our agency receive reports relating to their resilience-oriented functional responsibilities. This information is used to enhance the unit's efforts at improving our system resilience program.	Agency leaders and relevant unit managers are presented the results of agency-wide resilience monitoring as part of our normal system performance monitoring. This information is used by agency leaders to allocate resources to improve the resilience component of our transportation capital program and operating budgets.	We have achieved Level 2 maturity. In addition, agency leaders receive "after event" reports in order to identify how the agency can improve its resilience efforts. These reports are linked to agency performance measures relating to emergency response and incident/event recovery efforts.
10.3 Has the monitoring of system resilience led to changes in agency processes or outputs in order to achieve better system resilience?	The performance measure information is used to monitor trends and acts as an "early warning" system when system performance is starting to deteriorate. This information often leads to resilience- oriented actions implemented by unit managers, although there is no monitoring of how this information is used.	The information is used by our resilience-related units to improve their efforts. There are many examples of where such efforts have occurred because of the information produced from performance measures.	We systematically examine the trends in system resilience performance and use this information to identify where organizational and programmatic changes should occur. There is also a systematic and comprehensive monitoring of steps taken by agency units that feeds into an agency-wide perspective on resilience-related actions. There are many examples of where organizational change has occurred due to information provided from the performance monitoring system.

Maturity Characteristic	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
10.4 Is your resilience monitoring internally consistent amongst agency units?	We have developed unit-specific, resilience-oriented performance metrics, but have not looked at resilience measurement organization-wide to assure consistency and compatibility among all the units.	We have developed unit-specific performance metrics with specific consideration of similar and/or linked responsibilities in other resilience-oriented units (e.g., traffic operations and emergency response).	Our agency's resilience monitoring program was developed collaboratively amongst all units with internal consistency and interconnection in mind. Each unit's performance measures are linked directly to an agency-wide resilience performance metric.
10.5 Do you monitor the performance metrics of other agencies and partners who have a role in enhancing system resilience (e.g., enforcement or emergency response providers) to determine how your agency's actions affect their overall performance?	We informally monitor what partner agencies are reporting as their key performance metrics as they relate to system resilience. We consider this information to make our collaborative efforts more effective.	Certain units in our agency monitor the performance metrics of their partner agency units and collaborate closely with key partners to determine if our agency can implement actions to improve overall system resilience and benefit all those involved. Our collaborative efforts are linked closely to the unit's resilience performance metrics.	We monitor the performance metrics of our key partners and uses this information to determine jointly and periodically what actions can be taken to improve system resilience performance. These efforts to improve system resilience are linked closely to our agency's system resilience performance measures.
10.6 Have you used resilience metrics in communicating to key policy leaders and other decision-makers outside of your agency?	We provide resilience information from our agency's performance measures when requested by key decision-makers and stakeholders.	The resilience metrics are part of an overall agency communications strategy for informing key government leaders on what our agency has been doing to improve the resilience of the transportation system. The information is sent to these leaders and constituency groups as part of a periodic outreach effort.	We have achieved Level 2 maturity. In addition, the resilience performance measures are used to showcase our agency's contribution to a resilient transportation system to the general public.
10.7 Have you developed and reported on performance metrics relating to incident/event response?	We have developed incident/event performance metrics primarily for internal purposes. The information is provided to key decision-makers and stakeholders when requested.	The incident/event performance metrics are part of an overall agency communications strategy for handling incidents and disruptive events. The information is provided to the media as part of an incident/disruptive event communications effort.	We have achieved Level 2 maturity. In addition, the incident/disruptive event performance information is provided to key governmental leaders and constituency groups regularly as part of our agency's resilience outreach efforts.

Maturity Characteristic	Level 1 (1 point)	Level 2 (2 points)	Level 3 (3 points)
10.8 Have you assigned monetary estimates to the benefits of showing positive resilience outcomes?	We have considered (or is considering) the use of monetary benefits and expect to adopt them as part of the agency's performance measurement strategy.	Some of our agency's units use widely accepted BCA analysis to illustrate the benefits of resilience actions (e.g., monetary benefits of responding to incidents quickly).	We have developed monetary measures on a wide range of parameters relating to system resilience (e.g., economic impacts, user costs, freight impacts, and the like). Our agency regularly reports on what the expected monetary benefits are for agency-wide actions to improve system resilience.
Score Range	Description of Agency Maturity in Measuring Performance		
0 to 11	Your agency is emerging into this area and has taken initial steps to develop a resilience performance measurement program. However, much more can be done.		
12 to 20	Your agency has implemented several "measuring performance" strategies, not so much as part of an agency-wide strategy but primarily at the unit level. There are still important actions that can be taken to reach the next level of maturity.		
21 to 24	Your agency has reached significant maturity in developing and implementing a resilience performance management program. Major focus should be on maintaining and enhancing existing efforts when appropriate and take advantage of new opportunities as they become available.		

Recommended Actions to Maintain the Highest Level of Agency Resilience Capability

The highest level of capability for “Monitor and Manage System Performance” focuses on continual improvement in agency capability and actions leading to a more resilient transportation system. If your agency has reached a Level 3 maturity, the steps that can be taken to maintain this level include:

- Continue to monitor the resilience of the transportation system and consider changes in the performance measures currently used for the agency’s resilience program.
- Monitor changing data collection technologies from the perspective of whether they provide new opportunities for defining and collecting data on new resilience performance measures.
- Review how after-event reports are used by decision-makers and identify changes in the format or timeliness to make them more useful.
- Periodically review how performance measures are used to communicate with key stakeholders, support programs changes, and affect budgets. Make changes as appropriate to ensure such uses are occurring.
- Review agency resilience efforts with respect to collaboration with other organizations. Identify where changes in your agency and other organizations’ procedures could result in improved, jointly-conducted resilience efforts.
- Hold key agency/unit leadership meetings to brainstorm how resilience program monitoring and management can be made more effective.
- Hold meetings with key stakeholders to brainstorm how resilience program monitoring and management can be made more effective in terms of informing others of agency efforts.
- Reassess the use of traffic incident performance metrics as to their usefulness in improving agency response capabilities and in conveying to the public your agency’s effectiveness in handling such disruptions.
- Periodically update monetary estimates of the benefits of your agency’s resilience efforts. These updates should reflect the latest cost estimates from your agency’s asset management, maintenance, and other relevant unit programs.

If you did not score a “24” in the assessment (a perfect score in Level 3 efforts), identify those factors that were rated lower and identify a strategy or action steps to improve these particular components of Step 10.

Recommended Actions to Achieve Higher Levels of Resilience Capability

If you scored at Level 1 or 2, you can take steps to continue your evolution toward a more resilience-oriented agency as it relates to enhancements to monitor and manage system performance activities. In such cases, agency managers should identify which of the factors in Table 30 are most deficient and determine priorities for improving your agency’s organizational resilience capabilities in monitoring and managing system performance.

Table 31 is offered as a template to determine which steps your agency can take to improve your agency’s resilience capabilities in monitoring and managing system performance, who should be responsible, the timeframe for the implementation, and expected outcomes.

Table 31: Actions to Achieve Higher Maturity for Step 10: Monitor and Manage System Performance

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Assess your agency's use of resilience measures and how this use can be improved and enhanced, making sure all your agency's relevant units are involved in the process.			
	Examine how agency leadership is using resilience performance measurement information (such as after-event reports) to identify how the use of such information can be improved. This would likely require internal meetings with the agency's top leaders.			
	Track the use of resilience performance measure information and how it has been used to adopt changes in the agency. Use this information to illustrate both the usefulness of performance measure information as well as the effectiveness of your agency's resilience program.			
	Periodically monitor the trends in system disruptions from both natural and man-made causes. Relate this tracking to the appropriateness of currently-used resilience measures.			
	Update your agency's resilience-related procedures and processes based on jointly conducted assessments of incident/disruptive event performance with participation from those organizations your agency collaborates with. Identify jointly adopted performance measures for incidents and disruptions where collaborative efforts are common.			
	Periodically examine the use of resilience performance measurement information in your agency's communications efforts to key stakeholders and decision-makers. Make changes where necessary.			
	Hold meetings with agency leaders and staff, especially those who often speak in public forums, to make sure they understand the meaning, implications, and benefits associated with your agency's resilience program (as reflected in reported performance measures).			
	Given the importance of traffic incidents to system performance and perceived agency credibility, conduct after event assessments of the use of incident response and recovery performance information for both internal and external audiences.			
	Continue to investigate the most appropriate strategy for monetizing resilience benefits. Monitor the literature and examine best practice from other transportation agencies in how this can be done most convincingly.			

 Possible steps for “Implement Early Wins”

Useful References

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Chapter 17: Mainstreaming Resilience into Agency Functional Areas

The previous chapters have presented a framework and self-assessment tool for mainstreaming resilience concepts into a transportation agency's decision-making and support processes. This chapter builds upon this information and describes how the results of this assessment relate to specific functional responsibilities of a typical transportation agency. In essence, this chapter provides a roadmap for linking the self-assessment recommended actions from each step (which reflected the self-assessment factors) to agency responsibilities. For example, the recommended actions relating to understanding the hazards and threats facing an agency could be linked to the transportation planning function; those relating to enhancing operations and maintenance actions could be linked to traffic operations and maintenance units.

The key agency functions presented in this chapter include:

- Policy development/Agency leadership and management
- Planning
- Project development/Engineering
- System and traffic operations
- Construction
- Maintenance
- Asset management
- Emergency response/Agency preparedness
- Public outreach/Communications

The assignment of assessment factors/actions to individual agency functions in this chapter should not hinder an agency from using a different strategy for implementing the recommended actions. In some cases, an agency might want to assign all the recommended actions to a central authority or implementation group. Such a strategy would certainly be appropriate. Even if an agency did so, it would be important to include representatives of functional units in the deliberations.

Each section that follows places the resilience self-assessment recommended actions into the same table format that was presented at the end of each step in the resilience framework. This is done for ease of use in deciding which actions should receive priority and who should have responsibility. Appendix B presents these tables in stand-alone form.

Policy Development/Agency Leadership and Management

This function in an agency focuses on developing and adopting agency policies, mandates, or internal guidance on how resilience concerns can be mainstreamed in agency decision-making. It would include such things as incorporating resilience into the agency's strategic goals, strategic plan, policy documents, and adopted CEO/Board direction. It might also include incorporating resilience into an agency's enabling mandate, but this would typically require legislation to do so. This function also includes actions that could be requested by the CEO or Board that reports to the administrative management structure in the agency (but which do not fall logically into any of the other functional areas). An example of this is examining your agency's training and professional development programs/offering from the perspective of how resilience concerns are incorporated into materials. This responsibility usually lies in human resources or personnel units which report to agency senior managers.

The self-assessment factors/recommended actions that relate to this functional area are shown in Table 32.

Table 32: Potential Actions for Policy Development/Agency Leadership and Management

Let's do this (check)	Action	Responsibility?	Timeline?	Expected outcomes?
	If you have not done so, develop a business case for resilience investments that can be used to justify more such investments. If such a business case has been developed, update periodically as new information on benefits and costs become available.			
	Develop and implement a strategy for securing dedicated funding for resilience actions and project design components. This could be a stand-alone funding program or incremental additions to existing funding programs that allow resilience-related investments.			
	Involve the agency CEO/director in the resilience program. Periodically reassess the usefulness of the information provided to the CEO with respect to the types of decisions he/she must make relating to the resilience program.			
	Involve department heads in the resilience program. This could be part of a formal coordinating group or frequent meetings to coordinate resilience activities.			
	Create an institutional mechanism to coordinate resilience efforts. Such a mechanism (e.g., task force, coordinating committee, and the like) would be given a clear mandate and expected products as they relate to your agency's resilience program			
	Incorporate transportation system resilience into agency plans and policy statements in order to institutionalize a resilience "mindset" into agency staff.			
	Establish a formal resilience strategy/program. This might require legislative approval or at a minimum agency directives and guidance.			
	Assign leadership responsibilities of the resilience strategy/program in your agency. This might be structured as a central authority for all resilience efforts or the assignment of responsibilities for individual components of the program.			
	Undertake a systematic effort/study to identify "early" wins to enhance system resilience.			
	Conduct and document a self-assessment of your agency focusing on how effectively resilience is incorporated into agency functions.			
	Conduct self-assessments of specific agency functions that are particularly relevant to system resilience.			
	Assign staff to support the resilience strategy/program. Such assignments should be clear in terms of how activities contribute to program objectives, and QA/QC procedures that should accompany staff efforts.			
	Examine best practices from other agencies and organizations.			
	Review threat/hazard exposure and/or vulnerability studies to understand potential disruptions to your transportation system and possible demands on your agency.			
	Review staff roles and responsibilities to identify how they relate to enhancing system resilience.			
	Assign resilience-related job responsibilities to agency staff job descriptions and talent profiles. Enhancing transportation system resilience should be part of all relevant staff job activities, both for emergency response efforts and more long-term efforts to improve asset and system resilience.			
	Examine your training/professional development programs for their coverage of resilience.			

	Improve resilience coordination with local communities so as to place your agency in a leadership position for fostering enhance community resilience.			
	Enhance coordination with federal, state, and local agencies relating to various aspects of your agency's resilience program. This would include not only coordination efforts relating to emergency response, but also actions to include more resilience concerns into agency decision-making.			
	Others?			

Planning

The planning function in a transportation agency could include many different responsibilities and efforts having important linkages to system resilience efforts. For state DOTs, the development of the statewide transportation plan is the responsibility of the planning unit. Other types of planning—corridor, modal, multimodal and intermodal, freight, early project planning, and special topics (e.g., economic impacts, equity, and the impact of new technologies) -- often occur as well. In addition, most state DOTs have responsibility for rural transportation planning and for liaison with MPO metropolitan transportation planning. Transportation planning also provides much of the information that supports resource allocation decisions and influences which projects go into a capital program.

It is noteworthy that most of the resilience/climate change studies undertaken by states have been led by the DOT planning units. Not only can the planning unit provide agency leadership in adaptation studies, but vulnerability assessments can be utilized in early planning to inform capital program development and the project planning process. Vulnerability data in GIS platforms can be utilized to determine vulnerable locations early on in the planning process leading to decisions to conduct additional studies, seek project funding, or determine if project scheduling might be impacted. Planning is also where asset management data can feed into the assessment of the resilience of a project by informing the project manager if there are threats in the project area to be addressed.

For the purposes of this guide, such responsibilities are assigned to the planning unit. The planning group in your agency thus has a very important role to play in mainstreaming resilience concepts into decision-making.

The self-assessment factors/recommended actions that relate to planning are shown in Table 33.

Table 33: Potential Actions for Planning

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Conduct self-assessments of current planning functions with special emphasis on those relevant to system resilience. Identify actions that can be taken to enhance this linkage.			
	Incorporate transportation system resilience into agency plans and policy statements. This includes all plans that are produced by your agency---statewide, regional, corridor, project, site, modal, special topic plans and the like.			
	Review threat/hazard exposure and/or vulnerability studies to understand potential disruptions to your transportation system and possible demands on your agency. Provide information to planning staff and other planning agencies in your jurisdiction.			
	Apply threat-vulnerability worksheets (TVA) to assess threats to your system.			
	Collect and assess hazard and threat data and estimate the likelihood of events occurring in the future (including noting the uncertainty in results as appropriate).			
	Identify susceptibility factors that may worsen or reduce the system disruption caused by expected hazards.			
	Produce GIS mapping of hazard exposure across all assets in the transportation system for each hazard and threat.			
	Develop transportation-specific vulnerability indices to identify populations that are more adversely affected by service and system outages. Develop a methodology and planning guidance on how socio-economic and environmental impacts will affect different population groups.			
	Identify the assets at most risk across hazards and threats.			
	For different asset types, develop methodologies for combining physical and socio-economic costs that may occur over the asset life span by scenario, time period, and hazard.			
	Provide GIS mapping of entry points where other sectors may impact transportation operations have been identified.			
	Increase engagement and strengthen relationships internally among planners, asset managers, engineers, emergency management, and GIS specialists to better understand potential impacts from system disruptions.			
	Identify critical agency stakeholders and external partners who are crucial for supporting resilience project strategy prioritization. Establish a means of collaborating with these groups in the assessment and prioritization processes.			
	Improve resilience coordination with local communities so as to place your agency in a leadership position for fostering enhanced community resilience.			
	Increase engagement and strengthen relationships externally with governmental and university climate science research centers, state climatologists, health professionals, cyber and terrorist experts, geotechnical experts, and sector experts.			
	Develop a list of co-benefits for resilience projects that are important when considering agency priorities.			

	Continue to investigate the most appropriate strategy for monetizing resilience benefits. Monitor the literature and examine best practice from other transportation agencies in how this can be done most convincingly.			
	Develop and implement a set of prioritization criteria that will result in more investment in resilience projects and strategies. Periodically assess the influence of these criteria in supporting resilience projects. Adjust over time as needed.			
	Assess your agency's use of resilience measures and how this use can be improved and enhanced, making sure all of your agency's relevant units are involved in the process.			
	Examine how your agency leadership is using resilience performance measurement information (such as after event reports) to identify how the use of such information can be improved.			
	Track the use of resilience performance measure information and how it has been used to adopt changes in the agency. Use this information to illustrate both the usefulness of performance measure information as well as the effectiveness of your agency's resilience program.			
	Periodically monitor the trends in system disruptions from both natural and man-made causes. Relate this tracking to the appropriateness of currently-used resilience measures.			
	Work with representatives from other sectors that affect and are affected by disruptions to respective networks. Identify potential points of vulnerability and collaboratively identify strategies for minimizing failure.			
	Participate in national conferences and workshops to exchange information on best practices for linking resilience and planning.			

Project Development/Engineering

Project development/engineering includes those functions in an agency that take a project from initiation through plans, specifications, and estimates (PSEs). This could include more detailed project planning (than would occur in planning), environmental analysis, and preliminary and final engineering. Much of the activities in project development follow agency- adopted guidance such as environmental procedures, design manuals, and design standards. In most agencies, the project development pipeline transmits project information from one group to the next. Thus, for example, environmental analysis/review identifies the types of environmental concerns that must be mitigated, which goes to preliminary engineering where such mitigation is identified and conceptually defined, which then goes to final design where the actual design of the mitigation actions are specified.

The self-assessment factors/recommended actions that relate to this functional area are shown in Table 34.

Table 34: Potential Actions for Project Development/Engineering

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Conduct self-assessments of current project development/design functions with special emphasis on those relevant to system resilience. Identify actions that can be taken to enhance this linkage.			
	Review your agency's history of project designs withstanding hazards and the likelihood of handling future expected hazards and threats. Assess the effectiveness of design changes made to make assets more resilient.			
	Consider resilience concerns in project development, including natural hazards, climate change, and human-caused threats relating to physical security, crime prevention, personal safety, and emergency management's fire, life and safety requirements. Incorporate this consideration into project development guidance.			
	Begin to make design criteria more adaptive to expected future hazards and threats. Adopt a project development process like ADAP as the desired project development process. Incorporate into design guidance and manuals.			
	Pursue betterments when reconstructing facilities affected by federally-designated disasters/emergencies.			
	Incorporate resilience "add-ons" to project designs that take into account different types of risks. Document the costs associated with such add-ons and ultimate benefits, and provide to the asset management unit and agency leadership.			
	Monitor and record stressor/hazard/threat impacts on assets and related costs as they occur. Feed this information back into the project development process so that agency staff have the most up-to-date information on likely benefits of adaptive designs. Develop a catalog of impact functions for each asset type that may be exposed to the hazards and/or threats.			
	Make sure your value engineering process considers resilience measure costs as a valid expense when viewed from a lifecycle cost perspective.			
	Identify staff who are capable and interested in integrating resilience into asset-specific analyses. If necessary provide additional training to these staff members.			
	Where appropriate, conduct pilot studies of the application of an adaptive design process to illustrate key steps and what a resilience-sensitive project will look like.			
	Work with partner agencies (e.g., resource agencies) to explain the approach your agency is taking toward adaptive design and identify any changes to existing agreements and interactions that might be necessary to implement desired changes.			
	Monitor any activities or strategies already implemented that may serve as guides to future options/measures.			
	Document the overall project development process and in particular how resilience concerns were addressed for each project analysis.			
	Develop an internal communications strategy to convey to agency staff what is occurring with respect to resilience-oriented project development and how they can contribute.			

System and Traffic Operations

System and traffic operations includes those aspects of your agency's program delivery that relate to the operating and managing of your transportation system. For highway programs, this would include responsibility for traffic signals and signs, traffic management centers, traffic operations during disruptions (e.g., detours and construction traffic operations plans), and special events traffic management.

The self-assessment factors/recommended actions that relate to system and traffic operations are shown in Table 35.

Table 35: Potential Actions for System and Traffic Operations

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Conduct self-assessments of current system and traffic operations functions with special emphasis on those relevant to system resilience. Identify actions that can be taken to enhance this linkage.			
	Develop a process for conducting after-action and after-event reports that can be used to identify corrective actions with respect to improving system operations.			
	Review staff roles and responsibilities to identify how they relate to enhancing system resilience. Develop a strategy for institutionalizing system resilience into staff roles.			
	Review your agency's history of traffic operations and traffic engineering designs withstanding hazards and the likelihood of handling future expected hazards and threats. Make traffic operations- related design criteria more adaptive to expected future hazards and threats.			
	Assess your agency's system operations strategies with respect to the vulnerabilities identified in the vulnerability assessment. Emphasize the implementation requirements for additional actions that are deemed necessary.			
	Develop GIS layers of emergency evacuation routes and other layers that describe critical components of the transportation system.			
	Examine how operations data collection efforts can be modified to collect resilience-related data and information to improve resilience planning.			
	Examine how operations data can be used to inform lifecycle costing analyses in the asset management program or in other investment evaluation efforts in your agency.			
	Re-examine (or develop) contingency plans for traffic management centers or for other critical assets relating to transportation system management and operations. The contingency plans should reflect the types of disruptions that could occur and the key functions of the centers that might be lost for physical, power, and employee availability disruptions.			
	Reassess (or develop) multi-agency training and field exercises that reflect the likely operational circumstances that will be faced in a serious disruption event.			

	Examine your agency's (or jurisdiction's) cybersecurity plan from the perspective of vulnerabilities to operations functions. Investigate the extent to which redundant systems are in place and protected against cyberattacks.			
	Examine (or develop) a strategy for backing up critical operations data relating to the functions of traffic management centers. To what extent are these backup capabilities tested to assure uninterrupted traffic operations command and control actions during and following a disruption.			
	Document the resilience-related traffic operations efforts of your agency with the aim of informing your own staff as well as key stakeholders of what is in place and being developed on how your agency's operations capabilities will be used during and post-disruption event.			

Construction

The construction function within a transportation agency is responsible for delivering an agency's construction program and for managing actual construction projects as per contract requirements with a construction contractor (where the contract is based on the contractor bid, which reflects the plans, specifications, and estimates (PS&Es) produced by the agency). Resilience actions relating to construction can range from the types of materials used in project construction (usually pre-specified in the PS&Es), the use of construction equipment for emergency response to disruptions, traffic management strategies in work zones, and the pre-positioning of materials to allow rapid rebuilding of key assets.

The self-assessment factors/recommended actions relating to construction are shown in Table 36.

Table 36: Potential Actions for Construction

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Conduct self-assessments of current construction functions with special emphasis on those relevant to construction activities. Identify actions that can be taken to enhance this linkage.			
	Develop a process for conducting after-construction reports that identify actions to enhance system resilience in the construction process (or add such a focus in current after-construction reports).			
	Provide opportunities for construction staff to recommend construction-related resilience strategies and actions to those in the project development process prior the construction phase (e.g., those developing PS&Es or handling construction zone traffic management).			
	If your agency does not do so, examine how electronic as-built plans can be utilized throughout the agency for managing the system and of providing information that can feed into resilience efforts.			
	Keep abreast of the latest developments in resilient materials and work with your agency's materials certification unit to allow such materials in future projects.			
	Pre-position construction materials in strategic locations that allows rapid reconstruction of failed assets.			

	Put in place new contracts with independent contractors to supplement your own construction resources when responding to emergency situations.			
	Incorporate flexibility into regular construction contracts that allows your agency to assign emergency construction use for disaster recovery.			
	Work closely with the traffic operations unit to develop and assess after-project construction zone traffic management strategies. Collect and archive data on the major causes of delay through the construction zone (e.g., movement of construction equipment, lane shutdowns due to construction phasing, crashes, vehicles running out of gas and the like).			
	Examine those construction items and actions that relate to protection of the work zone against extreme weather events (e.g., drainage and erosion control). Assess the adequacy of such actions based on experience. Determine if future environmental conditions will increase the vulnerability of the work zone to such disruptions. Determine when contract provisions might have to change to reflect such threats.			
	Consider likely changes to the working conditions of your agency staff and contractor employees given threats from extreme weather (e.g., prolonged high temperatures and frequent high intensity precipitation events). Determine when employee safety steps and contract provisions might have to change to reflect such threats.			

Maintenance

Maintenance activities include such tasks as keeping facilities and other assets debris-free and safe, maintaining network appurtenances (such as signals, guardrails, and signs), responding to and replacing equipment when necessary, and serving as front-line staff when your agency needs immediate response to system disruptions.

The self-assessment factors/recommended actions that relate to maintenance are shown in Table 37.

Table 37: Potential Actions for Maintenance

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Conduct self-assessments of current maintenance functions with special emphasis on those relevant to system resilience. Identify actions that can be taken to enhance this linkage.			
	Develop a process for conducting after-action and after-event reports that are used to identify corrective actions with respect to system maintenance.			
	Develop a process for reviewing maintenance data to identify chronic disruptions to location-specific assets or facilities.			
	Review staff roles and responsibilities to identify how they relate to enhancing system resilience. Develop a strategy for institutionalizing system resilience into staff roles.			
	Review your history of maintenance responses to hazards and the likelihood of handling future expected hazards and threats. Make changes in standard responses where necessary.			
	Assess your agency's maintenance strategies with respect to the vulnerabilities identified in the vulnerability assessment. Emphasize the implementation requirements for additional actions that are deemed necessary (e.g., additional right-of-way vegetation clearance to minimize wildfire damage).			
	Investigate the extent to which your agency's vegetation management and control program reflects the likely changes in climate that your jurisdiction will face over time or are currently facing.			
	Develop or enhance your existing culvert cleaning program. Establish a regular inspection and cleaning schedule, if not already done.			
	Examine how maintenance data collection efforts can be modified or enhanced to collect resilience-related data that can be used for improved resilience planning. This includes collecting maintenance records and other cost information for use in identifying likely hazards and the costs of responding.			
	Examine (or implement) your maintenance management systems in terms of how they can assist in communication with the public and determine what work needs to be done and at what frequency. Also investigate how the systems track repair history that feeds into other agency processes.			
	Examine how maintenance data can be used to inform lifecycle costing analyses in the asset management program or in other investment evaluation efforts in your agency.			
	Collect damage and outage data after hazards/threat events for affected assets. Compare with and revise existing damage and outage data for use in the vulnerability analysis.			
	Document the resilience-related maintenance efforts of your agency with the aim of informing your own staff as well as key stakeholders of what is in place and being developed on how your agency's maintenance capabilities will be used during and post-disruption event.			

Asset Management

Asset management includes data collection and system/asset inventory, analysis of condition deterioration, prioritization of investments, risk analysis, life-cycle planning analysis and (often) financial analysis of system performance degradation given different investment scenarios. This capability will vary from one agency to another. State DOTs, for example, must have a risk-oriented asset management plan and program for NHS pavements and bridges. Some have developed such capabilities for culverts, street lighting, signals, and other appurtenances.

The self-assessment factors/recommended actions that relate to asset management are shown in Table 38.

Table 38: Potential Actions for Asset Management

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Conduct self-assessments of the asset management function with special emphasis on those relevant to system resilience. Identify actions that can be taken to enhance this linkage.			
	Identify the assets at most risk across hazards and threats.			
	Review staff roles and responsibilities to identify how they relate to enhancing system resilience. Develop strategy for institutionalizing system resilience into staff roles.			
	Develop and maintain a full and complete asset inventory, including asset location, condition, and use. Over time, this asset inventory should include all assets for which your agency is responsible. Tie asset failures and accelerated deterioration due to resilience stresses into the asset database and analysis.			
	Develop quantifiable hazard-to-impact relationships that are tailored to your geographic location and asset class.			
	Increase engagement and strengthen relationships internally with asset managers, engineers, emergency management, and GIS specialists.			
	Develop a catalog of impact functions for each asset type that may be exposed to identified hazards and/or threats.			
	Develop a menu of costs for each asset type identified as being potentially exposed to system disruptions.			
	Examine how O&M data collection efforts can be modified to collect resilience-related data that can be used for asset management.			
	Collect damage and outage data after hazards/threat events for affected assets. Compare with and revise existing damage and outage data used in the analysis.			
	Collect economic data after hazards/threat events. Compare with and revise existing economic data used in impact analyses.			
	Investigate the extent to which resilience-oriented condition and performance measures relating to natural and human-caused disruptions are included in the TAMP and asset management process. Add as appropriate.			
	When your agency conducts future performance gap assessment as part of the TAMP update processes, ensure that system resilience concerns are part of the risks considered in the assessment.			
	Utilize lifecycle costs in the prioritization process and determine which types of costs will be considered as part of the lifecycle analysis.			

	Ensure that all past and future hazards that could potentially disrupt system performance are part of the risk assessment.			
	Examine and improve the linkage between asset management and maintenance practices in your agency. Consider how tradeoffs in related costs can be considered in agency decision-making.			
	Develop a funding strategy for resilience-enhancing investments in your agency's TAMP financial plan.			
	Ensure during your agency reassessment of the TAMP process that resilience concerns and factors are incorporated more effectively into decision-making.			
	Develop training and professional development opportunities for your agency's asset management staff to enhance the consideration of resilience in asset management practices.			

Emergency Response/Agency Preparedness

Emergency response/agency preparedness consists of two types of functions. The first, emergency response, includes an agency's actions that are part of its first responders and those that follow to put in place strategies to minimize system disruption. Agency preparedness includes longer term planning and implementation of actions to minimize disruption to agency command and control processes, decision making, and administrative procedures relating to the day-to-day activities of your agency. As noted in this chapter, this includes steps your agency has taken to protect its IT capabilities.

The self-assessment factors/recommended actions that relate to maintenance are shown in Table 39. Given the distinct nature of the different actions in this section, note that the three major types of actions are separated.

Table 39: Potential Actions for Emergency Response/Agency Preparedness

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Emergency Response			
	Develop a 24/7 threat and hazard warning system			
	Create or modernize your agency's emergency notification system			
	Implement a multi-year exercise program that includes the conduct of emergency management drills, functional, and full scale exercises.			
	Assess the effectiveness of the multi-agency communications systems and protocols used during emergency response/management actions. Include in this assessment the effectiveness of the technologies and equipment used in the response.			
	Improve the coordination with emergency response agencies/organizations. This might include periodic reassessments of the institutional relationships for handling system disruptions, or after event debriefings to dissect what happened and what improvements should be considered.			
	Develop and periodically update a strategy and mechanism for emergency management and security staff to provide input into the decisions of other agency units.			
	Develop agreements or understandings with FEMA on procedures and requirements when a disaster has been declared.			
	Monitor the allocation over time of agency budget resources to the emergency response/management and disaster recovery capacity.			
	Determine if such allocations are adequate to prepare your agency for dealing with major disruptions.			

	Agency Preparedness		
	Publish an agency-wide Continuity of Operations Plan that identifies types of critical incidents or events, emergency activation criteria, and procedural guidelines to ensure safe internal and external operations.		
	Test the COOP on a periodic basis. Include in this test unexpected variations of likely hazards and threats (e.g., two major disruptions occurring at the same time).		
	If not already done, locate a COOP secondary site at a traffic management center (TMC), Fusion Center, or Statewide Emergency Management Operations Center		
	If not already done, develop an all hazards response plan and establish an update schedule.		
	Develop a strategy to pre-position equipment, materials, and other resources to respond to a disruption and/or support recovery. If such a strategy exists, continue to monitor the viability of this pre-positioning in relationship to different types of disruptions.		
	Establish a common set of cross-disciplinary criteria for prevention, preparedness, mitigation, disaster management, emergency management, environmental management and business continuity of operations.		
	Publish a training calendar and schedule for emergency management introductory level training for all agency personnel.		
	Create and support opportunities for agency staff involved in emergency response/management, disaster recovery, and cybersecurity efforts to interact with peers in other agencies and in professional organizations' meetings.		
	Cybersecurity		
	Develop, update, and test your physical and cybersecurity plan. The plans should be coordinated with the other agencies who have primary responsibility for the provision of security services. This includes steps to protect such systems as well as a cyber-incident response and recovery plan developed in collaboration with key internal and external stakeholders.		
	Implement a full range of basic cybersecurity techniques and cyber hygiene practices in your agency.		
	Conduct white hat hacker attacks against your agency's IT systems to identify vulnerable access points.		
	Back up some mission-critical data, preferably at remote sites with firewalls and other cyber defenses in place that will not allow attacks on my agency's primary IT systems to reach the remote sites.		
	Develop a training calendar and schedule for cybersecurity awareness for agency personnel and contractors. Update as new threats and vulnerabilities occur.		

Public Outreach/Communications

A successful agency resilience strategy will include a thoughtful and comprehensive public outreach and communications effort. This includes not only information dissemination during major disruptions and incidents, but also information exchange during an agency's efforts to implement a resilience program. In today's world, such an effort will include a range of dissemination media aimed at different audiences. In keeping with the theme of the need for multi-agency collaboration in resilience initiatives, coordinating your agency's communications efforts with other partner agencies is an important way of providing consistent resilience messaging.

The self-assessment factors/recommended actions that relate to external communications are shown in Table 40.

Table 40: Potential Actions for Developing an External Communications Strategy

Let's do this (check)	Action	Responsibility?	Timeframe?	Expected outcomes?
	Conduct a self-assessment of your overall agency's resilience external communication efforts.			
	Conduct self-assessments of the external communications role of those agency units that are particularly relevant to system resilience. Examine what roles these units can play in your agency's overall resilience communications strategy.			
	Create a coordination mechanism in your agency to contribute to the development of an external communications strategy.			
	Create a common point of contact for requests for resilience information.			
	Make sure your agency's communication strategy for major incidents/disruptions is clearly understood by agency staff. If not already, evolve the point(s) of contact for incident response into your point of contact for overall resilience information.			
	Examine the possibility of creating a coordinating mechanism (or participating in an existing one) among partner agencies to coordinate the resilience message and in producing common resilience material.			
	Prepare a written document describing your resilience external communications strategy (e.g., a communications plan). This documentation should describe the rationale for the program, how it will be structured, target audiences, action items, and implementation responsibilities.			
	Seek input from the public, key stakeholders, and other constituencies on the type of resilience information they would like to receive. Use this input to developed targeted outreach tools and media to provide such information.			
	Develop documentation that clearly outlines the intent, benefits and expected outcomes of your agency's resilience program and ensure that all agency personnel are aware of the key messages in this material.			
	Prepare and utilize graphic material to summarize the benefits of resilience programs that can be used in social media outreach efforts.			
	Establish a social media account that is clear and telling on relating information relating to resilience.			

Appendix A: Relationship to Other Resilience Frameworks

A variety of resilience-oriented frameworks have been developed by many different organizations and groups for a range of purposes. This has caused some confusion in the transportation profession about what approach should be used. The following table identifies some of these major resilience frameworks and their relationship to the Framework. The other frameworks are presented in reverse date of publication and are focused on examples from the United States (for international examples, see a review by the Overseas Development Institute).

As noted at the beginning of this guide, the Framework and its associated self-assessment tool provide a unique overarching perspective on organizational capability for implementing resilience-oriented actions. The guide offers guidance on how to make a transportation agency more capable in planning, providing, operating, and maintaining a resilient transportation system. Many of the other frameworks noted in the table can be used within the overall context of the Framework and the self-assessment tool. Determining organizational capability and capacity, however, needs to be done in a systematic way and requires its own comprehensive analysis approach.

Table 41: Examples of Resilience Frameworks Offered by Other Groups

Name	Group	Date	Description	Relationship to Guide Tool	Source
Resilience: A Primer for Transportation Executives	NCHRP	2020	High-level guidance to DOT chief executive officers (CEOs) on how resilience activities can be considered as part of their responsibilities. Eight categories of actions are presented, e.g., "integrate resilience throughout your agency."	Companion document to this guide. See Table 1 for comparison between this primer and the guide.	https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4260
Cyber Resilience Review	DHS	2017	Focus on cyber protection, assessment seeks to understand an organization's capacities and capabilities in performing, planning, managing, measuring, and defining cybersecurity practices and behaviors in ten domains: (1) asset management, (2) controls management, (3) configuration and change management, (4) vulnerability management, (5) incident management, (6) service continuity management, (7) risk management, (8) external dependency management, (9) training and awareness, and (10) situational awareness.	Tool is a useful more detailed approach for conducting risk assessments by cyberattacks and could be used in concert with this guide for such threats.	https://www.us-cert.gov/sites/default/files/c3vp/crr-fact-sheet.pdf
Vulnerability Assessment and Adaptation Framework, 3rd Edition	FHWA	2017	A manual that helps transportation agencies and their partners assess the vulnerability of transportation infrastructure and systems to extreme weather and climate effects. It also examines how agencies can integrate climate adaptation considerations into transportation decision-making. A framework provides an in-depth and structured process for conducting a vulnerability assessment. The framework describes the primary steps involved in conducting a vulnerability assessment. For each step, the framework features examples from assessments conducted nationwide between 2010 and 2017 and includes links to related resources that practitioners can access for additional information.	Provides approaches to conduct vulnerability assessments and for incorporating results into decision-making.	https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation-framework/

Community Resilience Guide	NIST	2016	For each hazard type, transportation infrastructure assets are identified and categorized by function. For transportation systems operations, resilience measurement focuses on a “bouncing back” aspect of resilience. Highlights the interdependencies of the transportation sector with other sectors, in particular,	Provides a broader community perspective on resilience within which transportation systems constitute one component.	https://www.nist.gov/sites/default/files/community-resilience-planning-guide-volume-2.pdf
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DHS - Department of Homeland Security

FEMA – Federal Emergency Management Agency

NCHRP - National Cooperative Highway Research Program

NIST – National Institute of Standards and Technology

RF - Rockefeller Foundation

Appendix B: Templates for Functional Unit Action

Table 42: Template for Assess Current Practice (Step 1)

Maturity Factor	Points (1 to 3)
Have you conducted and documented a self-assessment of your agency focusing on how effectively resilience is incorporated into agency functions?	
As part of your self-assessment process, have you examined best practices from other agencies and organizations?	
FHWA has developed self-assessment tools for transportation system operations areas aimed at improving the performance and reliability of the road system. Have you used any of these tools to improve the system operations capabilities of your agency: <ul style="list-style-type: none"> • Road Weather Management • Planned Special Events • Traffic Incident Management • Traffic Management • Traffic Signal Management • Work Zone Management 	
Have you used the Cybersecurity Evaluation Tool (CSET) or an equivalent tool to improve the cybersecurity performance of your agency's enterprise and industrial control cyber systems (ICS)?	
Do you review and update your resilience-oriented operations plans?	
Are after-action reports created after major incidents and disruptions?	
Are after-action reports reviewed systematically and analyzed for prospective corrective actions?	
Are maintenance data reviewed to identify assets with previous impacts / repeat failures?	
Have you examined human/physical threats, natural hazards, and cyber threats as potential sources of vulnerabilities to your transportation system?	
Have you reviewed your agency's design criteria to assess their adequacy for enhancing system resilience?	
Have you reviewed staff roles and responsibilities to identify how they relate to enhancing system resilience?	
Have you examined your training/professional development programs for their coverage of resilience?	
Other?	
Score for Assess Current Practice	/36 = %

Table 43: Template for Organize for Success (Step 2)

Maturity Factor	Points (1 to 3)
Does your agency have a resilience strategy/ program?	
Has a document describing your resilience strategy/program been developed?	
Has leadership of the resilience strategy/program been assigned in your agency?	
Have staff been assigned to support the agency's resilience strategy/program?	
Has some mechanism been established (e.g., an advisory group/task force/council) to coordinate resilience efforts?	
Is the agency CEO/director aware of and involved in the resilience program?	
Are department heads within the agency aware of and involved in the resilience program?	
Have resilience-related job responsibilities been assigned to staff?	
Does your agency use quality assurance/quality control processes in managing your resilience program?	
Has your agency been working closely with local communities in supporting local efforts to develop more resilient communities?	
Has coordination occurred with state, federal, and local agencies involved in setting climate adaptation policy?	
Other?	
Score for Organize for Success	/33 = %

Table 44: Template for Develop an External Communications Strategy (Step 3)

Maturity Factor	Points (1 to 3)
Does your agency have an external communications strategy that supports your resilience program?	
Has your agency published a communications plan or documented the strategy in some other way as part of your external communications strategy?	
To what extent has staff from different units in your agency been involved in the development of the external communications strategy?	
Does your external communications strategy provide information on the general topic of resilience as well as background on the natural and human-caused hazards and threats facing the transportation system?	
Does your agency's external communications strategy include multiple means of outreach (written materials, web-based capabilities, social media, speaker's bureau, and the like)?	
Does the external communications strategy include a social media outreach capability?	
Does your agency's website include information on your resilience strategies, programs, and projects?	
Does your agency have a point of contact/ spokesperson on resilience topics, including a contact for incident responses?	
Has your agency coordinated your external communications strategy with other partner agencies?	
Other?	
Score for Developing an External Communications Strategy	/27 = %

Table 45: Template for Implement “Early Wins” (Step 4)

Maturity Factor	Points (1 to 3)
Has your agency undertaken a systematic effort/study to identify those actions that could be implemented quickly and that would enhance system resilience?	
Has your agency adopted a policy where new projects are to explicitly consider resilience in terms of design and operations?	
Has your agency pursued betterments when reconstructing facilities that have been damaged by extreme weather events?	
Does your agency have a program for periodically cleaning culverts and other drainage infrastructure to make sure they will function as designed?	
Has your agency developed a strategy of pre-positioning equipment, materials, and other resources to respond to a disruption and/or support recovery?	
Has your agency developed and approved joint agreements or understandings with other agencies to share resources (e.g., staff and equipment) during emergencies?	
Has your agency developed agreements or understandings with FEMA on procedures and requirements for responding and recovering from a major disruption?	
Have you participated in AASHTO, FHWA, or other professional association resilience efforts?	
Has your agency implemented any resilience- related strategies beyond those listed in this step’s factors that can be considered “early wins” during the past two years?	
Other?	
Score for Implementing “Early Wins”	/27 = %

Table 46: Template for Understand the Hazards and Threats (Step 5)

Maturity Factor	Points (1 to 3)
Have you established a working group for the system-wide assessment?	
Have you identified natural hazards that could impact your transportation system?	
Have you identified physical or human-caused threats that may impact your agency?	
Have you identified cyber threats that may impact your agency?	
Have you identified relevant hazard metrics by asset type?	
Have you collected GIS-based transportation asset data necessary to perform an exposure analysis?	
Have you evaluated the current and future spatial extents of the natural hazards facing your agency?	
Have you identified the transportation assets exposed to the natural hazards?	
Have you developed written documentation that describes the data, methodologies, and the findings of the exposure analysis?	
Other?	
Score for Understanding the Hazards and Threats	/27 = %

Table 47: Template for Understand the Impacts (Step 6)

Maturity Factor	Points (1 to 3)
Have you assessed the potential degree of physical damage to the exposed assets from each hazard or threat?	
Have you estimated how long each asset will be unavailable due to an event?	
Have you identified network interdependencies with other sector networks that interface with your system?	
Have you estimated the socioeconomic costs on the affected communities in response to reduction of service?	
Have you considered the impacts of asset loss within the system for disadvantaged and/or underserved populations?	
Have you considered the impacts of asset loss to critical/lifeline routes?	
Have you considered the impacts of asset loss on freight movement?	
Have you disseminated the results of the impact analysis?	
Other?	
Score for Understanding the Impacts	/24 %

Table 48: Template for Determine Vulnerability/Risk and Prioritize (Step 7)

Maturity Factor	Points (1 to 3)
Have you characterized the vulnerability of each asset to each hazard?	
Have you characterized the vulnerability of each asset for all potential hazards/threats and hazard/threat combinations?	
Have you developed a prioritized list of vulnerable assets?	
Have you communicated the prioritization of assets to agency staff and key external constituencies?	
Other?	Other?
Score for Determining Vulnerability and Prioritize	/12 = %

Table 49: Template for Enhance Emergency Response and Agency Preparedness (Step 8A)

Maturity Factor	Points (1 to 3)
Does the agency have effective internal and external processes for communicating and sharing emergency response information?	
Do you have an “All Hazards Plan” for responding to emergencies?	
Does the agency factor the information obtained from prior emergency incidents or events into its all-hazards response plans?	
Does your agency periodically field test critical emergency management technologies, equipment, and systems to ensure performance?	
Does your agency’s emergency response/ management and security staffs interact with other units in your agency (e.g., planning, design, construction, and operations) to provide input on resilience-related aspects of their efforts?	
Does your agency have a training and exercise program for the emergency response and management program?	
Do your agency’s budget and management support systems consider the staff surge, equipment, and communications system needs of your emergency response and management strategy?	
Does your agency have a “continuity of operations plan” (COOP)/ Disaster Recovery Plan in the event of major disruptions to the agency and/or in the chain of command?	
Does your agency conduct training, drills, and exercises on its COOP/Disaster Recovery Plans, included response procedures and decision-making processes?	
Does the agency have a plan in place to address emergencies associated with Industrial Control Systems (ICS) and Information Technology (IT) System Cyber Threats?	
Has your agency identified cybersecurity roles and user categories for employees and contractors; and, developed and implemented policies and guidelines for these roles and categories (e.g., policies regarding mobile devices) to ensure the protection of the agency against information system external and internal threats?	
Does your agency use basic cybersecurity techniques and cyber hygiene practices?	
Has your agency developed and tested a cyber-incident response and recovery plan with the participation of key stakeholders?	
Does your agency regularly back up agency critical data in an accessible secondary digital location?	
Has your agency established a cybersecurity awareness training program?	
Other?	Other?
Score for Enhancing Emergency Response and Agency Preparedness	/45 = %

Table 50: Template for Identify Enhancements to Operations and Maintenance Activities (Step 8B)

Maturity Factor	Points (1 to 3)
Has your agency assessed current operations & maintenance (O&M) strategies based on potential vulnerabilities identified in Step 7?	
Does your agency provide O&M staff opportunities to report resilience-oriented problems and potential corrective actions?	
Has your agency examined changes vegetation control practices to keep pace with changes in climate (e.g., increase trimming frequency or planting more drought- or heat-tolerant species)?	
Has your agency coordinated the collection of asset condition data as part of its asset management program with on-going maintenance activities in order to identify the total costs of recurring asset failure?	
Does your agency have contingency plans in the event your traffic management centers are disrupted, e.g., alternative ways of providing traveler information when there is a disruption of the electrical grid?	
Has your agency developed field exercises and training exercises for O&M staff on the roles they play in overall system resilience?	
Has your agency implemented a cybersecurity protection plan for critical traffic management center and operations assets?	
Does your agency regularly backup data critical for operations? Is the backup data stored in a location separate from the original source?	
Has a document describing your O&M-related resilience strategy been developed?	
Other?	
Score for Enhancing Emergency Response and Agency Preparedness	/24 = %

Table 51: Template for Undertake Detailed Assessments of Exposed Assets and New Projects (Step 8C)

Maturity Factor	Points (1 to 3)
When projects are being developed, does your agency require the consideration of resilience concerns?	
When projects are being developed, do you utilize projected data on the future frequency, magnitude, and scope of natural hazards?	
When you develop projects, does your agency formally account for the uncertainty in natural hazard likelihood?	
When you develop projects, how are adaptation options determined?	
When you develop projects, do you use resiliency-driven economic analysis to determine the most cost-effective project design?	
Does your value engineering process consider resilience measures as a valid cost?	
Do you consider resilience in facility management plans?	
Do you document how resilience concerns were addressed for each project?	
Other?	
Score for Undertake Detailed Assessments of Exposed Assets and New Projects	/24 = %

Table 52: Template for Integrate into Asset Management (Step 8D)

Maturity Factor	Points (1 to 3)
What assets and asset attributes are included in your asset management process that relates to system resilience?	
Have you integrated vulnerability scores from Step 7 into your asset management plan (TAMP) and TAM process?	
Does your TAM process use asset condition and performance measures relating to natural and human-caused disruptions?	
Does your risk-based, performance gap assessment for your TAMP include risks associated with system resilience?	
Does your TAMP and TAM process use lifecycle costs that reflect potential system disruptions?	
Does your TAMP risk management analysis include risks associated with natural hazards?	
Is your TAMP process linked to your agency's maintenance program such that it considers the trade-offs between today's capital investment and tomorrow's O&M practices?	
Does your TAMP financial plan include a strategy for funding needed improvements to reduce system risks, whether as part of normal capital investment or as a stand-alone funding initiative and improve/enhance system resilience?	
Has your agency considered changes to the asset management process itself so as to enhance the consideration of resilience?	
Has your agency provided training or professional development opportunities to the asset management staff that include how to better consider system resilience in the asset management process?	
Other?	
Score for Integrate into Asset Management	/30 = %

Table 53: Template for Program and Implement Resilience Measures (Step 9)

Maturity Factor	Points (1 to 3)
Has your agency made the business case for investing in resilience-oriented projects and strategies?	
Has your agency/jurisdiction established a resilience project funding category or have you targeted funds to projects whose primary aim is to enhance system resilience?	
To what degree are project resilience-oriented considerations included in the capital program prioritization process?	
To what degree are project resilience-oriented considerations included in non-capital program prioritization processes (e.g., O&M program priorities)?	
Has your agency implemented projects where incremental increases in project costs were allowed to increase system resilience?	
Has your agency participated with partner agencies in jointly sponsoring projects that will enhance overall system resilience?	
If your agency uses public/private/partnership (P3) agreements, to what extent are resilience-oriented performance criteria incorporated into the contractual requirements of the investor/bidder responsibilities?	
Does your agency periodically monitor funding allocations to determine how many projects are being funded that have been defined from Step 8 has having system resilience benefits?	
Other?	
Score for Program and Implement Resilience Measures	/24 = %

Table 54: Template for Monitor and Manage System Performance (Step 10)

Maturity Factor	Points (1 to 3)
Have you identified, and are you using, resilience metrics to monitor transportation system performance and your agency's contribution to system resilience?	
Are the results of resilience performance monitoring reported on a periodic basis to agency leadership?	
Has the monitoring of system resilience led to changes in agency processes or outputs in order to achieve better system resilience?	
Is your resilience monitoring internally consistent amongst agency units?	
Do you monitor the performance metrics of other agencies and partners who have a role in enhancing system resilience (e.g., enforcement or emergency response providers) to determine how your agency's actions affect their overall performance?	
Have you used resilience metrics in communicating to key policy leaders and other decision makers outside of your agency?	
Have you developed and reported on performance metrics relating to incident/event response?	
Have you assigned monetary estimates to the benefits of showing positive resilience outcomes?	
Other?	
Score for Monitor and Manage System Performance	/24 = %