Project No. NCHRP 08-129

INTEGRATING RESILIENCE CONCEPTS AND STRATEGIES INTO TRANSPORTATION PLANNING

CONTRACTOR'S FINAL PROJECT REPORT

Prepared for

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Transportation owners and operators are responsible for delivering a range of services and functions through a complex network of interacting systems. These systems must be managed notwithstanding external threats, aging, and deteriorating infrastructure, and fiscally constrained sustainable resources. Agencies are also moving towards performance-based planning and resource allocation while simultaneously recognizing risks that may undermine their strategic goals. Investing in resilience strategies and enhanced recovery to reduce or eliminate the impact of external events is also paramount to ensuring a thriving, viable transportation system. Resilience planning is an emergent concept reflective of the recognition by transportation planners and operators that business as usual is not working. More effort is needed in the early stages of needs assessment and strategic direction to ensure considerations of uncertainty, external shocks, and societal stressors are incorporated into the transportation system to support resilient infrastructure and the communities.

While state departments of transportation (DOTs) understand the importance of incorporating resilience planning into transportation decision-making, the state of the practice varies. Guidelines are needed to help state DOTs, and other transportation agencies integrate resilience concepts strategically and systematically into the transportation planning process.

The main objective of this research was to develop a guide on how state DOTs and other transportation agencies can integrate resilience concepts into transportation planning efforts at all scales of application.

Research Highlights

This research highlights key areas or building blocks to focus on successfully incorporating resilience into transportation planning. It provides flexible information to identify where agencies are in their journey and what steps and tasks are needed to advance in incorporating resilience into planning and decision making.

In Phase I of the project, the research team reviewed the literature from domestic and international sources and conducted a gap assessment of the state of practice on how transportation agencies incorporate resilience concepts and efforts in planning. Additionally, the research team conducted a virtual stakeholder engagement to validate these gaps and to identify what agencies needed to help them on their journey to incorporate resilience into planning. This engagement was also used to identify candidates for the agency case studies and future engagements.

From there, the research team conducted a series of quick scan case studies with state DOTs, MPOs, and an international transportation agency. The literature review, gap assessment, and quick scans helped identify the key areas or building blocks where attention should be provided for successfully incorporating resilience. The identified areas include 1) leadership and agency

structure, 2) capacity and competency, 3) collaboration and communication, 4) resource requirements, 5) risk and resilience assessments, and 6) business processes.

Four agencies were selected for more in-depth case studies (deep dives). Information regarding the identified six key areas was collected through questionaries and interviews with key agency personnel.

Stakeholder Engagement

From this extensive research and stakeholder engagements, the research team developed a capability maturity framework (CMF) to help transportation agencies measure their maturity in each of the six key areas. In addition to the CMF, this guide includes a roadmap consisting of a step-by-step strategic plan to provide direction for agencies striving to advance their resilience program. The CMF and roadmap formed the basis of the guide produced for this project. Moreover, multiple tasks or actions were identified for each of the key areas to be used by agencies to improve their maturity level in the areas they need most.

These tasks or actions were further validated in a stakeholder engagement where participants had the opportunity to rank the proposed tasks and provide input on the different critical areas for successful incorporation. Finally, the feedback from practitioners was incorporated into the various sections of the final guide.

Guidebook Layout

The key features of the guide include:

- 11 quick scan case studies
- Four deep-dive case studies
- Capability Maturity Framework (CMF)
- Agency Roadmap
- Key Building Blocks and recommended tasks/actions
- Stand-alone Executive Summary

In addition to the guide, the research team also developed an implementation and communication plan with associated material, including two presentation slides and a Fact Sheet or flyer. The two sets of presentation slides include one set tailored to educate transportation agencies on details of the guide and outcomes of the project and a second set tailored to the audience to provide an overview of the project and final products.

The work developed for NCHRP 08-129 identified the key areas that need the most attention to successfully incorporate resilience in transportation planning. It provided the steps, strategies, and tools to guide transportation agencies in this journey.

INTRODUCTION

This document details the research conducted for National Cooperative Highway Research Program (NCHRP) Project 08-129: *Integrating Resilience Concepts and Strategies in Transportation Planning.* This report contains findings from the two phases of the project.

Phase I involved the following activities:

- Develop a robust literature review that investigates resilience concepts and how transportation agencies (State Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) are incorporating those concepts.
- Identify high-priority gaps in the state of practice.
- Stakeholder engagements to validate gaps, identify agencies for case studies, and obtain the necessary information to develop a roadmap and guide to incorporate resilience into transportation planning.
- Develop case studies highlighting the state of practice and lessons learned from transportation agencies.
- Develop a roadmap for further research.
- Interim report and panel meeting.

Phase II activities included:

- Develop strategies and actions to incorporate in the guide for integrating resilience into planning.
- Stakeholder engagement to validate strategies and actions.
- Develop a guide for helping agencies to incorporate resilience into planning.
- Develop an implementation plan.
- Develop communications plans and products.
- Develop final report.

The primary purpose of this report is to document the NCHRP 08-129 research efforts. Another research deliverable, under separate cover, provides a guide, tools, and a roadmap for incorporating resilience concepts and strategies into transportation planning. The steps outlined in this companion document are designed to walk an agency through the process of developing the knowledge, environment, and buy-in to guide transportation agencies on how to incorporate resilience into planning.

Background

With the public's growing attention to disasters, extreme weather, climate change, cyber-terrorism, and recent federal initiatives such as MAP-21, FHWA 5520, and, more recently, the Infrastructure Investment and Jobs Act (IIJA), transportation agencies have come to understand the need to integrate resilience concepts into their policies, planning, programs,

projects, and design information. State DOTs and MPOs have made considerable progress in this endeavor, incorporating risk and resilience goals and objectives into their transportation asset management plans (TAMP) and conducting risk and resilience pilot studies under the auspices of the Federal Highway Administration (FHWA). Nevertheless, recent stakeholder engagement and a literature scan reveal a continuing need for data, tools, metrics, frameworks, and funding. In addition, transportation professionals recognize a need for guidelines to assist state and local transportation agencies in integrating resilience into all levels and aspects of transportation activity.

Given the growing emphasis on resilience, NCHRP 08-129 could not come at a better time. This project aims to guide on incorporating resilience into transportation planning, recognizing the transportation sector's needs for all aspects of a resilience program – leadership, capacity building, data, tools, methodologies, business processes, metrics, and collaboration and communication strategies.

Research Objective

NCHRP 08-129, *Integrating Resilience Concepts and Strategies in Transportation Planning*, aims to develop a guide on how state DOTs and other transportation agencies can integrate resilience concepts into transportation planning efforts.

This research highlights best practices and lessons learned. It presents an agile, flexible guide that reflects where the agencies are in their journey of incorporating resilience into their agencies, particularly in transportation planning. The research approach provides practical advice, case studies, capability maturity framework, key strategies and actions, and an implementation roadmap that agencies can readily apply to incorporate resilience into planning.

Organization of Report

This NCHRP 08-129 final report is organized as follows:

Chapter 1. Introduction – This chapter introduces the report's background, objectives, and overview.

Chapter 2. State of Practice Review – This chapter provides an overview of the resilience frameworks and assessment methodologies, the transportation planning process, and the incorporation of resilience into transportation planning.

Chapter 3. Gap Assessment and Stakeholder Engagement – This chapter provides an overview of the gaps in the state of practice on incorporating resilience in transportation agencies, especially in transportation planning. In addition, it gives an overview of the validation of gaps through stakeholder engagements.

Chapter 4. Components to Effective Incorporation of Resilience into Transportation Planning (Key Building Blocks) – This chapter provides an overview of the identified key areas or building blocks needed for successfully incorporating resilience in transportation planning.

Chapter 5. Agencies Case Studies – This chapter accounts for the surveys and discussions with transportation agencies conducted to perform case studies and illustrate the current state of practice and lessons learned on resilience integration into planning.

Chapter 6. Guidance Development – This chapter describes the development of the guide, the maturity assessment framework, a roadmap, and an industry workshop to validate the guide's strategies and actions.

Chapter 7. Research Outputs and Next Steps – This chapter lists and briefly describes all other documentation created as part of the research effort, including communication material, executive summary, and implementation technical memorandum.

Chapter 8. Conclusions of Research – This chapter summarizes the findings based on a literature review, gap assessment, webinar, surveys and interviews, and industry workshop.

Appendices – The complete literature review, gap assessment, workshop summaries, case studies, communication material, and implementation memorandum are included here.

Key Terms

Risk and resilience are key terms used throughout this report. NCHRP Synthesis 527 found that transportation agencies used the terms risk and resilience interchangeably (Flannery, Pena, & Manns, 2018). Here are some definitions from the literature to provide clarification.

- Risk | "The potential for loss or harm due to the likelihood of an unwanted event and its adverse consequences." (ASME, 2009)
- Risk Assessment | "A process to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability/capacity that could pose a potential threat or harm to people, property, livelihoods, and the environment on which they depend." (UNISDR, 2002)
- Resilience | "The ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events." (AASHTO, 2017).
- Resilience Assessment | "… an assessment of the system's ability to (i) anticipate and absorb potential disruptions; (ii) develop adaptive means to accommodate changes within or around the system, and (iii) establish response behaviors aimed at either building the capacity to withstand the disruption or recover as quickly as possible after an impact." (Francis & Bekera, 2014)

Risk versus Resilience Assessment

Risk assessment and resilience assessment differ in the following ways. Risk assessment measures the likelihood that infrastructure will be negatively impacted, given that an adverse

event occurs. Risk is a measure of loss. In turn, a loss is a function of the event's severity and consequences. In contrast, resilience assessment examines a system's ability to resist, adapt and recover from an adverse event (Francis & Bekera, 2014). Example metrics for transportation resilience include restoration time (number of days until pre-event functionality has been restored), network redundancy (a measure of adaptability), and traffic-related (congestion index, throughput, and travel time) (Sun, Bocchini, & Davison, 2020).

STATE OF PRACTICE REVIEW

Phase I of the research involved developing a comprehensive literature review related to resilience and planning, a gap assessment of the state of the practice, industry engagement ("5-minute Drill"), and case studies. This chapter of the report describes the approaches used by the research team to conduct the state of practice review.

In the literature review, the research team reviewed well over 200 active and past research reports where risk and resilience were discussed in the context of transportation policy and practice. This list consisted of NCHRP reports, Transportation Research Board (TRB) publications, federal, state, and municipal reports, articles from peer-reviewed journals, risk and resilience tools, and federal and state policies and guidelines. In addition, while transportation is the central focus of this project, literature from other relevant fields was included for added insight. The search included:

- Google Scholar
- ResearchGate
- TRB's integrated database (TRID)
- American Association of Statewide Highway Transportation Official's (AASHTO) Transportation Asset Management Portal
- Review of U.S Department of Transportation (DOT) website, as well as state DOT websites and publications

Key observations

The research team made the following observations about the findings in the literature review:

- There is a misconception regarding the difference and relationship between risk and resilience. As a result, transportation agencies consider estimating their risks as their resilience efforts without considering all the phases of resilience.
- Most transportation agencies incorporate risk and resilience assessment into some areas, such as project development, emergency repairs, corridor planning, etc.
- Really few agencies incorporate resilience in transportation planning beyond TAMPs. Those agencies incorporating resilience into transportation planning do it at a high level, such as integrating resilience into their goals and targets.
- Few agencies have conducted pilot projects to investigate the incorporation of resilience into transportation planning
- Most findings were related to vulnerability and risk estimation, not resilience. However, fewer sources highlighted incorporating resilience definitions and metrics beyond risk assessments.
- Agencies estimated risk in a qualitative approach through the use of risk registers

in their Transportation Asset Management Plans (TAMPs) or by using other frameworks and methodologies such as the Federal Highway Administration (FHWA) Vulnerability Assessment Sensitivity Tool (VAST). However, few are using quantitative approaches that can be used to perform economic analysis.

- Most risk assessments conducted by transportation agencies focused on natural hazards.
- Only two sources from the literature thoroughly explored the concept of incorporating resilience in the different transportation planning areas but focused only on natural threats and targeted state DOTs and Metropolitan Planning Organizations (MPO).
- FHWA developed an Infrastructure Voluntary Evaluation Sustainability Tool (INVEST) tool to estimate transportation agencies' and practitioners' sustainability and climate resilience with two modules focusing on transportation planning.
- A recent study (NCHRP 20-117) developed a document, *Mainstreaming System Resilience Concepts into Transportation Agencies: A Guide*, to help transportation officials assess their resilience efforts and provide strategies and actions to help mainstream resilience into their agencies. However, this guide does not focus on incorporating resilience into transportation planning.
- FHWA is currently developing resources to help transportation agencies integrate resilience into the transportation planning process.

The whole literature review is provided in Appendix A of this report.

GAP ASSESSMENT AND STAKEHOLDER ENGAGEMENT

Gap Assessment

When conducting the literature review, the research team focused on possible gaps in the state of practice regarding how agencies incorporate resilience efforts and approaches at all levels in their organizations, particularly in transportation planning. The literature review results helped the research team identify those gaps.

The first gap was the lack of literature devoted to this topic. Keyword searches that include the words "resilience," "planning," and "transportation" yielded the following top search results – FHWA report and pilots, a RAND report, multiple NCHRP projects, TRB circulars, a few metropolitan and state department of transportation reports, and a few peer-reviewed articles pertaining mostly to resilience performance measurements and modeling.

Nevertheless, the current state of the literature yielded the following challenges when incorporating resilience into transportation planning:

- No formal definition of resilience
- Lack of formal/useable metrics
- Lack of a formal framework to assess risk and resilience
- Limited available models and tools to estimate risk and resilience
- Lack of data to support assessment of risk and resilience and validation of existing metrics
- Lack of research on emerging risks
- Need for a multi-discipline and cross-sector resilience approach
- Policies not translating strategies for resilience into practice
- Shortage of policies integrating national with state and local resilience efforts
- Shortage of investment and funding constraints
- Changes in the workforce could result in a need for necessary skillsets
- Lack of support from leadership
- Formal and detailed information on how to incorporate resilience from multiple threats in the different planning areas and levels

The gap analysis further investigated the challenges and barriers uncovered in the literature review helping the research team to develop a preliminary list of gaps that were compiled and organized into 5 categories:

- Policies, Definitions, Leadership, and Communication
- Data, Metrics, Methodologies, and Tools
- Multi-discipline and Cross-Sector System Approach
- Agency Resources and Funding
- Resilience Incorporation in Transportation Plans

A detailed gap assessment is provided in Appendix B of this report.

Stakeholder Engagement

The gap assessment was further validated at a virtual Industry Engagement called "Industry 2-min Drill". The research team conducted an hour and a half-long virtual engagement on December 14, 2020, at 2:30 PM ET. The "Industry 2-min Drill" was hosted through the Zoom online meeting platform and consisted of a short presentation by the research team followed by polling questions using Mentimeter as a polling tool.

The purpose of the "Industry 2-min Drill" was to:

- Identify and define what transportation agencies need to implement resilience into transportation planning successfully.
- Validate findings of gaps in the state of practice found while performing a literature review of the state of practice.
- Identify participants for Quick Scans and Deep Dive case studies.

Invitation to the "Industry 2-min Drill" was distributed to a wide variety of communities through email announcements from multiple TRB and AASHTO committee leaders and individual invitations outside of AASHTO and TRB, including individual invitations to international transportation agencies and universities. Some of the TRB and AASHTO committees that distributed the invitation included:

- AASHTO Committee on Planning
- AASHTO Committee on Transportation System Security and Resilience
- AASHTO Subcommittee on Risk Management
- TRB Committee on Critical Infrastructure Protection (AMR10)
- TRB Committee on Enterprise and Systems Resilience (AMR40)
- TRB Committee on Natural Hazards and Extreme Weather Events (AMR50)

A register was created using the Wufoo tool to track possible attendees to the workshop and necessary information regarding the attendees. People interested in participating in the workshop could use the link provided on the 1-pager to register and provide their contact information and background (see Appendix 2 for the Wufoo workshop register). The workshop had 121 individual registrants on the Wufoo site. However, there were 90 attendees at the workshop. Most of the attendees were primarily employees of state DOTs, with some representation from AASHTO, FHWA, MPOs, transit agencies, private sector, universities, and international agencies. Figure 1 represents a map with the geographical distribution of the

attendees to the industry engagement. Invitations were sent to transportation agencies in all states. States that responded and attended are symbolized in blue.

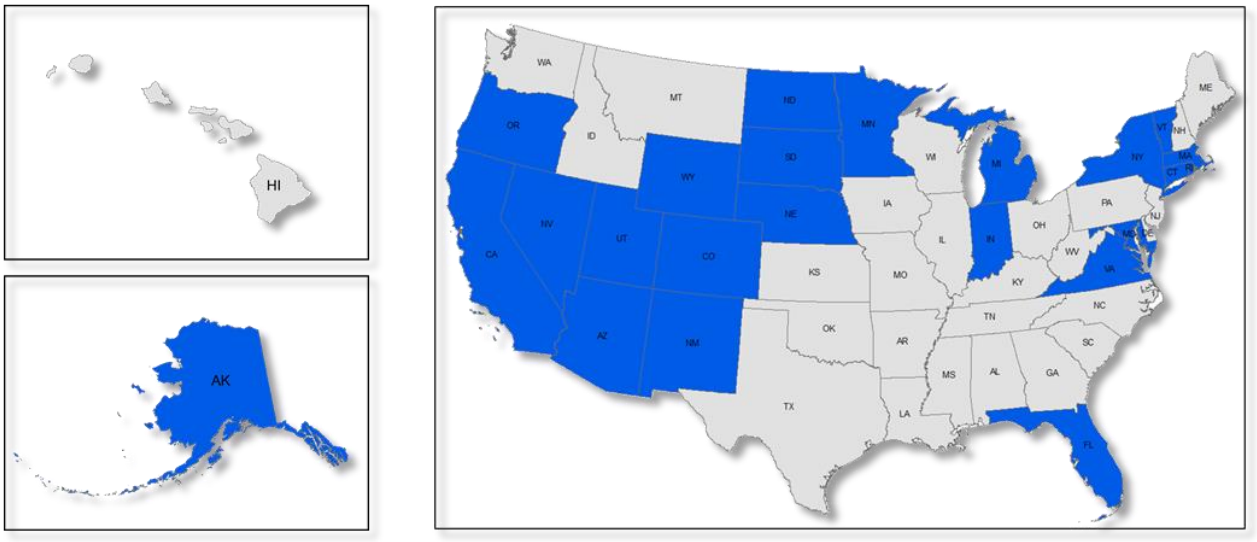


Figure 1. Map with Geographical Distribution of Industry Engagement Participants

The "Industry 2-min Drill" was developed around four main topic areas identified by the research team related to resilience in transportation:

- Resilience Approaches in Transportation Agencies
- Resilience in Transportation Planning
- Resilience and Agency Resources
- Resilience Communication and Collaboration

Summary of results

The results from the "Industry 2-min Drill" can be summarized as follows:

- Transportation agencies are incorporating resilience concepts and approaches into planning at some level.
- There is a need for a more formal definition, policy, process, tools, and metrics to help agencies to incorporate resilience into transportation planning at all stages and plans.
- The most significant benefits of adopting resilience management include proactivity, cost savings in the long term, continuity of operations during a disaster, asset management optimization, performance improvement, safety, increasing society resilience, breaking silos, and preserving connectivity of transportation systems during emergency events among others.
- The top 3 most significant challenges when incorporating resilience into transportation

planning include lack of established performance goals/metrics for risk and resilience, financial constraints, and lack of established assessment methods and tools.

- Need for more resources, including staff, funding, better training related to risk, and resilience assessment/implementation.
- Need for a holistic approach to incorporating resilience into transportation planning. Resilience should include all aspects affecting the transportation system, such as inter-agency communication (breaking silos) and communication among other agencies, cities, and modes of transportation.
- Leadership and champions for the integration of resilience into transportation planning are essential.

A Technical Memorandum summarizing the outcomes of the "Industry 2-min Drill" and the PowerPoint presentation is also provided in Appendix C of this report.

COMPONENTS TO EFFECTIVE INCORPORATION OF RESILIENCE INTO TRANSPORTATION PLANNING (KEY BUILDING BLOCKS)

Based on the information gathered from the literature review, including recent NCHRP studies such as NCHRP 08-36-Task 146- *Incorporating Resilience into Transportation Planning and assessment* and NCHRP 20-117- *Deploying Transportation Resilience Practices in State DOTs*, along with related FHWA projects, the gap assessment, and industry engagement, as well as the research team expertise in the topic, six major components or Key Building Blocks were identified to have effective incorporation of resilience concepts and strategies into Transportation Planning. Figure 2 shows the identified six Key Building Blocks that will be the basis for developing the guide, strategies, and actions.

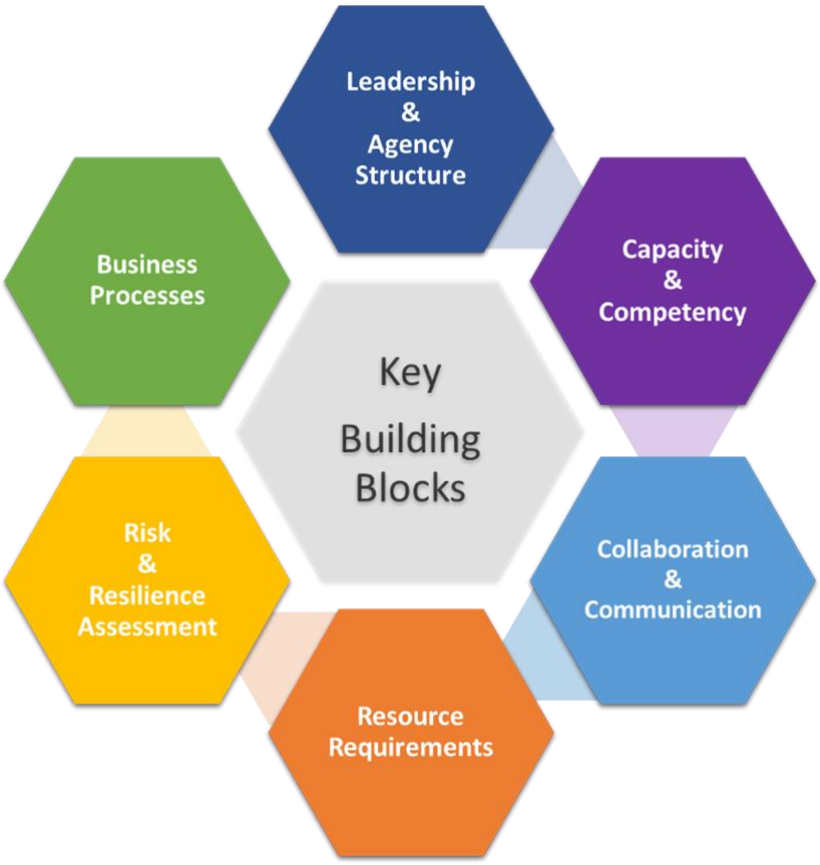


Figure 2. Key Building Blocks for an Effective Incorporation of Resilience into Transportation Planning

Leadership and Agency Structure

Leadership and Agency Structure are part of the key building blocks for successfully incorporating resilience into transportation planning. Leadership and Agency Structure consider the organizational structure of an institution and the level of support and endorsement by leadership. Agency structure determines how the roles, power, and responsibilities are assigned, controlled, and coordinated and how information flows between the different levels of management. Leadership is the art of motivating staff toward achieving a common goal, directing the entire agency toward strategies to move the agency's broader goals forward. Agency leadership helps support and progress toward integrating resilience strategies within transportation planning and enables modifying its organizational structure and policies to facilitate the integration of resilience. The needs and goals of individual departments and functions are incorporated into agency strategy to ensure the long-term success of resilience integration into planning and create a resilience understanding and culture.

Capacity and Competency

Transportation agencies need the capacity and competency to integrate resilient strategies effectively. Fundamentally, employees must have the skills and training to understand and support their roles in incorporating resilience. In addition, expectations and incentives for employees and groups should be tied to effectively integrating resilience within planning. Agency leadership must support resilience efforts and motivate staff to participate. Staffing needs should be regularly evaluated to ensure that new roles are created, and existing functions are modified to support evolving requirements within resilient strategies/practices and mitigation techniques. Furthermore, it is vital that knowledge retention tools and succession planning are woven into agency policy and structure.

Resource Requirements

Providing adequate, appropriate, and timely resources is crucial in developing efforts to incorporate resilience into planning activities. Often common challenges exist around the collection of reliable data and its management via information and communication technology systems, flexible programming, development of appropriate analysis tools, funding, and staffing. To facilitate the incorporation of resilience into planning activities, relevant data sources, computing facilities, funding, and human resources are made available in an appropriate and timely manner. Here there is room for considerable innovation to be applied to maximize the potential of available resources. Furthermore, providing necessary resources to facilitate professional training and development of current and future staff is vital in developing expertise and champions for resilience-related efforts.

Collaboration and Communication

Collaboration and communication with different internal groups within a transportation agency (e.g., planning, operations, emergency response, asset management, engineering, maintenance, etc.) and with other agencies (e.g., MPOs, transit agencies, freight agencies, utility owners and operators, etc.), stakeholders and the public, are critical factors for implementing resilience within an agency, in particular into transportation planning.

Creating these relationships and collaboration processes helps identify the different problems and needs in various agencies and the community and helps develop resilience strategies and plans to make more effective and sustainable decisions in the long term.

Risk and Resilience Assessments

RnR assessments are a critical responsibility of and for DOTs. Different agencies conduct these assessments using different approaches and at different levels. However, the application of RnR assessments in transportation planning varies amongst agencies, with some employing the analysis at a project level but not necessarily in detailed planning activities. As an essential criterion, the scope and boundaries of the analysis should be identified and clearly defined. The outputs of the analysis can facilitate prioritization. It is necessary to understand asset and corridor vulnerabilities and consider criticality in the face of relevant hazards and threats to perform RnR analyses. Assessments may be qualitative or quantitative, or a combination of these depending upon the objective of the analysis, the scale considered, and the available information. Qualitative methods are typically more suited to assess a network or system as a whole rather than individual elements. They can be employed to provide identify high-level results and facilitate comparative analysis. Quantitative tools provide an objective measure such that infrastructure components or networks may be analyzed in greater detail; however, this is commensurate with the level of effort required in the analysis. Quantitative analyses also have the advantage of quantifying uncertainty. The influence of uncertainty on the analysis results can be studied in detail and, where appropriate, reduced through collecting additional information. Key to both methodologies is the definition of risk and resilience thresholds against which the analysis outputs may be compared. This way, a range of actions/interventions can be considered and prioritized from alternative perspectives, e.g., Benefit-Cost Analysis (BCA). A significant benefit of quantitative assessments is objectively ranking alternative strategies.

Business Processes

The business process is a series of steps performed by a team within a transportation agency to achieve a goal. Each step in a business process denotes a task assigned to a team or staff member to ensure a tangible result. The business process within transportation planning provides transportation plans, such as the Long-Range Transportation Plan (LRTPs), Mid-Range

Plans, State Transportation Improvement Programs (STIPs), Freight Plans, etc., some standardized ways and procedures of integrating resilience. Further, that resilience is a component of the various planning documents within the agency. Therefore, business processes for resilience activities across the agency must be clearly defined, understood, and structured to incorporate resilience from a transportation planning perspective.

The six Key Building Blocks formed the basis for the case studies and strategies and actions to be provided in the guide.

DEVELOPMENT OF AGENCY CASE STUDIES

Quick Scan Case Studies

The research team conducted 11 stakeholder engagements (Quick Scans) between January and March 2021. The purpose of the Quick Scans was to gain ground truth concerning how transportation agencies incorporate resilience into their practice and identify the challenges and barriers. The main topics investigated on the Quick Scans included:

- Agency Overview
- Resilience Policies
- Definitions and Frameworks
- Integration Approaches for Resilience
- Resilience Assessment Data, Models, and Tools
- Resilience Performance Measures/Metrics

The Quick Scans included a thorough examination of documents available for selected agencies, a remote interview (Phone or WebEx), and an exchange of information. The methodology for choosing quick scan candidates was as follows:

- The initial list of 12 proposed agencies was based on willingness to participate (from "2-min Drill" engagement), geographical location, size, and type of threats/hazards.
- The list of agencies was revised based on panel comments and suggestions.
- The project team reached out to agencies on the list for confirmation of participation. Few agencies from the original list were not able to participate. However, replacements were found
- The final list of agencies that participated in the Quick Scans included:
  - Maryland DOT (MDOT)
  - Colorado DOT (CDOT)
  - Minnesota DOT (MnDOT)
  - Oregon DOT (ODOT)
  - Vermont Agency of Transportation (VTrans)
  - Georgia DOT (GDOT)
  - Arizona DOT (ADOT)
  - Florida DOT (FDOT)
  - Bay Area Rapid Transit (BART)
  - Texas Capital Area Metropolitan Organization (CAMPO)The Danish Roads Directorate (DRD)-International Agency

The completed 11 Quick Scans for each agency are provided in Appendix D of this report and will also be used as case studies and lessons learned in the guide developed for this project.

Deep Dive Case Studies

Based on the developed "Quick Scans" for the ten national agencies, a decision criteria matrix was designed to identify the four agencies to conduct the Deep Dive case studies. The decision was based on 12 criteria used to assign individual scores. One point was given to each criterion if the agency partially or fully met the standard. A total score was calculated out of 12 maximum points (see Table 1). The selection of the agencies to participate in the Deep Dive case studies was based on the total score, location, agency size, and characteristics. The section below presents the criteria for the decision matrix and each agency's scores.

Decision Criteria:

- Agency has a resilience policy.
- Agency has developed or adopted a resilience definition.
- Agency incorporates resilience into more than two plans or programs.
- Agency incorporates resilience into planning pre-event (e.g., risk assessment).
- Agency has developed or uses publicly available tools for resilience assessment.
- Agency incorporates resilience into planning post-event (e.g., emergency management, operations, etc.).
- Agency coordinates resilience initiatives within agency groups.
- Agency coordinates resilience initiatives with other agencies.
- Agency incorporates identification of resilience strategies into planning.
- Agency Implements resilience strategies into planning.
- Agency has a method for tracking and monitoring the performance of resilience improvement measures.
- Agency has a method to communicate resilience results internally and with stakeholders, the public, and other agencies.

Table 1. Matrix for Selection of Agencies to Conduct Deep-Dives Quick Scans

Agency	Decision Criteria												TOTAL SCORE
	1	2	3	4	5	6	7	8	9	10	11	12	
1. Colorado DOT (CDOT)	1	1	1	1	1	1	1	1	1	1		1	11
2. Maryland DOT (MDDOT)		1	1	1	1		1						5
3. Arizona DOT (ADOT)	1	1	1	1	1	1	1	1	1	1	1	1	12
4. Oregon DOT (ODOT)				1			1	1					3
5. Minnesota DOT (MNDOT)		1	1	1	1	1	1		1			1	8
▪ Vermont Transportation (VTRANS)		1	1	1	1			1	1	1		1	8
7. Georgia DOT (GDOT)			1	1		1		1	1	1			6
8. Florida DOT (FLDOT)	1	1	1	1	1	1	1	1	1	1		1	11
9. CAMPO	1		1				1	1				1	5
10. BART				1	1	1	1						4

Based on the scores obtained using the decision matrix above and other characteristics such as geographical location and agency size, the Project Team recommended conducting the 4 Deep Dives case studies on the following agencies: Colorado DOT, Arizona DOT, Minnesota DOT, and Florida DOT.

As observed on the matrix, Minnesota DOT and VTrans obtained identical scores; however, based on the agency's location, size, and characteristics, the Project Team recommended using MnDOT as a Deep Dive case study. Figure 3, map, shows the spatial distribution of the agencies selected for both Quick Scans and Deep Dives case studies.

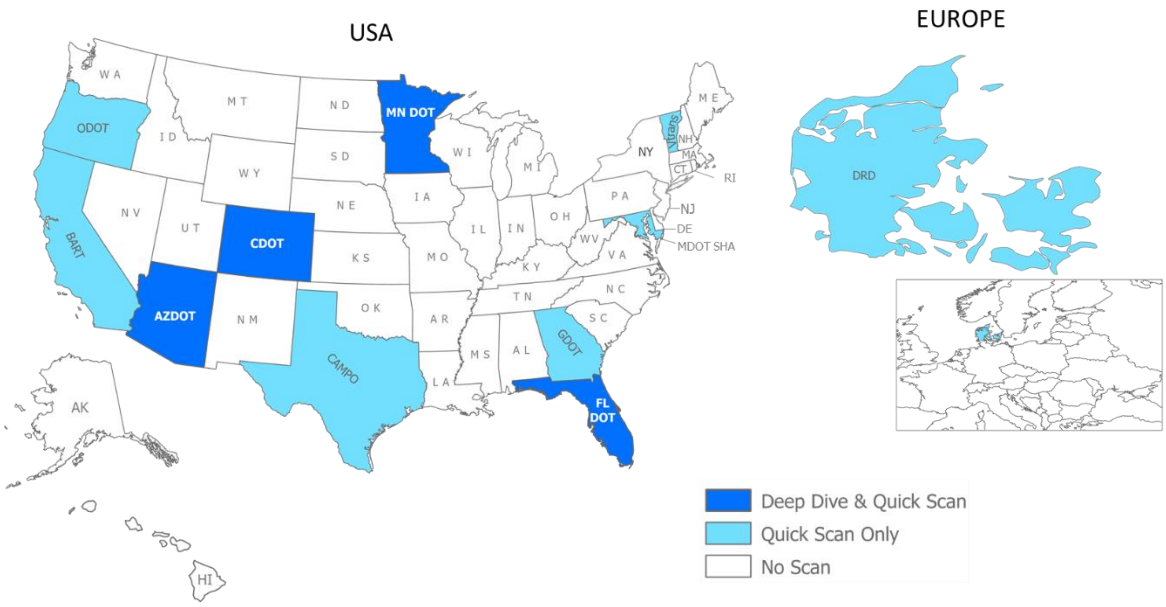


Figure 3. Agencies Selected for Quick Scans and Deep Dives Case Studies

The results of the Quick Scans and proposed agencies for the Deep Dives case studies were discussed and approved by the Panel on April 26, 2021.

Based on the selection of the four agencies, the Research Team developed Deep Dive case studies, including more detailed information on the current state of practice of these agencies and a thorough examination of the plans and programs where resilience is incorporated. The sections on the Deep Dive case studies were developed concerning the six Key Building Blocks identified by the research team and presented in Chapter 4.

A series of questions were developed to conduct the Deep Dives as a basis for the interview. Next, a survey was sent to the agencies participating, followed by a phone interview and follow-up emails to exchange further information.

The four Deep Dives case studies are provided in Appendix E of this report and will also be used as case studies and lessons learned in the guide developed for this project.

GUIDE DEVELOPMENT

The research team developed a guide, building off the literature review, gap assessment, industry webinar, and case studies presented in the previous chapters. The guide is based on the six Key Building Blocks presented in Chapter 4 (Figure 4-1), the capability maturity framework (Figure 6-1), and the resilience roadmap (Figure 6-2).

Agency Capability Maturity Framework (CMF)

Carnegie Mellon University developed the CMF in 1986 as a tool for the federal government to assess the quality of their software developer contractors. Levels of maturity can be thought of as phases of advancement in capability, but "maturity" has no pejorative connotation in this context. Agencies vary in resources and objectives. Understandably, agencies may also differ as to what level of maturity they seek.

A CMF was developed for this project to help agencies identify their capability maturity level for the six Key Building Blocks. Building from the Framework and Self-Assessment Tool from NCHRP 20-117, a more specific framework was designed to focus on resilience in transportation planning. A CMF provides flexibility by focusing on process development and institutional environments, making it a practical framework for research and implementation. Maturity frameworks refer to the degree of formality of processes for an agency or organization, from ad hoc practices to formally defined steps, managed result metrics, and dynamic optimization. A CMF offers an opportunity to the agency for process improvement. Figure 4 provides an overview of the levels for the CMF developed for this project.

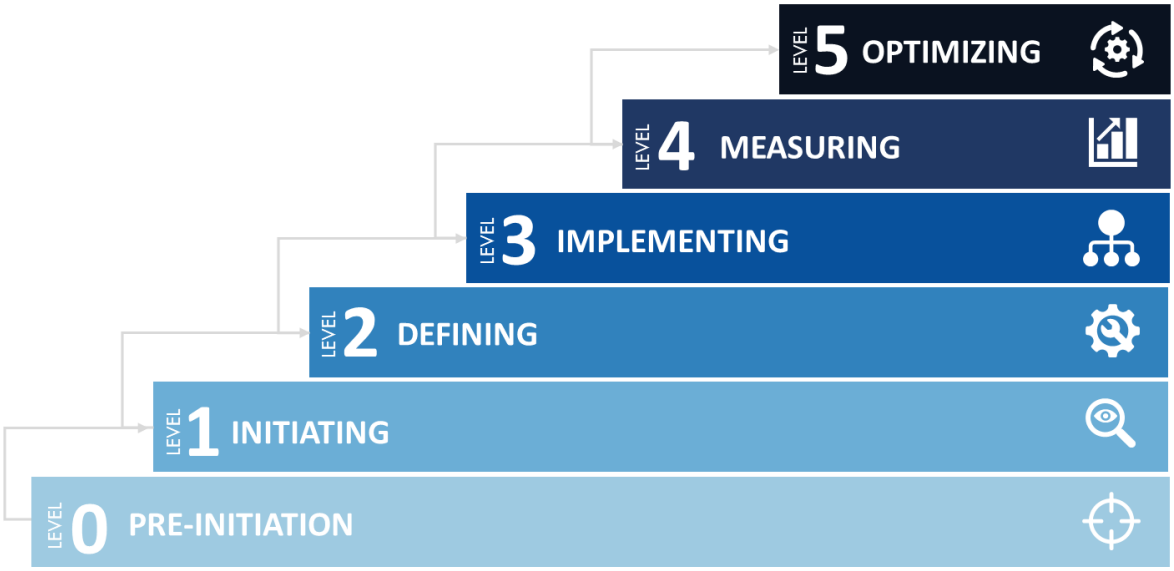


Figure 4. Comprehensive Capability Maturity Framework (CMF)

Specific CMFs were developed for each of the six Key Building Blocks for successful resilience incorporation into transportation planning. Each Key Building Block CMF is presented in Table 2.

Table 2. CMF Self-Assessment Tables

Building Block: Leadership and Agency Structure
Level 0: Pre-Initiation Stage Incorporation of resilience initiatives and strategies into transportation planning has not been initiated
Level 1: Initiating Leadership is beginning to consider incorporating resilience within transportation planning. Discussions are under development but do not align with the organizational agency structure and have not been formally executed within the agency.
Level 2: Defining Resilience strategies within transportation planning are documented and formally endorsed by executive-level management. However, the strategies are not widely shared within the agency and elements may be outdated or inconsistent with current policies.
Level 3: Implementing Resilience strategies within transportation planning are endorsed by executive-level management, fully aligned, and developed with input from a range of staff. They are consistent with other organizational policies and strategies and are committed to continual improvement. The signed-off documents have been communicated to relevant staff at all levels of the agency.
Level 4: Measuring Resilience strategies within transportation planning have been approved and are regularly reviewed and updated to ensure continued alignment with the agency's organizational objectives. In addition, the documents are demonstrably shared with all appropriate stakeholders, feedback is sought periodically, and any relevant updates are made and communicated.
Level 5: Optimizing The agency regularly looks externally to gauge if its agency structure is supportive and optimizing resilience efforts within the agency. Leadership fully supports resilience strategies, and an effective organizational structure incorporates resilience throughout the agency. Agency leadership is committed to monitoring the performance of resilience processes and actions and is continually improving the process.

Building Block: Capacity and Competency
Level 0: Pre-Initiation Stage The agency has not begun looking at necessary skillsets to ensure the incorporation of resilience strategies within transportation planning.
Level 1: Initiation The need to ensure the right skill sets within the agency to deploy resilient strategies across the agency has been elevated. However, a forward-looking approach to defining and understanding the knowledge, skills, and traits needed to create and execute resilience strategies in transportation planning has not yet matured. **Level 2:** Defining Capacity and competency have been identified, and descriptions of what is needed have been created; however, there are no clear strategies to gear up the agency to achieve those skillsets, nor is there a path to manage knowledge. Work within resilience is still being carried out on an ad hoc basis and focuses on short-term and formal requirements for legal compliance.
Level 3: Implementing The agency has identified and understands the skills and knowledge needed to integrate resilience within transportation planning, covering the short, medium, and long-term requirements (considering new technologies and changing skill sets). However, there may be limited staff involvement. Executive management is committed to fully developing and recruiting the right workforce to ensure resilience efforts are fully deployed within the agency, although this may not be implemented entirely. Work is underway that sets out the required competency for each role within resilience efforts but is either incomplete or inconsistently applied.
Level 4: Measuring A competency framework is in place, all relevant staff has been assessed against it, and gaps are elevated. There are documented required skills, knowledge management, and training policies, and those competencies and capacity requirements are communicated to the appropriate staff and are readily available. There is evidence that training is taking place and recruitment of required skills is being acted upon. Executive management and Human Resources are engaged in the periodic review of the resilience efforts within the agency.
Level 5: Optimizing The agency maintains a long-term view of staffing, knowledge management, and training vulnerabilities. It adopts appropriate strategies to mitigate these. Leadership actively incorporates the competency framework in organizational strategic planning activities and regularly reviews the

outputs of applying it to ensure it aligns with changing needs. Junior staff is being actively coached and mentored by senior staff to ensure knowledge transfer in resilience strategies and concepts. Advanced systems capture pertinent information effectively and ensure efficient communication with successors and other relevant staff. Training programs are robust and continually being improved.

Building Block: Collaboration and Communication

Level 0: Pre-Initiation

The agency has not begun collaboration and communication efforts related to resilience concepts and strategies.

Level 1: Initiating

The need for establishing inter- and intra-agency collaboration and communication relationships has been identified. Identify inter-agency groups, other agencies, and stakeholders that would play an important role in incorporating resilience initiatives.

Level 2: Defining

Working groups for inter- and intra-agency collaboration have been established. In addition, strategies to be incorporated into transportation planning have been identified. Initial conversations regarding resilience initiatives and needs are ongoing with internal groups, other external agencies, and stakeholders.

Level 3: Implementing

Inter- and intra-agency working groups and meetings are scheduled regularly to discuss resilience initiatives. An initial process to share data and ideas to support resilience initiatives has been implemented. In addition, conversations for improving collaboration strategies and new partnerships are happening.

Level 4: Measuring

The agency has established a strong collaboration with inter-agency groups and other transportation agencies, public and private sector agencies, and the community. Different groups and agencies are committed to collaborating and have established a relationship to share resilience needs and strategies that enhance the sustainability of the community. Collaboration and communication strategies have been reviewed and approved by all parties involved. As a result, a strong communication strategy for incorporating resilience initiatives in transportation planning is in use.

Level 5: Optimizing

The agency continually looks for new opportunities and partnerships to enhance collaboration and communication among agencies that are essential in improving community resilience. Therefore, the improvement of collaboration and communication strategies is a priority.

Building Block: Resource Requirements

Level 0: Pre-Initiation

The agency has not considered allocating necessary resources for integrating resilience strategies within transportation planning.

Level 1: Initiating

The agency has begun to consider, at a high level, the type and scale of resources necessary for integrating resilience strategies within transportation planning. Goals have been defined and communicated to key stakeholders. Initial scoping studies are underway to plan how the required suite of resources might be allocated.

Level 2: Defining

Resource requirements have been identified and planned with key stakeholders. Procedures and processes have been defined and documented for required data, information, and communication technology (ICT) systems, staffing, and funding resources providing processes by which these can be secured and deployed. In addition, collaborative activities have taken place, with some trial activities within the organization to facilitate optimization of resources, streamline practices, and ensure planned resources are sufficient for incorporating resilience within transportation planning activities.

Level 3: Implementing

Resources have been successfully deployed to facilitate adequate and appropriate incorporation of resilience-related activities into transportation planning. Key performance indicators have been established and implemented to ensure smooth operation and avoid barriers to implementation. In addition, communication, feedback channels, and processes have been instituted to avoid impediments to implementation.

Level 4: Measuring

A high-level group monitors resource allocations with oversight of all relevant activities. Regular reviews and timely updating procedures are implemented and communicated. Impediments are studied with resolutions discussed and agreed with relevant stakeholders. Feedback is sought periodically.

Level 5: Optimizing

The agency continually looks for improvement opportunities to optimize resource allocation processes and procedures to facilitate the total uptake of resilience-related opportunities within the planning process.

Building Block: Risk and Resilience Assessments

Level 0: Pre-Initiation Stage

The agency has not conducted RnR assessments to integrate resilience strategies within transportation planning.

Level 1: Initial Stage

The agency has begun to consider, at a high level, how RnR assessment activities might be integrated into developing resilience strategies within transportation planning. Processes have been considered and potentially established. Goals have been defined and communicated to key stakeholders. A timeline for implementation has been established.

Level 2: Defined Stage

The basis for conducting RnR assessments and the route to their incorporation within transportation planning has been planned, performed, and documented. Internal and external stakeholders have been consulted and onboarded. Procedures have been identified and documented. Initial small-scale pilot studies incorporating RnR assessments into transportation planning activities have been initiated. However, there is still a need for process improvement.

Level 3: Implementation Stage

Application/incorporation of RnR assessments within transportation planning activities is becoming systematic and implemented across relevant agency departments. Issues that have been addressed at Level 2 are being resolved. The agency is more proactive than reactive regarding RnR assessment incorporation into planning activities. Guidance for widespread implementation of RnR assessments across projects, programs, and portfolios is set. There is a comprehensive understanding of challenges, how to address them, and the goals for improvement.

Level 4: Measured Stage

Application/incorporation of RnR assessments within transportation planning activities is monitored top-down and bottom-up. A high-level group has been established to oversee all relevant activities and auditing responsibilities. Regular reviews and timely updating procedures are implemented and communicated. Impediments are studied with

resolutions discussed and agreed with relevant stakeholders. Feedback is sought periodically

Level 5: Optimizing

The agency continually looks for improvement opportunities to optimize the application/incorporation of RnR assessments within transportation planning activities.

Building Block: Business Processes

Level 0: Pre-Initiation

The agency has not begun to ensure that transportation planning business processes include resilience strategies.

Level 1: Initiating

The agency has just started to discuss a planned approach to business processes to ensure incorporating resilience strategies within the various plans developed by the transportation planning division. There is no documented plan for updating the processes & procedures of completing a Long-Range Transportation Plan, Mid-Range Transportation Plan, STIP, HSIP, or Freight plan to ensure incorporated resilience.

Level 2: Defining

The need to create a business process and standard operating procedures (SOP) to ensure resilience strategies are incorporated throughout all the plans created within transportation planning, such as the Long-Range Transportation Plan, Mid-Range Plan, STIP, HSIP, Freight Plan, etc. These business processes are understood, but there has been limited progress in this area. Specific business processes have been considered, and there is interest in developing the business processes and SOPs.

Level 3: Implementing

A specific business process (including process mapping and SOPs has been developed for all key activities and responsibilities for carrying out resilience strategies in all the planning documents generated within transportation planning throughout the agency. The business processes do not yet involve all relevant staff and have not been widely communicated, but process mapping has started, and progress is being made.

Level 4: Measuring

A clear business process (which includes the justification, detail, and timeline for the business processes and SOPs) has been identified for all planning documents such as the Long-Range Transportation Plan, Mid-Range Transportation Plan, STIP, HSIP, Freight, etc. to include resilience

strategies in transportation planning. The business process consists of a wide range of staff and has been communicated to the relevant staff. Clear roles and responsibilities have been agreed upon for implementing a business process to incorporate within each plan created within transportation planning. Appropriate training, support, and compliance with the business process are monitored and reviewed.
Level 5: Optimizing Staff is aware of the need to optimize processes and procedures and highlight where inefficiencies or organizational change are hampering the incorporation of resilience strategies within all the agency planning documents and plans. Resilience strategies are fully incorporated throughout the effective business processes and SOPs in place.

Agency Roadmap to Incorporate Resilience in Transportation Planning

The proposed guide will incorporate a roadmap to help transportation agencies integrate resilience concepts and strategies into their organization and Transportation Planning. Figure 5 shows the proposed roadmap and associated steps.

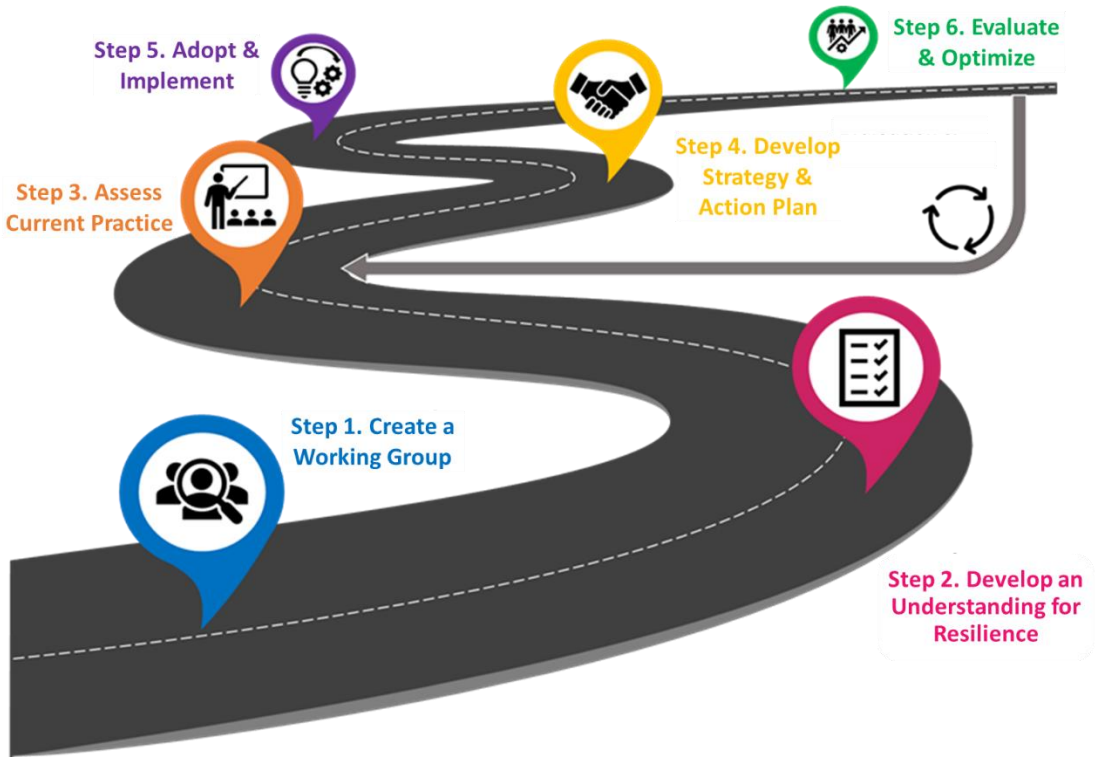


Figure 5. Roadmap to Incorporate Resilience into Transportation Planning

Step 1. Creation of Working Group

The first step in the roadmap involves the identification of champions and key staff from different areas of the agency engaged in transportation planning to create a working group. The working group will lead the process of incorporating resilience concepts and strategies into agency culture and activities, specifically into transportation planning.

Step 2. Develop Understanding of Resilience

Step 2 in the roadmap involves an agency champion or champions and the working group developing training material to provide knowledge and understanding of resilience. Training material can be developed using the information provided in the Guidance Document and various outside resources referenced at the end of Step 1. Some of the key topics to be included in the training material are:

- Risk and resilience definitions
- Understanding the difference between risk and resilience

- Detailing existing methodologies to estimate risk and resilience
- Implementation of risk and resilience analysis in different areas of the organization, including transportation planning
- Benefits of implementation of risk and resilience decision-based strategies

Step 3. Assess Current Practice

This step involves the assessment of the agency's level of maturity regarding the incorporation of resilience concepts and strategies in transportation planning. The Capability Maturity Framework (CMF) provided in Chapter 6.1 is for that purpose. In addition, the agency can measure its level of maturity at each of one of the Key Building Blocks that are needed to incorporate resilience into transportation planning, i.e.:

- Leadership and institutional capacity
- Capacity and competency
- Collaboration and communication
- Resource requirements
- Risk and resilience assessments
- Business processes

The provided CMF applies six levels of capability maturity. Using the CMF, the agency can determine its capability maturity level for each one of the core Building Blocks. The levels of capability maturity are:

- Level 0. Pre-Initiation
- Level 1. Initiating
- Level 2. Defining
- Level 3. Implementing
- Level 4. Measuring
- Level 5. Optimizing

Step 4. Develop Strategy and Action Plan

Based on the agency's assessment of their capability maturity levels identified in Step 3, the agency can develop an action plan to improve their capability maturity in each/all of the core Building Blocks by identifying possible strategies as provided in the Guidance Book. In addition, the agencies can determine how robust and efficient they genuinely want to become in all the areas of the core Building Blocks and can focus on priorities to ensure advancement within specific building block areas that have been identified as a priority.

Step 5. Adoption and Implementation of Action Plan

In this step, the agency will adopt and implement the developed action plan with the identified strategies from Step 4. The agency must identify the key component to support the adoption and implementation of the necessary process, including people, resources, structure, systems, and culture. All these components must be in place to move from the action plan development to the activation. In addition, it is critical to specifically outline the needed tasks that should be completed within the action plan and create some type of accountability (through performance measures) to ensure progress is being made.

Step 6. Evaluation and Optimization of Action Plan

It is essential to evaluate and optimize the plan as needed. As part of the monitoring actions, evaluate each strategy from the action plan to ensure it has been implemented correctly, on time, and achieved the expected outcome. The action plan must be continually improved based on the success of implemented strategies and new requirements and needs that may arise with time.

Industry Workshop for Guidebook Validation

The research team conducted a second and final invitational 3-hour virtual industry engagement on December 15, 2021. Thirty-four participants from 18 states plus the District of Columbia, Maricopa County, Arizona, and the New Jersey Transportation Planning Authority, were represented. Figure 6 shows the geographical representation of participants.

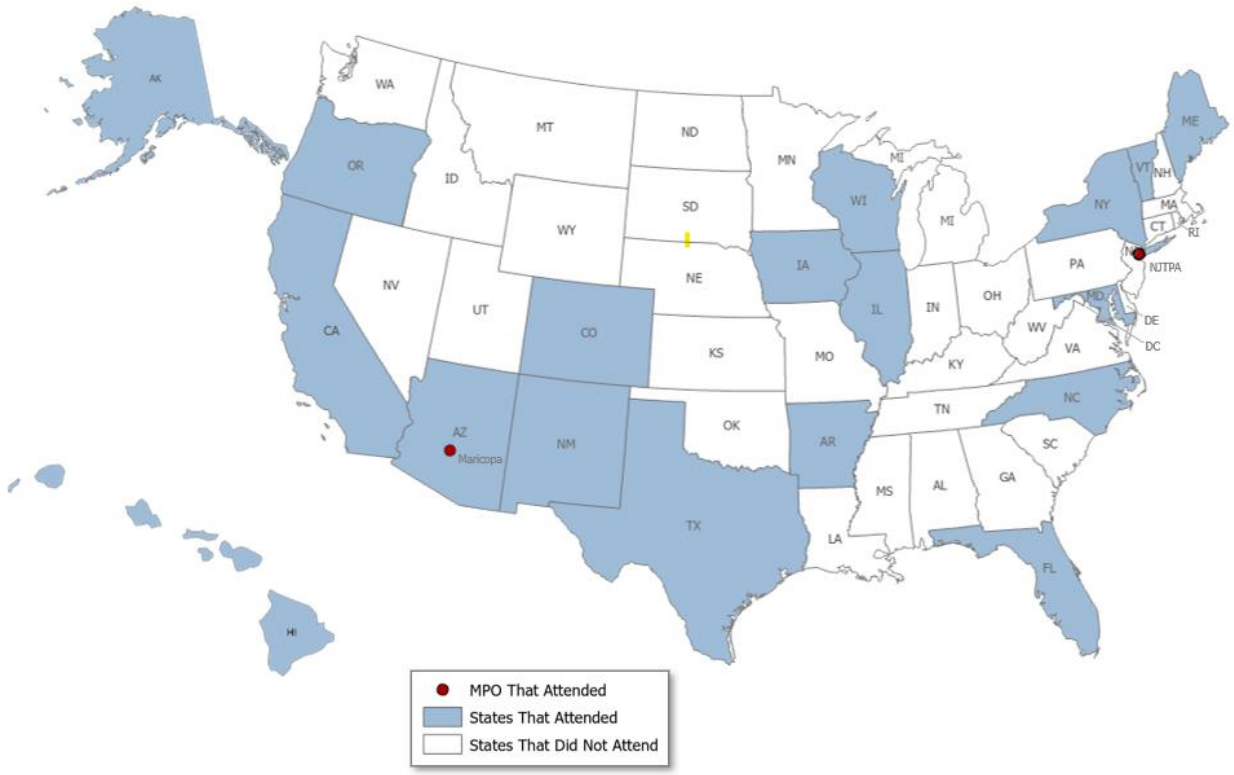


Figure 6. Map of Geographical Distribution of Workshop Attendees

The workshop was hosted through the Zoom online meeting platform and consisted of a short presentation by the research team, followed by polling questions using Mentimeter as a polling tool. The polling questions were followed by open conversation and participation of the attendees.

The workshop's purpose was to receive feedback from transportation agencies, especially state DOT professionals, to validate and enhance proposed strategies and tasks/actions for incorporating resilience into transportation planning.

The guide's key components include the 6 Key Building Blocks or strategies for incorporating resilience into planning, the roadmap, and the CMF. The workshop focused on presenting and soliciting feedback on tasks/actions proposed to support the 6 Key Building Blocks or strategies. The 6 strategies are:

- Leadership and agency structure
- Capacity and competency
- Collaboration and communication
- Resource requirements
- Risk and resilience assessment
- Business processes

The 6 strategies were subdivided into sub-strategies when appropriate. A total of 71 tasks/actions were proposed to support the strategies/sub-strategies and to be validated and discussed with the workshop participants. The feedback from this workshop was incorporated into the different guide sections.

The complete technical memorandum documenting the findings from this workshop can be found in Appendix F.

RESEARCH OUTPUT, RECOMMENDATIONS FOR FUTURE RESEARCH, AND NEXT STEPS

This section summarizes the outputs of this NCHRP 08-129 project, recommendations for future research, and recommended next steps.

Research Outputs

In addition to this final research report, other outputs of this research include:

- Guidebook for Incorporating Resilience in Transportation Planning – The guide corresponding to this research report builds off the literature review, gap assessment, industry webinars, and case studies with various transportation agencies. The guide is based on the six Key Building Blocks presented in Chapter 4 and integrates the CMF from Chapter 6.1 and the agency roadmap from Chapter 6.2. In addition, the guide provides multiple tasks/actions for each of the Key Building Blocks to help transportation agencies successfully incorporate resilience into planning based on their capabilities.
- Executive Summary – This is a stand-alone document that summarizes the key points of the guide and critical elements for successfully incorporating resilience.
- Implementation and Communication Technical Memorandum – The implementation plan recommends actions for disseminating and promoting the research products of NCHRP 08-129. In addition, the plan describes channels, venues, and professional organizations that will potentially assist in sharing and marketing the research products. See Appendix G for the entire implementation plan for this project.
- Communication Material –The communication material is designed to support the Implementation and Communication Plan and includes a *fact sheet* and *one set of presentation slides*. The fact sheet concisely helps to communicate the importance of incorporating resilience into planning and highlights the main sections of the guide. The presentation slides provide an overview of the project and can be used to advertise the outcomes of NCHRP 08-129. See Appendix H for the communication products developed for this project.

Opportunities for Implementing the Guidebook

The research team recognizes that the first step towards implementation is getting the word out by marketing the research through channels and organizations with a beneficial interest in the subject. There are such channels and organizations available. Primary means for promoting this research include distributing the guide, webinars, conference presentations, and workshops.

- Guide – The *NCHRP Research Report 1052: Incorporating Resilience Concepts and Strategies into Transportation Planning: A Guide* presents the roadmap, tools, and methodologies for developing a resilience-centric organization. The guide can be used as a guide by agencies

interested in initiating or expanding their resilience efforts in transportation planning. We propose the following distribution channels for the final report:

- Post the guide on the TRB website.
- Include a write-up in the TRB and AASHTO email newsletters to encourage. Transportation agencies to implement the findings and recommendations.
- Make an announcement to be posted to AASHTO's Transportation Asset Management. Portal Management Hub which provides access to an extensive menu of asset management resources, including tools, NCHRP reports, videos, training materials, and links to events: https://www.tam-portal.com/.
- Announce related TRB committees and subcommittees meeting newsletters or web presence, including AMR10 (Critical Infrastructure) and AMR20. (Disaster Response, Emergency Evacuations, and Business Continuity), AMR40 (Systems, Enterprise and Cyber Resilience), AMR50 (Extreme Weather and Climate Change Adaptation), ABC40 (Asset Management), AEP10 (Planning Policy and Processes), AEP15 (Planning Analysis and Application) and other committees on the Transportation Sustainability and Resilience Group.

- Webinar – FHWA hosted the AASHTO TAM-Guide Book Club webinar series. The complete series consisted of 8 webinars. Webinar number 5 was devoted to risk and resilience. The NCHRP 08-129 research team developed communication materials for webinars and presentations to develop the final products for this project. The research team can draw from these materials to develop a series of interactive webinars to cover the concepts and tools included in the guide:
  - Building blocks for resilience
  - CMF
  - Roadmap
  - Strategies for incorporating resilience into the building blocks
  - Case Studies

Each webinar would highlight opportunities and best practices for incorporating resilience into business processes and daily operations with examples from case studies. In addition, participating transportation agencies engaged in risk and resilience pilot studies or similar resilience initiatives could present their findings and lessons learned.

- Conference presentations and workshops – There is a multitude of opportunities to present materials like the proposed webinar series. Suggested conferences to target are proposed here:
  - TRB Annual Meeting, January 8 -12, 2023, Washington, D.C., provides several channels for sharing NCHRP 08-129-related materials--posters, conference sessions, and

subcommittee meetings. The abstract deadline has not yet been posted. https://www.trb.org/Calendar/Blurbs/180118.aspx
- AASHTO Spring and Annual Meeting 2023. All details are TBD. The AASHTO Spring and annual meetings provide opportunities for networking and knowledge exchange. https://meetings.transportation.org/overview/
- AASHTO Committee on Transportation System Security and Resilience Annual Meeting 2022 is another opportunity for peer exchange and technical sessions. All details are TBD. https://ctssr.transportation.org/annual-meetings/
- National Governor's Association Annual Meetings 2022-2023. Twice a year, the nation's governors meet to discuss the critical issues states face, such as pandemics and disaster response. The venue includes plenary sessions and committee meetings. https://www.nga.org/about/meetings/
- Western Governor's Association Annual Meeting 2022, July 25 – 28, will cover such topics as drought, cybersecurity, and clean energy with regional experts. https://westgov.org/meetings/details/2022-annual-meeting
- International Association of Critical Infrastructure Professionals Critical Infrastructure Protection & Resilience North America conference 2023, details TBD. https://www.ciprna-expo.com/
- ASCE Lifelines Conference 2023 TBD. https://www.asce.org/education-and-events/events/meetings/asce-ucla-lifelines-2022-conference/

- Multi-agency workshops & peer exchanges – A multi-agency workshop or peer exchange would provide an opportunity to share ideas and best practices through a collaboration of peers and experts. For example, the research team could develop, organize, and manage a 1-to-2-day interactive workshop with representatives from across the nation to discuss the research products and ways to implement the guide and associated tools.

Recommended Next Steps

The research team recommends two main tracks for the following steps: development of research to support agencies in conducting risk and resilience (R&R) assessment and management; and follow-up projects that build on the guide developed in this project.

- Development of research to support agencies conducting risk and resilience (R&R) assessments and management. Interest and need for incorporation of resilience in transportation planning were demonstrated during this research with the case studies and stakeholder engagements. However, there is still a need for standardized methodologies and tools to support resilience assessments and identify and prioritize resilience strategies. Therefore, efforts are aimed at developing these methodologies and tools, such as the NCHRP 23-09 project, which developed a research roadmap for developing a standardized manual to conduct quantitative R&R assessments, and the new *NCHRP 23-24 Methods to Allow Agencies to Incorporate Quantitative Risk Assessment at Project and Network Level* among others.

- Follow-up projects to NCHRP 08-129. The research team recommends piloting the guide with multiple transportation agencies, state DOTs, MPOs, etc., to obtain their feedback after implementing the capability maturity framework, roadmap, and tasks and actions provided for each Key Building Block.

CONCLUSION

This research validated the need and desire for transportation agencies to incorporate resilience into transportation planning. In addition, it helped identify the state of practice, successes, challenges, and gaps for integrating resilience in planning. At the time of this research, few transportation agencies were fully incorporating resilience into all planning activities. Moreover, the maturity level of resilience programs differs from agency to agency. However, as identified in this project, agencies do not need to achieve the highest level of maturity in this process, and it will depend on each agency's needs, capability, and resources.

The work completed in NCHRP 08-129 provides the necessary steps and tools to guide transportation agencies to incorporate resilience in transportation planning at the level that agencies feel more appropriate. By implementing the provided guide, agencies can make better-informed decisions, be more efficient and become more resilient.

APPENDIX A – LITERATURE REVIEW

Methodology for The Literature Review

The research team conducted a comprehensive literature review, focusing on resources relevant to incorporating resilience practices into transportation planning. This report is the result of that effort. The methodology for conducting the review followed a three-step process: (1) finding documents for review, (2) organizing and reviewing documents, and (3) presenting the results in this report.

Finding Documents for Review

The research team compiled a working list of over 200 active and past research reports where risk and resilience management were discussed and made a final selection of 193 for this report (See Appendix A). This information consisted of NCHRP reports, Transportation Research Board (TRB) publications, miscellaneous federal, state, and municipal reports, articles from peer-reviewed journals, risk and resilience tools, and federal and state policies and guidelines. While transportation was the focus, other relevant fields were included for added insight. The list of search tools included:

- Google Scholar
- ResearchGate
- TRB's integrated database (TRID)
- American Association of Statewide Highway Transportation Official's (AASHTO) Transportation Asset Management Portal
- Review of U.S Department of Transportation (DOT) website, as well as state DOT websites and publications

Organizing and Reviewing Documents

The research team developed an excel spreadsheet, listing each reference with a hyperlink to the source document for easy access. In addition, the references were ranked based on their level of importance and applicability. Priority was given to transportation-related publications (TRB, AASHTO, state DOTs, etc.) and papers directly relating to the research question topics. The team rated each publication by relevance on a scale from 1 to 3.

1. Contains some relevant information but does not align well with the objective of the report.

2. Contains moderately relevant information and can be included if it supports the overall objective of the report.

3. Contains highly relevant information and should be included in the report.

Resilience Policies in Transportation

Federal Resilience Initiatives

The September 11, 2001, terrorist attacks, the 2017 WannaCry ransomware attack, and the recent COVID-19 pandemic have energized the federal government to safeguard the nation's critical infrastructure against the threats of terrorism, and cyber warfare, climate change, and other hazards. Key pieces of legislation and federal policy are addressed in Table 3.

Table 3. Regulatory Drivers for Resilience

Legislation	Description	Year
Presidential Directive 63 (PDD-63)	In June 1996, it was established the President's Commission on Critical Infrastructure Protection (PCCIP) to investigate the vulnerabilities and threats to the nation's critical infrastructure (CI) with a focus on cyber security (President's Commission on Critical Infrastructure Protection, 1997) In 1998, PCCIP was followed up with PDD-63 (Clinton, 2015). PPD-63 identifies transportation as one of 8 critical infrastructures and describes a strategy for cooperation between the private and public sectors to establish a framework for critical infrastructure protection.	1998
The National Infrastructure Protection Plan (NIPP)	PPD-63 served as the basis for the NIPP. The purpose of the NIPP is to promote collaboration within the infrastructure community and build upon public and private partnerships with the objective of advancing the nation's security and resilience. The most recent version of the NIPP was published in 2013.	2006 (revised in 2009 and 2013)
Moving Ahead for Progress in the 21st Century Act (MAP-21)	On July 6, 2012, the transportation authorization bill MAP-21 (Moving Ahead for Progress in the 21st Century (MAP-21), 2012) was signed into law. Section 503 of the Act addresses research and development and states that research and technology activities carried out under this section may include studies of infrastructure resilience and adaptation measures. Section 167 says that the goal of the national freight policy is to improve "the safety, security, and resilience of freight transportation."	2012
EO 13653 – Preparing the United States for the Impacts of Climate Change	Signed into law on November 1st, 2013, under EO 13653, each Federal agency must enhance the nation's preparedness for climate change.	2013
FHWA Order 5520 - Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events	To implement EO 13653, Federal Highway Administration (FHWA) issued FHWA Order 5520, establishing FHWA's policy on preparedness and resilience to climate change and extreme weather events. The order addresses language in Title 23 United States Code (USC) that stresses the need to consider the impact of extreme events on programs	2014

Legislation	Description	Year
	and project delivery to comply with Executive Order 13653.	
The Fixing America's Surface Transportation (FAST) Act	On December 4, 2015, the FAST Act (Fixing America's Surface Transportation Act, Vol. 6), a $305 billion, 5-year authorization bill was signed into law. The FAST Act added language concerning resilience to Title 23 (highways) and Title 49 (transportation) of the US Code. The FAST Act required transportation agencies to consider resilience during the planning process.	2015
23 CFR 450.206(a)(9), 23 CFR 450.306(b)(9), and 23 CFR 324(g)	In response to the FAST Act and MAP-21, the FHWA and the Federal Transit Administration (FTA) updated transportation planning regulations for MPOs and State DOTs. The new planning rules include • A provision requiring MPOs to consider "improving the resiliency and reliability of the transportation system" in their planning (23 CFR 450.206(a)(9) and 23 CFR 450.306(b)(9)). • A recommendation for MPOs to develop their transportation plans and transportation improvement program in consultation with stakeholders responsible for natural disaster risk reduction (23 CFR 450.316(b)). • A mandate requiring metropolitan transportation plans to reduce the vulnerability of existing transportation infrastructure through capital investment and other means (23 CFR 450.324(g)(7)).	2016
23 CFR 515 - Transportation Asset Management Plans (TAMPs) Requirements	23 CFR 515 states that all State DOTs should develop risk-based asset management plans and must address risks associated with current and future environmental conditions. Periodic reviews described in 23 CFR Section 667 require TAMPs to incorporate the following. Specifically by April 2018, TAMPs should: • Establish a planning process for the full life cycle of assets that considers current and future conditions, i.e., climate change, extreme weather events, seismic events, etc. (23 C.F.R. 515.7(b)). • Establish a risk-based asset management plan that includes risk assessments that address current and future conditions, manage reoccurring damage and the associated costs, estimate the likelihood of risks, prioritize risks,	2017

Legislation	Description	Year
	and develop a mitigation plan for the highest priority risks (23 C.F.R. 515.7(b)).	
23 CFR Section 667 – Periodic Evaluation of Facilities Repeatedly Requiring Repair and Reconstruction due to Emergency Events	To conserve Federal resources and promote public safety, MAP-21 requires State DOTs to conduct periodic statewide evaluations of the road (including pavement surfaces and culverts), highways, and bridges that have needed repairs or reconstruction on two or more occasions due to catastrophic events and decide whether there are suitable alternatives. Specific deadlines for implementing this policy were published in 23 CFR Section 667. States had to do the first review by November 23, 2018, and then update the reviews every four years as needed. Follow-on reviews had to be completed by November 23, 2020. The results of these reviews must be summarized in TAMPS and integrated into transportation plans and programs (National Academies of Sciences, Engineering, and Medicine, 2020).	2017
EO 13834 – Efficient Federal Operations	"Executive Order 13834, signed on May 17, 2018, directs Federal agencies to manage their buildings, vehicles, and overall operations to optimize energy and environmental performance, reduce waste and cut costs." (USDOT, 2018) NOTE: Executive Order 13834. Efficient Federal Operations was revoked [except for Sections 6. Duties of the Federal Chief Sustainability Officer, Section 7. Executive Order (EO) 13834: Efficient Federal Operations was signed by President Trump on 17 May 2018	2018

State Resilience Policies

In response to MAP-21 and the FAST Act, state governments and transportation agencies have begun developing their resilience policies. This section gives examples of resilience policies from California, Maryland, Delaware, New York, New Jersey Port Authority, Colorado, and Florida (see Table 4).

Table 4. State Resilience Policies

State	Year	Title	Purpose
CA	2008	EO S-13-08	In November 2008, the Governor signed Executive Order (EO) S-13-08, requiring state agencies to consider sea-level rise (SLR) projections when planning construction projects in areas vulnerable coastal areas. California Transportation Department (Caltrans) staff can use this guide to determine how to integrate SLR projections with programs and project designs.
MD	2012	Climate Change and Coast Smart Construction EO	In December 2012, the Governor signed the Climate Change and "Coast Smart" Construction EO, including policies intended to increase Maryland's resilience to SLR and coastal flooding. Maryland responded to the EO with recommendations for the siting and design of state infrastructure to be included in state policies, programs, tools, and other resources.
DE	2013	EO 41	In September 2013, the Governor established the Governor's Committee on Climate and Resiliency by signing EO 41, Preparing Delaware for Emerging Climate Impacts and Seizing Economic Opportunities from Reducing Emissions. This executive order guides state agencies in minimizing the flood risk to state assets. It requires considering current and future flood risks during the planning and design of public buildings and infrastructure.
Port Authority of NY and NJ	2015	Climate Change Guidance	The Port Authority of New York and New Jersey published design guidance in 2015 on how to account for projected changes in precipitation, temperature, and SLR and how to establish the flood protection criteria for projects.
CO	2015	New Policy Directive 1905.0	On November 15, 2018, the Colorado Transportation Commission issued New Policy Directive 1905.0, "Building Resilience into Transportation Infrastructure and Operations." This directive requires the Colorado DOT to proactively manage the risk from floods, rockslides, avalanches, and manmade hazards by identifying threats and developing plans to reduce losses, minimize vulnerabilities, and minimize consequences to Colorado assets. The directive's scope extends to daily operational and enterprise activities and includes both physical and cyber threats. The

State	Year	Title	Purpose
			Resilience Program Coordinator must support Department staff in implementing resilience activities, research, creating a knowledge base, and identifying best practices.
FL	2020	Policy 000-525-053	In April 2020, Florida DOT Secretary Thibault signed Policy 000-525-053, Resiliency of State Transportation Infrastructure, to consider resiliency and incorporate resiliency into the Department's business practices and planning efforts.

International Resilience Policies

The international community has aggressively pursued new research and policies to enhance infrastructure resilience in the face of climate change and extreme weather. Table 5 lists some examples:

Table 5. International Resilience Policies

Policy	Description
European Union's Transport 2050 Roadmap	In 2011 the European Union published its "Transport 2050 Roadmap," which outlines a broad array of initiatives. For example, initiative number 34, under "Modern Infrastructure and Smart Funding," states the goal of ensuring that EU-funded infrastructure includes considerations for energy efficiency and climate change (EU Commission, 2011).
European Commission's 2013 Strategy on Adaptation to Climate Change	The European Commission's 2013 Strategy on Adaptation to Climate Change states three primary objectives (EU Commission, 2013a) 1. To increase the resilience of EU countries, regions, and cities. 2. To better inform decision-making on adaptation. 3. To increase the resilience of critical vulnerable sectors and EU policies. Annex A of the accompanying Staff Working Document (2013) (EU Commission, 2013b)addresses the anticipated impacts of climate change on transportation systems in Europe.
Great Britain's 2013 National Adaptation Program	Great Britain's 2013 National Adaptation Program includes actions to bolster transportation resilience. Specifically, the Department for Transportation is tasked to include climate change in its Transport and Roads Strategies (Great Britain, 2013)

Policy	Description
MOWE-IT	The MOWE-IT project, funded by the European Commission's 7th Framework Program, 2014 published its "Guidebook for Enhancing Resilience of European Rail Transport in Extreme Weather Events" (Silla, et al., 2014) . The goal of this project was to assist transport operators, authorities, and transport system users mitigate the impact of natural hazards and extreme weather on the performance of transport systems.
Canada's 2019 Emergency Management Strategy	Canada's 2019 Emergency Management Strategy addresses 5 national priorities (Canada, 2019): 1. Enhance whole-of-society collaboration and governance to strengthen resilience. 2. Improve understanding of disaster risks in all sectors of society. 3. Increase focus on whole-of-society disaster prevention and mitigation activities. 4. Enhance disaster response capacity and coordination and foster the development of new capabilities. 5. Strengthen recovery efforts by building back better to minimize the impacts of future disasters.
Ireland's Climate Action and Low Carbon Development Bill	--Ireland's Climate Action and Low Carbon Development Bill, promulgated in 2020, aims to make the Irish economy carbon neutral and climate resilient by 2050 and includes policies to reduce greenhouse gas emissions by 7% annually (Ireland, 2020)
The World Road Association's 2020-2023 Strategic Plan	The World Road Association's 2020-2023 Strategic Plan promotes these strategic themes: road administration, mobility, safety and sustainability, and resilient infrastructure. In addition, Strategic Objective 1.4.1 includes identifying hazards and environmental threats, approaches to risk management, the economics of resilience management, and integrating resilience into asset management practices (Work Zone Data Exchange (WZDx) Specification - v2.0, 2020).

Funding for Resiliency

There is increasing recognition that the nation has lacked the political will to make the necessary investments in resilience (J. Baylis, 2015) -- mainly because the threats of concern are high consequence but low probability. While financing resilience projects can be challenging, there are several federal sources that state DOTs and MPOs can access under certain circumstances, including funding available due to federal disaster declarations. Examples include the Stafford Act, Federal Emergency Administration (FEMA) Emergency Relief Grants, the Federal Transit Administration Relief Fund, and the new PROTECT program (see Table 6).

Table 6. Funding Programs for Resilience

Funding Program	Description
FHWA Emergency Relief and FEMA Recovery Grants (Robert T. Stafford Disaster Relief and Emergency Assistance Act. Public Law 93-288, 1988)	Transportation agencies can access FHWA Emergency Relief (ER) funds to repair roadways damaged by natural disasters. This program will provide 80-90% of the funding needed to make repairs. ER funds are intended to repair a road to its pre-disaster condition. However, betterments, i.e., improvements, may be authorized if the betterment will reduce the chance of damage in the future and the betterment is cost-effective (National Academies of Sciences, Engineering, and Medicine, 2020a), (Kirk, 2012)
The Stafford Act	This act amended the Disaster Relief Act of 1974, Public Law 93-288. The Stafford Act authorizes Federal disaster relief activities, especially those of FEMA (Robert T. Stafford Disaster Relief and Emergency Assistance Act. Public Law 93-288, 1988). The Disaster Recovery Reform Act of 2018 amended the Stafford Act to permit grantees to use funds to update facilities to the latest codes and standards (Pub. L. 115-254, 2018). In addition, the Building Resilience Infrastructure and Communities Program was created, enabling the President to reallocate a portion of the Disaster Relief Fund to hazard mitigation (Weilant, Strong, & Miller, 2019) (E. B. Abbot, 2018)
FEMA Recovery Grants	Roads that do not qualify for ER funds may be eligible for FEMA funds (National Academies of Sciences, Engineering, and Medicine, 2020a) in the event of a federally declared disaster (see Stafford Act). FEMA will pay 75-90 % of the cost of repairs. FEMA may authorize betterments under its Public Assistance Program as long as the betterments pass cost-benefit analysis requirements.
Federal Transit Administration (FTA) Emergency Relief Program	Relief fund grantees may use funds to increase the resiliency of the affected transportation systems to protect the systems from

Funding Program	Description
	future emergencies and disasters (U.S. DOT, 2014), (K. L. Chandler, 2015)

Risk Versus Resilience

While risk as a formal concept has a history going back at least 50 years, the idea of resilience is relatively new. There is some confusion between the two concepts because of their inherent yin and yang relationship. The difference is essential--how risk and resilience are defined influences how infrastructure owners prioritize their investments and when they make those investments.

Risk analysis asks the following questions: "(1) What can go wrong? (2) How likely is it? and (3) What are the consequences?" (NRC, 2021). If we describe the event cycle for an adverse event in terms of before, during, and after, risk addresses the point of failure in the "during" phase of the cycle. Looking at the "Resilience Triangle," an asset is 100% functional before the event (see Figure 7). The functionality drops dramatically when the event (t1) and then steadily returns to normal (Srivastava, 2020). Risk assessment targets t1 of the event cycle. Traditionally, risk management has focused on hardening assets to prevent failure. A critique of the risk-based approach is that fail-proof designs tend to be brittle and are vulnerable to catastrophic failure when subjected to surprise shocks or stresses (R. Moor, 2015), (Folke, 2006), (P. Jeryang, 2013).

In contrast, resilience considers the complete event cycle and recognizes that failure within a complex system is inevitable over time. Further, unpredictable shocks and stresses will occur. A resilient system is a system capable of absorbing a disturbance, reorganizing, and undergoing change while maintaining the original function (Folke, 2006).

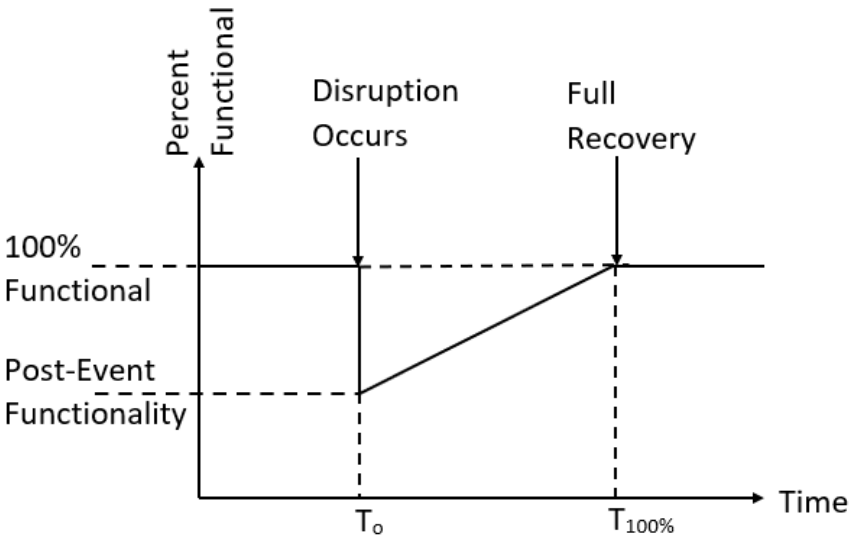


Figure 7. The Resilience Triangle

Table 7, adapted from (R. Moor, 2015), (P. Jeryang, 2013), summarizes the difference between the risk management and resilience approaches. The risk management approach minimizes the probability of failure through various design strategies: armoring, strengthening, oversizing, redundancy, etc. (P. Jeryang, 2013). On the other hand, the resilience approach minimizes consequences through design strategies emphasizing adaptability, flexibility, and rapid recovery while accepting more frequent failures (P. Jeryang, 2013).

Table 7. Risk Management vs. Resilience

Risk Management	Resilience
Risk analysis calculates the probability that known hazards will have known impacts	Resilience analysis improves the system's response to surprises and accepts uncertainty, incomplete knowledge, and changing conditions
The bottom-up analysis assesses the impact of hazards on components' critical functionality	The top-down analysis assesses interdependencies and interactions at a system level
Assesses the impact at one point in time	Includes a temporal dimension
Minimizes probabilities of failure	Minimizes consequences of failure
Strategies include robustness, strengthening, oversizing	Strategies involve adaption, innovation, flexibility, learning, diversity, redundancy, safe failure

Figure 8 demonstrates that a highly resilient system performs better despite high risk. The return to full functionality is shorter when resilience is high (blue or green), regardless of whether the risk is high or low (I. Linkov, 2014).

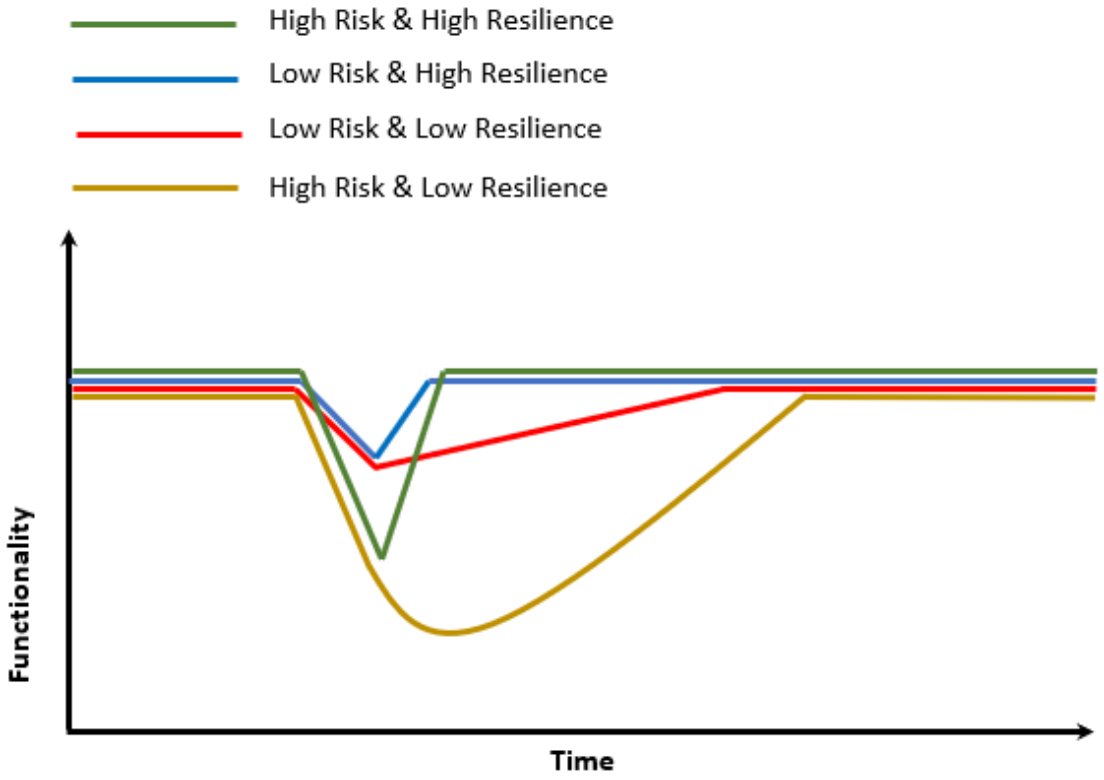


Figure 8. Schematic Representation of Changes in Critical Functionality Over Time, adapted from (I. Linkov, 2014).

Resilience Definitions, Metrics, and Frameworks

Section 3 addressed regulatory drivers that comprise part of the business case for integrating resilience into planning. Other reasons state and local transportation agencies expressed include economic benefits, improved safety, mobility and operations, experience with past disaster events, and preparing for climate change (Dix, Zgoda, Vargo, Heitsch, & Gestwick, 2018). Transportation agencies state their resilience goals in their TAMPs, Transportation Improvement Plans (TIP), Statewide Transportation Improvement Plans (STIP), and Long-Range Transportation Plans (LRTP). These goals are shaped in part by how agencies define resilience. To assess the progress in achieving resilience goals over time requires resilience metrics and tools. Risk and resilience are often confused because the domains of these terms overlap. Reducing risk does increase resilience. The remainder of this section discusses the relationship between risk and resilience and the definitions, metrics, and tools some transportation agencies adopt.

Defining Resilience and Other Key Terms

Different sectors have developed definitions for resilience. This section provides an overview of some definitions of resilience used in the transportation sector. A definition of resilience found in the 2009 edition of the NIPP encapsulates the essential elements found in definitions of resilience throughout the literature: “The ability to resist, absorb, recover from, or successfully adapt to adversity or a change in conditions” (DHS, 2009). The Rand Report (2019) expands upon these essential elements: “(1) reducing the likelihood of a disaster and increasing the ability of a community to absorb or resist a shock, (2) increasing the adaptability of a system while maintaining functions in the presence of a shock, and (3)

reducing the time to recovery to normal functioning, which might be different from pre-event functioning" (Weilant, Strong, & Miller, 2019). Other researchers have defined resilience similarly (Bruneau, et al., 2003), (J. L. Carlson, 2012), (A. A. Ganin M. K., 2017), (M. Omer, 2009), (Mohammed, 2017). Recent TRB published documents, as well as ongoing projects, have developed glossaries containing resilience-related terms, including NCHRP 20-124 (ongoing) *Deploying Transportation Security Practices in State DOTs*, NCHRP 23-09 (ongoing), *Scoping Study to Develop the Basis for a Highway Standard to Conduct an All-Hazards Risk and Resilience Analysis* (National Academy of Sciences, Engineering and Medicine, n.d.), NCHRP 527 (Flannery, Pena, & Manns, 2018) *Resilience in Transportation Planning Engineering, Management, Policy, and Administration* and NCHRP 15-61, *Applying Climate Change Information to Hydrologic and Hydraulic Design of Transportation Infrastructure* among others (R. Kilgore, 2019). Each glossary has a different focus, and some terms have been defined through the lens of each project and topic.

Definitions from Outside the Transportation Sector

Definitions of resilience from outside the transportation sector share this theme—the ability to withstand or recover from a disruption. Holling, who pioneered the concept of resilience, compared engineering resilience to ecological resilience (Holling, 1996). Engineering resilience "concentrates on stability near an equilibrium steady state, where resistance to disturbance and speed of return to equilibrium is used to measure the property." In contrast, ecological resilience "emphasizes conditions far from any equilibrium steady state, where instabilities can flip a system into another regime of behavior, that is, to another stability domain." From the field of economics, Rose separated static economic resilience— "efficient allocation of resources"—from dynamic economic resilience— "speedy recovery through repair and reconstruction of the capitol stock" (Rose, 2007).

Some sources describe resilience holistically in terms of factors critical to the community and society. For example, the United States Department of Homeland Security (USDHS, 2009b) divides resilience dimensions into 'hard' and 'soft' systems, hard systems of the technical and mechanical capabilities of infrastructure and organizations, and soft relating to the human needs, behaviors and psychology within organizations and communities. A seminal work in the field, Bruneau developed four dimensions of resilience: technical, organizational, social, and economic (TOSE) (see Table 8 from (Bruneau, et al., 2003)). They note that any single performance measure cannot measure these four TOSE dimensions; instead, they require different measures for each system under analysis.

Table 8. Dimensions of Resilience, adapted from (Bruneau, et al., 2003)

Resilience Dimension	Definition
Technical	Physical systems perform when subjected to earthquake forces.
Organizational	The ability to respond to emergencies and carry out critical functions.
Social	The capacity to reduce the negative social consequences of loss of critical services.
Economic	The capacity to reduce both direct and indirect economic losses.

A final, more simplistic example is that developed by the US National Infrastructure Advisory Council (NIAC, 2010), which distinguishes between those practices related to people and processes and those related to the structure of infrastructure and assets. Table 9 lists several definitions present in the literature outside of transportation.

Table 9. Definitions from Other Sectors

Author	Year	Resilience Definition
Bruneau et al. (2003) (Bruneau, et al., 2003)	2003	The ability of the system to reduce the chances of a shock, to absorb a shock if it occurs (abrupt reduction of performance), and to recover quickly after a shock (re-establish normal performance).
Subcommittee on Disaster Reduction (2005) (NSTC, 2005)	2005	Resilience is the ability of a community or system to adapt to hazards to maintain an acceptable level of service.
Murray-Tuite (2006) (Murray-tuite, 2006)	2006	A characteristic indicates system performance under unusual conditions, recovery speed, and the amount of outside assistance required for restoring its original functional state.
Battelle (2007) (Battelle, 2007)	2007	A characteristic that enables the system to compensate for losses and allows the system to function even when infrastructure is damaged or destroyed.
Litman (2008) (Litman, 2007)	2008	A system's ability to accommodate variable and unexpected conditions without catastrophic failure.
Ta et al. (2009) (Ta, Goodchild, & Pitera, 2009)	2009	The ability of the system to absorb the consequences of disruptions to reduce the impacts of disruptions and maintain freight mobility.
USDHS (2010) (DHS, 2010)	2009	Resilience is the ability of systems, infrastructures, government, business, and citizenry to resist, absorb, and recover from or adapt to an adverse occurrence that may cause harm, destruction, or loss of national significance
Ip and Wang (2011) (Wang, 2011)	2011	The ability of a system to return to a stable state following a strong perturbation caused by failure, disaster, or attack.
Serulle et al., (2011a) (N. U. Serulle, 2011a)	2011	The system can maintain its demonstrated level of service or restore itself to that level of service in a specified time frame.
Vugrin et al., (2011) (E. D. Vugrin, 2011)	2011	Given the occurrence of a particular disruptive event (or set of circumstances), the resilience of a system to that event (or events) is the ability to efficiently reduce both the magnitude and duration of the deviation from targeted system performance levels.
Henry and Ramirez-Marquez (2012) (Ramirez-Marquez, 2012)	2012	Describes the ratio of recovery at time *t* to loss suffered by the system at some previous point in time.

Author	Year	Resilience Definition
Freckleton et al., (2012) (Freckleton, Heaslip, Louisell, & Collura, 2012)		The ability of a transportation network to absorb disruptive events gracefully and return itself to a level of service equal to or greater than the pre-disruption level of service within a reasonable time frame.
Miller-Hooks et al., (2012) (E. Miller-Hooks, 2012)	2012	The network's inherent ability to cope with disruption via its topological and operational attributes and potential actions can be taken in the immediate aftermath of a disruption or disaster event.
Chen and Miller-Hooks (2012) (Chen & Miller-Hooks, 2012)	2012	A network's capability to resist and recover from disruption or disaster.
Adams et al., (2012) (T. M. Adams, 2012)	2012	The capacity to absorb a disruption's effects and quickly return to normal operating levels.
The National Academy of Sciences (National Research Council, 2012)	2012	The ability to plan, prepare for, absorb, recover from, and adapt to adverse events.

Definitions from the Transportation Sector—Definitions found within transportation frequently include one or more of the terms in Table 10.

Table 10. Key Terms Related to Resilience

Term	Definition
Absorptive Capacity	"…the ability of the system to absorb shocks and stresses and maintain normal functioning." (Weilant, Strong, & Miller, 2019)
Adaptation	"Adjustment in natural or human systems in anticipation of or response to a changing environment in a way that effectively uses beneficial opportunities or reduces negative effects" (FHWA, 2020)
Adaptative Capacity	"…is the ability of the system to change in response to shocks and stresses to maintain normal functioning." (Weilant, Strong, & Miller, 2019)
Exposure	"The nature and degree to which a system or asset is exposed to significant climate variations." (FHWA, 2015)
Hazard/Threat	"Stresses on transportation system performance and condition…" (National

Term	Definition
	Academies of Sciences, Engineering, and Medicine, 2021)
Mitigation	"…sustained action taken to reduce or eliminate long-term risk to people and property from hazards and their effects. Mitigation distinguishes actions that have a long-term impact from those that are more closely associated with preparedness for, immediate response to, and short-term recovery from a specific event" (FEMA, 1997)
Rapidity	"The speed with which disruption can be overcome" (Bruneau, et al., 2003)
Recovery	"Steps or stages a system goes through to regain the major functions of the system to pre-disruption performance and/or condition…" (National Academies of Sciences, Engineering, and Medicine, 2021)
Resilience	"The ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events." (AASHTO, 2017)
Resourcefulness:	**"**The capacity to mobilize needed resources and services in emergencies." (Bruneau, et al., 2003)
Restorative Capacity	"…the ability of the system to recover quickly following a shock or stress and return to normal functioning." (Weilant, Strong, & Miller, 2019)
Robustness	"The inherent strength or resistance in a system to withstand external demands without degradation or loss of functionality" (Bruneau, et al., 2003)
Vulnerability	"The degree to which a system is susceptible to, or unable to cope with

Term	Definition
	adverse effects of climate change or extreme weather events. In the transportation context, climate change vulnerability is a function of a transportation system's exposure to climate effects, sensitivity to climate effects, and adaptive capacity." (Filosa, Plovnick, Stahl, Miller, & Pickrell, 2018)

Through a synthesis of the literature, drew four definitions of resilience relevant to transportation (see Table 11):

Table 11. Definitions of Resilience from the Transportation Sector

Term	Definition
Resilience	"A system's ability to maintain its demonstrated level of service or to restore itself to that level of service in a specified time frame" (J. L. Carlson, 2012)
	"A characteristic that enables the system to compensate for losses and allows the system to function even when infrastructure is damaged or destroyed" (Battelle, 2007).
	"A system's ability to accommodate variable and unexpected conditions without catastrophic failure" (Litman, 2007)
	"A system's ability to absorb the consequences of disruptions to reduce the impact of disruptions and maintain freight mobility" (Ta, Goodchild, & Pitera, 2009).

The transportation sector has developed its definitions (see Table 12). In 2009, the AASHTO-TRB Transportation and Security Summit suggested the following definition of resilience for transportation: "The ability of a system to provide and maintain an acceptable level of service or functionality in the face of major shocks or disruptions to normal operations" ((AASHTO, 2016), (Flannery, Pena, & Manns, 2018)). Finally, FHWA Order 5520 defines resilience as "the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions."

Some transportation agencies have adopted FHWA's definition or developed similar definitions for their purposes. An FHWA project highlighted that most State DOT and MPOs resilience definitions focus on "the ability to prepare for and recover from disasters and disruptive events" but vary on "how agencies propose to build that ability, with some emphasizing adaptive capacity and robustness, while other prioritize swiftness in recovery response." In addition, it also highlights that some resilience definitions even incorporate a connection with climate change (Dix, Zgoda, Vargo, Heitsch, & Gestwick, 2018).

Table 12. Examples from Resilience Definitions used by Transportation Agencies

Transportation Agency	Definition
Minnesota DOT	"…reducing vulnerability and ensuring redundancy and reliability to meet essential travel needs.”
Wisconsin DOT	"A resilient transportation system can quickly respond to unexpected conditions and return to its usual operational state."
Anchorage Metropolitan Area Transportation Solutions	“Resilience means how to work around outcomes to get back up and running quickly. ”
Rockingham Planning Commission	"…a capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment."
Northeast Ohio Areawide Coordinating Agency	"Resiliency is a process for managing complex infrastructures rather than a single outcome… A resiliency framework takes an adaptive life-cycle approach to tackle the dynamic challenges that confront today's complex infrastructure systems. Embedded in it is the capability to protect its assets, anticipate and detect threats, prevent risks of known failures, withstand unanticipated disruptions, and respond and recover rapidly when the worst does happen.”
Arkansas DOT	“Resilience "also implies transformation, so not only is the infrastructure service able to survive or recover, but it can *adapt* to a changing environment in which it operates."
Metropolitan Transportation Commission	“…includes a desire to "enhance climate protection and *adaptation* efforts" in its definition of resilience. "”
Baltimore Regional Transportation Board	“…states that resilience means its system is "better able to *adapt* to a variety of potentially significant future changes."

Colorado DOT	"Resilience is the ability to keep our roads open and functional in the face of unexpected events and challenges." "The ability of a system to rebound, positively adapt to, or thrive amidst changing conditions or challenges, including human-caused and natural disasters, and to maintain quality of life, healthy growth, durable systems, economic vitality, and conservation of resources for present and future generations."

After reviewing definitions of resilience from inside and outside the transportation sector, the following section describes metrics and approaches to measuring resilience.

Resilience Metrics

MAP-21 and the FAST-ACT compel transportation agencies to measure the reliability of their systems. Resilience defines how well a system can maintain functionality in the face of various challenges to its operation. Metrics are needed to enable quantification of the system's resilience.

Flannery et al. (2018) (Flannery, Pena, & Manns, 2018) found that 92% of states responding to a survey had no specific metrics for resilience. The literature, however, yields a wide range of qualitative and quantitative metrics. Based on the Multidisciplinary Center for Earthquake Engineering Research's ubiquitous "four pillars of resilience" --Robustness, Redundancy, Resourcefulness, and Rapidity-- Parkany and Ogunye (2016) (Parkany & Ogunye, 2016) proposed the following transportation metrics (see

Table 13).

Table 13. The Four Pillars of Resilience

Resilience Pillar	Indicator
Robustness	Hours of congestion The spatial extent of congestion Travel time index Optimal spare capacity Pavement condition Weather impact Volume of congestion
Redundancy	Distance to alternative routes Percentage of a corridor with alternate routes Available capacity on alternative routes Congestion on alternative routes Graph theory connectivity score Transit alternatives Adjacent park & ride lots
Resourcefulness	Safety service patrol Average incident duration Availability of special transportation funding Message signs Weather stations The use of alternative routes Construction projects Weather mitigation capability
Rapidity	Regain time for the top 5% of incidents Average construction project duration

Sun et al. (2020) (Sun, Bocchini, & Davison, 2020) summarized the state of the art of transportation analysis and metrics (Invalid source specified.), describing three categories of metrics: topological, traffic-related, and functional (see

Table 14). Topological metrics include measuring the connectivity of a graph (minimum number of nodes or edges that need to be removed to disconnect the remaining modes from each other, and centrality – the more central a node is, the closer it is to all other nodes. Traffic-related approach metrics include travel-time delay caused by an extreme event, throughput (total sum of flows of passengers between origin and destination pairs divided by their respective distance, and congestion index, the travel delay in a network due to the disruption of an extreme event. The functional metrics could be quantitative or qualitative.

Table 14. Resilience Metrics

Class	Metric		Description
Topological	Centrality		The measure of the influence of a node in a network.
Traffic	Weighted Centrality		Same as Centrality except for links between nodes are weighted. Weights are typically based on link length, travel time, or distance.
	Travel time		Travel time is used to measure travel delay during and post-event.
	Throughput		The total sum of flows of shipments/passengers between origins and destinations.
	Congestion Index		A measure of travel delays due to a disruption, e.g., link delay to acceptable travel time.
Functionality	Resilience Triangle		A graph of functionality recovery starting from the extreme event until complete recovery.
	Resilience Index		Based on the resilience triangle, a measure of functionality over time.
	Capacity	Absorptive	Ability to absorb perturbations from an event.
		Adaptive	The ability of the system to gradually adapt itself to disruption.
		Coping	Ability to respond to and recover from events.
		Restorative	Ability to bounce back to the original performance level or better.

Resilience Triangle

The Resilience Triangle (see Figure 9 from (Bruneau, et al., 2003)) is a graph of the change in system functionality over time. Assuming that pre-event functionality is 100%, immediately after triggering an adverse event, functionality drops dramatically and then gradually returns to its original level. Over time, this can be quantified by measuring a resilience metric, such as traffic delay or congestion.

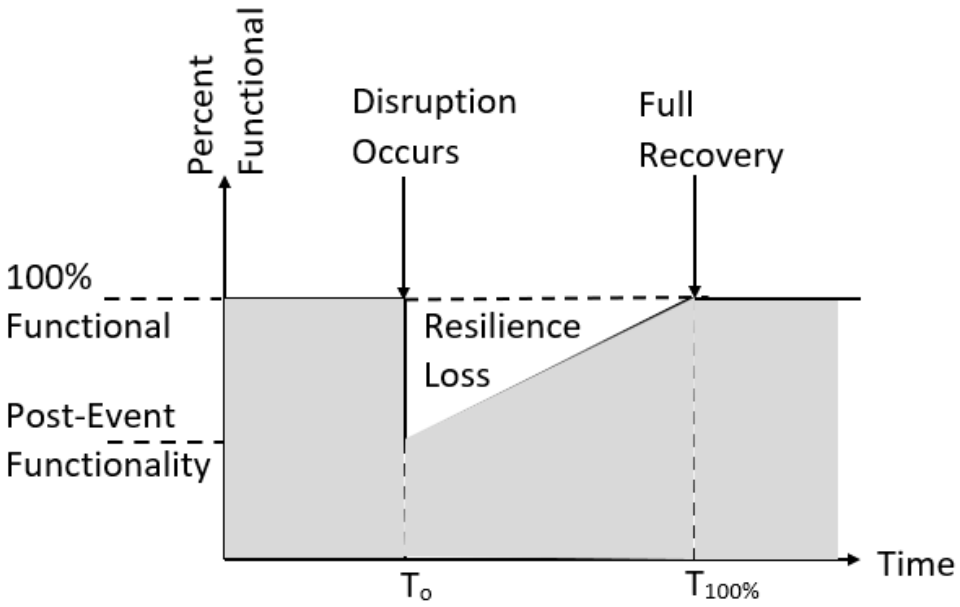


Figure 9. Resilience Triangle

Weilant et al. (2019) describe potential metrics for adaptive, absorptive, and restorative capacity (See Table 15, adapted from (Weilant, Strong, & Miller, 2019)).

Table 15. Example Metrics for Adaptive, Absorptive, and Restorative Capacities

Functional Capacity	Example metric
Adaptive Capacity	Number of available alternative routes - redundancy
Absorptive Capacity	Miles of roads exposed to a hazard (e.g., number of roads in the 100-year floodplain Number of culvert inspections completed on time Number of projects raising the road grade
Restorative Capacity	Counts of construction equipment Counts of maintenance equipment (e.g., snowplows) Percentage of community reachable within 24 hours

Measure of Resilience

The data used to fulfill the inputs required by resilience metrics may be empirical or model outputs. As an example of the former, Adams et al. (2012) (T. M. Adams, 2012) used traffic counts and sampled truck speeds collected along the I-90/I-94 corridor in Wisconsin during two significant rain events in 2008. The data was used to calculate two composite resilience metrics--reduction and recovery. As an example of using model outputs, (Zhang & Wen, 2009) used TransCAD software to generate Order-Destination flow

to calculate the Measure of Resilience (MOR), defined by Zhang as "the percentage of system performance measures degraded" (see Equation 1).

$$MOR = \frac{(RI_{before} - RI_{after})(1 + t^{\alpha})}{RI_{before}}$$

Equation 1

Where:

t = total rime required to restore capacity (year)
α = system performance measure being evaluated

Traffic Assignment-simulation Software

Murray-Tuite (2006) (Murray-tuite, 2006) used FHWA's traffic assignment-simulation software, DYNAMSART-P, to measure the network's adaptability, safety, mobility, and recovery. Adaptability is the ability of the network to reconfigure and adjust to adverse impacts, e.g., allowing all vehicles to use High Occupancy Vehicle (HOV) lanes. Safety can be measured as the number of traffic incidents that occur along a given stretch of roadway. The study measures mobility in 6 ways: first, the amount of time to evacuate a town; second, the average travel time for emergency response vehicles to reach a destination; third, queue length; fourth, average queuing time per vehicle; fifth, the amount of time that the speed of traffic on a given segment is lower than the posted speed limit; and sixth, the volume to capacity ration for each link. Finally, recovery is the amount of time and money required to restore network connectivity.

Frameworks for Resilience

A conceptual framework is an analytical tool used for showing the relationship between ideas that together provide an understanding of a phenomenon (Jabareen, 2009). Authors have provided comprehensive lists of principles for achieving and enhancing resilience. This section aims to overview a subset of recently developed conceptual frameworks for resilience and refer the reader to the many available resources.

Consistent with what has been presented to this point, Foster noted (Foster, 1997) that in "general, resilient systems are independent, diverse, renewable and functionally redundant, with reserve capacity achieved through duplication, inter-changeability, and interconnections." Furthermore, the Victoria Transport Policy Institute, Comfort, and Foster present principles which encompass: redundancy, diversity, efficiency, autonomy, strength, adaptability, and collaborative structures ((Victoria Transport Policy Institute, 2019), (Comfort, 1999), (Foster, 1993)).

Response Planning

As already highlighted, Bruneau et al. (2003) have presented four principles: robustness, redundancy, resourcefulness, and rapidity. To these, NIAC (2010) adds the principle of 'adaptability' in incident response planning (see Figure 10 from (NIAC, 2010)).

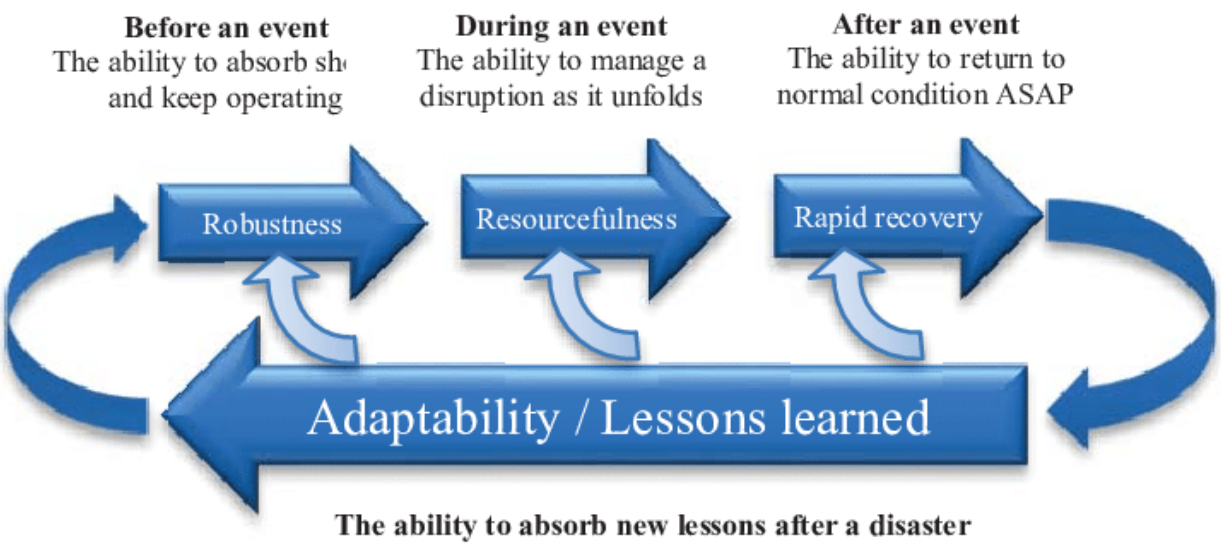


Figure 10. Resilience Framework

Madni et al. (2009) (Madni & Jackson, 2009) stress that in consideration of resilience in engineering systems and the development of frameworks to quantify resilience that resilience is a characteristic of how the system behaves (i.e., the process) as opposed to a property, which the system has (i.e., state). Park et al. (2013) (J. Park, 2012), while recognizing this, has established three overarching principles spanning the technical and organizational dimensions of the TOSE dimensions defined by Bruneau et al. (2003) (Bruneau, et al., 2003) (see Table 16 from (Parkany & Ogunye, 2016). By employing these dimensions, a framework for resilience quantification was developed by Hughes and Healy (2014) (Hughes & Healy, 2014).

Table 16. Framework for Resiliency

Dimension	Principle	Definition and Justification
Technical	Robustness	Strength, or the ability of elements or systems to withstand a given level of stress without suffering degradation (Bruneau et al., 2003) (Bruneau, et al., 2003)
	Redundancy	The extent to which elements, systems, or other infrastructure units are substitutable, i.e., capable of satisfying functional requirements in the event of a disruption (Bruneau et al., 2003) (Bruneau, et al., 2003)
	Safe-to-fail	The extent to which innovative design approaches are developed allows controlled, planned failure during unpredicted conditions (Park et al., 2013). (J. Park, 2012),

Dimension	Principle	Definition and Justification
Organizational	Change readiness	The ability to sense and anticipate hazards, identify problems and failures, and develop a forewarning of disruptions or threats and their effects through sourcing a diversity of views, increasing readiness, and understanding social vulnerability (Resilient Organizations, 2012)

TOSE Dimensions

Frameworks may be either quantitative or qualitative. As previously mentioned, the framework developed by Bruneau et al. (2003) (Bruneau, et al., 2003), considered seismic resilience around the TOSE dimension Table 17. Brabhaharan (2006) (Brabhaharan, 2006)developed a method to evaluate 'performance criteria' by which transport system elements could be measured post-event. These were based upon specific levels of service requirements following hazard events and performance criteria developed by relevant stakeholders for specific critical sections of the network.

Table 17. TOSE Dimensions

	Performance Criteria			
PERFORMANCE MEASURES	Robustness	Redundancy	Resourcefulness	Rapidity
TECHNICAL	Damage avoidance and continued service provision	Backup/duplicate systems, equipment, and supplies	Diagnostic and damage detection technologies and methodologies.	Optimizing time to return to pre-event functional levels.
ORGANIZATIONAL	Continued ability to carry out designated functions.	Backup resources to sustain operations.	Plans and resources to cope with damage and disruption (e.g., mutual aid, emergency plans, decision support systems).	Minimize time needed to restore services and perform key response tasks.
SOCIAL	Avoidance of casualties and disruption in the community.	Alternate means of providing for community needs (e.g., alternative sites).	Plans and resources to meet community needs.	Optimizing time to return to pre-event functional levels.

	Performance Criteria			
ECONOMIC	Avoidance of direct and indirect economic losses.	Untapped or excess economic capacity (e.g., inventories, suppliers)	Stabilizing measures (e.g., capacity enhancement and demand modification, external assistance, optimizing recovery strategies).	Optimizing time to return to pre-event functional levels.

Resilience Cycle

Heaslip et al. (2009) (K. Heaslip, 2009) developed a conceptual model built around a resiliency cycle of normalcy, breakdown, annealing, and recovery (see Figure 11 (K. Heaslip, 2009)). "Breakdown" is the measurement of a system's reduction in performance. Annealing and recovery are measures of how quickly a system returns to or exceeds its present level of service.

Figure 11. Resiliency Cycle

Dantas and Giovinazzi (2010) (Ferreira, Dantas, Seville, & Giovinazzi, 2010) developed a framework to assess the readiness of road authorities with the 4R's (reduction, readiness, response, and recovery). As previously discussed, several studies have developed quantitative frameworks for measuring the resilience of networks and defining it in terms of a resilience type index. These seek to (i) assess the impact of the event on the level of functionality, (ii) evaluate the time to restoration of functionality to an acceptable or enhanced level, and (iii) compare the performance with and without the proposed strategy.

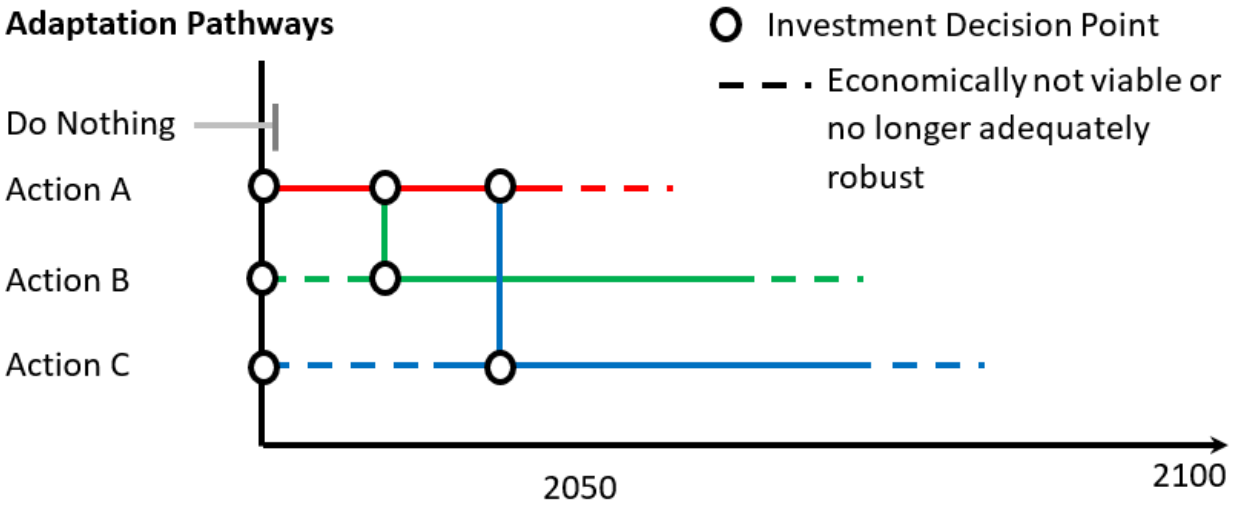
Overall, selecting an appropriate framework is contingent upon factors such as the scope, the availability and reliability of the information, the computational requirements, the ease of implementation, and the usefulness in (a) broader organizational resilience assessments and (b) assessing physical networks asset resilience, etc. Therefore, a qualitative or quantitative framework should consider this range of factors, as in Table 18.

Table 18. Summary of Qualitative and Quantitative Measurement

	Qualitative approach	Quantitative approach
Flexibility	Provides a flexible approach that can be adapted to a range of situations, scales and conditions.	Is typically applied only at a smaller geographical scale and at a more detailed level.
Data requirements	Can be applied with complete or incomplete data sets. Relies on subjective assessments in many cases.	Typically requires large, accurate data sets.
Computational requirements	None/minimal.	Requires significant computational effort.
Results	A relative, subjective assessment – often using a ranking scale	Typically delivers a discrete resilience index or measure by way of network modelling or fuzzy logic modelling.
Ease of implementation	Simple	Difficult
Use in targeting resilience improvements	Useful; however, is very much related to the design of the framework, how it is implemented, and subjectivity of the scores given.	Can be accurate for the network analysed.
Useful in wider organisational resilience assessments and engagement	Yes	No
Useful in assessing physical network asset resilience	Yes	Yes

Adaption Pathways

The traditional adaptation approach builds to a worst-case scenario to achieve a robust solution for even the most adverse events. However, criticisms of this approach include inflexibility, a failure to acknowledge the non-stationarity of climate and environmental conditions, and the potential of spending more than is necessary for mitigation or adaptation. Adaptation pathways offer a dynamic alternative that enables planners to evaluate adaptation options over time (M. Haasnoot, 2013). Figure 12 is an example Adaptation Pathways map, patterned after a metro train map. Each colored route represents an option that meets a minimum performance level. The gray path, representing current conditions or "business as usual," fails to meet minimum performance measures in the near term. Terminals (black circles) represent "tipping points" where a specific threshold is met, triggering an action. The dashed lines indicate that either a pathway is not yet economically viable or is no longer robust enough to meet minimum performance measures.



Action A	Erosion control
Action B	Erosion control and elevate road
Action C	Reroute road

Figure 12. Adaptation Pathways Map

Transportation Resilience Tools and Models

This section reviews some of the tools readily available to assist transportation professionals in assessing the resilience of their systems. Most of these tools are not resilience assessment tools per se but assist transportation professionals in evaluating their risks and improving the resilience of their systems. For example, Vtrans' Transportation Resilience Planning Tool (TRPT) is called a resilience planning tool because the output, a relative flood-risk score, aids in prioritizing potential mitigation projects. This again points out the overlap between risk and resilience.

Tools discussed here fall within the following groupings: climate change and extreme weather, community resilience, comprehensive index models for assessing system-wide resilience, and tools for assessing organizational efforts to incorporate resilience into programs, projects, and planning (see

Table 19). The first category, climate change, and extreme weather include online web map viewers and spreadsheet tools. Like the Vtrans TRPT, these tools help identify assets most vulnerable to extreme weather and climate stressors and thus inform decision-makers where to focus their resilience efforts, whether through mitigation projects or adaptive measures. Community resilience tools, like the web mapping tools, are GIS-enabled tools that facilitate disaster recovery, for example, planning evacuation routes, prepositioning emergency supplies, etc. The system-wide resilience tools are semi-quantitative indicator models, similar to risk registers. They are not hazard or asset-specific but are appropriate for a high-level desk review of a system. These tools could aid decision-makers in establishing resilience goals and objectives. Finally, the organizational self-assessment tools are maturity models for assessing an organization's level of achievement in incorporating resilience into policies, planning, and practice. Like the system-wide resilience tools, these tools could be beneficial in developing resilience objectives, goals, and policies.

Table 19. Resilience Tools

Category	Source	Tool Name	Hazards	Use in Planning
Climate Change/Extreme Weather	Boston MPO	Boston Harbor Climate Ready Map Explorer	Coastal flooding	Project prioritization
	University of Florida	Sea Level Scenario Sketch Planning Tool	Coastal flooding	Project prioritization
	Maryland DOT	Climate Change Vulnerability	Coastal flooding	Project prioritization
	FHWA	VAST	Climate Change	Project prioritization
	FHWA	Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool	Climate Change	Project prioritization
	Vtrans	Vermont TRPT	Riverine Flooding	Project prioritization
Community Resilience	FEMA	Resilience Analysis and Planning Tool (RAPT)	All-hazard	Disaster recovery
	ESRI	Resilience Dashboard	All-hazard	Disaster recovery
System-wide Resilience	New Zealand	New Zealand Transportation Agency Resilience	All-hazard	Goals and objectives
	European Union (EU)	Critical Infrastructure Resilience Assessment Tool (CI-RAT)	All-hazard	Goals and objectives
	EU	Post Assessment Resilience Enhancement Tool (PARET)	All-hazard	Goals and objectives
Organizational Self-Assessment	FHWA	Infrastructure Voluntary Evaluation Sustainability Tool (INVEST)	All-hazard	Goals and objectives
	TRB	NCHRP Mainstreaming System Resilience	All-hazard	Goals and objectives

Category	Source	Tool Name	Hazards	Use in Planning
		Concepts into Transportation Agencies		

Climate Change/Extreme Weather

For starters, Gulf Tree is an online search tool that aids the user in selecting the most appropriate climate tool (Gulf TREE, n.d.). Filters enable the user to search by geographical location, level of effort, tool cost, tool function (vulnerability, adaptation, recovery, etc.), climate change themes (carbon emissions, sea-level rise, changes in precipitation or temperature, etc.), and climate change topics (health, flooding, the built environment, ecosystems, etc.).

Sea-Level Rise Web Map Applications

There is a plethora of tools devoted to coastal resilience. NOAA's Sea Level Rise Viewer is just one example, a web map that enables the user to visualize coastal flooding up to 10 feet above average high tides (see Figure 13). Data.Gov's "Climate – Coastal Flooding" website lists 22 links to tools hosted by government and nongovernmental organizations "to help coastal communities and others analyze and assess vulnerabilities of sea-level rise, storm surges, and sinking lands" (U. G. S. Administration, n.d.). In addition, states and metropolitan agencies have developed online web map applications to inform the public about the risk of sea-level rise and flooding to their communities. Examples include Boston's Climate Ready Boston Map Explorer (see Figure 13). Florida's Sea Level Scenario Sketch Planning Tool, and Maryland DOT State Highway Administration's Climate Change Vulnerability web map.

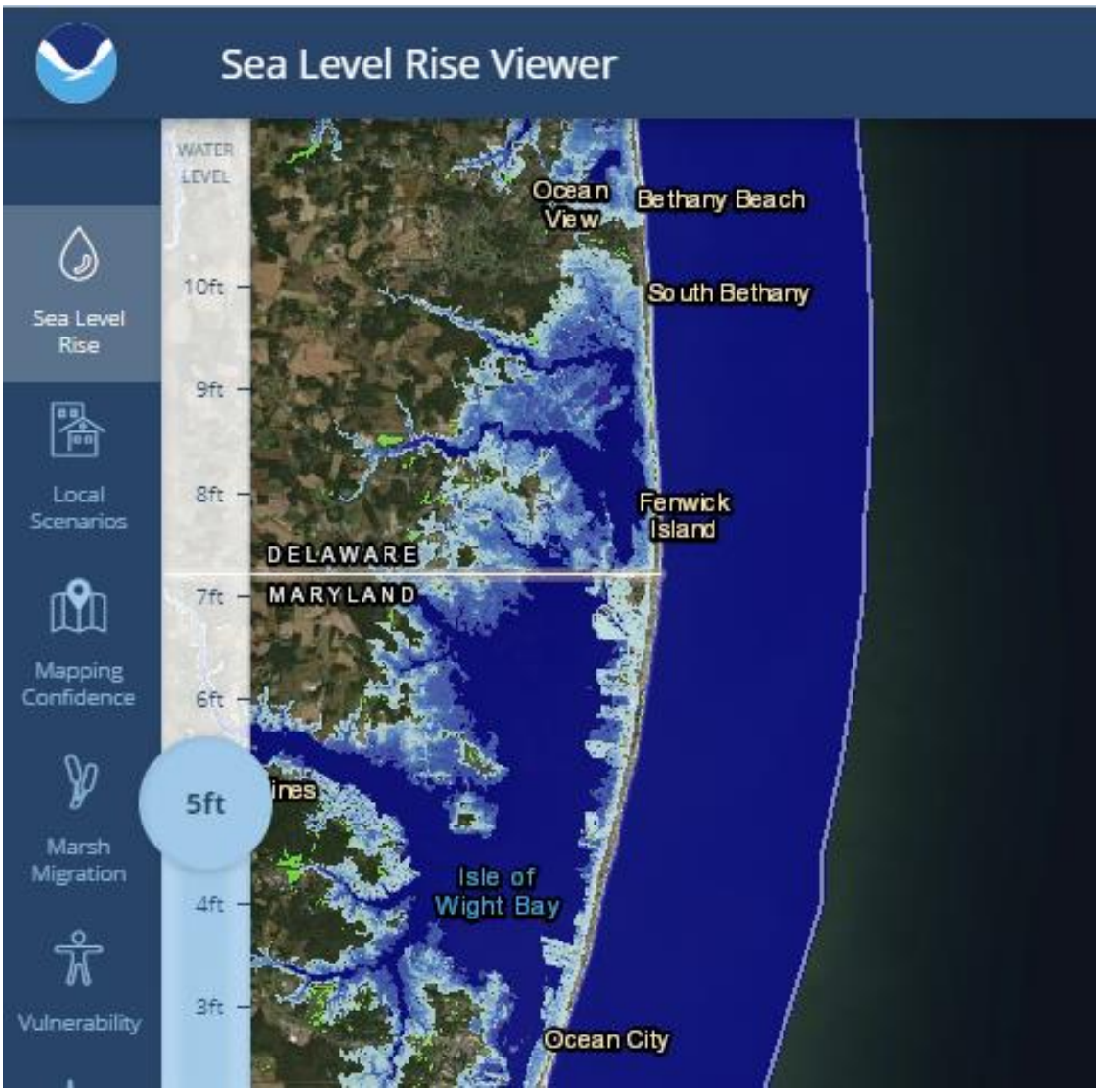


Figure 13. Screenshot of the NOAA Sea Level Rise Viewer

The Boston Harbor Climate Ready Boston Map Explorer enables the user to overlay maps representing projected high tide in 2030, 2050, and 2070, as well as 1% and 10% flood frequency for years 2030, 2050, and 2070, over representations of building footprints and roadways in the Boston metropolitan area (City of Boston, n.d.).

The University of Florida's Sea Level Scenario Sketch Planning Tool allows the user to select from either NOAA or United States Army Corps of Engineer projection curves to generate inundation maps for low to high scenarios, years 2040 to 2100. In addition, the user can select from various base maps, add roads, rail, and facilities, and add additional layers to represent the 100- and 500-year FEMA floodplain (University of Florida GeoPlan Center, n.d.).

The Maryland DOT State Highway Administration's Climate Change Vulnerability web map also offers the user a selection of base maps and checkboxes to select flood depth grids based on mean sea level for 10-,

25-, 50-, 100- and 500-year storms and flood depth grids based on mean higher high water for 0, 10%, 4%, 2%, 1% and 0.2% annual chance storms (MDOT SHA Climate Change Vulnerability, 2021).

U.S. Climate Resilience Toolkit

The U.S. Climate Resilience Toolkit is a portal managed by NOAA's Climate Program Office. Developed by a partnership of federal agencies and organizations under NOAA, the portal provides access to 158 case studies (9 relevant to transportation) and 517 tools (71 applicable to transport). The links to tools are similar to the coastal resilience tools described earlier – sea level rise, flood, storm surge, and climate change impact maps.

The FHWA's Sustainability website sponsors four tools targeting climate change adaptation (FHWA, 2021a).

3. CMIP Climate Data Processing Tool
4. Sensitivity Matrix
5. Guide to Accessing Criticality in Transportation Adaptation Planning
6. Vulnerability Assessment Scoring Tool

FHWA Coupled Model Inter Comparison Project (CMIP) Climate Data Processing Tool

The CMIP Climate Data Processing Tool uptakes downscaled CMIP5 Localized Constructed Analogs (LOCA) climate projections and produces spreadsheet outputs of a multitude of climate change variables relevant to transportation variables, e.g., number of days per year exceeding 95° F, mean annual inches of rain with an annual exceedance probability of 10%, etc. The Sensitivity Matrix is a spreadsheet database documenting the sensitivity of roads, bridges, airports, ports, pipelines, and rail to 11 climate impacts.

Prepared for the United States Department of Transportation's Center for Climate Change and Environmental Forecasting under *The Gulf Coast Study, Phase 2: Impacts of Climate Change and Variability on Transportation Systems and Infrastructure, t*he "Guide to Accessing Criticality in Transportation Adaptation Planning" illustrates approaches to assessing criticality, including desk reviews and stakeholder elicitation to identify assets, define criticality, select criticality criteria, and rank assets (ICF, 2014). The appendix lists all the criticality criteria used in the Gulf Coast Study.

FHWA Vulnerability Assessment and Sensitivity Tool (VAST)

The U.S. Department of Transportation's (USDOT) VAST (Bhat, et al., 2015) is an Excel spreadsheet tool designed to help planners at state DOTs and MPOs assess the vulnerability of their transportation assets to climate stressors. VAST is an indicator-based tool that assigns an index value to three factors:

- Exposure: the potential exposure of an asset to a climate stressor, such as the number of freeze-thaw days or days of extreme heat per year an asset is likely to experience.
- Sensitivity: the sensitivity (vulnerability) of an asset depends on asset characteristics, such as diameter for culverts or height for bridges, as well as condition state, such as rutting for pavement or scour rating for bridges.
- Adaptive capacity: the adaptive capacity reflects an asset's ability to accommodate or adapt to disruption and can be indicated by proxies such as Annual Average Daily Traffic, replacement cost, or detour length.

Vermont Transportation Resilience Planning Tool (TRPT)

Vermont TRPT (Vtrans, n.d.): The Vermont TRPT is a web map that lets the user visualize the relative flood risk to embankments, culverts, and bridges. The risk rating is based on a combination of criticality and vulnerability scores. Color-coded roadway segments indicate the level of risk: low (green), medium (orange), and high (red). Low levels of vulnerability may mean slight damage due to inundation or minor erosion, whereas high vulnerability may mean complete failure of the asset due to severe erosion or deposition (Vtrans, 2019). When the user clicks on a roadway segment, a panel opens on the right, revealing a graph of the relative vulnerability (x-axis) and criticality (y-axis) scores and a table that lists mitigation strategies with associated costs per cubic yard.

Community Resilience

FEMA Resilience Analysis and Planning Tool (RAPT)

FEMA's RAPT is not an analysis tool per se but a free, online GIS web mapping tool that allows users to overlay census data and infrastructure with hazard layers, historical disasters, and real-time weather hazards (see Figure 14). Available hazard layers include the National Flood Hazard Layer, seismic hazard (peak ground acceleration), historic tornado, and historical hurricane tracks.

Figure 14. Screenshot of FEMA's RAPT Tool: Regulatory Floodplain Overlapping I-70 in Colorado

Environmental Systems Research Institute's (ESRI) Resilience Dashboard—preconfigured web-based dashboard that runs in ArcGIS Online (ESRI's cloud). Designed to help emergency management make informed decisions through the visualization of risk and the interdependencies between assets, the dashboard includes drop-down windows to enable users to filter the features displayed by asset class and a limited number of attributes relevant to resilience and criticality, such as "importance to the community – high," or "dependent upon flood pumps – yes." In addition, the tool displays an overall resilience ranking, aggregated by county (ESRI, n.d.). Users are required to have an ArcGIS Pro license.

System-Wide Resilience Assessment Tools

New Zealand Transportation Agency Resilience (NZTAR)--The NZTA commissioned a report, which was completed by AECOM, entitled *Measuring the Resilience of Transport Infrastructure* (Hughes & Healy, 2014).

Based on two of the four dimensions of resilience developed by Bruneau et al. 2003 (Bruneau, et al., 2003), namely, technical, and organizational aspects, a detailed qualitative tool was developed. A range of resilience measures was combined to give an overall resilience score between 1 (very low resilience) and 4 (very high resilience). Weightings can also be applied at the user's discretion to give an aggregate overall score for a principle (e.g., robustness), dimension (e.g., technical), or overall. The complete database can be found in Hughes and Healy (2014) (Hughes & Healy, 2014).

The technical dimension included robustness, redundancy, and safe-to-fail (measured from structural, procedural, and interdependencies perspectives). Finally, the organizational dimension assesses change readiness, networks, and leadership and culture under several categories, assessing the community preparedness, availability of information, financial strength, and overall organizational performance (European Union, 2020).

RESILIENS--The European Union project RESILENS developed two complementary qualitative/semi-quantitative resilience measurement tools, CI-RAT and PARET (RESILIENS, 2016). These tools were intended to be employed by a panel of CI operators. How to hold panel sessions is explained in RESILIENS Deliverable 2.2 (RESILIENS, 2016).

CI-RAT—This tool employs a semi-quantitative indicator approach to appraise the pre-event resilience of critical infrastructure. RESILIENCE Deliverable 2.2 includes detailed tables for each indicator, complete with description and assessment criteria. Each criterion is rated on a scale from 0 to 5. The indicators fall within these three domains (see Table 20 from (Morga & Jones, 2019)):

- Requisite 1: Prepare, prevent, and protect (before the disruption)
- Requisite 2: Mitigate, absorb, and adapt (during the disruption)
- Requisite 3: Respond, recover, and learn (after the disruption)

Table 20. CI-RAT CI resilience components included in CI-RAT tool

Requisite	Elements
Preparedness, Prevention, protection	Organization and coordination
	Organization dynamics, including leadership, culture, decision-making, internal and external relationship
	Risk management
	Safeguarding CI assets with electronic and physical means
	Safeguarding mission-critical systems
Mitigation, absorption and adaptation	Building codes and infrastructure hardening
	Early warning and information management systems

Requisite	Elements
	Robustness, redundancy, and backup
	Immediate actions
Response, recovery, and learning	Education and learning, including training, education, openness, and improvement
	Responsiveness, including business continuity planning and exercises
	Resource provision
	Learning from others, i.e., actions and information sharing

PARET--The PARET tool was developed to address issues identified from the CI-RAT tool and to facilitate the enhancement of the overall system. PARET explains what the CI resilience score means and how the score can be used to improve the resilience of the CI system. The steps involved in the PARET tool are given in Table 21 (RESILIENS, 2016). By following the outlined process, it is possible to develop a prioritized list of tasks in consultation with CI operators and stakeholders. A list of priority components may be established by comparing the component item resilience scores obtained from the assessment process to the minimum criteria level deemed necessary for minimal functionality (see Table 22, adapted from (RESILIENS, 2016)).

Table 21. PARET Tool Steps

Steps	Description	Output
1	Classify the resilience components (and their importance) based on the criticality of their function	Priority list of components items
2	Determine the crossover links between identified resilience components and the rest of the system	Crossover links
3	Incorporate considerations on the investigated CI system particular situation, and external political, economic and societal factors	Internal/external factors impacting on the resilience component
4	Identify the improvements required to "enhance" the resilience components and system resilience (and their relative relevance)	Improvement costs and timescale involved
5	Calculate the allocation of resources in order to maximise utility	Funding and other resource breakdown
6	Using the information gathered distribute the resources in order to maximise CI resilience	Allocation of resources and updated enhancement strategies

Table 22. PARET Tool – Sample CI Resilience Component Priority List

Component number	Component item	CI-RAT tool score (x/5)	Minimum criteria level (from step 1)	Ranking
2.11	Immediate actions to prevent loss of essential information and core services	2	3	1
2.3	Early warning system	2	3	2
3.13	Liquid financial sources for recovery from disasters ('rainy day fund')	2	3	3
1.9	Identification of risks and determination of the DBTs	3	4	4
3.7	Availability of engineering equipment, necessary during most severe and most probable scenarios	3	3	5
2.1	Building codes for hardening structures, infrastructures and critical physical assets	4	4	6

Tools for Assessing Organizational Efforts to Incorporate Resilience

INVEST

INVEST is FHWA's online self-assessment tool (FHWA, n.d.). This tool was designed to help transportation agencies and practitioners assess their projects and programs' sustainability and climate resilience. The tool consists of four modules: System Planning for States (SPS), System Planning for Regions (SPR), Project Development (PD), and Operations and Maintenance (OM). Each module consists of 14 to 33 criteria. Three of these modules contain a criterion related to infrastructure resiliency – SPS, SPR, and PD. The SPR and PD criterion focuses on incorporating resilience into planning. SPR focuses on regional planning, including LRTPs and TIPs, while PD focuses on project-level planning and infrastructure design. The assessment is based on points depending on how well specific requirements are met for each criterion or module.

NCHRP Research Report 970 Capability Maturity Framework

In 2021, The National Academy of Sciences released *Mainstreaming System Resilience Concepts into Transportation Agencies (NCHRP Research Report 970)*. This guide outlines a 10-step process for assessing an organization's efforts to incorporate resilience concepts into decision-making and procedures (National Academies of Sciences, Engineering, and Medicine, 2021). Each section details one of the ten steps. In addition, tables in each section describe the maturity factors and define three maturity levels for each factor.

Conclusion

This section covered a variety of tools that may assist transportation professionals in assessing their system's resilience and their organization's success in incorporating resilience into business practices. Most online platforms' tools linked to "resilience" are web-based GIS applications for visualizing hazards

and climate data. In addition, there are index-based models, such as PARET and CI-RAT, for evaluating system-wide resilience. Finally, FHWA's INVEST tool and NCHRP 970's maturity model aid transportation professionals in assessing their organization's resilience practices.

Risk Assessment Tools

The US Department of Homeland Security defines risk as "the potential for an unwanted outcome resulting from an incident, event, or occurrence, as determined by its likelihood and the associated consequences" (DHS, 2010a). In contrast, from a transportation agency perspective, "risk means the positive or negative effects of uncertainty or variability upon agency objectives" (23 CFR § 515.5).

This section explores the principles of risk assessment, model types, and tools available to the public. It concludes with a discussion of the FHWA's widely used Vulnerability Assessment and Adaptation Framework (VAAF) (Filosa, Plovnick, Stahl, Miller, & Pickrell, 2018), a conceptual framework for incorporating climate data into risk models. Users of the conceptual framework can employ deterministic, probabilistic, or a combination of approaches to calculate the inputs into the framework.

Qualitative Tools and Models

Qualitative tools include index models and risk registers. The risk register is the tool most commonly used by state DOTs and is typically used in conjunction with a 5-by-5 risk matrix. Risk registers are documents for logging risks. Often, an Excel spreadsheet is used, recording each risk's likelihood and severity of consequences. In addition, a matrix may be employed to intersect likelihood with severity to calculate a risk ranking ranging from low to high. NCHRP 08-36(126) (Patrick, Senesi, & Molenaar, 2016) details developing a risk register.

Quantitative models may be deterministic or probabilistic. Deterministic models do not attempt to address randomness or uncertainty, producing a single outcome for every risk calculation. In a simple deterministic model, risk can be expressed as Consequences (C) X Vulnerability (V) X Threat (T), where C is the quantification of the elements at risk (number of persons, the replacement value of the asset, etc.), V is the physical vulnerability of the assets at risk (e.g., percentage of damage if an event occurs), and T is the temporal probability that an adverse event occurs. The FHWA-sponsored 2017 Colorado I-70 corridor study is an example of a project that used this method for estimating expected annual losses (AEM Corporation, 2017). Details of how the analysis was accomplished were outlined in the Colorado DOT Risk and Resiliency Manual (CDOT, 2020). Values for C, V, and T may be derived from historical data, expert opinion, or model outputs. The American Society of Mechanical Engineers' methodology, Risk Analysis and Management for Critical Asset Protection (RAMCAP Plus) (ASME, 2009) and Van Westen et al.'s (2011) Multi-hazard Risk Assessment, Distance Education Course Exercise Book (Westen, Alkema, Damen, Kerle, & Kingma, 2011) give thorough explanations for the deterministic approach.

Probabilistic Models

Probabilistic models attempt to account for aleatoric uncertainty by employing random variables with their respective probability distributions to produce a set of possible outcomes for every risk calculation. Example approaches to probabilistic modeling include Monte Carlo simulation, Bayesian Belief Networks (BBN), and Markov chains. Koller and Friedman (2009) (Koller & Friedman, 2009) give a thorough explanation of probabilistic, graphical modeling, including BBN and Markov chains, while Bratvold and Begg (1992) (Bratvold & Begg, 2010) explain Monte Carlo simulation as well as graphical modeling and deterministic methods.

Example Publicly Available Risk Assessment Tools

Some example tools available to the public include FEMA's Hazards U.S. (HAZUS), FHWA's HYRISK model (Pearson, Stein, & Jones, 2000), Cornell University's culvert model (Truhlar & Gold, 2018), the European Commission's InfraRisk (InfraRisk Project, 2020) web application, and the Colorado DOT' Risk and Resilience Excel Spreadsheet Tool (CDOT, 2020a).

HAZUS--Long considered the state-of-the-art risk tool for natural hazard risk assessment, HAZUS is a GIS-based tool provided freely to the public by the Federal Emergency Management Administration (FEMA). However, the tool is an add-in to ESRI's ArcGIS Desktop application, which requires a licensing fee. The latest version, 4.0, was released in 2017. The HAZUS earthquake model (FEMA, 2020) includes fragility curves for roads and bridges. The HAZUS flood model (FEMA, 2018) can generate depth grids that can be used to estimate flood extent and the likelihood of overtopping. The flood model also includes a scour risk model for bridges but does not include models to address damage to road surfaces. Quantitative outputs for the earthquake model include estimates of direct losses, calculated as a fraction of the replacement value. For the flood model, estimated losses are computed for bridges but not roads.

HYRISK—Sponsored by the FHWA, HYRISK (Pearson, Stein, & Jones, 2000) is an Excel-based scour risk assessment tool for bridges. The tool requires inputs from the National Bridge Inventory to calculate the probability of failure due to scour; inputs require items from the National bridge inventory.

Cornell University Culvert Model—Cornell University has developed an ArcGIS toolbox that computes a vulnerability score for culverts. Vulnerability is based on comparing a culvert's estimated hydraulic design to the discharge of a selected design storm. Required inputs include a digital elevation model, point shapefile representing the culvert inventory, soil data, and precipitation data (Truhlar & Gold, 2018).

InfraRisk—The European Commission funded the InfraRisk project, a web-based, geospatial tool that calculates estimated losses for roads and bridges from earthquakes, landslides, and floods. InfraRisk is unique because it was designed to facilitate stress testing of linear infrastructure against not only single but interactive and cascading threats, using a probabilistic Bayesian Belief Network engine (InfraRisk Project, 2020).

Colorado DOT's Risk and Resilience Excel Spreadsheet Tool. Colorado DOT developed a Risk and Resilience Analysis Procedure to calculate risk and resilience for highway infrastructure from flood, rockfall, and scour. Based on this procedure, Colorado DOT developed a Risk and Resilience Excel Spreadsheet tool (CDOT, 2020a).

FHWA VAAF--The FHWA VAAF is a guide for state DOTs and MPOs on how to incorporate vulnerability to climate change and extreme weather events into their planning (see Figure 15 from (Filosa, Plovnick, Stahl, Miller, & Pickrell, 2018)). States have employed the FHWA VAAF under the auspices of the FHWA Resilience Pilot program. The steps are defined as follows:

Step 1: Define Project Scope. Step 1 is where the analysis defines the objectives of the investigation, the assets to be analyzed, and the relevant climate variables. In addition, it is essential to address the target audience, the level of detail needed, and what products are required.

Step 2: Assess Vulnerability. Step 2 requires the compiling of asset data and climate data, as well as determining asset sensitivity to climate stressors, probability of failure, etc.

Step 3: Analyze Adaption Options. Once the vulnerability assessment has been completed, benefit-cost analysis can be conducted to weigh the cost-effectiveness alternative adaptation/mitigation options.

Step 4: Incorporate Results into Decision-Making. The vulnerability and economic analysis results can be integrated into asset management plans and assist in project prioritization.

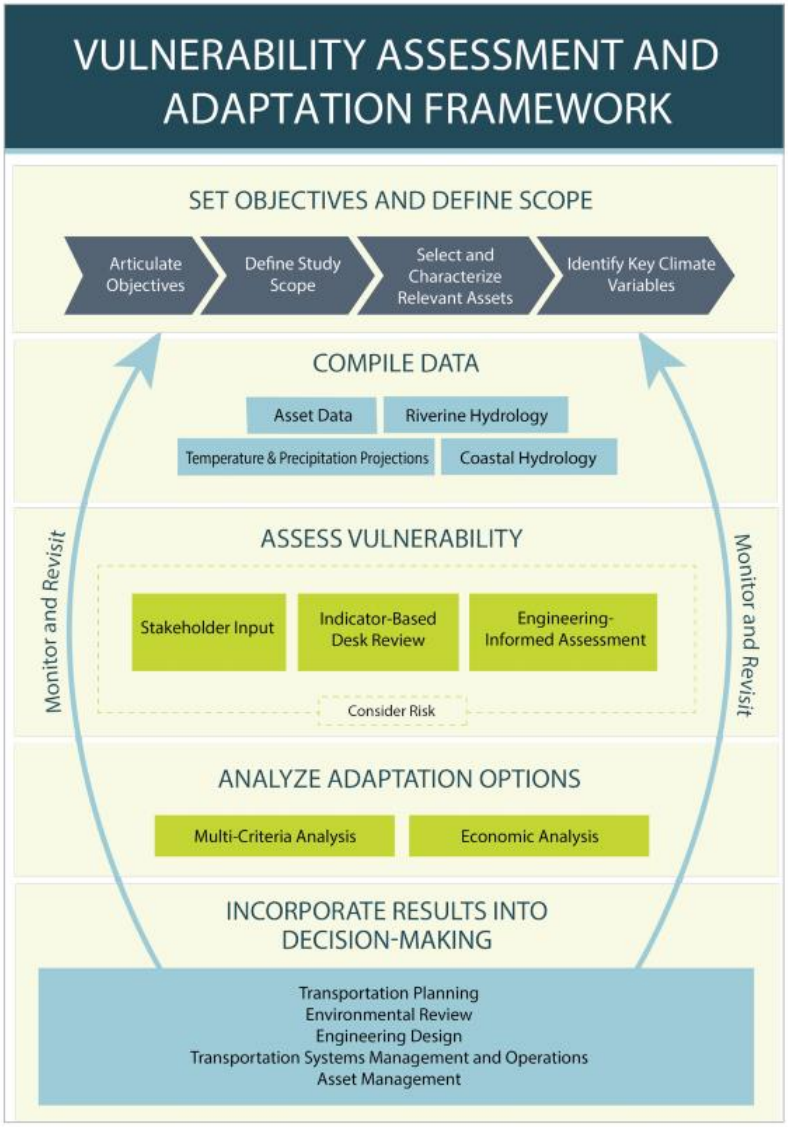


Figure 15. FHWA VAAF

The risk is the expected annual loss due to some adverse event. Risk can be estimated with either qualitative or quantitative models. Quantitative models can be deterministic, producing a single outcome, or probabilistic, producing a range of outcomes to account for the uncertainty in the model. Several risk assessment tools are available to transportation planners and the public. Examples include HAZUS, VAST, HYRISK, Cornell University's culvert model, and InfraRisk. Finally, the FHWA VAAF provides transportation planners with a framework for incorporating climate projections into their risk assessments. The following section addresses the similarities and differences between risk and resilience.

The Four Rs of Resilience

An example of how metrics, risk, and resilience can be tied together can be found in Utah DOT's FHWA-sponsored US-40 Risk and Resilience Pilot study (UDOT, 2019). Utah DOT developed a three-by-5 matrix to calculate a qualitative measure of resilience, called "Level of Resilience" (LOR), based on Bruneau's "four Rs of Resilience" principle (see Figure 16 from (UDOT, 2019)). The proposed Level of Resilience (LOR) Index incorporates Bruneau's resilience components, merging the annual risk and the criticality for systems resilience. First, the risk is defined as the annual risk in dollars ($) or dollars per lane-mile ($/lane-mi) per 1-mile segment length. The annual risk is divided into five quantiles, each representing 20 percent of the overall database and ordered from low to high (Quantiles 1 through 5). Next, the Criticality Score for Systems Resilience is divided into low, moderate, and high categories. Finally, the Level of Resilience (LOR) Index is developed, as shown in

Annual Risk (Robustness/Rapidity)	Criticality for Systems Operations (Resourcefulness/Redundancy)		
	Low	Moderate	High
Quantile 1 (Cumulative Distribution 20%)	A	B	C
Quantile 2 (Cumulative Distribution 40%)	B	B	C
Quantile 3 (Cumulative Distribution 60%)	C	C	C
Quantile 4 (Cumulative Distribution 80%)	C	C	D
Quantile 5 (Cumulative Distribution 100%)	D	D	E

, with five categories of resilience. The LOR Index varies from A through E, where A means the system or network has a "Very High" resilience and E means a "Very Low" Resilience Figure 17 presents the LOR Index table and the relationship between annual risk and criticality level implemented in this pilot project (UDOT, 2019).

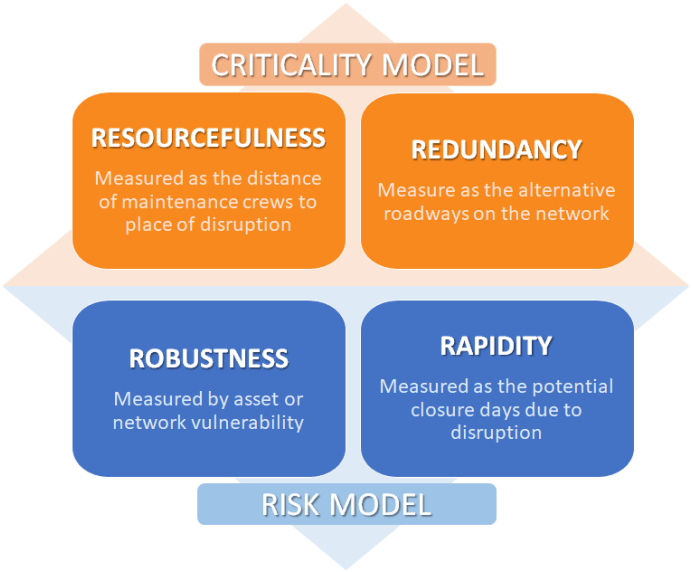


Figure 16. The four Rs of Resilience

Annual Risk (Robustness/Rapidity)	Criticality for Systems Operations (Resourcefulness/Redundancy)		
	Low	Moderate	High
Quantile 1 (Cumulative Distribution 20%)	A	B	C
Quantile 2 (Cumulative Distribution 40%)	B	B	C
Quantile 3 (Cumulative Distribution 60%)	C	C	C
Quantile 4 (Cumulative Distribution 80%)	C	C	D
Quantile 5 (Cumulative Distribution 100%)	D	D	E

Figure 17. LOR Matrix

This section discussed resilience metrics, the relationship between risk and resilience, and various risk and resilience assessment tools. The following section addresses initiatives Federal and State agencies are taking to bring resilience into practice.

Transportation Resiliency Initiatives

MAP-21 and the FAST Act compel the federal government to take initiatives to promote resilience. As a result, federal agencies, such as the FHWA, and non-governmental organizations, such as the TRB, have contributed a wealth of resources concerning risk and resilience through research, conferences, publications, and even software tools. Table 23 summarizes some of the resilience initiatives taken within the last 10 years, grouped under three categories – vulnerability assessment (V), engineering (E), and resources that cover a broad spectrum of topics related to resilience (I). Following the table is a more detailed description of each resource.

Table 23. Resiliency Initiatives

Agency	Initiative/Program	Cat.
FHWA	Climate Change Resilience Pilots (2013-2014)	V
	Resilience and Durability to Extreme Weather Pilot Program (2018)	V

Agency	Initiative/Program		Cat.
	Transportation Engineering Approaches to Climate Resiliency (TEACR) (2016-2017)		E
	Hydraulic Engineering Circulars	HEC 17 (2016)	E
		HEC 25 (2020)	E
	Nature-Based Solutions		E
	MPO Peer Exchanges (2018 – 2020)		I
TRB	Resilience Innovations Summit and Exchange (RISE) (2018)		R
	International Conference on Resilience to Natural Hazards and Extreme Weather Events	2016	R
		2019	R
	Multiple TRB Research Projects (2016 to present)		R
AASHTO	Resilient and Sustainable Transportation Systems Technical Assistance Program (RSTS)		R
	Understanding Transportation Resilience: A 2016 – 2018 Roadmap (2017)		R
	Resiliency Peer Exchange on Extreme Weather and Climate Impacts (2017)		R
	Center for Environmental Excellence		R
PIARC	Strategic Plan 2023-2025		R
NIST	Community Resilience Planning Guide, Volumes 1 & 2 (2016)		C
NRC	Disaster Resilience: A National Imperative (2012)		C

Climate Change Resilience Pilots--Since 2010, FHWA has sponsored a series of climate change studies, providing research grants to state DOTs and Metropolitan Planning Organizations (see Table 24). For example, FHWA sponsored 5 State DOTs and MPS in 2010 – 2011 to conduct vulnerability and risk assessments of their transportation systems. The studies were called pilots because they tested the FHWA Climate Change and Extreme Weather Vulnerability conceptual model. Based on results from the pilot studies, FHWA revised its conceptual model to create the Climate Change and Extreme Weather Vulnerability Assessment Framework. In 2013 – 2014 (ICF International, 2016), FHWA sponsored 19 state DOT and MPO climate change and extreme weather vulnerability studies, testing the Climate Change and Extreme Weather Vulnerability Assessment Framework (Filosa, Plovnick, Stahl, Miller, & Pickrell, 2018).

Resilience and Durability to Extreme Weather Pilot Program (FHWA, n.d.-a)--In 2018, FHWA launched the Resilience and Durability to Extreme Weather Pilot Program, seeking to partner with state DOTs and MPOs to address one of three areas concerning the deployment of resilience solutions:

- "Integrating resilience and durability into agency practices."
- Using available tools and resources to conduct risk-based assessments of transportation projects or systems (including HEC-17 (Kilgore, Thomas Jr, & Thompson, 2016), HEC-25 (Douglass, Webb, & Kilgore, 2020), and the FHWA Vulnerability Assessment Framework (Filosa, Plovnick, Stahl, Miller, & Pickrell, 2018)).
- Deployment and performance monitoring of resilience solutions.

Table 24. FHWA Risk and resilience pilot projects.

Program	Participating in State DOTs/MPOs	Timeline
Climate Change Vulnerability Assessment Pilots (FHWA, 2017a)	New Jersey, Virginia, Washington, Oahu MPO, San Francisco Bay Metropolitan Transportation Commission	2010-2011
Climate Change Resilience Pilots (FHWA, 2017c), (FHWA, 2016a)	Arizona, Alaska, California, Connecticut, Iowa, Maine, Massachusetts, Michigan, Minnesota, New York, Oregon, Tennessee, Washington, and Maryland. Participants from local transportation agencies included the Capital Area MPO (Austin, TX), North Central Texas Council of Governments (COG), the Metropolitan Transportation Council, Broward County (of Florida) MPO, and the Hillsborough (Florida) MPO	2013-2015
Resilience and Durability to Extreme Weather Pilot Program (FHWA, n.d.-a)	Caltrans, Utah DOT, Pennsylvania DOT, Massachusetts DOT, Naval Facilities Engineering Command, Bi-State Regional Commission, Mid-America Regional Council, Houston-Galveston Area Council, and the Corpus Christi MPO	2018-2020

The FHWA TEACR Study Program (R. Hyman, 2014), (A. Choate, 2017) –With the increased impacts of climate variability compounded by land-use changes, engineers recognize that current design standards may not be adequate for future conditions. The purpose of the planning phase in project development is to determine the needs that the project will address and the features that will allow the project to meet those needs. The TEACR Study Program aims to help transportation professionals incorporate climate change considerations early in the planning phase. If current standards are insufficient, then transportation planners must consider investing in projects that accommodate updated design standards.

The TEACR Study program was implemented to explore best engineering practices for evaluating project-level vulnerabilities to climate change and extreme weather. The two stated goals of the program include 1) "demonstrate the process for translating projections of future environmental conditions into information that transportation agencies can use in project-level specifications and design and 2) "develop methodologies and solutions that project engineers across the nation can use in developing transportation infrastructure that is resilient to future environmental conditions."

The TEACR program included four steps: 1) Gap assessment of integrating climate change assessment with transportation engineering; 2) Engineering case studies, focusing on impacts of sea-level rise, impacts of temperature and precipitation on pavement and geotechnical assets, and economic analysis of design alternatives; 3) recommendations to help engineers improve resilience at project and system levels; and, 4) a new module added to the FHWA Vulnerability Assessment Framework to help agencies identify project-level vulnerabilities.

Synthesis of Approaches for Addressing Resilience in Project Development (A. Choate, 2017) -- This report summarizes the outcome of the TEACR studies. The purpose is to provide transportation engineers with a guide to incorporating climate concerns into project development, basic climate science and economic analysis information, and lessons learned on assessing vulnerability to projected climate change impacts.

HEC-17 (Kilgore, Thomas Jr, & Thompson, 2016--Hydraulic Engineering Circular (HEC) 17 provides engineering guidance on assessing the vulnerability of transportation assets to extreme events and climate change in the riverine environment. This manual also guides federal policies governing floodplain management and development. HEC-17 addresses the uncertainty associated with hydrologic models and provides a primer on climate change science. In addition, the manual describes tools for estimating future flood frequency considering climate change projections.

HEC-25 (Douglass, Webb, & Kilgore, 2020) —The 3rd edition of HEC-25 was published in January 2020. This manual is for designing roads near the coast likely to be impacted by waves, storms, and coastal tides. The manual describes engineering tools for addressing waves, water levels, and sand movement. In addition, the manual during storms.

Nature-based solutions for coastal highway resilience: an implementation guide (B. Webb, 2019). This guide is the outcome of the four FHWA-sponsored peer exchanges held in the Spring of 2018, as discussed earlier. This guide intends to help transportation planners devise nature-based adaptation measures to increase the resilience of coastal roads and bridges. The guide addresses planning, site assessment, engineering, and ecological design issues, construction, monitoring, and maintenance. In addition, the appendix includes decision support tools, metrics, and other resources.

MPO Peer Exchanges--In the Spring of 2018, FHWA conducted four regional peer exchanges on nature-based solutions to improve the resilience of coastal highways (C. Cherry, 2018). The exchanges were conducted at the following locations and times.

- Mobile, Alabama – February 15, 2018
- Oakland, California – April 10, 2018
- Lewes, Delaware – April 17, 2018
- Wilmington, North Carolina – April 19, 2018

Example projects discussed include the following:

- Reconstruction of Florida SR A1A after Hurricane Matthew. Remediation included rebuilding dunes with sand and vegetation in one location, sloping the roadway to drain towards the median instead of the dunes, and building a buried secant pile wall covered with sand and vegetation.
- Pacific Coast Highway (Highway 101). Existing rock revetments were augmented with native cobble stones in front of rip rap, dunes built from native materials, and the planting of native vegetation.
- Delaware Coastal project. The project was intended to remediate the disrupted flow of sand due to inlet jetties built in the 1930s. The project included building a Bypass Plant to recreate the natural flow low of sand as if the inlet jetties were not there.
- Plumb Beach, New York. The USACE built a beach berm to combat erosion at a popular recreation beach.
- San Francisco Bay Living Shorelines Project. This project created native ecosystems by establishing oyster beds and panting eel grass. The result of the experiment may reduce water flow, attenuate waves, and increase sedimentation.

FHWA sponsored two relevant MPO peer exchanges in 2020: 1) the "Integrating Natural-Hazard Resilience into Transportation Planning" conference, held by the Indiana MPO on September 29th (Holsinger, Lupes, Davis, & Thorne, 2020) and 2) the "Using the MPO Planning Process to Increase Transportation System Resilience," held by the Florida MPO, August 27 – 31 (ICF, 2020). Key takeaways from the Florida MPO peer exchange include:

1. MPOs across Florida are promoting resilience to natural hazards in their planning process.
2. Florida MPOs must address hazards besides coastal flooding, including inland flooding, wildfires, and extreme heat.
3. Collaborating with regional partners is essential.
4. Funding is still a challenge.

USDOT Climate Adaptation Plan (U.S. DOT, 2014). --This plan outlines the steps DOT will implement to integrate climate change adaptation and resilience into policies, programs, and operations.

1. Planning. USDOT will ensure that investment decisions address climate change's impact on state and metropolitan planning and project development to protect federal assets.
2. Asset Management. DOT will strive to incorporate consideration for climate change impacts into asset management plans.
3. Tools. DOT will provide tools, best practices, case studies, and other resources to assist in incorporating climate change into decision-making.

TRB is a division of the National Academy of Sciences and serves as an independent advisor to the President. TRB has published over 77,000 papers, articles, and reports. In addition to research, TRB sponsors national and international conferences, such as the Transportation Resilience Innovations Summit and Exchange (RISE) and the TRB Extreme Weather Conferences. TRB's contributions to furthering the public's understanding of risk and resilience include the Transportation Rise Conference, the Resilience to Natural Hazards and Extreme Weather Conferences, and NCHRP reports.

Transportation RISE (TRB, 2018)--In Denver, Colorado, the TRB held Transportation RISE, a conference to exchange ideas about including risk and resilience practices within daily and emergency management operations. The conference included a poster presentation. Each participating agency was asked to prepare a poster that stated the agency's definition of resilience, the agency's resilience successes, and areas that could be improved.

TRB Resilience to Natural Hazards and Extreme Weather Conferences--TRB has hosted two international conferences on resilience to natural hazards and extreme weather, the first in 2015 (TRB, 2015) and the second in 2019 (Flannery, Burton, Pena, & Moser, 2019). These conferences were designed to inform transportation professionals about best practices and state of art in adaptation to natural hazards and extreme weather for surface transportation systems.

The outcome of the 2016 conference included several best practices applicable to cyber security: redundancy and backup systems are necessary to reduce the impact of cyber disruptions; system specifications should address both physical security and cyber security; organizational resiliency plans should address all risks simultaneously, taking into account the impact of interrelated risks and cascading effects; personnel must be trained in both cyber and physical security risks and mitigation strategies (Flannery, Burton, Pena, & Moser, 2019).

Best practices coming out of the 2019 conference included recommendations for climate change modeling, asphalt resilience, and risk modeling. Anne Stoner from Texas Tech recommended using as many GCMs as possible to account for the uncertainty in the models. Similarly, Roger Kilgore recommended using as many GCMs as possible from the "Group 1" GCMs listed in NCHRP 15-61. Group 1 GCMs are well-established models whose performance is frequently cited in the literature and thus considered the most reliable. Furthermore, Kilgore justified using the RCP 4.5 emissions scenario for assessing climate risk, explaining that in H&H modelling, the practice is to pick the mean value and not the extremes. Benjamin Bowers from Auburn University reported the findings of the 2019 National Center for Asphalt Technology (NCAT) Workshop (Flannery, Burton, Pena, & Moser, 2019). Several case studies presented at the NCAT conference showed that rapid emergency repairs could be made if DOTs establish relationships between contractors and stakeholders well before disasters, if DOTs and contractors can work closely together, and if the contracting process is accelerated. Finally, Cassandra Bhat from ICF International discussed best practices for index-based climate change risk assessments: limit the number of indicators to avoid collinearity, derive indicators from existing data, tie indicators to absolute or relative thresholds, ground-truth the results, ensure transparency in methodology, and ensure the outputs of the model are accessible and valuable (Flannery, Burton, Pena, & Moser, 2019).

TRB Research Projects--Some of the completed TRB projects related to risk and resilience are listed in

Table 25, with further descriptions given below:

Table 25. Completed NCHRPs Relating to Resilience

Report Number	Title	Publication Date
ACRP Research Report 199 (National Academies of Sciences, Engineering, and Medicine, 2019)	*Climate Resilience and Benefit-Cost Analysis: A Handbook for Airports*	2019
NCHRP Project 15-61 (R. Kilgore, 2019)	Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure.	03/15/2019
NCHRP Synthesis 527 (Flannery, Pena, & Manns, 2018)	*Resilience in Transportation Planning, Engineering, Management, Policy, and Administration* (2018).	2018
NCHRP Project 08-36, Task 142 (S. Resetar, 2020)	*Guidebook for Multi-Agency Collaboration for Sustainability and Resilience*	02/2020
NCHRP Project 08-36, Task 146 (TRB, 2019)	Economic Resilience and Long-Term Highway Transportation Infrastructure Investment	2019
NCHRP Project 20-59 (53) (M. Mampara, 2016)	FloodCast: A Framework for Enhanced Flood Event Decision-Making for Transportation Resilience	10/2016
NCHRP Project 20-59 (54) (The City of Columbus, 2020)	Transportation System Resilience: Research Roadmap and Whitepapers	04/2021
NCHRP Project 20-59(56) (TRB, 2019)	"Support for State DOT Transportation Systems Resilience and All-Hazards Programs"	5/2019
NCHRP Research Report 938 (National Academies of Sciences, Incorporating the Costs and Benefits of Adaptation Measures in Preparation for Extreme Weather, 2012)	*Incorporating the Costs and Benefits of Adaptation Measures in Preparation for Extreme Weather Events and Climate Change Guide*	2020
TCRP Web-Only Document 70, Volumes 1 – 3 (National	*Improving the Resiliency of Transit Systems Threatened by Natural Disasters*	2017

Report Number	Title	Publication Date
Academies of Sciences, Engineering, and Medicine, 2017), (National Academies of Sciences, 2017), (National Academies of Sciences, Engineering, and Medicine, 2017)		

ACRP Report 199 (National Academies of Sciences, Engineering, and Medicine, 2019)--*Climate Resilience and Benefit-Cost Analysis: A Handbook for Airports*. Provides information on benefit-cost analysis for improved decision-making when planning infrastructure projects to improve the resilience of airports to climate change and extreme weather.

NCHRP Project 15-61 (R. Kilgore, 2019) Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure. Addresses both inland and coastal hydrology; this manual guides how to incorporate climate change projections (sea-level rise, changes in timing and distribution of precipitation, temperature rise, etc.) into H&H design.

NCHRP Synthesis 527 (Flannery, Pena, & Manns, 2018) *— Resilience in Transportation Planning, Engineering, Management, Policy, and Administration* (2018). This report investigates the state of the practice in integrating resilience into transportation planning and engineering through a literature review, interviews, and surveys of State DOTs and MPOs.

NCHRP Project 08-36, Task 142 (S. Resetar, 2020) Guidebook for Multi-Agency Collaboration for Sustainability and Resilience. This guide aims to assist transportation agencies (State DOTs, MPOs, cities, counties, etc.) in collaborating with governmental and nongovernmental agencies on a wide range of policy objectives.

NCHRP Project 20-59 (53) (M. Mampara, 2016) FloodCast: A Framework for Enhanced Flood Event Decision Making for Transportation Resilience. This project produced a framework for flood response planning and a prototype software tool for transportation agencies and emergency managers to evaluate the impacts of flooding on surface transportation.

NCHRP Project 20-59 (54) (Fletcher & Ekern, 2021)--Transportation System Resilience: Research Roadmap and Whitepapers. The goal of this report was to document and share knowledge of certain aspects of resilience within the transportation sector, as well as augment the work of NCHRP 20-59 (55), Transportation System Resilience: Chief Executive Officer (CEO) Primer & Engagement, and NCHRP Project 20-59 (117), Deploying Transportation Resilience Practices in State DOTs. The research for this project has been completed but not yet published.

NCHRP Web-Only Document 27-- Guidelines to Incorporate the Costs and Benefits of Adaptation Measures in Preparation for Extreme Weather Events and Climate Change.

NCHRP Research Report 938: Incorporating the Costs and Benefits of Adaptation Measures in Preparation for Extreme Weather (National Academies of Sciences, Incorporating the Costs and Benefits of Adaptation Measures in Preparation for Extreme Weather, 2012) This report describes the state of the practice in using cost-benefit analysis in decision making, and how to incorporate cost-benefit analysis into the planning process in conjunction with assessing the cost-effectiveness of climate change adaptation options.

TCRP Web-Only Document 70: Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 1: A Guide (National Academies of Sciences, Engineering, and Medicine, 2017). This guide explains identifying and implementing appropriate resilience strategies to strengthen an agency's operations and infrastructure.

The guide is followed by *Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 2: Research Overview* (National Academies of Sciences, Engineering, and Medicine, 2017) and *Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 3: Literature Review and Case Studies* (National Academies of Sciences, Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 2: Research Overview, 2017).

TRB is sponsoring at least 7 active National Cooperative Highway Research Program (NCHRP) projects relevant to resilience and transportation. They are described here (see Table 26):

Table 26. NCHRP Reports in Progress

Report Number	Title	Completion Date
NCHRP Project 08-118 (National Academies of Sciences, Engineering, and Medicine, 2022)	"Risk Assessment Techniques for Transportation Asset Management"	6/23/2021
NCHRP Project 08-113 (Sumner, Gettman, Toppen, & Obenberger, 2018)	"Integrating Effective Transportation Performance, Risk, and Asset Management Practices"	1/29/2021
NCHRP Research Report 796 (National Academies of Sciences, Engineering, and Medicine, 2021a)	*Resilience Primer for Transportation Executives*	12/31/2020

Report Number	Title	Completion Date
NCHRP Web-Only Document 293 (National Academies of Sciences, Engineering, and Medicine., 2021b)	*Deploying Transportation Resilience Practices in State DOTs*	9/30/2020
NCHRP Project 20-125 (National Academies of Sciences, Engineering, and Medicine, 2022a)	"Strategies for Incorporating Resilience into Transportation Networks"	3/29/2022
NCHRP Project 20-127 (National Academies of Sciences, Engineering, and Medicine, 2022b)	"Business Case and Communications Strategies for State DOT Resilience Efforts"	12/15/2022
NCHRP Project 23-09 (National Academies of Sciences, Engineering, and Medicine, 2022c)*	"Scoping Study to Develop the Basis for a Highway Standard to Conduct an All-Hazards Risk and Resilience Analysis"	4/20/2022
NCHRP Project 02-26 (National Academies of Sciences, Engineering, and Medicine, 2022d)	"Implementation of Life-Cycle Planning Analysis in a Transportation Asset Management Framework"	4/4/2021
NCHRP Project 08-124 (National Academies of Sciences,	"Quantifying the Impacts of Corridor Management"	9/16/2021

Report Number	Title	Completion Date
Engineering, and Medicine, 2022f)		

*Note: Completed. Waiting for final deliverables to be published.

AASHTO Initiatives--"AASHTO's Resilient and Sustainable Transportation Systems Technical Assistance Program (RSTS) is designed to help state DOTs understand the potential effects of climate change and the range of strategies and options; for climate change mitigation and adaptation." "RSTS is a voluntary pooled-fund program that provides timely information, tools, and technical assistance to AASHTO members in meeting the difficult challenges related to climate change, energy efficiency, energy security, infrastructure adaptation, alternative vehicles, and fuels, and other relevant topics" (National Academy of Sciences, 2022e).

AASHTO hosted the two-day *Resilience Peer Exchange on Extreme Weather and Climate Impacts* peer exchange in Washington, D.C., bringing together state transportation officials from across the U.S. to discuss their challenges and successes in preparing for and recovering from extreme weather events (AASHTO, 2017a)

AASHTO's *Center for Environmental Excellence by AASHTO* website hosts links to resources such as conference materials, case studies, videos, reports, and webinars, some of which are relevant to extreme weather, vulnerability assessment, etc. (AASHTO).

AASHTO Understanding Transportation Resilience: A 2016 – 2018 Roadmap (2017) (AASHTO, 2017b)is a report that aims to provide SCOTSEM and other AASHTO and TRB resilience-oriented committees and projects a discussion tool to guide their approach to sponsoring and participating in national transportation resilience-related activities.

PIARC Strategic Plan 2020-2023. Permanent International Association of Road Congresses (PIARC) – The World Road Association. Founded in 1909, the World Road Association is a non-profit organization to muster expertise to develop and share information to improve the state of roads and transportation worldwide (Climate ADAPT, 6). The World Road Association fulfills its mission by publishing a five-year strategic plan. The Strategic Plan for 2020-2023 is comprised of four strategic themes (PIARC, 2020).

- ST1 Road Administration
- ST2 Mobility
- ST3 Safety and Sustainability
- ST4 Resilient Infrastructure

NIST Community Resilience Planning Guided for Buildings and Infrastructure Systems, Volume I (NIST, 2016) --This guide outlines a 6-step planning process to aid communities in establishing affordable priorities and allocating resources to enhance their resilience.

NIST Community Resilience Planning Guided for Buildings and Infrastructure Systems, Volume II (NIST, 2016a)--Volume II discusses community resilience by sector – social, buildings, energy infrastructure, transportation, performance goals, regulations and standards, and the impact of cascading hazards.

National Research Council. Disaster Resilience: A National Imperative (National Research Council, 2012)-- This report defines national resilience, provides goals and performance metrics, describes the state of the knowledge of hazards and disasters, and outlines gaps and obstacles to national resilience.

Resilience in Transportation Planning

Resilience planning is an emergent concept reflective of the recognition by transportation planners and operators that business as usual is not working. More effort is needed in the initial stages of needs assessment and strategic direction setting to ensure considerations of uncertainty, external shocks to infrastructure, and societal impacts, are incorporated into the transportation system to support resilient infrastructure and the communities.

Recognizing the need to incorporate resilience into planning, Public Law 23 CFR 450.216(c) requires state DOTs to address emergency relief and disaster preparedness in their long-range statewide transportation plans. Similarly, 23 CFR 450.324(f)(7) requires MPOs to address strategies to reduce vulnerability to natural disasters in their transportation plans.

As part of these federal and other state or agency requirements, transportation agencies have begun incorporating resiliency practices and processes into their transportation plans. While State DOTs and other transportation agencies understand the importance of incorporating resilience planning into transportation decision-making, the state of the practice varies.

Some of the transportation plans where resilience shall be incorporated include:

- Transportation Asset Management Plans
- Metropolitan Transportation Plans
- Long-range statewide transportation plans
- Transportation Improvement Programs
- State Multimodal Transportation Plans
- Freight Plans
- Safety Plans
- Statewide Bike/Pedestrian Plan
- Statewide Aviation Plan
- Statewide Port Plan
- Statewide Transit Plan
- Others

As part of the efforts to improve the state of practice and include resilience and sustainability early during decision-making, agencies have participated in federal and non-federal pilot projects to develop and enhance resilience strategies and processes. In addition, FHWA, AASHTO, and TRB also recognize the importance of helping guide state DOTs and other transportation agencies in incorporating resilience at various levels of their organizations.

Federal initiatives- FHWA has sponsored numerous pilot projects related to risk and resilience, including Vulnerability Assessment Pilots (2010-2011), Vulnerability Assessments and Adaptation Options Pilots (2013-2015), Nature-based Resilience for Coastal Highways Pilots (2016-2017), Asset Management, Extreme Weather, and Proxy Indicators Pilots (2017-2019) and Resilience and Durability to Extreme

Weather Pilots (2018-2020/2024) (FHWA, 2021a). Figure 18 maps the states and agencies participating in the FHWA resilience pilots. Links to final reports for these Pilots can be downloaded from FHWA's Sustainability website (FHWA, 2021a).

Figure 18. FHWA Resilience Pilots

As an outcome of these pilots, FHWA has sponsored and published numerous documents to help transportation agencies to achieve their goals and requirements of incorporating risk and resilience into planning.

In 2017, FHWA published a guide to help incorporate risk into TAMPs to meet the risk-based requirements (FHWA, 2017). The guide provides definitions and background on risk in asset management and how to consider the risk -performance. In addition, the guide highlights the findings and contributions from the *AASHTO Guide for Enterprise Risk Management,* including a risk management process/framework (AASHTO, 2016).

Further, in 2018 FHWA published a white paper, followed by a handbook, to guide transportation professionals on how to incorporate resilience into all stages of the planning process (e.g., LRTPs, TIPs, STIPs, environmental reviews). This effort assessed 52 DOTs and 101 MPOs and identified how they incorporate these concepts and at what levels into their planning. Figure 19 is a generic representation of the planning process that can be applied to any plan (B. Dix, 2018)

Figure 19. Transportation Planning Process

Table 27 displays the number of DOTs and MPOs incorporating resilience into each of the 6 stages of the planning process illustrated in Figure 19.

Table 27. Summary of MPOs and DOT Integration of Resilience into Planning Stages

Planning Area	DOTs (out of 52)	MPOs (out of 101)
Goals and Objectives	17	45
Assessment of Problems and Needs (Conducted/In Progress of a Vulnerability Assessment)	11	19
Performance Measures, Targets, and Evaluation Criteria	5	19
Resilience Strategies	21	64
Implementation of Strategies	Unknown	Unknown
Ongoing Monitoring and Reporting	1	3

As shown in Table 27, most of the resilience efforts were incorporated in Stage 1 (Goals and Objectives) and Stage 4 (Resilience Strategies), with lesser effort in Stage 3 (Performance Measures, Targets, and Evaluation) and Stage 6 (Ongoing Monitoring and Reporting).

Table 28 (FHWA, 2017) presents examples of how state DOTs and MPOs have integrated resilience into different stages. The examples represent four outcomes from the FHWA 2013-205 Climate Change Resilience Pilots (FHWA, 2017c).

Table 28. Integrating Resilience into Each Stage of Planning

Regional Vision & Goals: Establish goals and performance measures related to resilience (e.g., system reliability, sustainability, reduced delays).	In Tampa, Florida, the Hillsborough MPO's long range transportation plan includes an objective to increase the security and resiliency of the multimodal transportation system, with an associated performance measure on reducing the recovery time and economic impact of a major storm. The plan also outlines an investment plan needed to achieve the objective of the vulnerability reduction program.
Long Range Transportation Plan: Use information on resilience to identify strategies and investment scenarios during development of statewide and metropolitan long range transportation plans.	The Capital Area Metropolitan Planning Organization (CAMPO) in Austin, Texas integrated the results of its vulnerability assessment into its 2040 Regional Transportation Plan. The plan summarizes the climate-related risks to the region's transportation system and identifies potential measures that the CAMPO region can implement to proactively increase the transportation system's climate resiliency. Priority action items included in the plan are: increasing extreme weather resiliency by evaluating the adequacy of potential wildfire and flood evacuation routes; identifying opportunities to increase system redundancy and alternate routes; and advancing best practices in addressing drought related impacts on the transportation system.
Project Evaluation and Prioritization: Use resilience as a factor for project prioritization.	The Maryland Department of Transportation's State Highway Administration (SHA) is using the results of its vulnerability assessment to delineate coastal locations vulnerable to flooding. This data is intended to help the agency screen new project plans and designs for resilience to future climate impacts. The SHA will use the screening mechanism to inform its Highway Needs Inventory, a planning document that lists major capital construction projects.
Project Development: Consider resilience in project design and engineering.	The Massachusetts Department of Transportation developed the Highway Project Intake app, a web-based GIS application designed to improve agency coordination and expedite project delivery. The app allows users to access over 30 location-based transportation, safety, environmental, and vulnerability data layers, including an inventory of flood prone areas. Project planners can utilize the tool to identify vulnerability issues and adaptation solutions early in the project planning process.

Other non-federal studies have also tried identifying how state DOTs and MPOs incorporate resilience into long-term transportation planning. For example, a RAND Corporation-led project for NCHRP project 08-36, Task 146, focused on how DOTs and MPOs could implement a modified version of the FHWA Vulnerability Assessment Framework (VAF) to incorporate resilience strategies and all hazards into long-term decision-making and planning. This NCHRP project developed a resilience framework based on the resilience AREA approach (absorptive capacity, restorative capacity, equitable access, and adaptive capacity). This approach helps focus on the criticality of assets and their exposure to different threats and helped develop a suite of resilience metrics to be used in planning (Weilant, Strong, & Miller, 2019).

A transportation system logic model with different steps to incorporate metrics was developed based on the AREA approach. Table 29 presents the actions of the logic model and the applicable metrics categories for each stage (Weilant, Strong, & Miller, 2019).

Table 29. Measures for measuring AREA resilience

Step of Logic Model	Area Category	Categories of Metrics
Inputs	Absorptive capacity Restorative capacity Equitable access Adaptive capacity	Exposure metrics Available response metrics Availability of public transit; availability of alternative mode choices Availability of alternate routes and alternative mode choices
Activities	Absorptive capacity Restorative capacity Equitable access Adaptive capacity	Maintenance metrics Measures of community planning efforts; measures of communities' communication capabilities Measures of communities' communication capabilities Network expansion
Outputs	NA	Intensity of route use or vehicle miles traveled (VMT); measures of the transportation system's state of repair; reliability metrics
Outcomes	NA	Measures of congestion, travel time, and travel speed; measures of transportation system safety; reliability metrics; accessibility metrics

This logic model was proposed to help map the transportation system and utilize the proposed metrics to incorporate resilience in different AREA categories. Even though this logic model or framework aims to help DOTs and MPOs to integrate resilience into long-term planning, it is also recognized that each agency has its own planning needs and goals and that "there is no one-size-fits-all approach to resilience."

NADO Research Foundation Framework

The NADO Research foundation led another initiative to help transportation agencies incorporate resilience into planning. This project focused on developing a framework to help practitioners consider economic goals and lead them towards a practice of performance-based planning (Kissel, 2018). The primary purpose of the guide from this project was to introduce concepts that can be used to measure economic development progress, vitality, and resilience and its integration into planning processes. The primary audiences for this guide are regional planning and development organizations (RDOs), regional transportation planning organizations (RTPOs), metropolitan planning organizations (MPOs), and state and local partners with an interest in transportation and economic development. This project highlights how planning organizations with metrics that lack a system to track the measures will not have time or staff to measure performance. In addition, this project highlights that the federal requirements regarding

the performance management process (MAP-21 and FAST Act) have helped advance the state of practice in this area for transportation agencies. The key takeaways from this project include:

• "Take a systems perspective to understand economic resilience goals, regional prosperity, and transportation's role. Multiple systems frameworks exist; the rural wealth creation framework is one focused on existing community assets. "

• "Embed measurement into the regional planning process, rather than treating it as a standalone task."

• "Measure regional wellbeing across several emphasis areas, track it through plan updates, and use the measures in multiple planning efforts. Where appropriate, " repurpose measures used by partners, such as state agencies."

• "Develop transportation project prioritization criteria that implement the vision, goals, objectives, and measures adopted through the planning process."

• "Communicate progress over time to make performance measurement a feedback loop that influences future planning and development decisions."

• "Intentionally include economic development stakeholders, including both private sector leaders and intended beneficiaries of development such as low-income residents, throughout the planning process" (Kissel, 2018).

Another crucial factor in incorporating resilience into transportation planning is looking at the entire transportation system and the intermodal dependencies. FHWA states that "resilience and sustainability should be considered early during decision-making at the systemwide level when options and priorities are considered for transportation investments to meet multiple community goals."

State/Local Agency Examples of Integrating Resilience into Planning--As an example of looking at resilience at the system and network level, the Florida Department of Transportation (Florida DOT) sponsored a study to focus on analyzing their Strategic Intermodal System (SIS) highway network to identify critical infrastructure and network vulnerabilities and risk from a wide range of hazards, including storm surge, flooding, sea-level rise, wildfire, extreme heat, and sinkholes to incorporate pre-disaster mitigation into their long-term planning. Florida DOT used the SIS Risk Assessment Framework to support improving the climate resilience of their SIS facilities. The proposed framework incorporates 5 modules: (FDOT, 2018).

- Set mission goals and objectives.
- Collect and process data.
- Conduct vulnerability and risk assessment.
- Develop recommendations for adaptation strategies.
- Integrate assessment outcomes into Florida DOT's decision support systems.

Some other examples of transportation agencies' efforts to include resilience into planning include:

Delaware Department of Transportation--Developed a Strategic Implementation Plan for Climate Change, Sustainability, and Resilience as an initiative based on Executive Order 41(EO41), Preparing Delaware for Emerging Climate Impacts and Seizing Economic Opportunities for Reducing Emissions, issued in 2013. DelDOT developed a Climate Framework with a series of recommendations to support funding and decisions for project development based on resilience parameters (DELDOT, 2017).

Atlanta Regional Commission (ARC)--ARC adapted the FHWA VAF to develop its ARC vulnerability and resilience framework. This resilience framework integrates extreme weather threats, asset criticality, and vulnerability into their planning and engineering process (ARC, 2018).

Bi-State Regional Commission--Conducted a vulnerability assessment from extreme weather events to identify short and long-term strategies to improve the resilience of the multimodal transportation system in the border cities between Iowa/Illinois metropolitan planning areas. Incorporated findings into their 2050 Long Range Transportation Pan (Holsinger H. , 2018).

Colorado DOT I-70 Risk and Resilience Pilot--Colorado DOT sponsored a project to assess the risk from multiple hazards, including floods, rockslides, landslides, avalanches, and high wind on their I-70 corridor transportation infrastructure (AEM Corporation, 2017). Following this pilot, Colorado DOT developed a Risk and Resilience Analysis Procedure to assess their highway transportation infrastructure's criticality, risk, and resilience (CDOT, 2020). Colorado DOT is currently exploring how these efforts can be integrated into future asset management and prioritization process.

Florida DOT/MPOs--Due to Federal Regulation 23 CFR 450.306(b)(9), Florida MPOs consider resilience when assessing projects, strategies, and services in their LRTP. Some of the threats included extreme weather events (frequency of severe storms with high winds and rainfall, duration of droughts, etc.), weather, environmental changes (inland flooding, sea-level rise, etc.), and economic shifts (recessions), cyber-attacks and operations disruptions. In addition, the Florida DOT Office of Policy Planning (OPP) developed a Resilience Quick Guide to help MPOs incorporate resilience into their LRTP (FDOT, 2020). The Guide highlights the opportunities to integrate Resilience in each planning step:

- Goals and Objectives Section
- Performance Measures and Targets
- Risk and Vulnerabilities Assessment Section
- Needs Plan Development Section
- Cost Feasible Plan – Investments and Project Prioritization

Hillsborough, Florida MPO - The Hillsborough Metropolitan Planning Organization, in partnership with the Pinellas and Pasco County MPOs, the Tampa Bay Regional Planning Council, participated in the FHWA-sponsored 2018-2020 *Resilience and Durability to Extreme Weather* pilot study (Cambridge Systematics, 2020). The project team employed the FHWA Vulnerability Assessment framework to assess the vulnerability and durability of transportation infrastructure to flooding inundation in the Tampa Bay region. The vulnerability assessment results were cross-referenced with a criticality assessment to identify priority locations. As a result, several adaptation strategies were identified, ranging from green solutions – using beachgrass to control erosion – to gray solutions, such as revetments and sea walls. Final recommendations included incorporating the proposed adaptation strategies for priority locations in the three MPOs' LRTPs (Cambridge Systematics, 2020).

North Florida Transportation Planning Organization (TPO) (Cambridge Systematics, 2019)– With assistance from Cambridge Systematics, North Florida TPO assessed their transportation network's vulnerability to SLR, storm surge, and inland flooding and developed four resilience objectives to be incorporated into the 2045 LRTP:

- "Incorporate climate risk in project planning, system preservation, and maintenance."
- "Provide reliable mobility access and minimize the impact of disruptions to regional mobility."
- "Support regional evacuation needs as reflected in municipal Emergency Management Plans."

- "Address social equity in adaptation/resilience strategy implementation."

North Jersey Transportation Planning Authority (NJTPA) and New Jersey DOT (NJTPA, 2010) – In 2010, NJTPA and New Jersey DOT received an FHWA grant to conduct a vulnerability and risk assessment of transportation infrastructure from the impacts of climate change. The pilot study superimposed SLR for the years 2050 and 2100 over New Jersey's transportation asset inventory (rail, highway, bridges, tunnels, buses, and evacuation routes) to estimate exposure to flooding and storm surges. The analysis also considered extreme precipitation and temperature. The project team employed FHWA's VAAF to conduct the vulnerability assessment and used the results to populate an adaptation strategy matrix, complete with guidelines for planning, design, and operations for each asset-threat pair.

Vermont LRTP (Vtrans, 2018) –Vermont Transportation Agency (VTrans) LRTP has 6 strategic goals. Goal 1, "Improve safety and security across all transportation modes, includes the supporting objective, "Improve the resilience of the transportation system," with corresponding strategies, including:

- Design infrastructure to withstand severe weather events.
- Advance VTrans' understanding of transportation system vulnerabilities to severe weather events through ongoing research and development of analytical tools.
- Incorporate resilience as a factor in project identification, prioritization, and planning and design.
- Provide technical assistance and support to municipalities to prepare for, withstand, and recover from severe weather events.
- Update Vtrans' Continuity of Operations Plan (COOP) to address flooding, cybersecurity, and other emerging threats.

Ohio DOT (ODOT, 2020) - Ohio's most recent LRTP, AO45, was explicitly drafted to meet the requirements of MAP-21 and the FAST Act. The 13 strategies of AO45 include an emphasis on resilience.

Oklahoma Transportation (Oklahoma Transportation, 2020) - Section 6 of Oklahoma's latest LRTP addresses resilience, describing the seismic, severe weather, and cyber-security threats to its system; and Section 10, "Multimodal Transportation Policies and Strategies," states resilience as a goal: "Improve the security and resilience of the transportation system, including highways, transit, rail, ports and marine, air cargo, and passenger aviation, through identification of "safety-critical" assets."

Washington State DOT Statewide Freight System (C. Caplice, 2008) – Following emergencies such as the 9/11 terrorist attack, Hurricane Katrina (2005), and the Nisqually earthquake (2001), WSDOT realized the importance of recognizing the interdependence between public sector critical infrastructure and private business. As a result, in 2008, WSDOT partnered with the Massachusetts Institute of Technology to review all state hazard mitigation plans for disaster responses and recovery while conducting interviews with private and public sector representatives to develop a statewide freight resiliency plan. The research team developed the plan in three phases. In phase 1, the Identify Phase, the research team identified the freight system's customers. In phase 2, the Assessment Phase, the research team conducted a vulnerability assessment of the freight system, identified public and private sector collaboration mechanisms, and needed policies. Finally, in phase 3, the Implementation Phase, the research team tested the plan with a tabletop simulation where decision-makers had to respond to a simulated emergency.

Texas DOT (Texas DOT, 2011) – The Texas DOT adopted this definition of resiliency for the freight transportation system -- "the ability for the system to absorb the consequences of disruptions, to reduce the impacts of disruptions and maintain freight mobility." In 2011 Texas DOT published its two-volume framework for a resilient freight system. Volume I of the *Statewide Freight Resiliency Plan* identifies

hazards, freight system vulnerability, and assessments for individual corridors. Volume II discusses the communications needs of shippers and carriers, followed by a description of the Texas DOT communications network.

Wyoming DOT (WYDOT, 2018) – Wyoming's freight resiliency plan includes:

- a methodology for determining the criticality of its transportation assets
- a qualitative index scoring tool for risk analysis
- and a summary of risk, prioritization, and recommendations for each corridor

How Other Sectors Incorporate Resiliency

Since 2001, shocks such as Hurricane Katrina, the COVID-19 pandemic, and the 2017 WannaCry ransomware attack have galvanized global interest in resilience. Several examples of these efforts in other industries are detailed further below.

PlaNYC

In 2017, the Bloomberg administration initiated a long-term sustainability plan called PlaNYC (now OneNYC) (Bloomberg, 2007) for New York City in response to their long-term challenges. The city conducted panels on climate change in 2008, 2013, and 2015, with the most recent publishing their latest report, Building the Knowledge Base for Climate Resiliency: New York City Panel on Climate Change 2015 Report (R. Horton, 2015). These initiatives help provide projections through 2100, as well as "new coastal flood risk maps; enhanced dynamic flood inundation modeling, including effects of sea-level rise; and a process for improving the city's resilience indicators and monitoring systems (Flannery, Pena, & Manns, 2018).

Federal Transit Climate Risk Reductio Project

In 2013, the Federal Transit Administration (FTA) funded Sound Transit's Climate Risk Reduction Project as part of its Transit Climate Change Adaptation Assessment pilot program. The key objectives in achieving this were adjustments to infrastructure, operations and maintenance, design changes, and decision support and capacity-building activities. For example, adapting to heat impacts has the potential to prevent rail buckling, while adapting to precipitation impacts can prevent mudslides. In addition, the project identified ways climate change could impact agency objectives and measures to adapt and mitigate climate change (FTA, 2013).

Urban resilience depends on the "urban system's ability to simultaneously maintain social and ecological functions," making achieving these resilient and sustainable cities challenging. Over the years, various ecosystem services were assessed in New York City, with early efforts including valuation of watershed quality, water provision, and forest ecosystem services. More recently, efforts to expand and enhance ecosystem services to NYC residents have developed. Locally produced ecosystems include urban gardens, runoff mitigation in urban forests, and local climate regulation. In addition, better coordination among stakeholders and adaptation of land use planning is crucial to meeting the cities' sustainability and long-term resilience goals (T. McPhearson, 2014). The report, "Building Resilient Cities--from Risk Assessment to Redevelopment," presents a four-stage strategic planning framework tested and refined in these workshops, along with workshop participants' diverse ideas and innovations. The approach, summarized in the table below (Table 30) is proposed for use as the second stage of climate adaptation planning, following the completion of local vulnerability and risk assessments (Brugmann, 2013).

Table 30: Four cornerstones of a resilience zone strategy

The Four Cornerstones of a resilience Strategy			
ASSET-FOCUSED RISK MANAGEMENT Develop mechanisms to support household & enterprise level action.	LOCAL AREA RISK MANAGEMENT Develop mechanisms for risk management & transfer at the scale of the local area	RESILIENCE UPGRADING Design risk reduction measures to enhance today's performance and benefits.	COMMUNICATING RESILENCE BENEFITS Ensure understanding of benefits and effective use of the new "Resilience Zone".
Strategy Questions for Stakeholders			
How could we motivate and support asset owners to fully manage their climate and disaster risk exposures?	How could we manage, pool, spread & transfer the remaining risks on a district or other local area basis?	Could risk management investments be designed so as to improve the area's benefits today"	How would users be supported to fully secure new benefits? How would the area's unique benefits be communicated to the market?
Factoring the above, to which risks will, the local area remain exposed over the near/medium term?	How could such new approaches be developed into market opportunities for insurers and other city-building enterprises?	How could the area's increased amenities & resilience be measured? How could they be compared with competing locations?	How do you help establish resilience as a new standard in city-building and location choice?

Water and Wastewater Sector

In 2017, the Water and Wastewater Sector Working Group updated its "Roadmap to a Secure and Resilient Water and Wastewater Sector" (Water and Wastewater Sector Strategic Roadmap Working Group, 2017), to address joint priorities between the water and wastewater sectors and coordinate action for the next five years. The most significant update to the roadmap was the categories of threats selected to focus on the four Priority Activity Areas: natural disasters, contamination incidents, infrastructure degradation, and cyber risk.

The Priority Activity Areas include:

1. "Establish the critical lifeline status of the Water and Wastewater Sector and translate that definition into strong support for the sector's needs and capabilities."
2. "Improve detection, response, and recovery to contamination incidents.
3. Advance preparedness and improve capabilities of the Water and Wastewater Sector for area-wide loss of water and power".

1. "Advance recognition of vulnerabilities and needed responses related to cyber risk management."

One of the hallmark successes of the wastewater sector is the establishment of a key standard for risk and resilience analysis, ANSI/AWWA J100-10: Risk Analysis and Management for Critical Asset Protection (RAMCAP®) Standard for Risk and Resilience Management of Waste and Wastewater (AWWA) (AWWA, 2010).

Tracking Mechanisms for Resilience Initiatives

Some mechanisms that can be used to track resilience initiatives include recurring reports, dashboards, and risk registers. This section presents some examples of these mechanisms.

Recurring Reports--A visioning process started in 2011. The *MinnesotaGo* (Minnestota go: Planning Minnesota's transportation future, 2020) program was created to align the MnDOT system more strategically with the public regarding quality of life, economy, and the natural environment. This ongoing effort regularly updates progress on targets identified in the community-engagement-resourced visioning process. These targets are updated in the "Trend Library" and include metrics around aging infrastructure, autonomous vehicles, mobility, climate change, and others. The complete metrics reports are included in links and the summary data visualization graphics for each target.

Dashboards--Using UPLAN (UDOT, n.d.) as the primary data resource hub, Utah DOT regularly updates and shares data visualization and target dashboards with the public. The Risk Priority Analysis resource is part of Utah DOT's Enterprise Risk and Resiliency program and details the risk and resiliency modeling factors considered in the analysis and defines industry terms to connect more effectively to the public. In addition, links are provided for GIS maps displaying existing risk and resiliency conditions on the existing system and performance-based targets that detail the intended impact on system vulnerability.

Risk Registers--Caltrans' TAMP (Caltrans, 2018) is risk-based and includes targets and objectives to endorse asset and system resiliency transparency and improvement. The discussion within the TAMP concerning the Risk Register consists of a prioritization process that elevates critical impact improvements. Resiliency measures and metrics from these assessments, done at the district level, allow for easier integration with agency performance goals.

Agency Requirements for Implementation of Resilience Concepts and Strategies in Planning

For agencies to implement resilience concepts and strategies in transportation planning areas, they must consider specific requirements. This section presents some of the requirements needed for implementation, focusing on the following dimensions: organizational structure, data, policies, and workforce. Common themes related to these dimensions include the need to breakdown institutional silos through inter- and intra-agency collaboration (organization), the need for a knowledge base to support resilience analysis (data), the need for professional development and training of staff (workforce) in adaptation planning and cost-benefit analysis, and the incorporation of resilience into design standards and LRTP (policy).

Table 31 lists some recommendations from the literature.

Table 31. Implementation of Resilience

Dimension	Recommendation
Organizational Structure	Strengthen and leverage public-private partnerships (J. Baylis, 2015).
	Effective organizational resilience management must consider the resilience of other organizations depending on (J. Baylis, 2015).
	Establish clear leadership and act on shared priorities during crises (E. Seville, 2006)
	Break down silos between DOT administrations and across agencies by promoting inter- and intra-agency collaboration (SSTI, 2012).
Data	"Promote and enable data-sharing both within the DOT and between DOTs and MPOs, RPOs, and other state and local agencies." (National Academies of Sciences, Engineering, and Medicine, 2015a)
	"Assess agency data management practices, either through self-assessment or an external review, to evaluate how well existing data resources align with strategic needs and identify where gaps exist in agency approaches to data administration." (National Academies of Sciences, Engineering, and Medicine, 2015a).
	Transportation agencies need access to comprehensive datasets that can support their analyses, e.g., data on transportation assets, LiDAR or other elevation data, relevant data on climate projections, and historical impacts and associated costs (FHWA, 2016a)
	Transportation agencies should have "default" values for costs and benefits of adaptation when historical data is inadequate (FHWA, 2016a).
Workforce	"Conduct strategic hiring and train existing staff to improve the agency's overall data management capabilities, including awareness of the full range of resources available and the effective use of these data sources to inform agency decision-making." (National Academies of Sciences, Engineering, and Medicine, 2015a)
	"Transportation professionals require training on all aspects of adaptation planning. This includes identifying critical assets, describing climate and extreme weather threats, assessing vulnerability, and especially, identifying and selecting adaptation strategies" (J. Dowd, 2017)
Policies	Develop "regulatory standards or legislation in the next one to five years to ensure that siting and design decisions for state-funded structures use the best available climate science and flood risk information." (Dix, Zgoda, Vargo, Heitsch, & Gestwick, 2018)

Dimension	Recommendation
	Use "climate projections instead of historical data to plan, maintain, and construct system elements such as pavements, bridges, and drainage systems" (Dix, Zgoda, Vargo, Heitsch, & Gestwick, 2018).
	"Develop a project-level checklist to evaluate facility risks and vulnerability due to climate change at the time funding is programmed and incorporate project design features to improve resiliency of facilities and infrastructure;" and "incorporate system impacts from climate change, risk, and vulnerability assessments into collaborative and proactive construction, operations, and maintenance activities" (Dix, Zgoda, Vargo, Heitsch, & Gestwick, 2018).
	"Considering climate change in planning and design, such as evaluating vertical clearance for bridges on waterways and impacts of wind: 2. Evaluating bridge expansion joints and design. 3. Evaluating pavement design and monitoring pavement conditions. 4. Improving stormwater management practices." (Dix, Zgoda, Vargo, Heitsch, & Gestwick, 2018)

Summary and Gap Analysis

In this study, we conducted a comprehensive literature review to investigate the state of the practice in incorporating resilience concepts into transportation planning. First, relevant publications were selected through keyword searches that included the words "resilience," "planning," and "transportation." The search yielded 193 sources, prioritizing publications from the transportation sector, including AASHTO, FHWA, TRB, state DOTs, and MPOs. From these sources, the research team extracted information concerning the regulatory drivers, resilience definitions, metrics, tools, programs, and initiatives developed to promote the incorporation of resilience into transportation planning.

While the literature review demonstrated that state and local transportation agencies had made progress in incorporating resilience, some challenges and barriers remain. An in-depth gap assessment was performed along with this literature review to explore these remaining challenges and obstacles. The gap assessment focused on five themes:

1. Policies, Definitions, Leadership, and Communication

2. Data, Metrics, Methodologies, and Tools

3. Multi-discipline and Cross-Sector System Approach

4. Agency Resources and Funding

5. Resilience Incorporation in Transportation Plans

The complete results of the gap assessment will be provided as a separate document.

APPENDIX B – GAP ASSESSMENT

Introduction and Background

Resilience is a concept that has been incorporated into different sectors. However, it is still a relatively new concept in the transportation sector. Transportation owners, planners, and operators are responsible for the transportation systems' health and users' health. These systems must maintain functionality and operations regarding potential threats to their assets, including asset deterioration and aging infrastructure, natural and manmade threats, and fiscally constrained sustainable resources, among others.

Transportation agencies recognize the potential risks that may undermine their system functionality and strategic goals; therefore, risk and resilience approaches have been incorporated in areas, including planning. Agencies are also moving towards performance-based planning and resource allocation. Investing in resilience strategies and enhanced recovery to reduce or eliminate external events' impact is paramount to ensuring a thriving, viable transportation system. In addition, incorporating these concepts in the early strategies will help reduce future impacts from external and internal threats improving infrastructure and community resilience.

Resilient infrastructure and communities are known to have these characteristics:

- Reflective: using experience to inform future decisions
- Resourceful: recognizing alternative ways to use resources
- Inclusive: prioritize broad consultation to create a sense of shared ownership in decision making
- Integrated: bring together a range of distinct systems and institutions
- Robust: well-conceived, constructed, and managed systems
- Redundant: spare capacity purposively created to accommodate disruption
- Flexible: willingness and ability to adapt in response to changing circumstances

(*The Rockefeller Foundation*)

Incorporating some or all of these characteristics into the transportation planning process is the challenge for the industry today to provide the transportation backbone necessary to support resilient communities. A recognized need for proactive assessment and understanding of vulnerabilities to the transportation system now and in the future is invaluable in the planning process to protect assets, services, the public, and limited resources.

Agencies must understand the vulnerabilities of their system and develop resilience strategies accordingly to respond to and curtail the likelihood of losses from such events to improve the resilience of their transportation networks. To improve resilience, agencies must identify and assess threats, evaluate potential mitigation actions to reduce negative consequences, and prioritize mitigation plans that align with overall agency strategic performance goals. Recently, asset management has been the focus of identifying and assessing external threats; however, agencies recognize the need to incorporate resilience at all levels of planning to ensure a

cohesive, consistent agency-wide approach to improving system resilience. Figure 20 demonstrates various methods by which resilience concepts and strategies can be incorporated in the long-range through the Statewide Transportation Improvement Program (STIP) Project.

Figure 20. Resilience Concepts and Strategies in The Transportation Planning Process

The prioritization process is similar to how we already address safety, operational, and mobility goals throughout the planning process. Transportation agencies are adopting several strategies to integrate resilience into the planning process. Strategies include identifying the data needs for monitoring the performance metrics mandated by MAP-21 and the FAST Act, leveraging climate projections to conduct vulnerability assessments for assets that may be impacted by climate change, weighting adaptation options, and possibly revising design guidelines. However, some challenges still need to be addressed to integrate resilience into planning areas successfully.

Key Knowledge Gaps

This chapter aims to explore the gaps found in the literature concerning the implementation or application of resilience to planning in the transportation sector. The first gap was the lack of literature devoted to this topic. Keyword searches that include the words "resilience," "planning," and "transportation" yielded the following top search results – FHWA report and pilots, a RAND report, multiple NCHRP projects, TRB circulars, a few metropolitan and state department of transportation reports, and a few peer-reviewed articles pertaining mostly to resilience performance measurements and modeling.

Nevertheless, the current state of the literature yielded the following challenges when incorporating resilience intro transportation planning:

- No formal definition of resilience
- Lack of formal/useable metrics
- Lack of formal framework to assess risk and resilience
- Limited available models and tools to estimate risk and resilience
- Lack of data to support assessment of risk and resilience and validation of existing metrics
- Lack of research on emerging risks
- Need for a multi-discipline and cross-sector resilience approach
- Policies not translating strategies for resilience into practice
- Shortage of policies integrating national with state and local resilience efforts
- Shortage of investment and funding constraints
- Changes in the workforce could result in a shortage of necessary skillsets
- Lack of support from leadership
- Formal and detailed guidelines in incorporating resilience from multiple threats in the different planning areas and levels.

Four key themes or knowledge gaps were considered based on the challenges identified. The following sections will present the main topics for the gap assessment.

- Policies, definitions, leadership, and communication
- Data, metrics, methodologies, and tools
- Multi-discipline and cross-sector system approach
- Agency resources and funding
- Resilience incorporation in transportation plans

Key Knowledge Gap – Policies, Definitions, Leadership, and Communication

Resilience Policies and Definitions

Even though resilience strategies have been incorporated in the transportation sectors, there is still a need for more formal definitions, policies, and approaches. Flannery et al. (Flannery, Pena, & Manns, 2018) found that decision-makers and operators do not fully understand what resilience is and, consequently, have not effectively integrated resilience into the procurement process, management procedures, and daily operational practices. Likewise, Baylis et al. determined that while there might be abundant policy and strategic guidelines, transportation agencies have yet to implement such information effectively (J. Baylis, 2015). While national resilience policies are in place, no comprehensive national policy exists to coordinate risk management at all levels -- national, state, and local (J. Baylis, 2015).

Lack of Standard Definitions of Resilience

While resilience is a widely used concept in different sectors, the state of the practice identified that in transportation, there is a lack of a standardized definition. Several researchers have pointed out that there is a lack of consistency in definitions of resilience (A. A. Ganin A. C., 2019), (A. Hickford, 2017), (E. Ibanez, 2016), (Beinovic, 2020). In addition, it has been noted that resilience is a relatively new and evolving term in the transportation field and, consequently, there is a wide range of definitions (Flannery, Pena, & Manns, 2018). More formally, FHWA defines resilience or resiliency as "the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions (FHWA, 2014)." However, no formal metrics or measures are tied to this definition.

A study sponsored by FHWA stated that state Department of Transportations (DOTs) and Metropolitan Planning Organizations (MPOs) use similar definitions to FHWA but vary in their approach and integration (B. Dix, 2018).

AASHTO has asserted that there is no need for a common definition, that it would be cumbersome to derive one, and that the benefits would be moot (AASHTO, 2017). However, other opinions differ and state that a well-formed definition will support resilience goals by helping transportation agencies develop their investment strategies (C. Ta, 2009). Two common themes in resilience definitions include the ability to withstand a shock and the ability to recover from a shock (Tirpak, 2006). These themes could imply different investment strategies. The first, the ability to withstand a shock, suggests engineering resilience, i.e., hardening an asset to resist a particular event, such as a 100-year flood. The second, the ability to recover from a shock, could suggest focusing on building redundancy, and expanding the workforce or inventory of emergency response equipment. Agencies need more formal definitions and policies that help them integrate resilience into their practices.

Leadership Support and Communication

To implement resilience policies and strategies, it is essential to have strong support from leadership with the necessary knowledge to act as champions for these initiatives. Agencies with solid backing from leadership regarding this concept tend to have better results and implementation. Figure 21 represents the relationship between leadership and climate adaptation planning (ICLEI, 2022).

Figure 21. Role of leadership in climate adaptation planning

Strong leadership will also develop strong communication strategies to effectively communicate risk and resilience modeling results to stakeholders and communities. Good resilience communication strategies will help stakeholders make better decisions about investments and designs and help get more efficient engagement with the public, especially on topics such as climate change and significant weather events.

Key Knowledge Gap – Data, Metrics, Methodologies and Tools

Data Availability

Data availability and accuracy are impediments and challenges when incorporating resilience. Data such as asset location, condition, replacement cost, asset vulnerabilities, deterioration models, etc., should be part of a risk and resilience assessment. However, on occasion, data is not appropriately collected using standard procedures, or it is not stored correctly or accessible to the necessary stakeholders. These challenges are highlighted in the ongoing *NCHRP 08-113 Integrating Effective Transportation Performance, Risk, and Asset Management* project during the development of the agency's roadmaps.

The lack of available or accurate data makes it challenging to validate existing models and metrics (Sun, Bocchini, & Davison, 2020). Examples of data supporting validation include historical, and emergency repair cost data. In addition, qualitative assessments can be validated with survey data. However, this data type is often lacking, making validation difficult.

In addition, data available to support knowledge and understanding of emerging risks is a challenge. Baylis et al. identified a lack of knowledge of these emerging threats (J. Baylis, 2015):

- Cyber disruptions
- Extreme weather
- Sea Level Rise
- Aging infrastructure
- Workforce changes

FHWA Climate Change Adaptation Guide

The FHWA Climate Change Adaptation Guide for Transportation Systems Management Operations, and Maintenance (FHWA, 2015a), discusses data collection best practices. While MAP-21 compels transportation agencies to develop risk-based Transportation Asset Management Plans, data necessary for informing risk assessments and decision-making is lacking. For example, to support quantitative risk and resilience assessments, transportation agencies need data documenting the frequency and intensity of extreme weather, emergency repairs, number of closure days, etc.

Here are some examples of data fields the FHWA recommends being added to Transportation Asset Management Plans (TAMPs) databases:

1. Work order frequency
2. Design standards (e.g., 25-yr, 50-yr, 100-yr flood)
3. Detour length
4. Criticality
5. Frequency of flooding

To address the gap in data collection, Ohio DOT (ODOT) made the recommendation in its 2016 infrastructure resilience plan (RSG, 2016) to "improve data collection and expand ongoing weather analytics." In addition, Minnesota DOT (MnDOT) explicitly states in its 2020 resiliency report the intention of finding ways to leverage MnDOT's inventory of asset data to increase system resilience (MnDOT, 2020). MnDOT also stressed the need for integrating downscaled climate data into its adaptation assessments.

Resilience Metrics

It has been found that even though some agencies have incorporated resilience definitions into their processes and planning, there is still a lack of metrics to measure both system resilience and the expected benefit from investments in resilience (Flannery, Pena, & Manns, 2018). In addition, it was noted that existing resilience metrics and cost data are insufficient to support analysis and decision-making (J. Baylis, 2015). Weiland et al. determined that resilience metrics found in the literature do not address the interdependencies across systems, nor does the literature offer any validation of the metrics used (Weilant, Strong, & Miller, 2019). It has been

pointed out that the effort to quantify the resilience of transportation systems has been hampered by the complexity of the modeling itself (A. A. Ganin A. C., 2019). Attempts to model network performance are data-intensive and require expert knowledge of the system itself.

Moreover, other metrics should assess risk and resilience at different levels– asset, network, and systems. For example, an asset-level analysis may depend on a specific asset's replacement value or cost and costs incurred due to travel detours. Network-level analysis may rely on topological measures of centrality or traffic-demand models. In contrast, a systems-level analysis may depend on a broader metric such as the economic impact on the community due to disruption or a weighted index model that includes a variety of societal, economic, and environmental factors. Some researchers conclude that there are metrics available. Still, there is a need for standardized metrics based on available data, as well as a need for training on the resilience assessment tools (Machado-Leon & Goodchild, 2017).

In addition, the proper measure of the economic impacts of a disruption economic analysis should be paired with network analysis, including redundancy, roadway type, and capacity, to calculate changes in user economic consequences.

Florida DOT's Resilience Quick Guide

Moreover, a critical factor in implementing resilience metrics is implementing mechanisms to monitor such metrics' success. Florida DOT's *Resilience Quick Guide: Incorporating Resilience in the MPO Long Range Transportation Plan* cited the data-driven performance goals of MAP-21 and the FAST Act (FDOT, 2020). Indeed, metrics relevant to performance management also apply to resilience. National performance areas identified by MAP-21 include safety, infrastructure, condition, system reliability, freight movement, economic vitality, economic sustainability, and reducing project delivery delays. To monitor infrastructure condition, state DOTs rely on 3rd party software applications, such as AASHTOWare Bridge, to record bridge inspection data for the National Bridge Inventory (NBI) and AASHTOWare Pavement, to record pavement condition in the Highway Pavement Management System (HPMS).

Risk and Resilience Frameworks and Methodologies

Many resilience models lack robust methods to quantify the risk and resilience of transportation systems. They tend to rely on qualitative methods, such as risk registers, that do not support benefit-cost analysis nor account for uncertainty. More sophisticated models incorporate network and travel demand modeling to stress test the system against a hypothetical disruption. However, Koc pointed out that analysts tend to use overly simplified networks (for example, only incorporating major roads and not surface roads) to perform network analysis for large metropolitan networks (Koc, 2018). This oversimplification does not promote realistic simulations. In addition, Koc argues that the economic costs to communities caused by disruptions have not been sufficiently studied from a user perspective (Koc, 2018).

Key Knowledge Gap – Multi-Discipline and Cross-Sector System Approach

Even though agencies are already incorporating resilience into some areas, research has indicated a need for a multi-discipline approach to address interdependencies across sectors. It is recommended that agencies take a multidisciplinary approach to address the interdependency of water, telecommunications, and transport. Also, it is recommended to develop a combined data source to support this need. In addition to interdependencies with other sectors, there should be an emphasis on the need for understanding the major dependencies within different modes and between modes of transportation as well as cross-sector – "owners and operators have a limited visibility of risks in adjoining systems, jurisdictions, modes, and critical, independent infrastructures" (Beinovic, 2020).

Looking at a larger spatial scale, it was also identified that tools and knowledge are lacking to assess systems at a national or regional level and the interdependencies of systems across sectors, such as energy and transportation (E. Ibanez, 2016).

Key Knowledge Gap– Agency Resources and Funding

Funding for Resilience

It has been found that an overall lack of investment in the nation's transportation infrastructure has hampered the ability to integrate resilience with investment (Flannery, Pena, & Manns, 2018). In addition, some research has also pointed out a lack of national consensus supporting investment in resilience due to a lack of understanding of what resilience is (J. Baylis, 2015). While there are Federal funding sources, they are spread across multiple organizations, tend to be siloed and result in uncoordinated investment strategies. This situation makes it difficult for owners and operators to determine their investments when the uncertainty and aleatoric nature of risks, such as cyber, aging infrastructure, extreme weather, or climate change, is so great. The result is that owners, planners, and operators may prefer to prioritize investment in short-term emergency response rather than long-term resilience.

Workforce and Training

Changes in the workforce could result in a shortage of necessary skillsets to implement resilience strategies. In a 2019 article, the Eno Center for Transportation reported that the transportation industry suffers from a growing lack of qualified professionals (ENO Center for Transportation, 2019). Baylis et al. added that a large proportion of the public transportation workforce is not trained in the concepts of risk management and systems resilience; thus, today's workforce may not be equipped to analyze or mitigate emerging threats such as cyber (J. Baylis, 2015). Better training on the concept of resilience is needed to implement such processes.

Key Knowledge Gap – Resiliency Incorporation in Transportation Plans

Part of the challenges and gaps in the state of practice includes clear and practical information for transportation agencies on incorporating resilience concepts and strategies at all planning levels. Some research has been developed to fill these gaps. However, further efforts are needed in this sector. Some existing measures include a sponsored project by *FHWA – Integrating Resilience into the Transportation Planning Process* (B. Dix, 2018). This project aimed to develop a handbook to help state DOTs and MPOs incorporate resilience from natural hazards and changes in environmental conditions. The research proposed integrating resilience approaches and strategies at different stages of the typical planning process, as shown in Figure 22 (B. Dix, 2018).

Figure 22. Typical transportation planning process

Even though this project offers an excellent start on incorporating resilience into transportation planning, the primary audience of this product is state DOTs and MOPs, and it only covers natural hazards and environmental changes. In addition, the handbook for this project is still under publication process and might be a little outdated by the time it is published.

In addition to this project, RAND Corporation led NCHRP 08-36 project Task 146 (Weilant, Strong, & Miller, 2019), which focused on how DOTs and MPOs could implement a modified version of the FHWA Vulnerability Assessment Framework (VAF) to incorporate resilience strategies and all hazards into long-term decision making and planning. Similar to the FHWA project, the framework developed was tailored to stated DOTs and MOPs and mainly applies to long-term decision-making and planning.

Broader and detailed information that incorporates more recent resilience strategies and approaches that can be used by other transportation agencies and offers a multimodal approach, and a more extensive range of threats/hazards are still needed.

NEXT STEPS

These gaps will frame the survey questions to develop an industry workshop to help identify the industry successes, challenges, and needs to incorporate resilience into planning. In addition, the industry workshop's gaps and the outcome will help develop the focus areas for further research in the Quick Scans and Deep Dive case studies. Accounting for practitioners' feedback, these case studies will be used to create a Guidance document to guide transportation agencies to incorporate resilience strategies in planning processes and a Final Report.

APPENDIX C – INDUSTRY ENGAGEMENT

Overview

The research team conducted an hour and half-long industry engagement called "Industry 2-min Drill" on December 14, 2020, at 2:30 PM ET. The industry engagement was conducted as part of Task 2 on the NCHRP 08-129 project. The main objective of this project is to develop a guide to help transportation agencies to integrate resilience concepts and approaches into transportation planning.

The purpose of the "Industry 2-min Drill" was to:

1. Identify and define what transportation agencies need to implement resiliency into transportation planning successfully.
2. Validate findings of gaps in the state of practice found while performing the literature review of the state of practice.
3. Identify participants for "Quick Scans" and "Deep Dive" case studies.

The "Industry 2-min Drill" was hosted through the Zoom online meeting platform and consisted of a short presentation by the research team followed by polling questions using Mentimeter as a polling tool. Attendees were muted and only allowed to participate using the Zoom chat function to facilitate an efficient meeting.

The polling questions helped the research team validate the industry's current gaps and successfully identified the need to integrate resilience approaches in transportation planning. Results from the industry engagement and more detailed case studies will help as the basis for developing a guide to help transportation agencies incorporate resilience concepts and approach into transportation planning.

Logistics and Content

Invitation

Invitation to the "Industry 2-min Drill" was distributed to various communities through email announcements from multiple TRB and AASHTO committee leaders and via individual invitations outside of AASHTO and TRB, including individual invitations to international transportation agencies, public sector practitioners, and universities. As part of the invitation, a 1-pager with information about the project and the purpose of the "Industry 2-min Drill", along with a link for registration was distributed (see Appendix 1). Some of the TRB and AASHTO committees that distributed the invitation included:

1. AASHTO Committee on Planning, Transportation System Security and Resilience
2. AASHTO Subcommittee on Risk Management
3. TRB Committee on Critical Infrastructure Protection (AMR10)
4. TRB Committee on Enterprise and Systems Resilience (AMR40)

5. TRB Committee on Natural Hazards and Extreme Weather Events (AMR50)

To track possible attendees to the "Industry 2-min Drill" and necessary information regarding the attendees, a register was created using the Wufoo tool. People interested in participating could use the link on the 1-pager to register and provide their contact information and background (see Appendix 2 for Wufoo register). The "Industry 2-min Drill" had 121 individual registrants on the Wufoo site. However, there were 90 attendees at the "Industry 2-min Drill". Most of the attendees were primarily employees of state DOTs, with some representation from AASHTO, FHWA, MPOs, transit agencies, private sector, universities, and international agencies.

Content

The content of the "Industry 2-min Drill" included research team introductions, an overview of the project objective, lessons learned and gaps on the state of practice, the purpose of the "Industry 2-min Drill", polling questions, and next steps.

The identified gaps in the state of practice presented at the "Industry 2-Minute Drill" for validation with practitioners included:

1. No formal definition of resilience
2. Lack of formal/usable resilience metrics
3. Relationship between risk and resilience
4. Limited available models and tools to estimate risk and resilience
5. Lack of data to support resilience assessments and validation of existing metrics
6. Lack of research/knowledge on emerging risks
7. Need for multi-disciplinary and cross-sectoral approaches
8. Policies not translating strategies for resilience into practice
9. Shortage of Policies Integrating National with State and Local strategies
10. Shortage of investment and funding constraints
11. Lack of buy-in from leadership or staff

In addition, the "Industry 2-min Drill" was developed around four main topic areas related to resilience in transportation identified by the research team:

1. Resilience Approaches in Transportation Agencies
2. Resilience in Transportation Planning
3. Resilience and Agency Resources
4. Resilience Communication and Collaboration

A series of related polling questions were developed and presented as part of each topic at the "Industry 2-min Drill". The type of questions utilized at the "Industry 2-min Drill" using the Mentimeter polling tool included multiple-choice, word cloud, and short open-ended questions. In addition, the Zoom chat function was used for people to communicate as/when needed. The full list of questions can be found in the appendix.

Three principal research team members led the presentation of the topics, and an assistant research team member conducted the presentation and polling questions in the background.

Polling Overview

Through the series of polls related to each of the main topics identified for the "Industry 2-min Drill," valuable information was collected regarding how agencies incorporate resilience into planning and their challenges and needs regarding combining resilience approaches.

Polling Questions

Below are the questions and responses corresponding to each of the four topic areas selected by the research team.

Topic 1: Resilience Approaches in Transportation Agencies

This segment topic focused on the approach to resiliency in transportation agencies and what they are currently doing to ensure resiliency is embedded throughout all transportation planning – including all modes and all levels of planning (Figure 23).

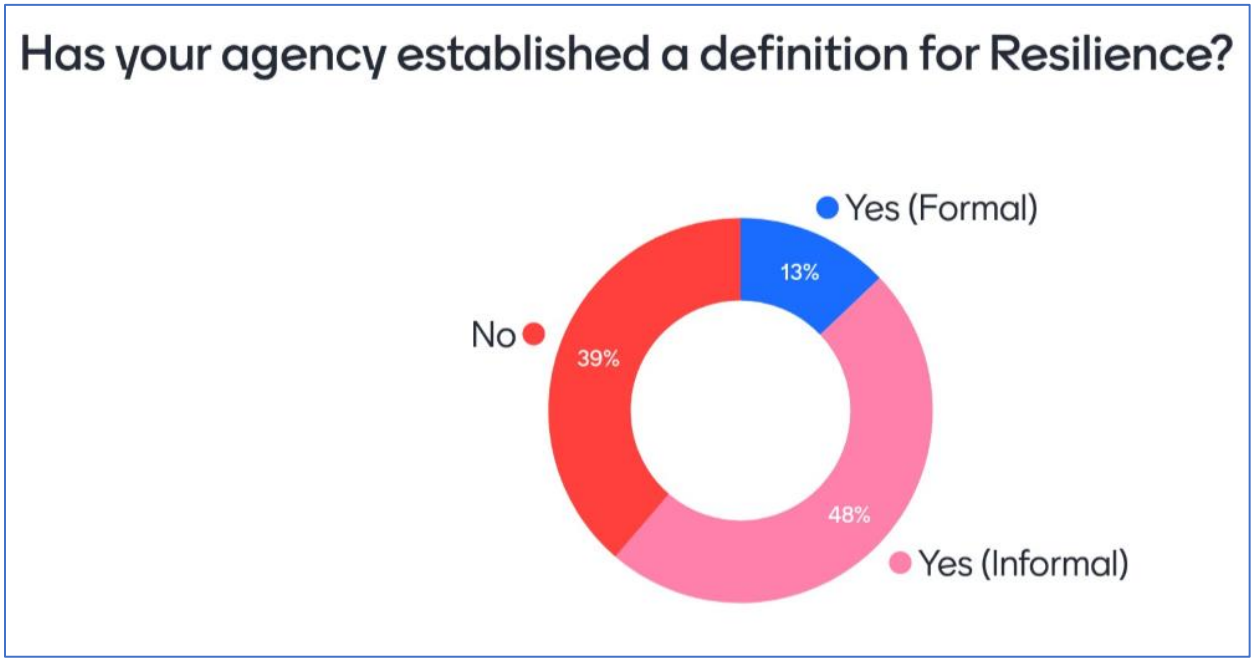


Figure 23. Has your agency established a definition for resilience?

Sixty-two people answered this question (Figure 24). As shown in the answers, most agencies have established either a formal or informal definition of resilience, with the majority having an informal report. However, some agencies still have no formal or informal established definition. Some participants stated in the chat that they are using the FHWA definition, while others are currently developing their definition for resilience.

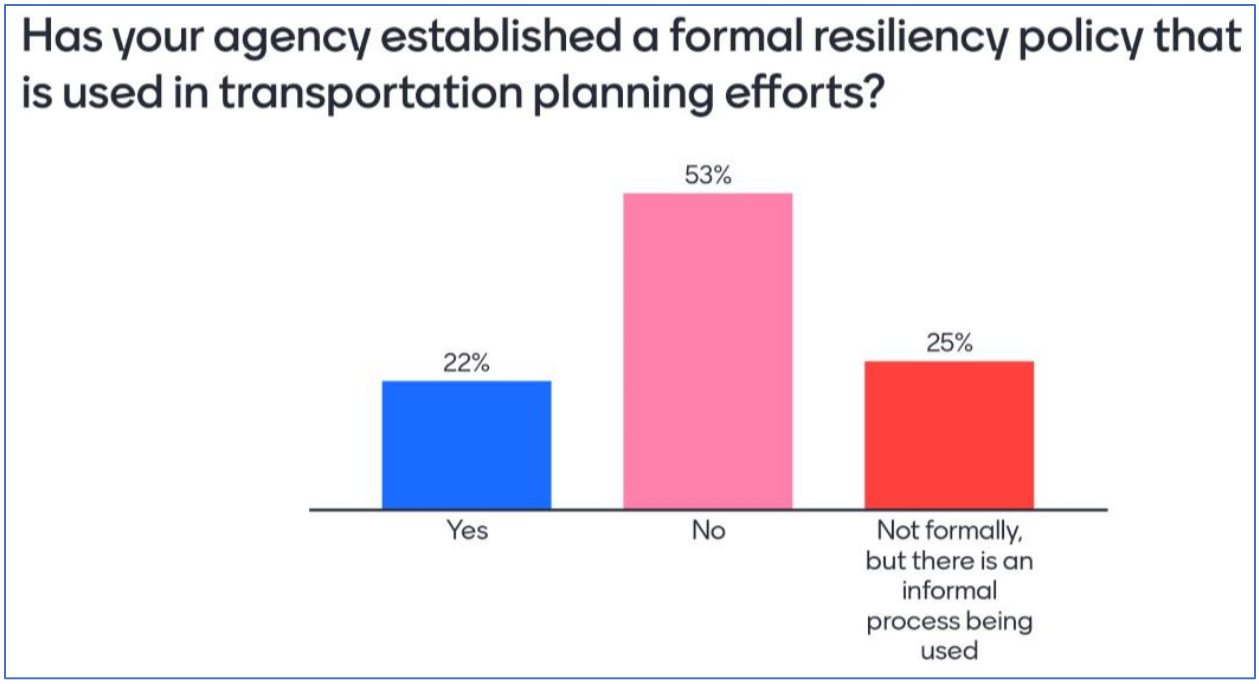


Figure 24. Has your agency established a formal resilience policy?

Sixty participants answered this question (Figure 25). Most (53%) have not established a resiliency policy, and the rest (47%) have established either a formal or informal resiliency policy. Some participants stated that their agency has formal policies, but they focus on elements of resiliency- seismic, climate, etc., and do not necessarily have a comprehensive policy yet.

Figure 25. If no formal policy has been established, describe why not?

Sixty-one participants responded to this question (Figure 26). Most (95%) think having a formal resiliency policy will be more or somewhat effective for their agencies, with only 5% thinking a formal resiliency policy will not be effective.

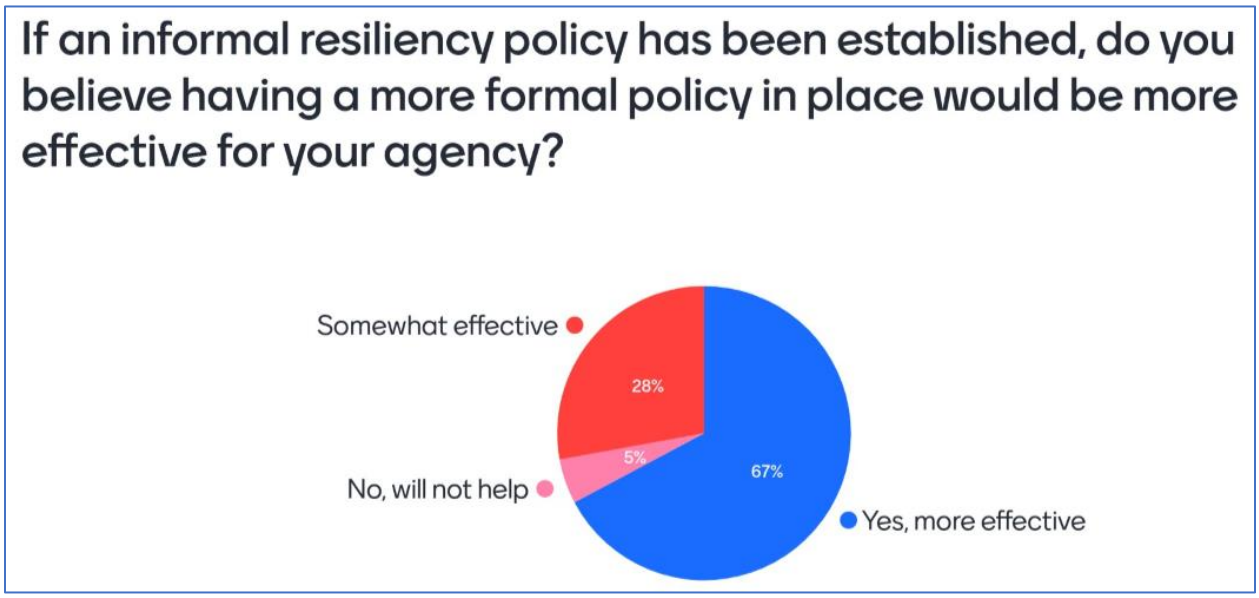


Figure 26. Do you believe having a formal resilience policy would be effective?

Sixty-two participants answered this question (Figure 27). However, only 8% have established formal resilience metrics, 55% have established formal, informal, or metrics under development, and 45% do not have resiliency metrics.

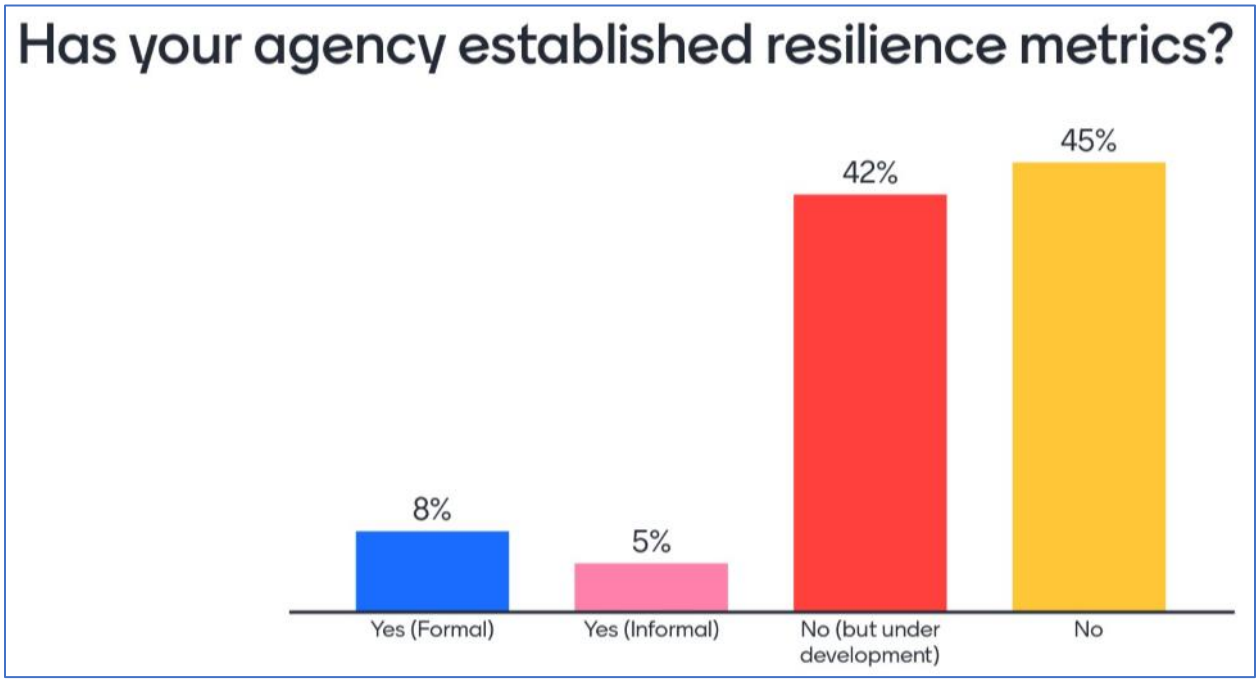


Figure 27. Has y our agency established resilience metrics?

Topic 2: Resilience in Transportation Planning

This segment topic was focused on the specific use of risk and resiliency in the planning efforts and how agencies are currently weaving resiliency into their Long-Range Transportation Plans (LRTPs), State Transportation Improvement Programs (STIPs), etc., and the motivations for doing so. Sixty-six participants responded to this question. Most (85%) responded that their agencies produce at least some resilience-related plans (Figure 28). However, only 8% produce all resilience-related plans, and 15% do not produce any plan.

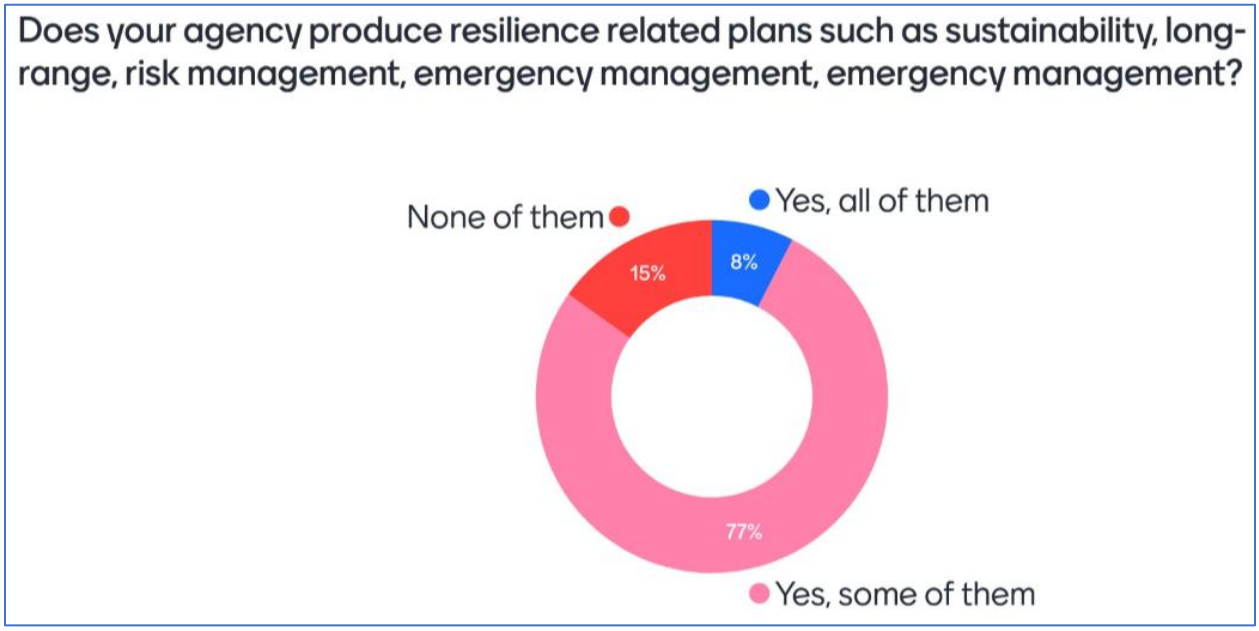


Figure 28. Does your agency produce resilience-related plans?

Sixty participants responded to this question (Figure 29). Twenty percent responded that their agency includes resilience in their LRTP, 15% include it on Transportation Asset Management Plans (added as "Other"), 15% on TIPs/STIPs, 15% on Freight Plans, 9% on State Multimodal Transportation Plans, 8% Metropolitans Transportation Plans, 6% on Safety Plans, and 5% or less in aviation, transit, port or bike/pedestrian plans. In addition, some participants added on the chat that their agency incorporates resilience into corridor plans and Planning and Environmental Linkages (PELs).

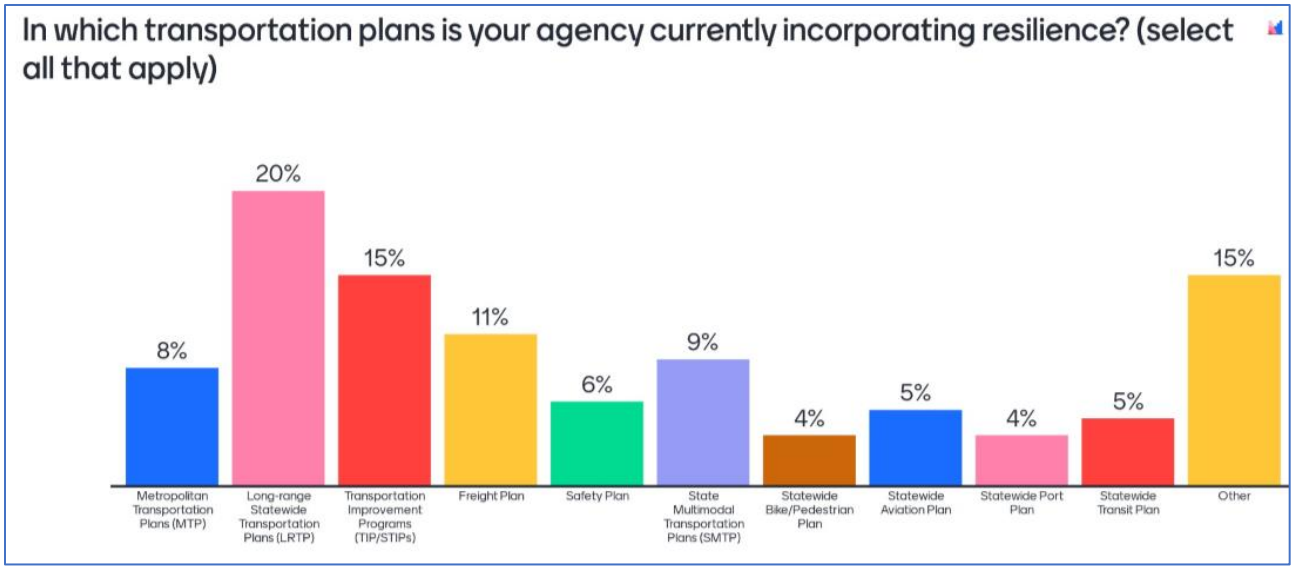


Figure 29. In which transportation plans are you incorporating resilience?

Sixty-two participants (Figure 30) responded to this question. Seventy-one percent responded that their agencies have their resiliency plans either very well or somewhat integrated. Five percent are very well integrated, and 20% are not integrated at all.

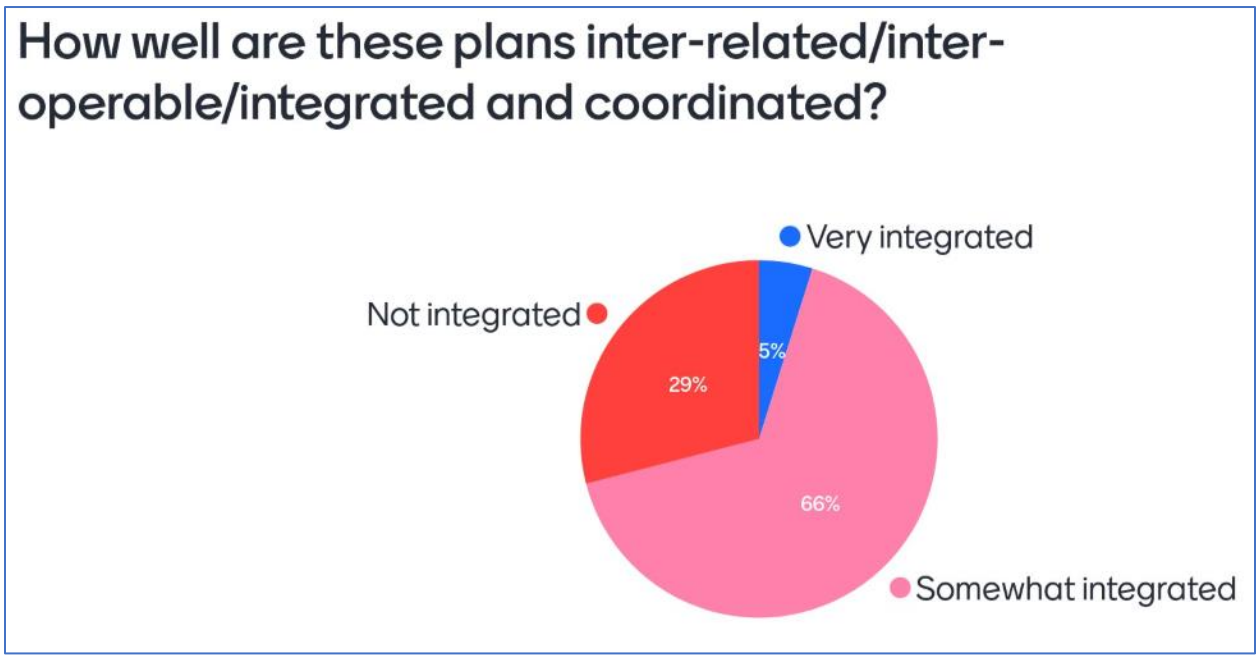


Figure 30. How well are these plans inter-related/inter-operable/integrated?

Forty-nine participants responded to this question (Figure 31). The responses show that agencies have incorporated resilience into their planning stages. For example, stage 1 (Goals and Objectives), Stage 2 (Problems and needs), and Stage 4 (Strategies Identification, Evaluation, and Adoption) are the stages where agencies have incorporated resilience into their planning process the most. Conversely, stage 6 (Monitor and report) is the planning stage where agencies include resilience least.

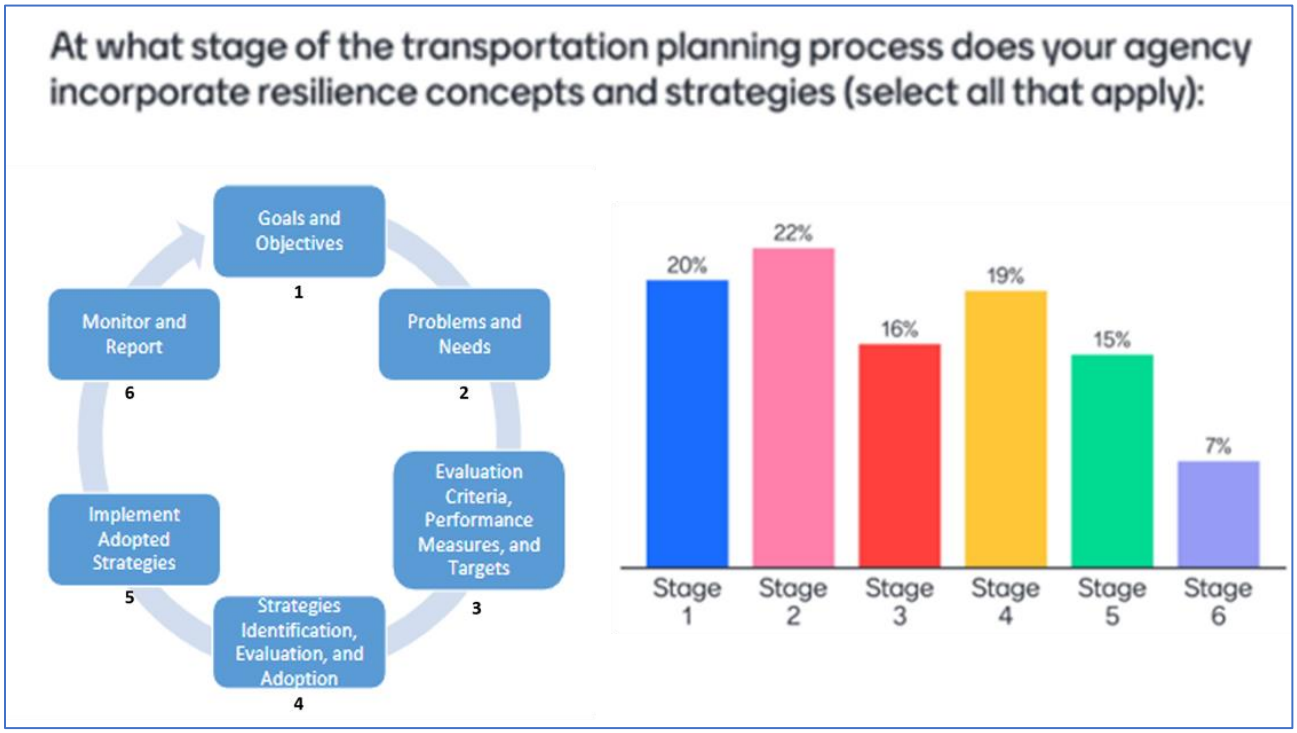


Figure 31. Picture Source: FHWA. Integrating resilience into the transportation planning process: White paper on literature review findings 2018.

Sixty-one participants responded to this question (Figure 32). Most (62%) responded that their agencies incorporate qualitative or quantitative vulnerability assessments into their planning documents, with more agencies incorporating qualitative assessments. Thirty-eight percent do not include any vulnerability assessment. NJDOT stated that they are in the process of creating vulnerability assessment frameworks, with the intent of eventually incorporating them into project planning/delivery. In addition, some agencies might contain a combination of both qualitative and quantitative vulnerability assessments.

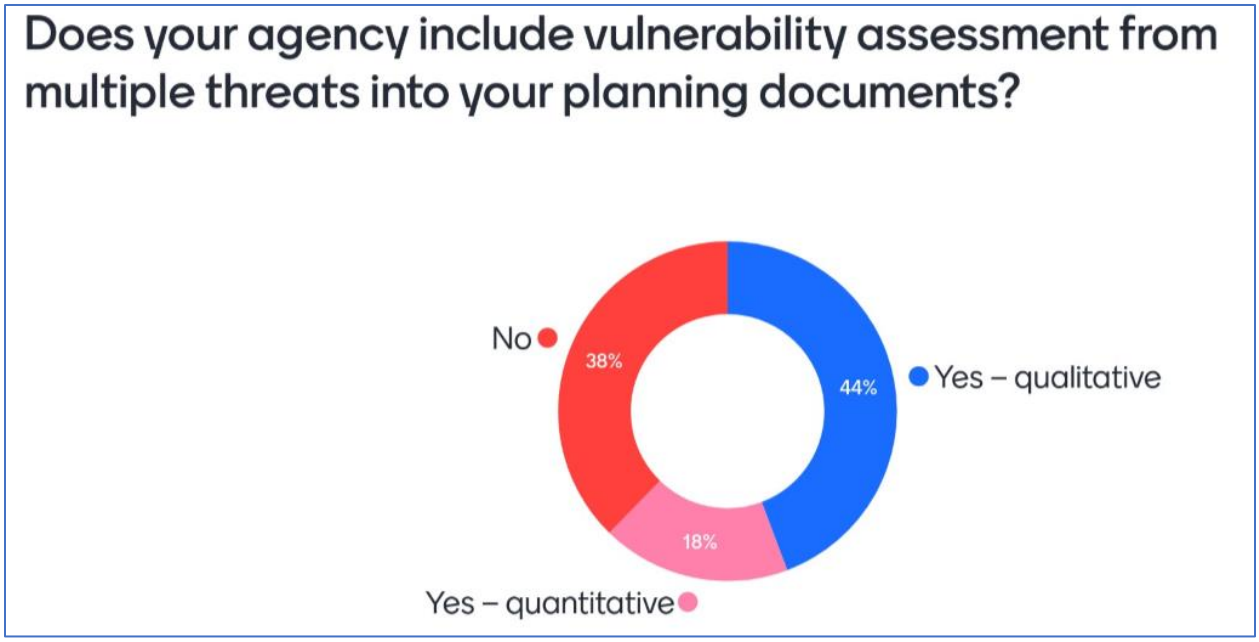


Figure 32. Does your agency vulnerability assessments into planning documents?

Fifty-seven participants responded to this question (Figure 33). The most common threats in vulnerability assessments are flooding, sea-level rise, cyber, hurricanes, earthquakes, tornadoes, heat climate change, slope failures, and wind. As a comment in the chat, it was also stated that rockfalls and mudslides are a major priority for much of the country, including several states in the Southeast.

Figure 33. What threats does your agency include in vulnerability assessments?

Fifty-seven participants responded to this question (Figure 34). Most agencies incorporate resilience into transportation planning due to past damages from catastrophic events and federal regulations, followed by the need to maintain mobility and operations and adapt to climate change and sustainability. State regulations were the lowest reason along with 'other' reasons. In addition, as part of the comments on the chat, it was added that local governments and communities are pushing for incorporating resilience approaches into transportation planning.

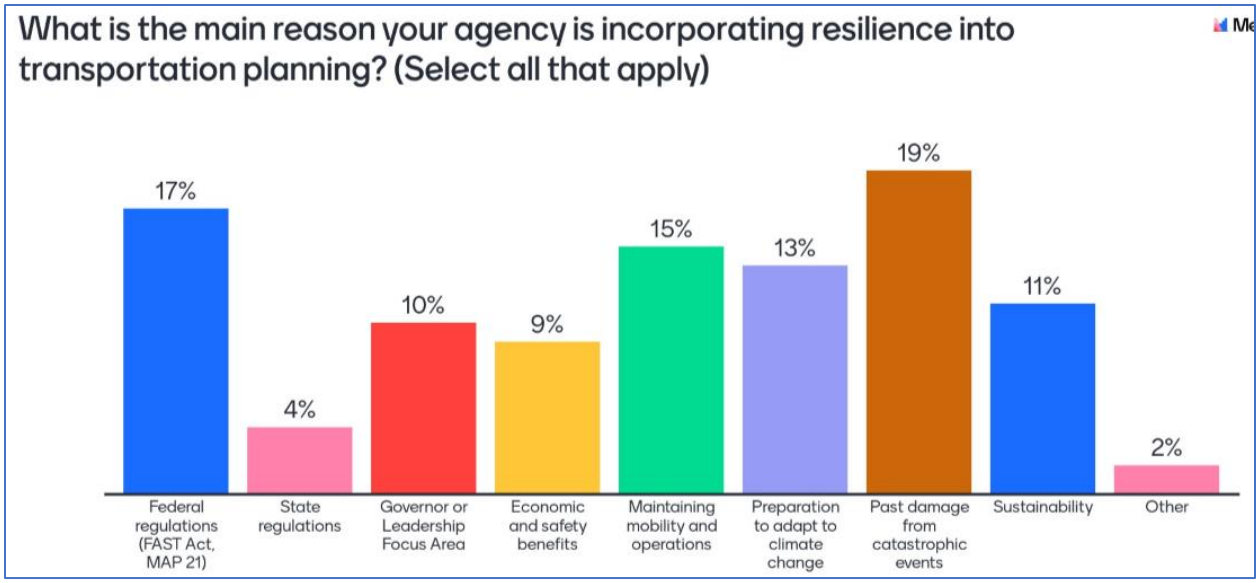


Figure 34. What is the reason your agency is incorporating resilience into planning?

Fifty-eight participants responded to this question (Figure 35). Most (22%) identified lack of established performance goals/metrics for risk and resilience, financial constraints (22%), and lack of established assessment methods and tools (17%) as the top 3 challenges when incorporating resilience into planning.

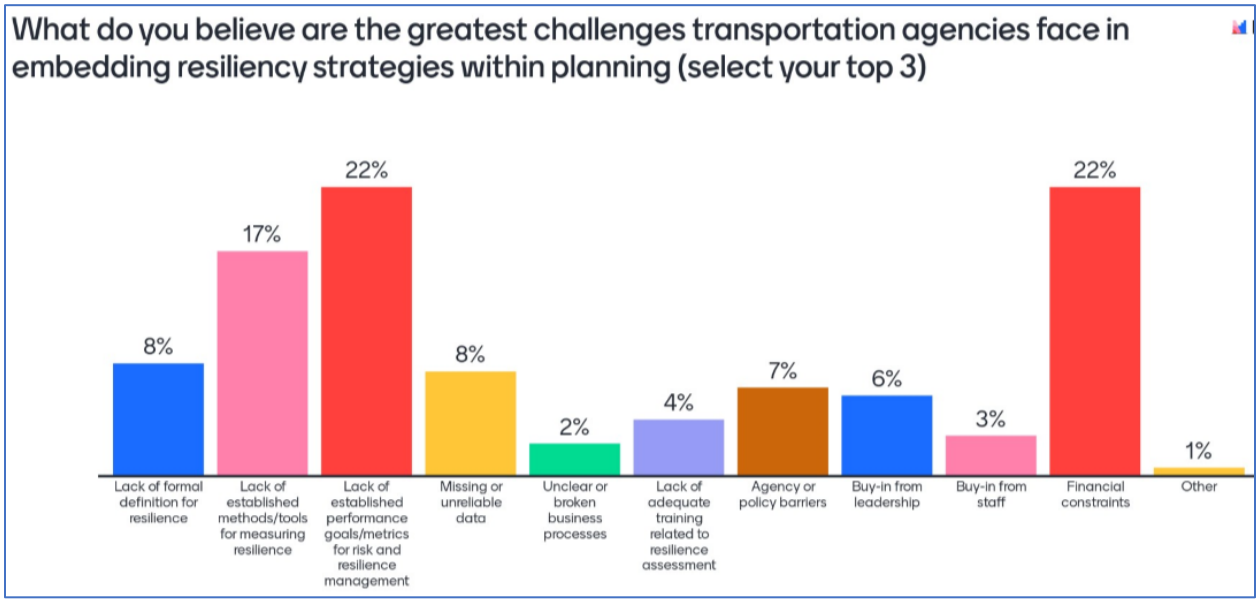


Figure 35. What are the greatest challenges agencies face in embedding resiliency?

Fifty-nine participants responded to this question (Figure 36). Most (31%) identified the overall understanding of resilience and organizational culture/Governance structure (26%) as the top two barriers that impede the incorporation of resiliency into transportation planning practices at

their agencies. In addition, a comment on the chat stated that broken processes might be similar/same as agency barriers. Other barriers that were added to the chat include:

1. Not having a design methodology for resilience
2. Low staffing levels
3. Time scales for threat probabilities (e.g., 100 years vs. 10-year, 6-year)
4. Need for more research on the Return on Investment (ROI) of resilience programs. What is the value of the infrastructure we are systematically trying to protect? What is the business case for taking action to reduce risk and increase resiliency in advance of the natural hazard event?
5. Need for training in integration into Asset Management (AM)

Regarding ROI, a reference to a recently released Business Case for Resilience in Southeast Florida (led by Urban Land Institute) was mentioned.

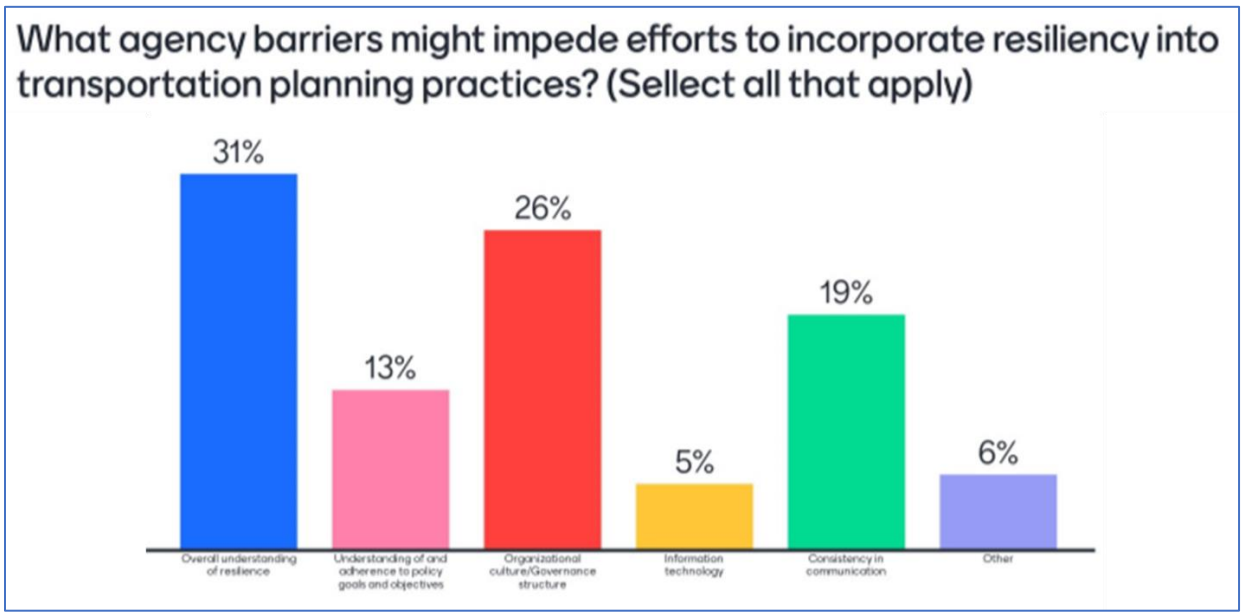


Figure 36. What are the agency barriers impeding efforts to incorporate resilience?

Fifty-two participants responded to this question (Figure 37). Many identified being proactive, cost savings in the long run, continuity of operations during a disaster, asset management optimization, performance improvement, safety, increasing society resilience, breaking silos, and preserving connectivity of transportation systems during emergency events as some of the most significant benefits of adopting a resilience management strategy.

What do you believe would be the greatest benefits to adopting a resilience management strategy?

Mentimeter

Cost savings in long run	Proper consistent guidance!	Protection of our resources
Risk management	Protect investment	Top-down directive across divisions
proactive	Being able to trade off resilience against other needs	safe & efficient transportation in all conditions
Preparation	Continued operations during a disaster.	Longer life for the agency's assets
Improved public safety in the face of climate change	Managing transportation system more cost effectively in the long term	Safer and more reliable transportation system
Proactive, saves money long term.	Asset management optimization	Reduce the impact of unexpected disasters
Ability to avoid maintenance costs	Better coordination between players in responses	Getting ahead of problems
Improve people's lives	Securing investments, protecting revenue, continuity of service.	Proactive
Performance improvement	protect transportation investment and a more reliable system	Proactive asset management
safety, level of service, and funding benefits	being proactive and cost efficient	Efficient response time
Targeted proactive approach to addressing locations of repeated failure for continued operation	Proactive Investment	Effective Planning and Protection of Investments
Stewardship	Best use of limited funds	A management strategy would integrate all the "government silos" within our department into a cohesive objective.
Safety	Long-term safety and financial benefits.	Good stewardship of public funds
Incorporate resiliency into all modes	Continuity of operations and quick return to service.	Saving money and protection of asset and the natural environment from further degradation.
increasing resilience of society	Public good and benefits	whole asset life cycle perspective

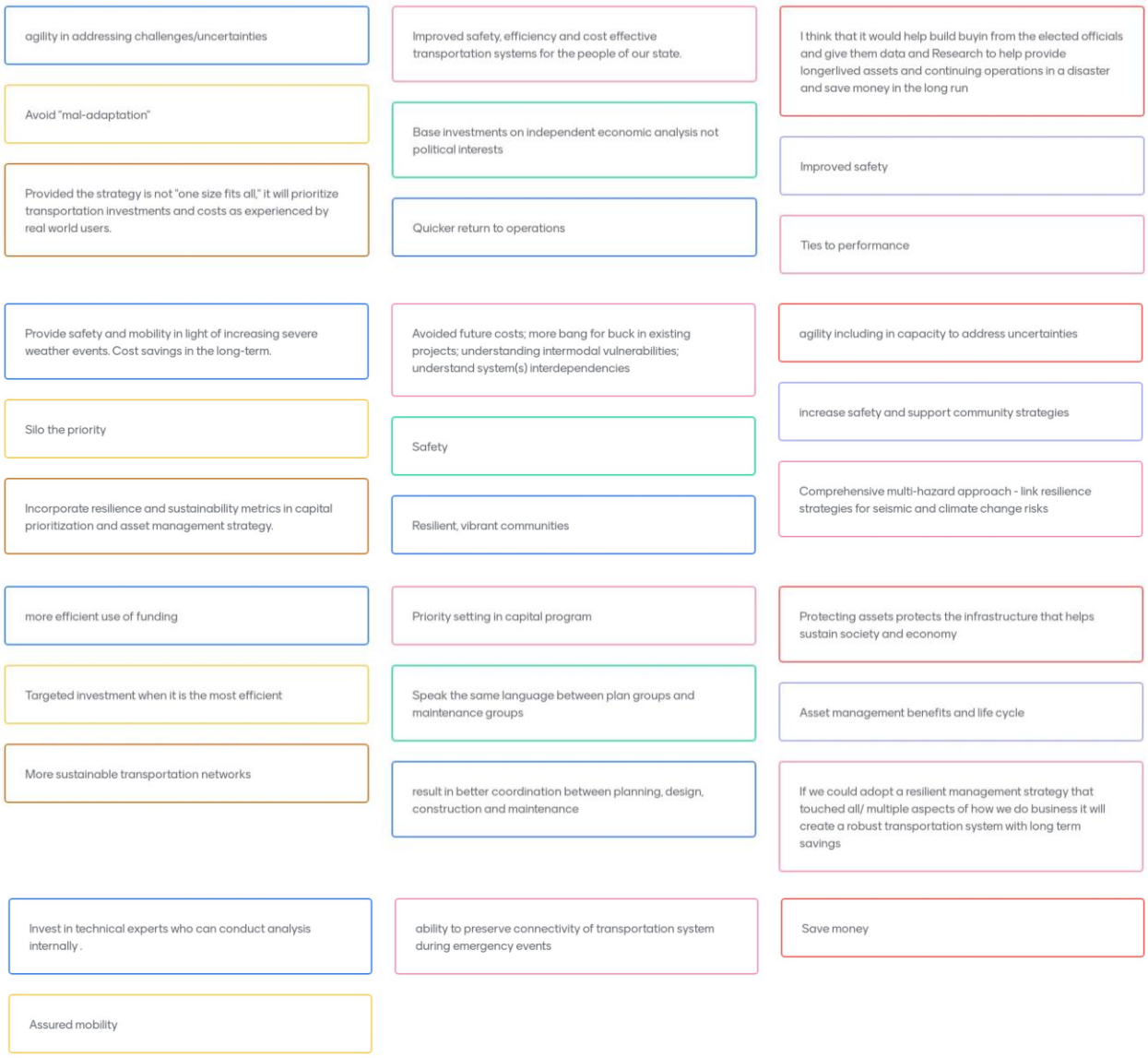


Figure 37. What do you believe would be the greatest benefit to adopting resilience?

Topic 3: Resilience and Agency Resources

This segment topic focused on the resources, or lack of resources, within the agency for incorporating risk and resiliency into their planning efforts, on what resources are available, and what are required.

Sixty participants responded to this question (Figure 38). Most (85%) responded that their agencies have the institutional knowledge to incorporate resilience into planning; however, 65% stated that more training is needed in this area.

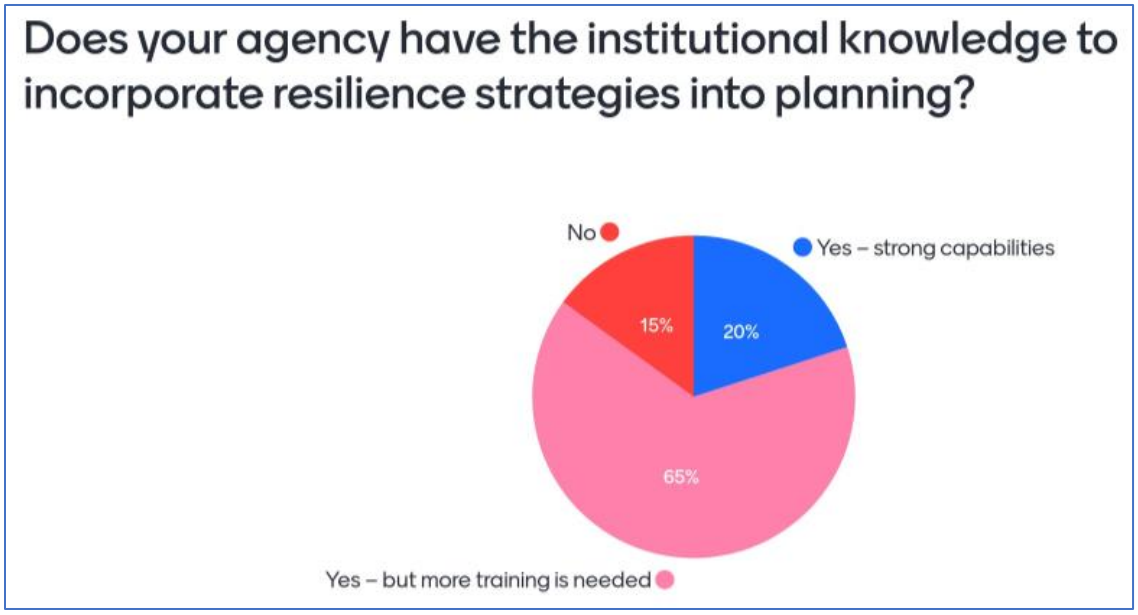


Figure 38. Does your agency have the institutional knowledge to incorporate resilience strategies?

Sixty participants responded to this question (Figure 39). Most (32%) stated that training on evaluation methods for risk and resilience is needed, followed by trends, data, and projections to informed planning and project development (24%); and understanding of the agency's goals, objectives, performance measures and targets (23%). In addition, comments from the chat stated that:

6. Training is needed in integration into Asset Management (AM)
7. There are some capabilities and knowledge, but it is not well integrated into transportation planning
8. The knowledge is in the hands of a very small number of staff. Need training and more precise roles/responsibilities to expand the knowledge base
9. Need training at Executive Levels. Buy-in at the highest levels is important
10. Need buy-in and coordination between state and local governments. We all need to be on the same plan
11. Needs to be more holistic beyond transportation planning because it needs to be certain it will be implemented

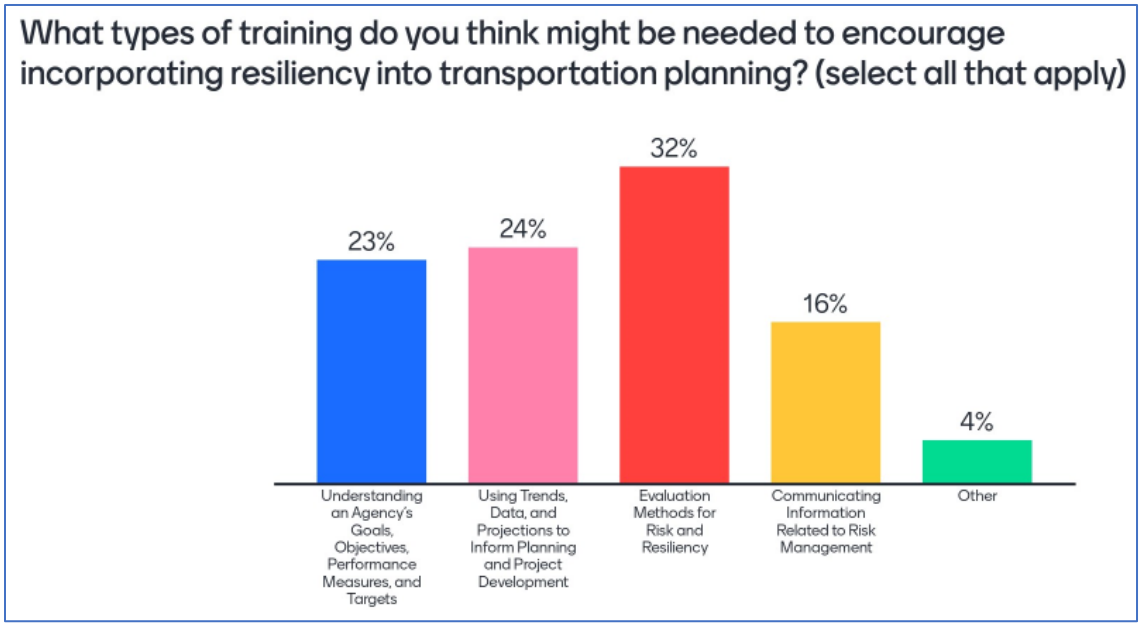


Figure 39. What types of training do you think might be needed to incorporate resilience into planning?

Fifty-seven participants responded to this question (Figure 40). The top 3 activities where agencies have enough personnel are asset condition (21%), qualitative risk assessment (18%), and development of a risk management plan (16%). On the other hand, the activity with the least personnel was risk and resilience assessment from a multimodal perspective (8%). In addition, other activities added to the chat include:

12. Redundant alternative modes review
13. Geospatial analysis - could include in quantitative/qualitative analysis

Other comments included using consultants to perform these activities due to the lack of internal personnel or time constraints.

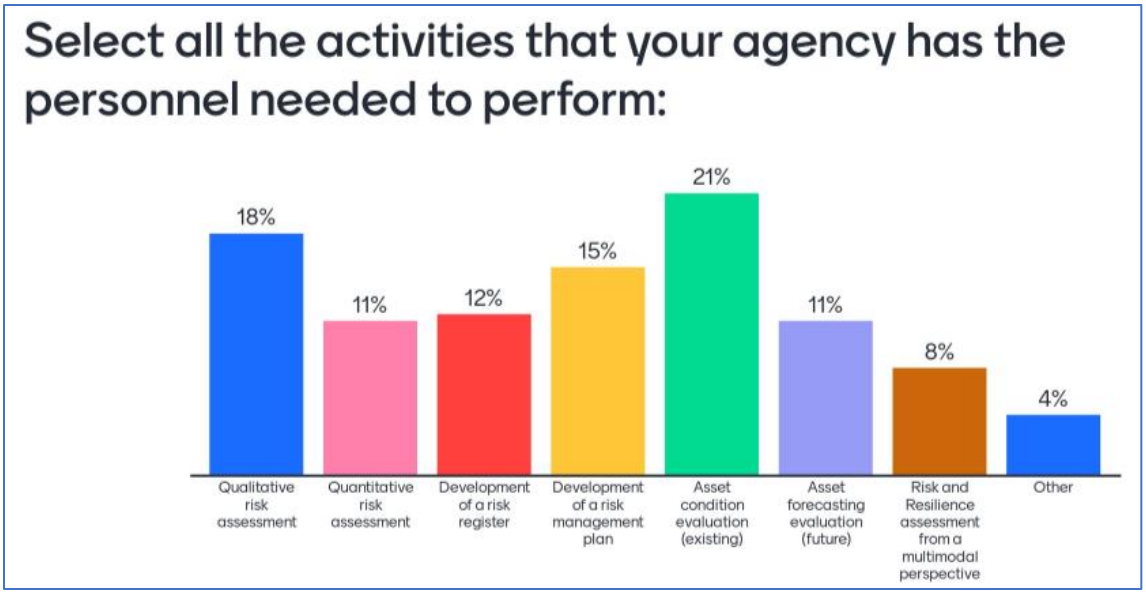


Figure 40. Select the activities your agency has the personnel needed to perform

Fifty-three participants responded to this question (Figure 41). The top 3 data set that agency feels are reliable are the geographic location of assets (20%), asset condition data (19%), and operational impact information (13%). With the less reliable data sets are systems interdependencies (2%), losses from applicable threats (3%), and risk visualization data (5%).

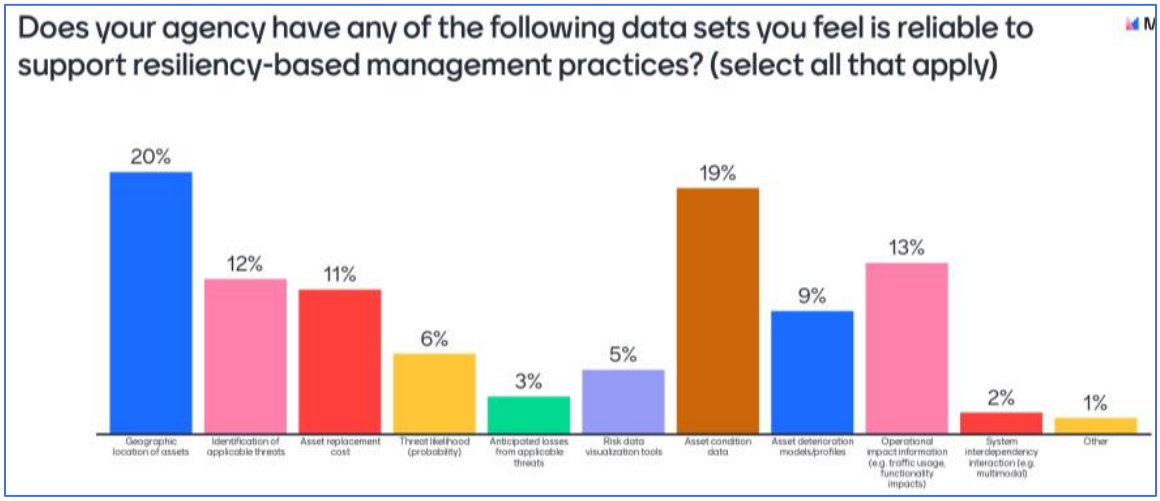


Figure 41. Does your agency have any of the following data sets to support resiliency-based management practices?

Fifty-three participants responded to this question (Figure 42). Almost the same percentage of people (51%) stated their agencies currently utilize, at some level, predictive methods or potential impact projections to support resiliency in planning. A comment from the chat highlighted the use of revenue forecast.

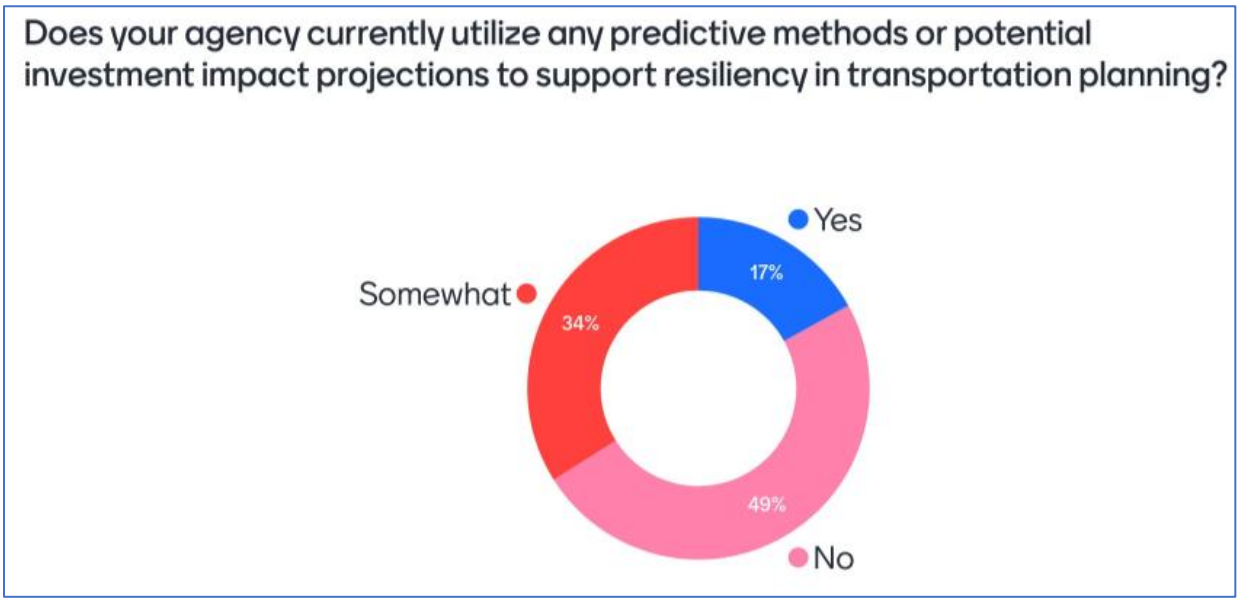


Figure 42. Does your agency have any predictive methods or investment impact projections?

Forty-seven participants responded to this question (Figure 43). Most agencies (66%) do not utilize publicly available software. However, 34% utilize software to analyze or visualize data to support risk management programs. Some of the software mentioned on the chat that agencies are currently using includes:

14. Agile Assets software
15. State mapping that shows predictions of Sea Level Rise (SLR),
    1. Sea Level Rise effects on roads and Marshes (http://www.cteco.uconn.edu/projects/SLAMM/index.htm)
    2. FDOT/UF GeoPlan Sea Level Scenario Sketch Planning Tool (https://sls.geoplan.ufl.edu/)
16. dTIMS
17. FHWA: VAST, HVI
18. ArcGIS
19. Asset-specific management systems
20. Climate Change Vulnerability Viewer (CCVV) (https://maryland.maps.arcgis.com/apps/webappviewer/index.html?id=86b5933d2d3e45ee8b9d8a5f03a7030c)
21. Osprey- Aviation Risk Management

22. NJ Flood Mapper tool (https://www.njfloodmapper.org/)
23. RA2CE (https://www.deltares.nl/app/uploads/2020/07/RD-Highlights-2020_digital.pdf)

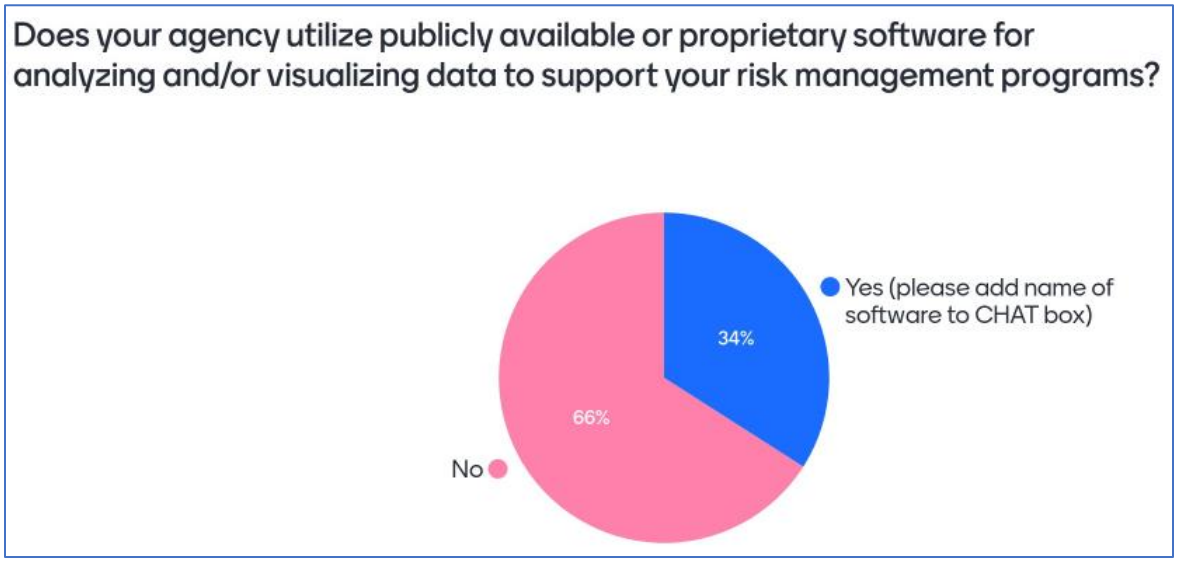


Figure 43. Does your agency utilize publicly available or proprietary software to support your risk management program?

Forty-seven participants responded to this question (Figure 44). Most (96%) stated funding uncertainty affects their agency's ability to incorporate resilience strategies, with 65% stating it has a significant impact. A comment from the chat said that Federal funding might only be a small component of their STIP budget.

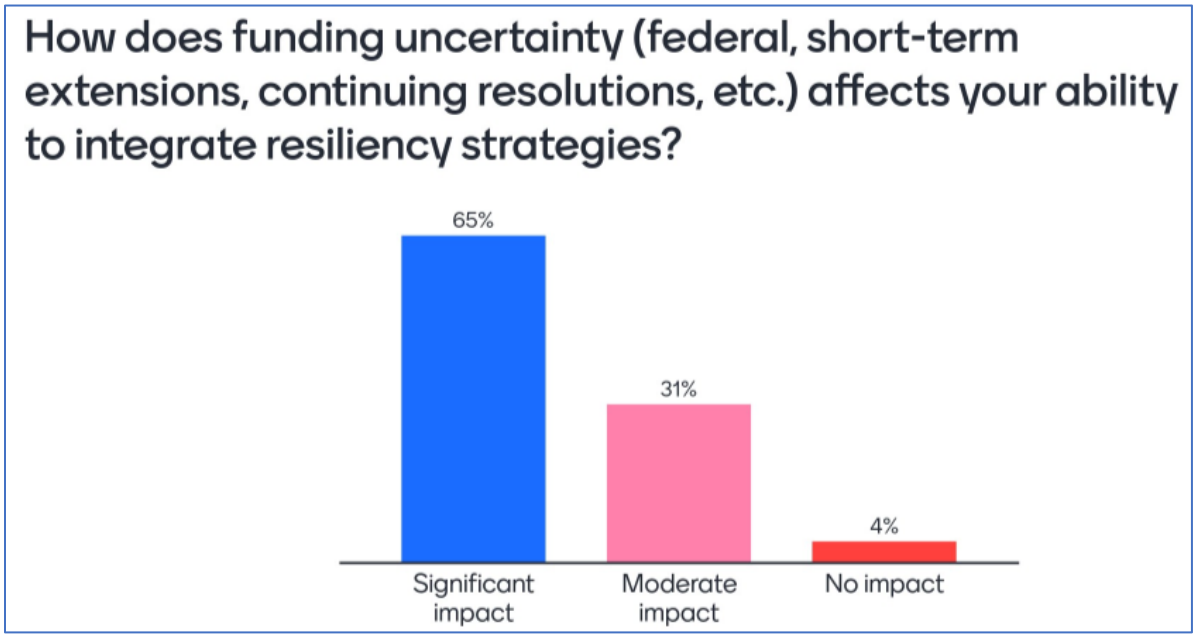


Figure 44. How does funding uncertainty affect your ability to integrate resiliency strategies?

Topic 4: Resilience Communication and Collaboration

This segment topic focused on communication and collaboration efforts exercised by the agency (both internally and externally) for incorporating risk and resiliency into their planning efforts and on what strategies are in place and to what level they are followed through on.

Forty-eight participants responded to this question (Figure 45)(. Most (73%) responded that their agencies have a strategy to share resilience data and strategies with their departments. However, the majority (63%) stated that these strategies need improvement.

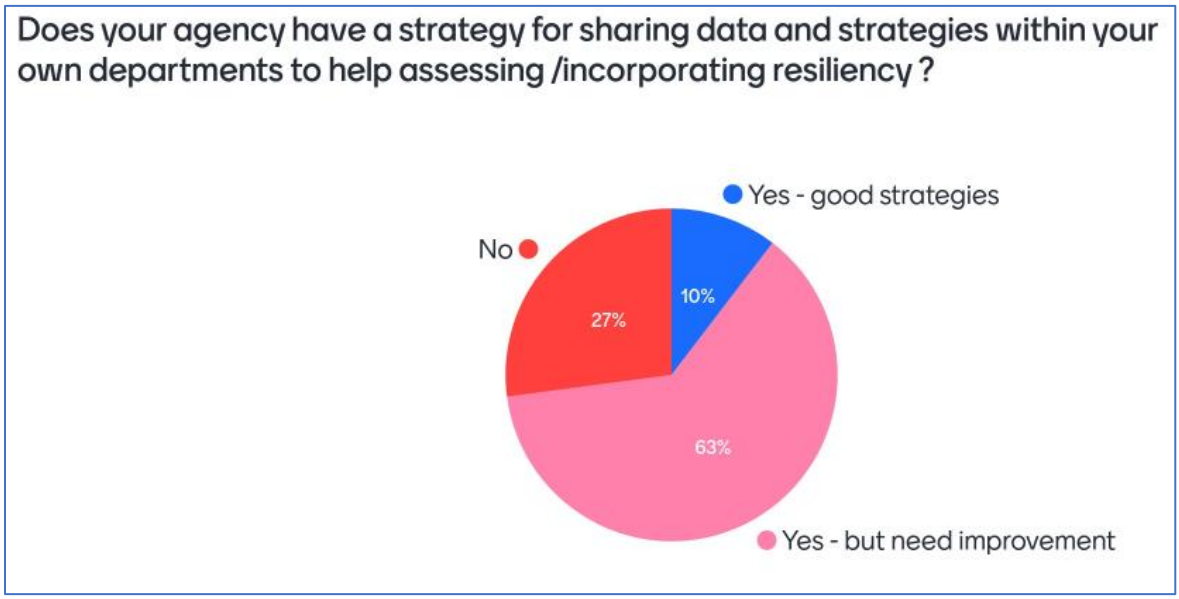


Figure 45. Does your agency have a strategy for sharing strategies and data to help assess resiliency?

Forty-seven participants responded to this question (Figure 46). Most (54%) replied that their agencies have a strategy to share resilience data and strategies with other agencies, cities or modes. However, most of these (45%) stated that these strategies need improvement. In addition, comments on the chat stated that Statewide Climate Change Commission helps MDOT. In NJ, agency collaboration on resiliency is performed within the framework of an interagency council led by the Governor.

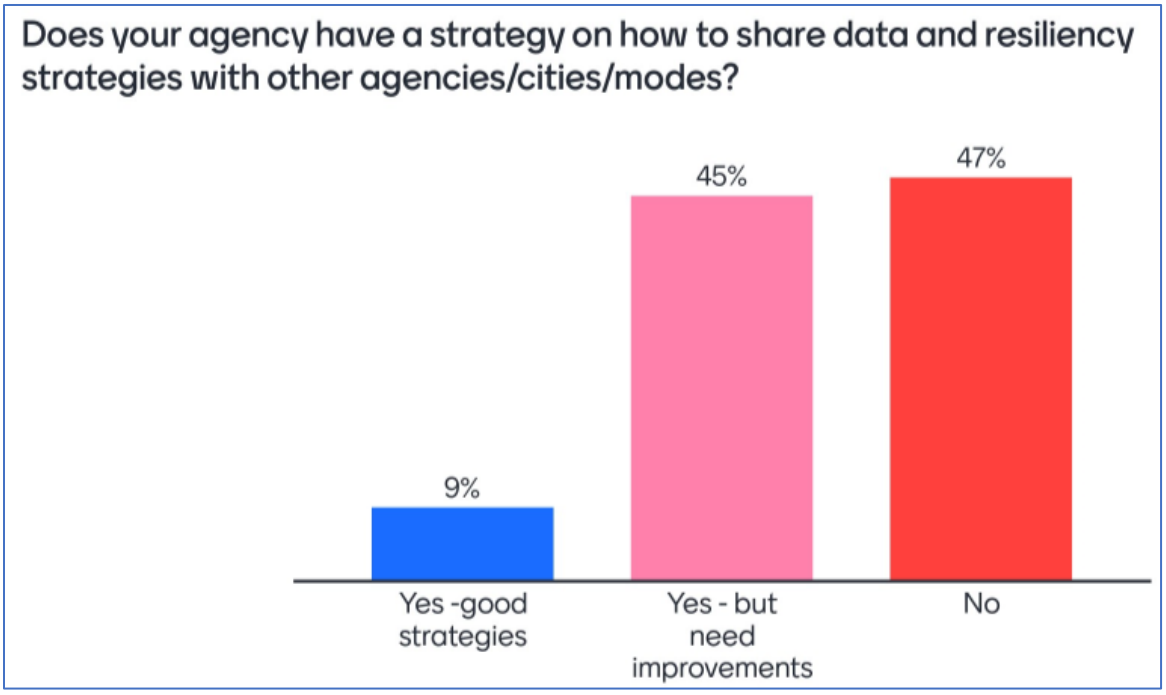


Figure 46. Does your agency have a strategy on how to share data and resiliency strategies externally?

Thirty-three participants responded to this question (Figure 47). The highlighted agencies included state DOTs, MPOs, emergency management, FHWA, local government and municipalities, natural resources and environmental agencies, FTA, etc.

Figure 47. Name some of the agencies you share resilience strategies with

Forty-one participants responded to this question (Figure 48). Most (76%) replied that their agencies have some communication with other entities supporting transportation systems.

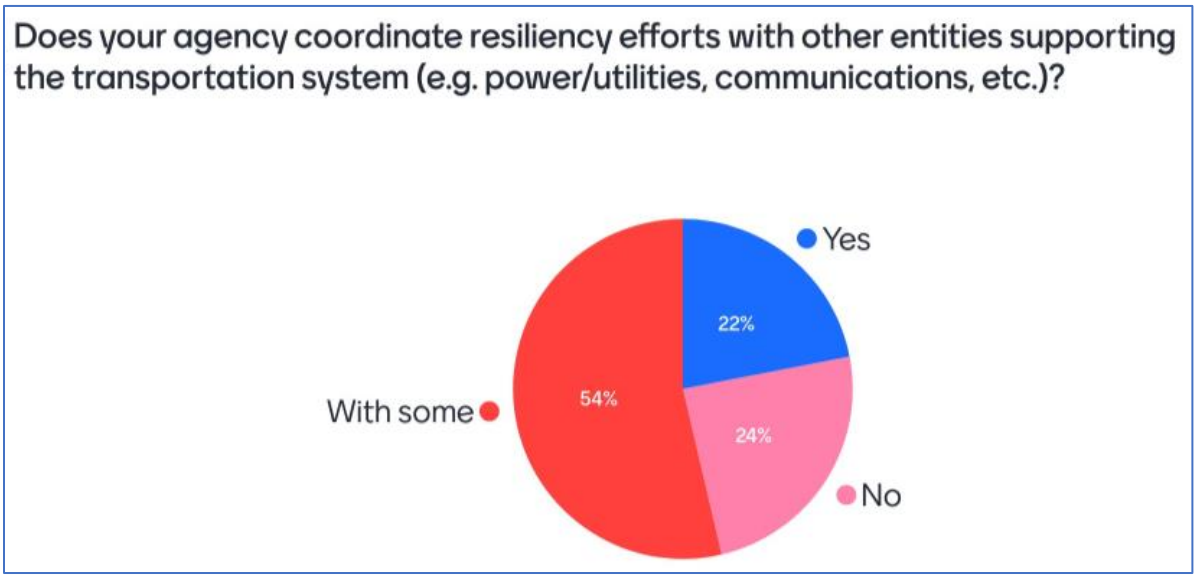


Figure 48. Does your agency coordinate resiliency efforts with other entities supporting transportation?

Forty-seven participants responded to this question (Figure 49). Most (70%) replied that their agencies have a method for communicating resilience results with stakeholders and the public that either is adequate (4%) or could be improved (66%).

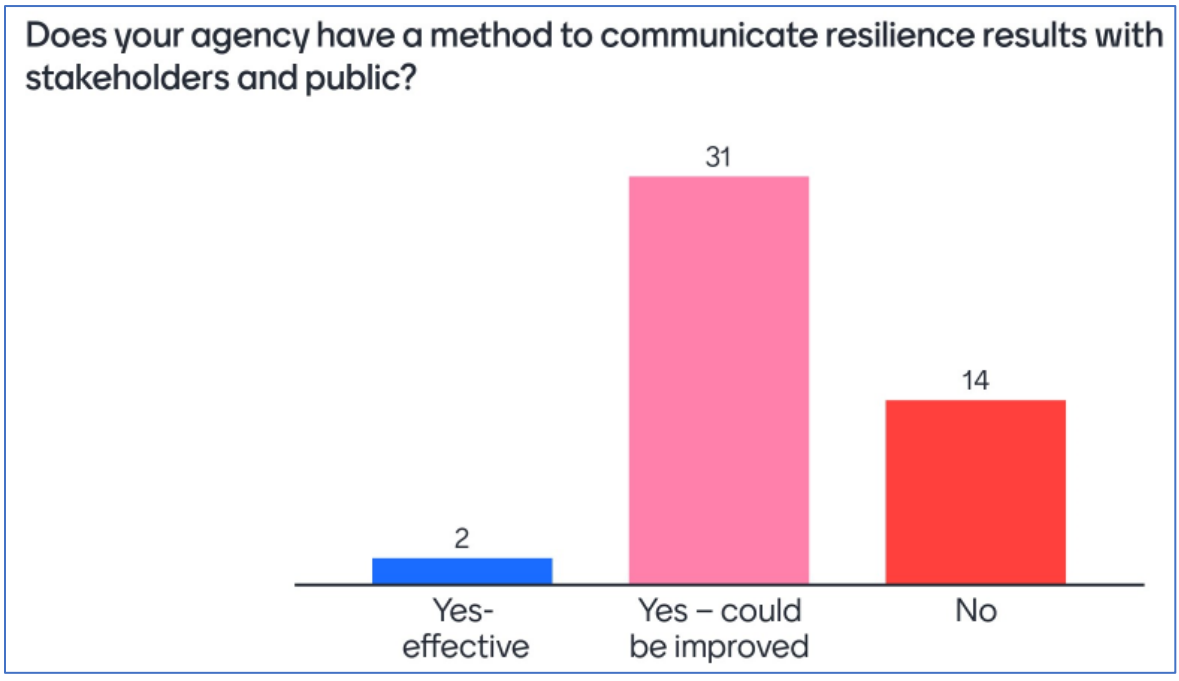


Figure 49. Does your agency have a method to communicate resilience with stakeholders?

Closing Questions: Agency Maturity Level

Fifty-one participants responded to this question (Figure 50). Most considered that their agencies have a medium maturity level when incorporating resilience into their planning process or areas, followed by low and high maturity levels. A comment in the chat stated that their agency is at least medium in terms of incorporation into project planning but not so much in other types of planning.

Figure 50. What do you think your agency's overall maturity level for incorporating resilience is?

Results and Conclusions

Based on the polling questions for each one of the topics presented at the "Industry 2-min Drill" the research teams validated the gaps in the state of practice and the need for a successful implementation of resilience approaches in transportation planning. The gaps and needs identified during the industry engagement are summarized below:

1. Transportation agencies are incorporating Resilience concepts and approaches into planning at some level.
2. There is a need for a more formal definition, policy, process, tools, and metrics to help agencies to incorporate resilience into transportation planning at all stages and plans.
3. The greatest benefits of adopting resilience management include proactivity, cost savings in the long run, continuity of operations during a disaster, asset management optimization, performance improvement, safety, increasing societal resilience, breaking silos, and preserving connectivity of transportation systems during emergency events among others.

4. The top 3 greatest challenges when incorporating resilience into transportation planning include lack of established performance goals/metrics for risk and resilience, financial constraints, and lack of established assessment methods and tools.
5. More resources, including staff, funding, and better risk and resilience assessment/implementation training, are needed.
6. A more holistic approach for incorporating resilience into transportation planning is needed to include all aspects affecting the transportation system, including internal agency communication (breaking silos) and communication among other agencies, cities, and modes of transportation.
7. Leadership and champions for the integration of resilience into transportation planning are key.

In conclusion, it was found that state DOTs and other transportation agencies are currently incorporating resilience at different levels and in some of their transportation plans. However, there is still a need for more resources and better information on successfully incorporating resilience concepts and approaches into the different areas of transportation planning. The NCHRP Project 08-129 will use these gaps and needs and more detailed case studies to develop a guide that helps transportation agencies incorporate these concepts into transportation planning.

Invitation

What:

We need you to participate in a virtual polling Industry "2-Minute Drill" to help us identify and define what transportation agencies need to successfully implement resiliency into transportation planning.

Why:

While transportation agencies understand the importance of incorporating resilience planning into transportation decision-making, the state of the practice varies.

Our research team is working on **NCHRP 08-129** – ***Incorporating Resilience into Planning***. Our objective is to develop a guidebook on how state DOTs and other transportation agencies can integrate resiliency planning into decision-making. The guidebook should consider:

- Effective strategies for prioritizing planning and investment decisions to improve systemwide resilience
- Processes to identify and plan for the effects of natural- and human-caused hazards;
- Identification of available and gaps in data and analytical tools and techniques to facilitate proactive and effective resilience planning
- Process to integrate resilience planning into existing institutional practices
- Identification of obstacles to incorporating resilience into state DOT transportation planning and decision-making
- Identify how state DOTs integrate and share resilience planning procedures with other agencies/modes

When: December 14th, 2:30 pm – 4:00 pm ET.

Where: Invitation with details will be sent to registered participants. Please save the date!

How: REGISTER today – your opinion matters!

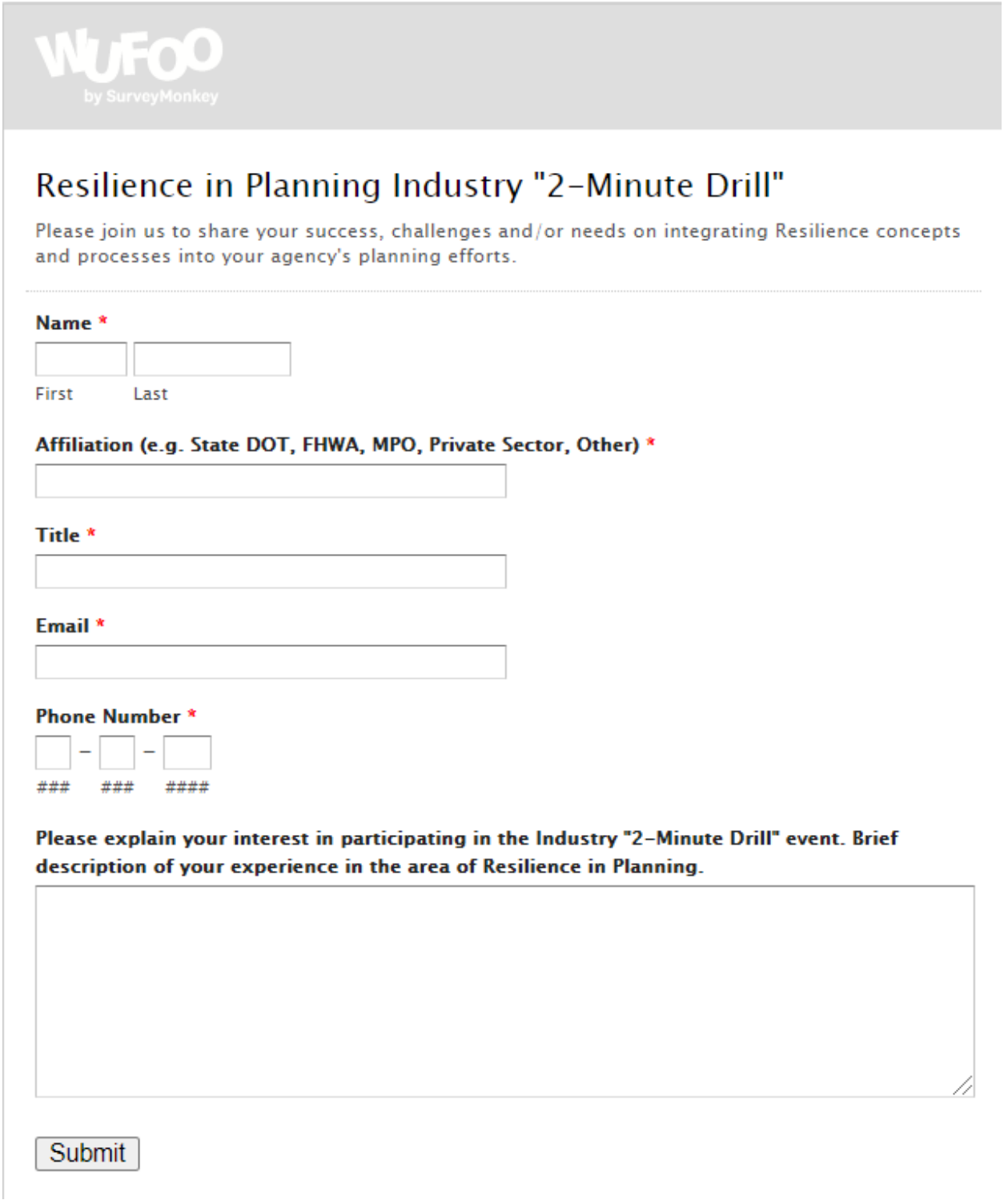
NCHRP NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

For further project information click HERE

For more details and information about getting involved, contact Maria Pena at maria.pena@aemcorp.com

aem Jacobs AJOC Consulting Engineers

Wufoo Attendee Registration Page



WUFOO
by SurveyMonkey

Resilience in Planning Industry "2-Minute Drill"

Please join us to share your success, challenges and/or needs on integrating Resilience concepts and processes into your agency's planning efforts.

Name *

First Last

Affiliation (e.g. State DOT, FHWA, MPO, Private Sector, Other) *

Title *

Email *

Phone Number *

####

Please explain your interest in participating in the Industry "2-Minute Drill" event. Brief description of your experience in the area of Resilience in Planning.

Submit

APPENDIX D – QUICK SCAN CASE STUDIES

Arizona Department of Transportation

Agency/Organization	Arizona Department of Transportation (ADOT)	
Location	Arizona, United States	
Contact Title/Dept.	Senior Program Manager, NEPA Assignment, Innovative Programs, Major Studies	

Overview

"It is difficult to see another way to do planning or resilience-building or resilience-funding unless you have the appropriate tools and measures.", Arizona Department of Transportation (ADOT).

ADOT program-level planning links resilience to Transportation Programming, specifically the 5-year construction program and transportation asset management. Transportation asset management is a program-level planning activity at ADOT which includes major corridor studies, the currently underway next Long-Range Transportation Plan, and Agency level adoption of new and novel science, engineering, risk, and technology adoption. ADOT identifies the main reasons for incorporating resilience in transportation planning as being related to (i) safety benefits, (ii) maintaining mobility and operations, (iii) climate adaptation planning, (iv) experience/past damage with catastrophic events, (v) sustainability and (vi) emergency response planning.

Resilience Policies, Definitions, and Frameworks

ADOT defines resilience as found in FHWA Order 5520 – "anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions."

At the Resilience Program level, ADOT emphasized that effective risk management for assets exposed to extreme weather, climate stressors, and natural hazards is critical to ensure the traveling public's safety and improve transportation infrastructure's long-term life cycle. Further, ADOT expressed that having a resilience definition is "extremely helpful" as it is a way to keep the different divisions of the agency organized and builds a consistent message.

From a framework perspective, ADOT considers it far easier to implement where the issues are 'front and center," such as in project planning. ADOT has protocols and procedures to monitor and track the impact of measures taken at a project level to enhance resilience; for example, monitoring instances where a risk-informed decision was taken not to incorporate resilience enhancement measures. ADOT stressed the importance of incorporating appropriate ongoing monitoring into developed frameworks to assess the efficacy of actions taken to enhance resilience.

Highlights

1. Resilience policy established and in use.
2. A formal definition for resilience has been established and communicated.
3. A resilience definition is beneficial for ADOT planning efforts and interagency coordination.

Integration Approaches for Resilience

ADOT recognizes that the integration of resilience is critical in the context of specific weather and natural hazard risks in project development, planning, operations, administration, etc., as there is a history/experience with such events being impactful on the system. This experience has led to maturity in applying risk and resilience modeling/analysis as a matter of necessity. Without this level of maturity of understanding of risk modeling/analysis, it is difficult for agencies to engage with appropriate resilience analysis in lifecycle planning and asset management.

ADOT considers that long-range planning, outreach planning, and program development provide a natural foundation for applying/integrating resilience approaches. However, other less mature areas in terms of application may struggle at this stage to incorporate. The importance of differentiating definitions of planning in a DOT environment from the perspective of discussing resilience planning was recognized, e the difficulties of adopting and implementing resilience approaches/strategies without recognition of different entry points within the planning environment were highlighted.

ADOT has incorporated resilience concepts and approaches into multiple transportation plans, including Long-Range Statewide Transportation Plans, Transportation Improvement Programs (TIP/STIP), TAMP, and its 5-year ($1.1bn) program for various levels. The multimodal planning area performs long-range transportation plans, stewards the asset management plan, and participates in the overall state development of STIP. ADOT considers the range of maturity in implementation to evolve in stages from (1) defining goals and objectives, (2) identifying problems and needs, (3) identification of resilience strategies, (4) implementation of resilience strategies, (5) defining appropriate evaluation criteria, performance measures and targets and (6) developing the processes and tools to facilitate appropriate monitoring and reporting. LRTP is currently at stage 1, TIP/STIP at stage 2, and TAMP and the 5-year program have achieved application up to and including stage 6. Enhancing the application level in terms of the LRTP and TIP/STIP is a function of the externalities involved. It is in part dependent on outreach activities and external consensus. ADOT highlighted the difficulty in achieving overarching application throughout these multiple transportation plans as a significant challenge, particularly in avoiding unhelpful generalizations.

One major obstacle to the integration of resilience approaches in state agencies is the lack of a specific place for it to reside, i.e., in administration or planning or operations or design engineering/project development?

ADOT communicates resilience approaches to develop consensus with internal and external entities, for example, within Metropolitan Planning Organizations (MPO) and Councils of Government (COG). Furthermore, ADOT plays an active role in collaborating with AASHTO, FHWA, and TRB. The challenge in this regard is crafting a messaging structure that applies to a broad range of participants.

ADOT considers that funding is easier to secure for resilience assessment at the project level. It isn't as easy to define how the Federal Aid program can assist in planning. However, a part of the regional transportation planning budget mechanism can be assigned to facilitate resilience assessment from the Federal Aid program. A key issue is who has control over other developments and who has control over funding associated with those developments.

HIGHLIGHTS

1. The management of the roadway system evolved from a decentralized, project-based focus to

one that encompasses enterprise-wide endeavors: administration, asset management, technology adoption, planning, design, construction, operations, and maintenance

2. Long-range planning, planning outreach, and program development provide a natural foundation for applying/integrating resilience approaches

Resilience Assessment Data, Models, and Tools

Since 2010, ADOT has developed 8-10 tools, approximately 1/year, to facilitate the assessment/quantification of resilience and the benefits of resilience enhancement from a planning perspective. Examples include tools to identify the necessary steps for resilience planning up to and including the benefits of incorporation into planning activities such as the 5-year plan. For example, ADOT has (i) a resilience financial hierarchy model, (ii) a planning/screening tool, (iii) an end-to-end engineering process tool, (iv) a climate influence model, and more. Overall, an excellent 'toolbox' has been developed to be utilized in resilience assessment and planning, which facilitates the development of financial justification approaches and consideration of sustainability criteria in a 'total systems approach.' Centralized warehousing of all relevant data has been a 'gamechanger' for ADOT is working on resilience. A resource compendium has been established by ADOT via a resilience GIS database using ArcGIS. This way, base layer mapping already available in the agency was combined with traffic and incident data and information supplied by the USGS, NOAA, National Weather Service, Forest Service, Dept. of Interior, etc. The platform as developed is applicable to project development and consideration/analysis of over 30,000 lane miles in the system from a planning standpoint of 'areas of interest.' To minimize uncertainty from a planning perspective, such data sets must be regularly monitored, updated, and validated. ADOT considers the TAMP, with its requirement for regular updating, to be an excellent facilitator in this regard. In addition, ADOT performs risk and resilience assessments internally.

HIGHLIGHTS

1. Formally incorporated resilience into 8-10 major efforts
2. Resilience tools used to screen and prioritize activities from a planning perspective
3. Performs risk and resilience assessments internally

Resilience Performance Measures/Metrics

ADOT has established resilience metrics-driven and tracked them through Resilience building software tools, e.g., dollars spent, the number of screened activities, asset types, State Route vs. Interstate, etc. For example, metrics are employed in the economic justification for project building. ADOT has to date, completed 10 resilience-building efforts. Other models: 24-hour precipitation design threshold and scour critical status, were selected as sensitivity metrics in ADOT's Asset Management, Extreme Weather, and Proxy Indicators Pilot Project.

Bay Area Transit Authority

Agency/Organization	Bay Area Transit Authority (BART)	
Location	San Francisco Bay, California, United States	
Contact Title/Dept.	Principal Engineer	

Overview

"There is a consensus regionally that something needs to be done, though no consensus as to exactly what."

The primary integration of resilience concepts at Bay Area Rapid Transit (BART) is through applying the BART Facilities Standards (BFS), the agency's guiding resource for how projects are designed and constructed. Resiliency is also included as a point of consideration in developing a local hazard mitigation plan.

Because BART is focused on resilience measures that consider natural hazards and the coastline includes varying landowners, appropriate and effective mitigation in planning is a complicated topic. There is little direction for coordinating, incorporating, and integrating resilience. BART anticipates the needs, but with a lack of regional framework, efforts at this point are more toward engagement rather than actual implementation.

Resilience Policies, Definitions, and Frameworks

BART currently does not have an established resilience policy in transportation planning efforts. A sustainability policy that considers resilience is in place, but there is no stand-alone document focused on incorporating resilience into planning. The sustainability policy gives a direction for advancements but lacks implementation plans. BART's assessment of the current policies is that they are effective, and a policy change would not currently provide additional benefits.

BART itself does not have an established definition for resilience. Still, it adopts and implements the state definition, which states, "Resilience is the capacity of any entity – an individual, a community, an organization, or a natural system – to prepare for disruptions, to recover from shocks and stresses, and to adapt and grow from a disruptive experience." Resilience is identified through a Local Hazard Mitigation Plan (LHMP) rather than a single statement definition and uses what they establish in the plan as a guide for incorporation. The hazard mitigation definition overlaps with resilience, and because of this, there is no immediate need for a formal, stand-alone resilience definition.

While there are no formal risk and resilience frameworks, there are indirect ways BART incorporates resilience concepts and approaches into its planning goals and objectives. For example, using BFS helps to ensure the incorporation of resiliency, as well as through design review, which allows for identifying concerns during the planning process. BART also uses the LHMP to identify natural threats from sea-level rise and extreme heat to earthquakes, floods, landslides, and droughts.

HIGHLIGHTS

1. No established resilience policy
2. No formal agency definition of resilience
3. Lack of formal risk/resilience frameworks

Integration Approaches for Resilience

BART incorporates resilience mainly through design and construction regarding any project required to comply with BART Facilities Standards. This ensures all projects comply with at least some standard of resilience standards. While BART anticipates risk and the need for resiliency, the implementation is not as straightforward. Regarding sea-level rise, BART does not own any of the shoreline property; thus, it cannot mitigate on its own. Most of BART's adaptation efforts are directed at how they can engage various landowners to assist in planning and supporting their assets. Currently, resilience integration is focused on engagement and putting in place plans to move forward together. A regional framework would benefit the city to create a comprehensive impact. However, it might take a significant enough disruption to bring public and political attention for that change and forward movement to occur.

At the regional level, discussions and engagements acknowledge the problems and prove the understanding of resiliency is needed. The next steps to be taken are identifying what should be done and how to do it.

Resiliency is considered a standard design consideration in the planning development and does not have funding. While BART expressed that more money would increase capacity and ultimately do more, they are making progress with the current tools and initiatives. If the budget was increased, resilience could be put toward key assets and critical locations where BART knows it would be beneficial to address right now.

BART shares the regional consensus that something must be done, and the next steps determine exactly what that means moving forward.

HIGHLIGHTS

1. Projects must comply with BFS
2. Resilience integration is currently focused on engagement between stakeholders due to the complexity of land ownership
3. No specific funding for resilience

Resilience Assessment Data, Models, and Tools

BART does utilize publicly available software and tools for analyzing and visualizing data to support its resilience programs. They overlay hazards with assets using ArcGIS to determine vulnerability and high-impact areas. Other tools indicated that would be beneficial to encourage resilience in planning would be BIM modeling for all BART assets.

BART has reliable data sets for the geographic location of assets, asset replacement costs and values, threat mapping or identification tools, and asset/system criticality models. Compiled or organized elevation data for flooding would be beneficial for BART to improve resilience objectives. They currently have the data, but the current issue is accessing the data when needed. Making information readily available and easy to access would be the greatest benefit to BART.

Agency collaboration does occur at BART through BCDC (Bay Conservation and Development Commission), Caltrans, and the Port of San Francisco, among other agencies. Information like tools, datasets, and funding is shared to help assess and incorporate resilience throughout the City of San Francisco. While this collaboration does occur, there is no formalized strategy to share resilience strategies. Therefore, any interaction between agencies is opportunistic.

HIGHLIGHTS

1. Utilization of publicly available software and tools
2. Multiple reliable data sets, but more could be beneficial
3. Out-of-agency collaboration occurs, but no formalized strategy

Resilience Performance Measures/Metrics

BART has not developed and does not have performance indicators dedicated solely to resilience. However, they do prioritize and keep performance metrics mainly for asset management, expressly, by observing operational downtime and minimizing it to become more efficient. In addition, BART performs resilience assessments, with adaptation efforts identified as part of the study, leading to during-and-after event planning to improve asset recovery and assessment of future resiliency.

At BART, the risk is observed as threats and the likelihood of consequence, while resilience is the concept of adapting to disasters and disruption of operations. These two ideas work together, and when doing assessments performed by BART staff, risk and resilience assessments are seen as the same study. These studies include BART looking at the sea-level rise and adaptation measures to incorporate resilience measures.

There is no method to communicating resilience results internally, externally, or publicly, but BART believes it is helpful to discuss these findings and share results. Again, no standard process exists, but internal training and meetings could be beneficial.

HIGHLIGHTS

1. No resilience-based performance indicators developed or in-use
2. Resilience and risk assessments are done internally and utilized to improve asset recovery and future assessment
3. No standardized communication methods for results, but could be beneficial to have

Capital Area Metropolitan Planning Organization

Agency/Organization	Capital Area Metropolitan Planning Organization (CAMPO)	
Location	Texas, United States	
Contact Title/Dept.	Regional Planning Officer	

Overview

CAMPO is at the beginning stages of incorporating resilience into its overall operations. The organization has incorporated resilience concepts into planning documents and conducted a risk assessment of critical assets. In addition, CAMPO has designated resilience metrics and resilience targets. However, CAMPO has no definition of resilience, special funding for resilience, nor has it completed a resilience assessment of its system.

Resilience Policies, Definitions, and Frameworks

CAMPO incorporates resiliency into transportation planning through policy development, project evaluation, prioritization, and funding; and by awarding planning studies to jurisdictions to create and preserve resiliency in the transportation system. Resilience concepts are included in Metropolitan Transportation Plans (MTP), Transportation Improvement Programs (TIPS/STIPS), safety plans, transit plans, freight plans, and bike/pedestrian plans.

CAMPO has created plans designed to improve the connectivity of roadway networks in urban, suburban, and rural parts of our region that generate a measurable impact on future transportation demand and network efficiency. Multiple planning efforts have resulted in reductions in emergency response times and in larger geographies being accessible within benchmark emergency response times. Additionally, CAMPO has prioritized and funded projects like river crossings that significantly improved access, reduced travel times, and reduced VMT and VHT throughout the region.

Currently, CAMPO does not have a definition of resilience. The remaining barriers to pursuing a resilience approach remain the lack of tools and funding, data reliability, and the complexity of the problem.

HIGHLIGHTS

1. Incorporated resilience concepts into MTP, TIPS/STIPS, and transit, safety, freight, and bike/pedestrian plans
2. Implemented plans to reduce emergency response times
3. No resilience definition or separate funding for resilience programs

Integration Approaches for Resilience

CAMPO has integrated resilience concepts into multiple plans and programs. In addition, CAMPO participated in the FHWA Climate Resilience Pilot Program. Under this program, in 2014, CAMPO collaborated with the City of Austin Office of Sustainability to assess vulnerabilities to 10 critical assets from 3 asset classes (roadways, bridges, and rail), within CAMPO's jurisdiction. The project team held a conference to identify the critical assets and then conducted a vulnerability analysis to determine the risk of five threats (flooding, wildfire, rainfall, drought, extreme cold, and ice, to these assets. CAMPO

identified flooding, drought, extreme heat, wildfire, and extreme cold as threats. The analysis results were incorporated into the 2040 CAMPO Long Range Transportation Plan (LRPT). CAMPO's long-term resiliency goal is termed "Platinum Planning." The resiliency goal considers the environment, economic development, equity, mixed-use, multimodal transportation, and housing. Platinum Planning also considers environmental and social factors as key criteria for assessing land suitability for transportation projects.

HIGHLIGHTS

1. Assessed critical asset vulnerability to extreme weather
2. Integrated risk analysis results into RPT
3. Added environmental justice and equity to resilience goals

Further, CAMPO has added environmental justice and Title IX housing considerations to its vulnerability assessments. CAMPO's strategy for sharing resilience strategies and collaboration includes maintaining partnerships with the City of Austin, local governments, and the Texas Division of Transportation.

Resilience Assessment Data, Models, and Tools

One of the barriers to pursuing resilience is the lack of reliable data. Currently, CAMPO has reliable spatial data for mapping highway assets and natural threats but lacks data for asset life cycle cost, replacement cost, asset condition, and threat probability. CAMPO also lacks asset deterioration curves and models. However, the organization successfully gathered and employed population data, current and future congestion data, and downscaled climate data to conduct its FHWA Climate Resilience Pilot study.

To assess the vulnerability of its critical assets to climate stressors, CAMPO used FHWA's VAST, a spreadsheet tool and indicator-based semi-quantitative model. For the pilot study, additional special tools were used – the MC1 dynamic vegetation model for wildfire susceptibility and Vflo®, a physics-based hydrologic model.

Other tools regularly employed by CAMPO include TransCAD and regional travel demand models to stress test the transportation network when subjected to disruptions. CAMPO also uses ArcGIS and Adobe Create Cloud for visualization.

In addition, CAMPO relies on Subject Matter Expert input from the Austin Public Works Department, City of Austin Homeland Security and Emergency Management, and the City of Austin Fire Department.

HIGHLIGHTS

1. Employs FHWA VAST for vulnerability assessments
2. Stress tests the network with travel demand modeling
3. Leverages Subject Matter Input from stakeholders from multiple organizations

Resilience Performance Measures/Metrics

Currently, CAMPO uses three performance metrics for resilience: VMT, VHT, and travel time, and has expressed a need for additional metrics. CAMPO has also designated the following resilience targets: improving air quality and improving access to the transportation system for vulnerable and disadvantaged populations. While CAMPO has conducted risk and benefit-cost analyses, the organization has not yet conducted a resilience assessment of its system.

HIGHLIGHTS

1. Employs VHT, VMT, and travel time as resilience metrics
2. Plans air quality and equitable transportation access as resilience targets
3. Expressed need for additional resilience metrics

Colorado Department of Transportation

Agency/Organization	Colorado Department of Transportation (CDOT)
Location	Colorado, United States
Contact Title/Dept.	Resilience Program Manager, Planning and Finance

Overview

Since 2013, the Colorado Department of Transportation (CDOT) has aggressively integrated resilience into planning and developed its own in-house risk and resilience framework and tool. CDOT has successfully employed benefit-cost analysis to win federal funding for multiple resilience projects. In addition, CDOT has a central repository for sharing and visualizing transportation and asset data.

Resilience concepts are embedded in CDOT's TAMP and Long-Range Plans (LRTP). However, CDOT has expressed a need for better resilience metrics and tools for incorporating climate change into risk and resilience analysis.

Resilience Policies, Definitions, and Frameworks

CDOT has adopted the Colorado Resiliency Office definition for resilience as, "the ability of communities to rebound, positively adapt to, or thrive amidst changing conditions or challenges—including human-caused and natural disasters—and to maintain quality of life, healthy growth, durable systems, economic vitality, and conservation of resources for present and future generations." Additionally, AASHTO's resilience definition is also used.

On November 15, 2018, the Colorado Transportation Commission issued Policy Directive (P.D.) 1905.0 "Building Resilience into Transportation Infrastructure and Operations." This policy extends efforts to encourage resilience activities initiated after the catastrophic 2014 flood. The Directive requires CDOT to take proactive steps to manage risk to Colorado's highway infrastructure from the threat of floods, rockslides, avalanches, and man-made hazards.

Other drivers include federal regulations (Moving Ahead for Progress in the 21st Century (MAP-21), the Fixing America's Surface Transportation Act (FAST Act)), state leadership, economic benefits, safety benefits, and the need to maintain mobility. Under the auspices of the FHWA Risk and Resilience Pilot grant program, CDOT leveraged GIS tools and digital hazard layers to conduct a quantitative risk assessment for highway assets along the I-70 corridor.

The CDOT's Resilience Program followed this effort by developing the CDOT Risk and Resilience (RnR) Manual risk assessment procedures manual for bridges, pavement, and culverts at risk from flooding, rockfall, and post-fire debris flow. The methodology largely implements the RAMCAP™ framework. In addition, CDOT has developed a statewide criticality map to assist decision-makers in prioritizing projects.

HIGHLIGHTS

1. Colorado Transportation Commission issued Policy Directive (P.D.) 1950.0
2. Conducted corridor-wide quantitative risk assessment

3. Adapted RAMCAP to develop a manual for risk and resilience assessments

Integration Approaches for Resilience

CDOT has incorporated resilience concepts and approaches into its Long-Range Statewide Transportation Plan, Transportation Improvement Programs (TIP/STIP), TAMP, and freight plans. CDOT celebrates its greatest resilience success as its effective response to the 2013 Front Range Floods. CDOT developed a tool for benefit-cost analysis and was able to justify multiple "build-back-better" projects, winning over $100 million in emergency repair funds to enhance the resilience of Colorado's transportation infrastructure with multiple roadway improvement projects. Since 2013, CDOT has been working to incorporate resilience concepts into every aspect of CDOT's day-to-day business. CDOT has a resiliency integration project underway that will demonstrate how to do that in 5 case studies—including project prioritization and selection and incorporation into asset management and environmental studies. In addition, communication, and data sharing within different groups at the agency and with other external groups facilitate their resilience efforts. Vehicles for supporting collaboration on resilience include the Statewide Transportation Advisory Committee, Statewide Transportation Metropolitan Organization (MPO) Group, and the Colorado Resiliency Office (led by Colorado's Department of Local Affairs (DOLA)). Currently, CDOT is also in the process of writing an appendix to the agency's recently updated statewide plan to address resiliency. The remaining barriers to resilience activities include lack of funding, staff, knowledge/skills in the topic, and metrics.

HIGHLIGHTS

1. Integrated resilience concepts into LRTP, TAMP, TIP/STIP, and freight Plans
2. Leveraged over $100 million in E.R. funds to build resilience into Colorado highways
3. Updating statewide resiliency plan

Resilience Assessment Data, Models, and Tools

CDOT's Online Transportation Information System (OTIS) hosts a wealth of spatial and attribute data, including traffic data, asset conditions, and asset design characteristics. CDOT has accumulated a reliable asset data inventory, including replacement cost, life cycle cost, condition state, linear referenced location data, etc. All this data is easily shared both inter-and intra-agency through OTIS. In addition, OTIS offers visualization tools. The OTIS portal hosts Straight Line Diagrams to display selected highway characteristics and a map view for viewing transportation data. Publicly available hazard maps are referenced in the CDOT Risk Assessment Procedures Manual.

CDOT uses spreadsheets and proprietary tools in conjunction with the RAMCAP™ framework. The development of the CDOT RnR Manual was followed by the full implementation of deterministic, quantitative risk models as a spreadsheet tool. The tool includes risk models for bridges, roadways, and culverts for flood, rockfall, and debris flow hazards.

HIGHLIGHTS

1. Shared spatial and attribute data is easily accessible through OTIS
2. Developed a Risk and Resilience Assessment Manual (RnR Manual)
3. Developed quantitative spreadsheet risk assessment tool

Resilience Performance Measures/Metrics

The CDOT RnR Manual includes calculations for annual risk and a metric for resilience called Level of Resilience (LOR). The LOR is a composite metric based on asset criticality and annual risk. The criticality component of the LOR is based on social, environmental, environmental factors, and network redundancy. The risk component is based on classifying a system's aggregated annual risk into 5 quantiles. Thus, the LOR is determined by where the criticality scale and risk quantiles intersect. CDOT has improved its criticality model by replacing the redundancy factor with travel demand modeling. In addition, CDOT has expressed an interest and need for additional resilience metrics that consider climate change.

HIGHLIGHTS

1. Developed quantitative Risk metric ($/yr.)
2. Developed a qualitative Level of Resilience (LOR) metric based on Criticality and Risk
3. Improved criticality model with travel demand modeling
4. Expressed need for better resilience metrics and climate change tools

Danish Roads Directorate

Agency/Organization	Danish Roads Directorate (DRD)	
Location	Copenhagen, Denmark	
Contact Title/Dept.	Academic Specialist, Climate Change, and Infrastructure	

Overview

"There is an increased awareness and resource allocation to adequately dimension and maintain [infrastructures] to ensure full capacity for optimum conditions in a climate with an increase in extreme precipitation occurrences." The Danish Roads Directorate (DRD).

The DRD focus, in terms of program-level planning, centers on maintaining mobility and operations. The strategic importance of infrastructure elements is critical in prioritizing resource allocation. The DRD recognizes and realizes socioeconomic benefits from adopting adaptation measures.

Resilience Policies, Definitions, and Frameworks

The DRD defines resiliency as when 'adaptations are implemented to ensure designs are effective.' The DRD has established resilience policies employed in transportation planning efforts. Furthermore, the concepts and objectives of resilience approaches are integrated into developing planning goals and objectives.

At the Resilience program level, the major successes, and advantages, which the DRD accrues from incorporating resilience approaches into planning frameworks, relate to 'maintaining safety and passability.' Developing policies to obtain and maintain the 'trust of road users' in extreme weather events was highlighted. For example, one consequence of extreme precipitation events resulting in flooded road segments is eroding this hard-won trust. Therefore, every effort must be placed to mitigate such consequences.

The DRD has protocols and procedures in place to monitor and track the impact of measures taken at a project level to enhance resilience. In addition, clear reporting lines are in place to record event performance and revise strategies/procedures/protocols as required/appropriate.

HIGHLIGHTS

1. Formal definition for resilience established and communicated
2. Resilience framework established and in use
3. Obtaining and maintaining road user trust is of major importance to the DRD

Integration Approaches for Resilience

The DRD has developed and published a Climate Adaptation Strategy due to the history/experience with extreme weather events impacting the system. The strategy is central in integrating approaches for resilience in project development, planning, operations, administration, etc.

The' Blue Spot model is one example of how DRD integrated resilience into planning. The model provides a methodology to identify flood-sensitive areas in transportation networks. The definition of 'blue spots'

refers to stretches of the network where the likelihood of flooding is high, and the consequences are significant. The process is not only used to identify existing vulnerabilities under current weather conditions. Still, it is also employed to identify new potential 'blue spots,' which may appear in the future based on IPCC scenarios. As a result, calculations are performed for the years 2050 and 2100, considering projected future climate change scenarios. A link to the report highlighting the process can be found using this link: (https://en.klimatilpasning.dk/media/297917/the_blue_spot_concept_report_181.pdf).

The process facilitates the integration of resilience approaches into both short- and long-term transportation planning initiatives.

Obstacles to the integration of resilience approaches in the DRD are the lack of (i) reliable data and (ii) appropriately trained staff to implement the operable approaches. Furthermore, the DRD does not allocate a separate budget to incorporate resilience into transportation planning.

HIGHLIGHTS

1. Incorporates resilience concepts in transportation planning
2. Developed both a Climate Adaptation Strategy and the Blue Spot Methodology to integrate resilience in short and long-term transportation planning

Resilience Assessment Data, Models, and Tools

The DRD has developed processes via data, models, and tools to facilitate the identification of threats that might impact the transportation network. Tools are mainly GIS-based. A central tool, in this context, employed by the DRD in resilience assessment centers around the aforementioned 'Blue Spot' analysis model. The analysis is implemented in a GIS environment. The data used include digital terrain models with hydrological adaptations, climate factors, precipitation statistics, soil morphology information, demography, and traffic loads. Furthermore, daily data is gathered and analyzed to inform the system. The model is subdivided into three levels of analysis, with each subsequent level providing enhanced information: (i) Level 1 – initial screening of local depressions, (ii) Level 2 – precipitation sensitivity analysis regarding capacity depressions, and (iii) Level 3 – an in-depth hydrodynamic model of surface reservoirs and depressions.

The DRD employs the Blue Spot model to select and prioritize assets and projects for resilience improvement. The process has proven 'very effective in focusing resources' in transportation planning.

Centralized warehousing of all relevant data is important to the DRD in managing resilience. Reliable datasets are available for (i) geographic location of assets, (ii) asset replacement cost/value, (iii) asset life cycle cost, (iv) asset condition, (v) asset deterioration curves/models, (vi) threat/hazard mapping, (vii) threat/hazard probability of occurrence, (viii) anticipate consequences, and (ix) asset/system criticality.

The DRD shares data both internally and externally to help in assessing/incorporating resilience in transportation planning. Significant collaboration on resilience initiatives exists in the context of climate change effects.

The DRD performs risk and resilience assessments internally.

HIGHLIGHTS

1. Predictive quantitative tools to manage/enhance resilience were developed for prioritization in planning
2. Risk and resilience assessments internally performed

Resilience Performance Measures/Metrics

The DRD has established resilience targets for transportation planning. Furthermore, resilience-based performance indicators are employed in identifying resilience improvement strategies. Economic analysis is employed with associated processes to implement resilience improvement strategies in project planning/development.

Formal communication lines exist to communicate resilience initiatives/results internally and with other stakeholders.

HIGHLIGHTS

1. Resilience targets established
2. Resilience initiatives/results communicated internally, with stakeholders, other agencies, and the public

Florida Department of Transportation

Agency/Organization	Florida Department of Transportation (FDOT)	
Location	Florida, United States	
Contact Title/Dept.	Statewide Community Planning Coordinator/Office of Policy Planning, Director/Office of Policy Planning, Intergovernmental Program Administrator/Office of Policy Planning, and State Drainage Engineer/Roadway Design Office	

Overview

"The past damage we've had in Florida and the current events happening are all justification for change; how we adapt and mitigate these events are the challenges that lie ahead."

The Florida Department of Transportation (FDOT) incorporates resilience into various statewide and district-level transportation plans, including the Florida Transportation Plan (FTP). Through a wide range of efforts related to resilience, FDOT integrates resilience into policy, tools, and guideline development as well as "resilience-related research projects and studies," such as the Strategic Intermodal System Resilience Planning Study.

Resilience Policies, Definitions, and Frameworks

FDOT has a resilience policy established titled "The Resiliency of State Transportation Infrastructure," which is used in transportation planning efforts. The policy states it is the policy of FDOT to "consider resiliency of the State's transportation system to support the safety, mobility, quality of life, and economic prosperity of Florida and preserve the quality of our environment and communities." This policy is implemented through FDOT's long-range and modal plans, work program, asset management plans, research efforts, internal manuals, tools, guidelines, procedures, related documents, guiding planning, programming, project development, design, construction, operations, and maintenance.

The FDOT definition for resilience comes from FDOT Policy 000-525-053 and states, "Resiliency includes the ability of the transportation system to adapt to changing conditions and prepare for, withstand, and recover from disruption." This definition originated from the working definition of Florida's Chief Resilience Officer and was intended to facilitate interagency coordination on resilience topics and efforts.

FDOT expressed that having a resilience definition is "extremely helpful" as it is a way to provide a focus for the Department and bring a consistent message across the board. It also shows that resilience is essential and is on the radar of the Department.

HIGHLIGHTS

1. Resilience policy established and in use
2. The formal definition of resilience has been communicated
3. Resilience definition effective for FDOT planning efforts and interagency coordination

Integration Approaches for Resilience

FDOT integrates resilience effectively at a high level and is making huge strides at the policy level, engaging resilience needs. FDOT is decentralized, and all districts have varying priorities, so it is difficult to fully incorporate blanket agency resilience policies at the district or project level. However, FDOT has incorporated resilience concepts and approaches into multiple transportation plans, including Metropolitan Transportation Plans (MTP), Long-Range Statewide Transportation Plans, Transportation Improvement Programs (TIP/STIP), TAMP, and Freight Plans, and Port Plans, as well as their Seaports Plan and Aviation Office.

To improve system continuity and recovery, FDOT does a lot in preparedness and response to the stage for immediate recovery and assessment of damages. There are protocols for these stages as part of their standard workings that get turned into lessons learned. The Florida Transportation Plan, which makes up FDOT's LRTP, focuses on four areas of resilience, weather, environmental changes, economic shifts, and operational disruptions, to identify and address possible threats and mitigation strategies.

FDOT communicates resilience approaches in planning both internally and externally. State agencies, federal agencies, regional and local agencies, environmental partners, and transportation partners are among those FDOT collaborates.

Funding for resilience is built into the project planning but not budgeted as a separate line item. FDOT sees resilience as being considered in every project but not separated. Specific resilience funding is also dependent on legislature.

HIGHLIGHTS

1. Integrates effectively, but still room to grow
2. District and project-level considerations segmented due to agency structure
3. Utilizes internal and external collaboration

Resilience Assessment Data, Models, and Tools

Additional datasets and tools that would benefit FDOT would focus on operational costs and mitigation efforts. FDOT also utilizes publicly available software and tools, including ArcGIS, Sea Level Scenario Sketch Planning Tool, and Strategic Intermodal System Strategic Investment Tool. The last two are being developed by and for FDOT, specifically. In addition, FDOT is continuously evaluating ways to improve its existing tools. For example, it could be beneficial to have compound flooding data and for local areas to access data when planning. Finally, FDOT performs risk assessments, typically in the form of vulnerability assessments to address the extent of assets being impacted, and resilience assessments, typically done by consultants.

HIGHLIGHTS

1. Active consideration of resilience in performance measures development
2. Metric development focuses on resilience integration into existing metrics

Resilience Performance Measures/Metrics

FDOT does not have any established resilience metrics or indicators. Some indicators are noted in their FTP, but it only goes as far as to look at what could be tracked. FDOT's resilience practices are not

developed enough to utilize performance indicators effectively. Lack of failure for any asset is a positive measure, showcasing the forward progress seen in the overall response after an event.

HIGHLIGHTS

1. Active consideration of resilience in performance measures development
2. Metric development focuses on resilience integration into existing metrics

Georgia Department of Transportation

Agency/Organization	Georgia Department of Transportation (GDOT)	
Location	Georgia, United States	
Contact Title/Dept.	Maintenance Engineer, Technical Services and Air Quality Branch Chief, Assistant State Emergency Operations Coordinator	

Overview

"We need guidelines about what the Federal Agencies think and what rules are they going to implement so we can align our policies"

GDOT considers resilience in transportation planning as having the '*ability to anticipate, prepare for and respond back when things happen.*' Whilst no formal policies or procedures are in place for incorporating resilience into transportation planning, informally, resilience is considered throughout the process by various responsible areas/divisions. GDOT considers the lack of federal guidelines as an inhibitor to formal adoption and stresses the need for such guidelines as a critical facilitator for incorporating resilience concepts into transportation planning.

GDOT sees the main reasons for incorporating resilience in transportation planning as being related to (i) safety benefits, (ii) maintaining mobility and operations, (iii) experience/past damage with catastrophic events, (iv) sustainability, and (v) emergency response planning.

Resilience Policies, Definitions, and Frameworks

GDOT has no formal definition for resilience but understands resilience as "*the ability to anticipate, prepare for and respond back when things happen*." Mitigation is also considered an important aspect of resilience planning.

Currently, there are no formal strategies to incorporate resilience approaches into project development, but it was highlighted that informal/implicit approaches are in place.

The need for formal/specific guidelines from federal agencies (e.g., USDOT, FHWA) was emphasized to provide instruction on how to implement/develop a structured resilience policy and align it with federal approaches. GDOT recognizes that optimal approaches to resilience planning may vary as a function of the requirements of different divisions/stakeholders. In this context, a resilience committee would be desirable, spanning multiple offices/divisions. Formalized federal guidelines would strengthen its function and ability to attract resilience-specific funding.

HIGHLIGHTS

1. An informal resilience policy is in use
2. Federal guidelines on a formal definition for resilience are sought

Integration Approaches for Resilience

GDOT does not currently formally incorporate resilience approaches into transportation planning but rather does so on an informal basis. Whilst not explicit, it implicitly defines goals and objectives, identifies problems and needs, and implements resilience strategies into multiple transportation plans. For example, where scour hazard is identified in the management of bridge structures, foundations are routinely enhanced, although this is not formally classified under planning for resilience. Significantly, a research project has recently started in collaboration with Georgia Tech to define a path forward and a formal framework. The project has its genesis in a preliminary analysis, which was performed to determine the vulnerability of coastal infrastructure in Georgia to the sea level rise of different severity.

The project had its first workshop in February 2021, aiming to raise awareness and baseline the problem with a view to levels in definition and understanding. Now, information on appropriate evaluation criteria, performance measures, and targets is significantly lacking. The need for official, federal guidelines to provide clarity was highlighted.

GDOT collaborates informally internally and externally to help in assessing/incorporating resilience into transportation planning. Interaction with other states' DOTs, AASHTO, and Emergency Response entities has provided helpful information.

Currently, there is no allocation of a separate budget to incorporate resilience into transportation planning. However, it is recognized that resilience management is integral to planning, design, and operation. In this context, GDOT would like to see a move towards consistency at federal and local creating a roadmap to define standard operating procedures to increase understanding of resilience and formalize its adoption in the transportation planning process.

The main obstacles to the integration of resilience approaches were seen as (i) lack of formal definitions and policy, (ii) issues of data reliability, (iii) lack of funding and (iv) lack of specific knowledge and skills. In addition, GDOT would like to understand better the distinction between risk and resilience analysis to facilitate integration. Finally, and consistently, GDOT points to the lack of federal guidelines on scope and expectation as a significant obstacle to integration/implementation.

HIGHLIGHTS

1. GDOT recognizes that resilience management is an integral part of planning, design, and operation
2. GDOT implicitly incorporates resilience concepts and approaches into multiple transportation plans
3. A research project is underway together with Georgia Tech to define a formal path to incorporate resilience into planning activities

Resilience Assessment Data, Models, and Tools

As a part of the aforementioned research project, in collaboration with Georgia Tech, GDOT emphasized the value of developing GIS tools to manage/enhance resilience. It is anticipated that predictive quantitative tools will be developed by the project which will work in harmony with, for example, the Georgia statewide traffic demand model where vulnerability indices could be analyzed and explored, and a resilience matrix incorporated into need and purpose statements for projects. Once such tools are in place, GDOT has a vision for how these could be formally incorporated into the TIP & STIP to facilitate a prioritization process for projects. Data sources from the model include those from NOAA, National Weather Service, Dept. of Agriculture, and internal loss data.

Currently, GDOT uses software tools such as (i) Bridge Watch, (ii) Vasailia, RWIS, and (iii) WebEOC for visualizing/analyzing data to support risk and resilience assessment. Considering the economic cost to repair and the 'useful' cost of a particular highway segment was stressed as a driver for incorporating resilience strategies.

GDOT highlighted issues associated with (i) lack of data and (ii) too much data to sort through. Again, the importance of federal guidelines on how to incorporate data sources and which sources to collect and analyze was highlighted. While no formal process is in place, data associated with recovery is captured, e.g., cost of repair, which could be utilized in a formal framework. The importance of developing/providing tools that fit specific purposes, e.g., emergency response vs. planning considerations, was emphasized.

The need for education/communications in the functionality of planning functions/data platforms/proprietary tools between central and district offices, divisions, etc. was stressed.

GDOT performs risk and resilience assessments internally.

HIGHLIGHTS

1. Seeking to develop predictive quantitative tools to manage/enhance resilience and facilitate prioritization
2. The importance of federal guidelines on the use of fit-for-purpose tools was highlighted
3. Risk and resilience assessments internally performed

Resilience Performance Measures/Metrics

GDOT has not yet established formal resilience metrics/performance indicators.

GDOT foresees the development of a resilience matrix approach as a tool for planning and project prioritization and would consider such an implementation a huge success. GDOT is aware that consideration of resilience attributes should form a significant part of the transportation planning process.

HIGHLIGHTS

1. Developing a resilience matrix approach for planning and project prioritization
2. Consideration of resilience attributes should be given enhanced emphasis in planning

Maryland Department of Transportation

Agency/Organization	Maryland Department of Transportation, State Highway Administration (MDOT SHA)
Location	Maryland, United States
Contact Title/Dept.	Assistant Division Chief, Innovative Planning and Performance Division

Overview

As a result of championing efforts, the Maryland Department of Transportation, State Highway Administration (MDOT SHA) promotes awareness of resilience throughout the agency. MDOT SHA has exercised considerable effort to develop tools for assessing Maryland's vulnerability to flooding and sea-level rise. The results of this analysis support senior management in prioritizing projects and making investment decisions. MDOT SHA has incorporated resilience goals into their Long-Range Transportation Plan (LRTP), Statewide Transportation Improvement Program, and State Multimodal Transportation Plan (SMTP). Their TAMP includes resilience in project evaluation and evaluation and evaluation prioritization.

Resilience Policies, Definitions, and Frameworks

MDOT SHA's TAMP defines resilience as the "ability to withstand or overcome changes or challenges." MDOT SHA is committed to maintaining a resilient and adaptive transportation network to meet the community's needs. While MDOT SHA does not have a resiliency policy, the agency incorporates resilience principles into its TAMP. The agency cites federal drivers, such as MAP-21, as well as the economic benefits, maintaining mobility and operations, and adapting to climate change as reasons for adopting a resilience approach to asset management. For example, MDOT SHA implemented procedures to track, and document repeat flooding events for TAMP Part 667 analysis. The agency recognizes that provisions within the FAST Act necessitate conducting vulnerability assessments and incorporating the findings into project plans and designs. In addition, the passage of House Bill 514 in 2016 also requires annual reporting of the agency's progress toward resiliency. As an example of SHA putting these regulatory mandates into practice, the agency completed the Maryland Adaptation and Vulnerability Assessment in 2016 by examining the impacts of sea-level rise, storm surge, and extreme precipitation on Maryland's highway infrastructure. The agency believes its promotion of awareness and readiness is its greatest resiliency success. The remaining barriers to incorporating a resilience approach include a lack of formal definitions, policy, and a lack of knowledge and skill.

HIGHLIGHTS

1. Resilience principles incorporated into the TAMP
2. Funding available for projects that enhance resilience
3. Awareness of resiliency is promoted agency-wide

Integration Approaches for Resilience

MDOT SHA incorporates resilience into transportation planning by collecting and analyzing climate data to inform decision-making. MDOT SHA's Climate Risk and Resilience Program has analyzed climate risk

vulnerability for bridge and pavement assets statewide, developed an agency-wide methodology for determining asset criticality, and is a tool for visualizing climate data and analysis. In addition, MDOT SHA works with internal stakeholders, agency-wide, to identify strategies to improve resilience. The agency is decentralized into multiple divisions. All divisions are responsible for preparing asset management plans, identifying critical assets, and how to make those assets more resilient to climate change.

Other ways the agency integrates resilience include 1) criticality assessments that address post-event recovery plans and 2) staff from Planning, Operations, Design, and Maintenance that prepare a resilience strategy guide to identify data needs and how to use the data to promote resilience. Overall long-term plans' resilience goals are encapsulated in the 2040 LRTP.

HIGHLIGHTS

1. Individual departments are responsibly considering resilience
2. Criticality assessments address post-event recovery
3. Resilience goals included in LRTP

Resilience Assessment Data, Models, and Tools

To prepare for the emerging threats from climate change, MDOT developed a vulnerability index for pavement for four return periods (10-, 250, 50-, 100-, and 500-year) using flood depth grids, sea level rise data, and projected rainfall data for 2050 and 2100. In addition, MDOT SHA is looking to refine its data analysis and modeling around central elements of vulnerability assessments and expand its statewide threats, vulnerability, and consequences within a Risk and Resiliency for Highways framework. For starters, MDOT SHA conducted a Climate Risk and Resiliency Pilot Study on MD 450 (Defense Highway) in Anne Arundel County along U.S. 50. The pilot assessed and prioritized hydraulic asset treatments in the MD 450 corridor along with the state-owned roadway network and shared criticality information through the cloud-based MDOT SHA Climate Change Vulnerability Viewer.

The CCVV is an ArcGIS Online (AGOL) that enables the visualization of geospatial data products related to climate change and the potential impact on the State of Maryland's transportation infrastructure. MDOT SHA boasts a wide inventory of geospatial asset data, accessible through Maryland's open geodata portal. While the agency has a mature inventory of asset data, including life cycle cost data, replacement cost data, and asset conditions, the agency would like to enhance its threat data with statewide landslide maps and precipitation-related flood maps. The current threat inventory does include flood depth maps for hurricanes, sea-level rise, nuisance flooding, storm surge, and extreme high tide.

HIGHLIGHTS

1. Completed corridor risk assessment
2. Developed web map for sharing criticality and flood vulnerability data
3. Assessed bridges with VAST

Resilience Performance Measures/Metrics

At present, MDOT SHA has not developed resilience metrics or completed resilience assessments per se but has developed risk assessment metrics. For example, as part of its Climate Adaptation Vulnerability Study, MDOT SHA developed the Hazard Vulnerability Index (HVI) to evaluate sea-level rise and the

vulnerability of roads to flooding. The HVI is a composite of criticality (road functional class and evacuation route designation) and vulnerability based on projected flood depth. The Vulnerability Study used U.S. DOT's VAST to quantify bridge vulnerability to climate stressors. In addition, the agency conducts economic analysis to assess alternatives for project design.

HIGHLIGHTS

1. No metrics yet established specifically to resilience.
2. Hazard Vulnerability Index is a composite of criticality and flood vulnerability
3. Assessed bridges with VAST

Minnesota Department of Transportation

Agency/Organization	Minnesota Department of Transportation (MnDOT)
Location	Minnesota, United States
Contact Title/Dept.	Asset Management Planning Director, Statewide Planning Manager, Project Manager, Office of Sustainability and Public Health

Overview

"Minnesota is a land of extremes, a key multimodal state heavily impacted by climate, with a strong history of looking at risk and incorporating resilience at all levels."

The Minnesota Department of Transportation (MnDOT) incorporates resilience approaches into transportation planning through goals, objectives, monitoring, reporting, and risk and vulnerability assessments. While resilience is incorporated throughout, consideration is project-specific, and application looks different for each planning effort. Therefore, resilience planning at MnDOT is a developing process intended to be "broader than climate consideration only" but comprehensive of all potential resilience concepts.

Resilience Policies, Definitions, and Frameworks

MnDOT incorporates resilience into all plans, with varying levels of detail for each project. Some plans are more detail-oriented, while others have integrated resilience throughout the plan. Eventually, plans will be fully integrated when it is time to update them. There are varying robust approaches depending on the policy or implementation level.

Due to Minnesota being a land of temperature extremes and a key multimodal state, they need to incorporate resilience into transportation plans. Therefore, threats that stress the system are amplified and highlighted as relevant issues. State requirements for resilience were included before MAP21 and still stand to be a high priority for the MnDOT. As a result, resilience is actively and effectively incorporated into the planning process, intending to improve the implementation and maintenance process. The uncertainty in the data and data projections make implementation difficult, but MnDOT sees a path forward and opportunities to grow and improve the integration process.

While there is no established resilience policy, MnDOT has a statewide multimodal plan that integrates resilience and incorporates resilience in standard practices to increase the overall resilience. Therefore, having an outline for the design process could be of value, making integration a more comfortable process. Still, MnDOT is unsure if it would be worth the effort and solve any barriers they experience.

MnDOT has successfully created a growing community of practice from their agency's incorporation of resilience approaches into planning. This effort has been helpful in further research and securing funding for vulnerability assessments. However, there are still barriers to the agency when incorporating resilience, including uncertainty beyond levels their design engineers are comfortable working with,

resourcing, competing priorities, lack of support for funding and investments, confusion about how resilience is defined, and how to measure resilience.

To mitigate the impact of these barriers and further understand and improve the incorporation of resilience concepts, MnDOT has a system resilience definition for resilience. However, until the full concept of resilience is understood, "a definition won't be the answer."

HIGHLIGHTS

1. Incorporates resilience into all plans with varying levels of effort
2. Legislative and policy support, with a growing community of practice
3. Definition for system resilience is in place, but more is needed to understand the full concept

Integration for Approaches for Resilience

MnDOT incorporates Statewide Multimodal Transportation Plan (SMTP), TAMP, Freight Plans (statewide and district), Statewide Pedestrian Plan, Statewide Aviation Plan, Statewide Port Plan, Statewide Transit Plan, Emergency Response Plans (ERPs), and State Highway Investment Plan (MnSHIP) into their agency's goals and objectives for transportation planning. They identify and understand which hazards and vulnerabilities threaten their systems through TAMP, Freight Plans, Statewide Pedestrian Plan, Statewide Aviation Plan, Statewide Port Plan, ERPs, and MnSHIP.

Performance measures and targets to estimate system resilience are established and used in MnDOT's TAMP, Freight Plans, Statewide Pedestrian Plan, and Statewide Aviation Plan. They also have a process for identification of resilience improvement strategies through their SMTP, TAMP, Statewide Pedestrian Plan, Statewide Aviation Plan, and Statewide Port Plan.

Strategies and processes to implement selected strategies for resilience improvement have been developed for TAMP, Statewide Pedestrian Plan, and Statewide Port Plan. Also, MnDOT has developed strategies or uses tools to monitor and report the performance of resilience efforts in their TAMP, Freight Plans, and Statewide Aviation Plan.

MnDOT utilizes an Enterprise Risk Management Steering Committee to identify threats that might affect their transportation systems. They look at key risks that might impact the entire transportation system and put together climate risks and annual reviews on how to mitigate them over the next few years. MnDOT is also trying to identify climate risks through a new GIS algorithm that would run statewide and give a better idea of what areas are vulnerable and at risk.

MnDOT has a resiliency advisory team comprised of 8 coordinating offices that meet every other month. They also participate in an interagency climate adaptation team with over 20 different agencies every month, allowing them to share resilience strategies or data beyond their walls.

As of right now, there is no separate funding for implementing resilience. As part of MnDOT's 20-year Highway Investment Plan, they are discussing creating resilience funding, but it is still in discussion. Resilience is part of the investment strategy when developing mid-range plans and is funded in that way.

HIGHLIGHTS

1. Integration of resilience through all transportation plans
2. Committee in place to identify and propose mitigation strategies for possible threats
3. No separate funding but in discussion

Resilience Assessment Data, Models, and Tools

MnDOT utilizes various data sets and tools to support resilience-based practices, including asset life cycle cost, asset condition, and asset deterioration curves/models. These are used on varying levels based on the specific asset. Better data on previous extreme events would be beneficial to MnDOT and a way to flush out robust data sets to measure resilience and track the frequency of damages and closures.

MnDOT performs risk and resilience assessments, used interchangeably, at different planning levels. For example, MnDOT tracks the inventory and condition of assets with ArcGIS and Excel to create a risk matrix; however, districts are in charge of selected projects after planning. In addition, an informal process is used to make tradeoffs between assets.

HIGHLIGHTS

1. Asset life cycle cost, asset condition, and asset deterioration curves/models are successfully used
2. Risk and resilience assessments are mostly informal but developed and utilized

Resilience Performance Measures/Metrics

MnDOT does not have any official resilience metrics but several metrics that indirectly relate to resilience (e.g., culvert inspections and conditions). There are some targeted measures taken but nothing full-scale. They want to learn more about two areas: (1) an investment in infrastructure that increases resilience and (2) tracking asset climate vulnerability through the GIS algorithm they are creating. MnDOT focuses on incorporating resilience into the metrics already in place instead of creating new ones.

HIGHLIGHTS

1. Active consideration of resilience in performance measures development
2. Metric development focuses on resilience integration into existing metrics

Oregon Department of Transportation

Agency/Organization	Oregon Department of Transportation (ODOT)	
Location	Oregon, United States	
Contact Title/Dept.	Climate Office Policy Lead and Statewide Transportation Planning Unit Manager	

Overview

Resilience is included in the overall sustainability goal of the Oregon Transportation Plan, forming the foundation for the Oregon Department of Transportation's (ODOT) resilience priorities and informal funding through the Transportation Improvement Programs (TIP/STIP). ODOT's Climate Office is currently leading a statewide climate risk assessment and adaptation plan outlining resilience priorities and actions. Oregon's key takeaway is, "Planning for multiple crises is important, and organizationally, the goal is figuring out how we respond and plan together."

Resilience Policies, Definitions, and Frameworks

At ODOT, resilience is incorporated through the Oregon Transportation Plan sustainability goal. The ODOT Climate Office has led climate change vulnerability assessments to inform planning, research, and project priorities. This has also led to several funding efforts focused on resilience. This effort by ODOT is effective in some areas and not as much in others.

Good things are happening, but for some projects, there needs to be improvement. While no official resilience policy was established at ODOT, their Lifeline Routes policy in the Oregon Highway Plan has been foundational to the agency's resilience planning for various hazards. Sometimes resources can be limited, and investments must be prioritized. Having the policy to follow would help make tradeoffs and pinpoint which things need help.

While the Oregon Highway Plan does not officially define resilience, ODOT has a working definition as part of its statewide climate change risk assessment and adaptation plan. It is defined as "The capacity of a system to prevent, withstand, respond to, and recover from a disruption," and was created from previous statewide risk assessments. Having a national standard for resilience would be helpful to ODOT as there is sometimes pushback in considering resilience, so a federal standard would assist in justifying that discussion.

HIGHLIGHTS

1. No formal policy, but positive progress
2. Resilience definition developed from past assessments
3. Improved funding and national structure around resilience consideration would be beneficial

Integration Approaches for Resilience

At ODOT, resilience is incorporated through the TIP/STIP) and TAMPSs. There is no formal guideline, but the Climate Office plan will outline resilience priorities and actions across the five regions for

implementation when complete. While not insurmountable obstacles, some barriers to implementation are seen in the need to update statewide plans sooner rather than later. ODOT utilizes emergency operation plans during or after an event to improve system continuity and recovery but recognizes there is more needed, like a long-term policy, as an agency to move forward.

ODOT shares resilience strategies externally through an inter-agency coalition led by the Department of Land Conservation and Development. The coalition is made up of 15 agencies from different sectors. It is effective since each agency varies in its management but comes together to combat disasters that impact them all. Internally, ODOT collaborates with the state and local districts to communicate and share relevant and helpful information. Incorporating resilience approaches into planning helps ODOT set policy goals and priorities and lay the foundation for funding requests and the study of critical areas.

ODOT does not allocate a separate budget to incorporate resilience into planning; instead, resilience is included in the project planning process. While there have been discussions to create a separate budget, it is ultimately money from the same source and might not be worth the effort. Therefore, ODOT is currently focused on incorporating resilience with what is available.

HIGHLIGHTS

1. No formal guidelines but implementation plans assist in helping to incorporate
2. Resources shared internally and externally
3. Resilience is considered in project planning, but no separate funding

Resilience Assessment Data, Models, and Tools

Now ODOT utilizes datasets and tools to support resiliency-based practices such as the geographic location of assets, asset replacement cost/value, and asset condition, with a few others currently under development. For example, a tool that looks at cost-benefit to help justify investments could be beneficial to resilience consideration at ODOT. Additionally, ODOT sees a lack of tools and models for assessing resilience as a barrier to incorporating resilience.

ODOT conducts climate assessments using climate data to screen for hazards and mapping tools to share with planning and project teams. They also internally perform risk assessments by creating a risk register and conducting resilience assessments to enhance their system's resilience. One barrier ODOT cites in incorporating resilience approaches is data reliability. In addition, as presently defined, resilience is a broad and complicated topic, so transportation agencies need more clarification to implement resilience strategies successfully.

HIGHLIGHTS

1. Cost-Benefit tool for resilience consideration justification would be beneficial
2. Complicated coordination and lack of formal definition understanding restricted effectiveness

Resilience Performance Measures/Metrics

By having no resilience targets that have been established, ODOT is moving in that direction with a focus on statewide assessment and understanding where they have vulnerable areas.

ODOT currently does not have any resilience-based performance measures developed. This is being discussed as a dashboard concept, but it is challenging to decide what to report and if it is an efficient use of resources. ODOT also does not have a method to communicate resilience results internally and with

stakeholders, other agencies, or the public. A lot is being done to update the commission, though, to connect the leadership and commission with what is currently being done.

Highlights

1. No formal guidelines but implementation plans assist in helping to incorporate
2. Resources shared internally and externally
3. Resilience is considered in project planning, but no separate funding

APPENDIX E – DEEP DIVES CASE STUDIES

DEEP DIVE CASE STUDY SUMMARY

Arizona Department of Transportation

Introduction

This document summarizes the deep-dive interview conducted with the Arizona Department of Transportation (ADOT) in support of Task 3 of NCHRP Project 08-129. An extended phone interview was held with Senior Program Manager on Thursday, May 27, 2021. Follow-up emails were exchanged to obtain further information. The topics discussed included the incorporation of Resilience approaches into Plans and Programs, Policies and Concepts, Leadership, and Institutional Capacity, Internal and External Collaboration, Resource Availability, Risk and Resilience Assessment (RnR), Identification of Resilience Improvement Strategies, Professional Training and Development, and Public Outreach/Communications, all of which are discussed in the following sections.

ADOT's vision is to "Moving Arizona to become the most reliable transportation system in the Nation."[1] ADOT is responsible for the construction, operation, management, and maintenance of the State Highway System, which comprises more than 21,000 lane miles and over 5,000 bridges, with a historical cost of more than $22 billion.[2] Transportation planning is delivered under the offices of the Deputy Director, with services delivered by the organizational structure as illustrated in Figure 51.

The main strategic areas of focus related to planning include (i) the development of the State Transportation Improvement Plan (STIP) and, as a subset, the ADOT 5-year construction plan, (ii) the Long-Range Transportation Plan (LRTP), (iii) working with representatives of individual tribes, MPOs and Council of Governments (COGs), (iv) Performance and (v) Asset Management.

Key Findings

- Resilience program is established and in use.
- A formal definition for resilience has been established and communicated.
- Resilience definition is effective in ADOT planning efforts and interagency coordination.
- The management of the roadway system has now evolved from a decentralized, project-based focus to one that encompasses enterprise-wide endeavors: administration, asset management, technology adoption, planning, design, construction, operations, and maintenance.
- ADOT considers that long-range planning, planning outreach and program development provide a natural foundation for applying/integrating resilience approaches.
- ADOT has developed and is developing tools for resilience quantification.
- ADOT has formally incorporated resilience into several major efforts.

[1] ADOT, "Inside CDOT," [Online]. Available: https://azdot.gov/about/inside-adot. [Accessed 7th June 2021].
[2] ADOT, "Transportation Asset Management Plan" Arizona Department of Transportation, June 2019

- ADOT recommends a 'bottom-up' approach to integrate resilience into planning.
- ADOT uses resilience tools to screen and prioritize activities from a planning perspective

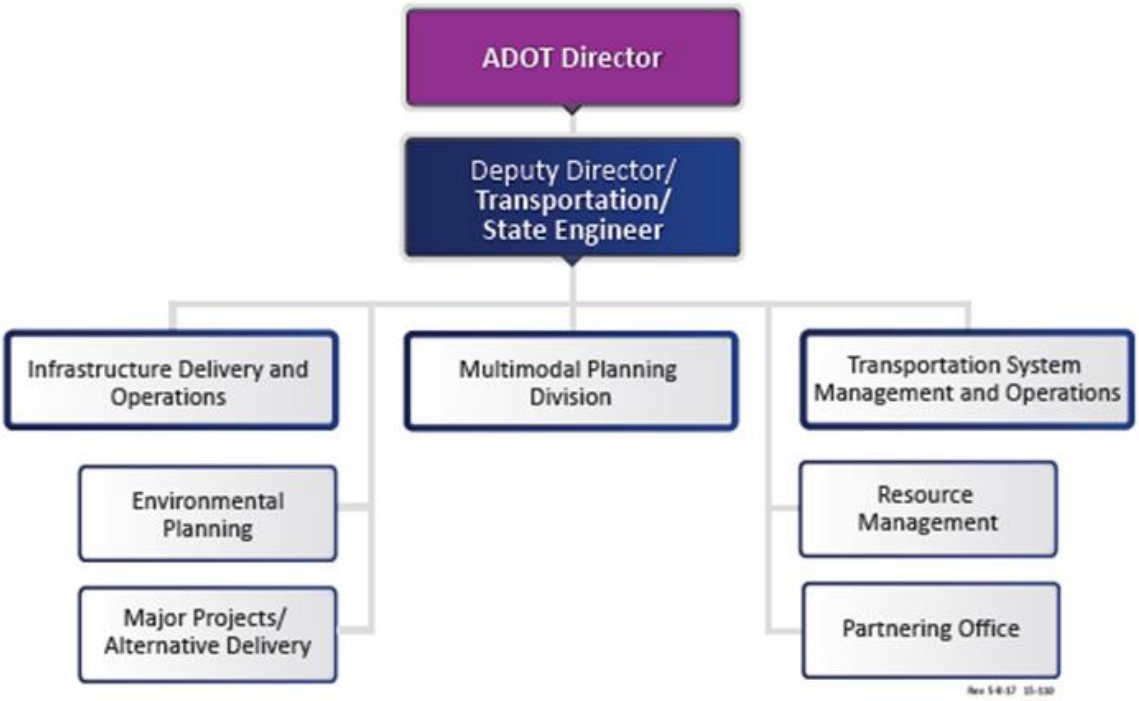


Figure 51. ADOT Organizational Chart

ADOT seeks to combine risk, science, technology, and engineering to improve the understanding of risks to its transportation system and accomplish its mission, "Connecting Arizona. Everyone. Every Day. Everywhere."[3] A programmatic approach has been developed to address weather and natural hazards issues through a formal Resilience Program. The scope and goals of the program encompass risk-based asset management and life cycle planning approaches. In March 2020, ADOT published the results of its Asset Management, Extreme Weather, and Proxy Indicators Pilot Project.[4] The program identifies those stressors which pose the greatest threat to ADOT's transportation system, considering:

- Intense Precipitation
- System Flooding
- Wildfires
- Wildfire-Induced Floods
- Drought-related Dust Storms
- Rockfall Incidents
- Slope Failures

[3] https://azdot.gov/business/environmental-planning/programs/sustainable-transportation/resilience-program [Accessed 8th June 2021]

[4] ADOT, "Asset Management, Extreme Weather and Proxy Indicators Pilot Project" Arizona Department of Transportation, March 2020. https://azdot.gov/sites/default/files/media/2020/03/ADOT-Asset-Management-Infrastructure-Resilience-Study-Report%20Final-2020.pdf [Accessed June 14, 2021].

- Increased Surface Temperatures

The outlined approach targeted extreme weather and climate stressors and prioritized asset classes susceptible to the considered stressors. It used GIS to advance how scientific evidence-driven decision-making informs transportation systems management and integrates with asset management processes. The project aimed to demonstrate how lifecycle planning plays a crucial role in improving resilience to extreme weather and natural hazard events by providing tools to link stressors, natural hazards, extreme weather, and measurable long-term climate-related risks to their impacts on transportation infrastructure in Figure 52. The developed methods are appropriate to serve ADOT in "identifying mitigation/adaptation options throughout the different stages of an asset life cycle, including planning, design/engineering, construction, maintenance, and operations. The purpose of the methods is to integrate information regarding current measures being used within ADOT and identify innovative ideas to mitigate risk through lifecycle planning."

Figure 52. Lifecycle Planning Template Process to Link Extreme Weather Climate Adaptation, Asset Management, and Infrastructure Resilience[5]

5 ADOT, "Asset Management, Extreme Weather and Proxy Indicators Pilot Project" Arizona Department of Transportation, March 2020. https://azdot.gov/sites/default/files/media/2020/03/ADOT-Asset-Management-Infrastructure-Resilience-Study-Report%20Final-2020.pdf [Accessed June 14, 2021]

Plans and Programs

ADOT incorporates resiliency concepts and approaches into its multi-modal, Long-Range Transportation Plan (LRTP), Statewide Transportation Improvement Program (STIP), Transportation Improvement Programs (TIPs), TAMPs, and its 5-year $1.1 billion construction program.

The LRTP represents the 30,000-foot view and the entry point for resilience-related to introducing the topic. It juxtaposes to approximately $100 billion in need in Arizona with circa $30 billion in revenue over 30 years (2021 dollars). It represents an opportunity to craft what resilience means and introduce it to the planning partners internally and externally. An example is via interaction on the regional transportation plans developed by the two largest planning partners, the Maricopa Association of Governments (MAG) and the Pima Association of Governments (PAG) out of Phoenix and Tucson, respectively.

By contrast, the STIP focus is on what can reasonably be afforded. Collaboration with local partners is vital as they bring to the table resilience-related issues associated with, for example, flooding and wildfires. In this regard, it is noted that:

'All highway and transit projects in the State, funded under Title 23 and the Federal Transit Act, must be included in a federally approved STIP. Projects in the STIP must be consistent with the statewide Long-Range Transportation Plan and Metropolitan Transportation Improvement Programs (TIPs). The program must reflect expected funding and priorities for programming, including transportation enhancements. Additionally, the Clean Air Act Amendments (CAAA) require MPOs within nonattainment areas to perform conformity determinations before the approval of their Regional Transportation Plans (RTPs) and Tips. [6]

The 5-year construction program provides for goals already being implemented in terms of project-based resilience assessment. It contains not just the federally funded efforts but also the regional plans (RTPs). In addition, it has a public outreach component. ADOT's Planning to Programming (P2P) Guidebook[7] connects the LRTP to the 5-Year Construction Program through performance, as required by Arizona Revised Statutes (ARS) Title 28, Chapter 2, Article 7 (§ 28-501 through § 28-507), 23 USC Section 135(d)(2), and 49 USC Section 5304(d)(2).[8]

P2P Guidebook

The P2P Guidebook is the key planning entry point for resilience at ADOT. Indeed, Section 2.0 Project Identification states, "Each May, the P2P Manager requests any new planning study recommendations from ADOT Planning staff, COGs, and MPOs, as well as any District project nominations."[9] Table 32, reproduced from Table 1, *ADOT Planning to Programming Scoring Guidebook*, highlights resilience entry points from a strategic planning step and as a 'supplement and addition' to Section 4.0 Technical Score Criteria.[10]

Table 32. ADOT Technical Groups[11]

[6] https://azdot.gov/planning/transportation-programming/state-transportation-improvement-program-stip. [Accessed June 7, 2021]
[7] https://azdot.gov/sites/default/files/media/2020/09/FY20_P2P_Guidebook.pdf [Accessed June 10, 2021]
[8] https://www.azleg.gov/arsDetail/?title=28 [Accessed June 10, 2021]
[9] https://azdot.gov/sites/default/files/media/2020/09/FY20_P2P_Guidebook.pdf [Accessed June 10, 2021]
[10] ibid
[11] ibid

Technical Group	Division
ADA / Civil Rights	Infrastructure Delivery & Operations (IDO)
Bridge	IDO
Geohazard / Rockfall	IDO
Railroad Coordination	IDO
Rest Area	IDO
Roadway	IDO
Stormwater & Erosion Control	IDO
Winter Operations Support	IDO
Pavement Management	Transportation Systems Management & Operations (TSMO)
Safety / Technology / TSMO	TSMO
Port of Entry	Enforcement & Compliance (ECD)

Another area flagged as a resilience planning entry point in the P2P Guidebook context relates to Section 7.0 District Score.[12] The heavy weighting of this factor, in addition to the workshop component, was considered an 'additional point of resilience reinforcement.' It was considered that 'it could be utilized as an additional resilience project prioritization trigger because the final decision on what project to pursue comes with visiting the sites and getting on the ground District input from the folks that know that specific location and the weather and natural hazard issue.'

By 2023, it is anticipated that the annual plan will be thoroughly screened for resilience in terms of the additional year adding to the 5-year program, with comprehensive coverage throughout planning documents expected by 2024. However, this will require partnership and collaboration with the regional planning entities. By developing such a process, it will be possible to identify and prioritize projects where resilience-building is desirable early in the planning/preliminary engineering process. The result is that optimal early interventions can be placed in a root cause analysis and implemented more efficiently than later in the process. Effects can also enhance benefits which can be quantified in a life cycle analysis from an asset management perspective.

The key is identifying and understanding the nuances between planning, programming, and where preliminary engineering fits to capitalize on possible benefits before initiating the initial design. By

[12] ibid

screening, from a resilience perspective, the possibility exists all at once to extract as much benefit as possible.

In the initial stages of developing resilience policies and practices, the focus was to interact with activities addressing weather-based natural hazard risks. The point of entry was at the project level as opposed to the planning level. From these activities, a toolbox was developed in a bottom-up approach, which facilitated screening at the planning level from an asset class perspective, e.g., drainage structures, roadways, bridges, etc. As a result, ADOT has become skilled in looking at a program from an asset class approach.

Based on their experience, ADOT would see the bottom-up approach, i.e., initial entry at the project level, with a focus on pilot studies considering asset classes, etc., as optimal in developing the competencies necessary to consider resilience assessment/incorporation at the planning level. It is simply regarded as infeasible to develop these competencies and critical mass from a top-down approach simply due to the inertia of the planning process. Project level up provided the best route to success for ADOT as actionable resilience planning, assessment, and integration steps can occur daily, weekly, or monthly. However, ADOT recognizes that a mature resilience program is not fully validated without integration throughout planning and administration. Therefore, it is essential to note that scale cannot be achieved without other avenues also pressing the overall resilience planning and program need. Consequently, it was concluded that whether working bottom-up or top-down is preferable to have concurrent activities going on, i.e., if going top-down has some contemporary bottom-up activities going on and vice versa.

Barriers to Incorporating Resilience

The main barriers which ADOT faced/faces in incorporating resilience into transportation planning relate to (i) a lack of a specific place for it to reside, i.e., in administration, planning, operations, or design engineering/project development, (ii) a lack of funding, (iii) a lack of staff, and (iv) a lack of metrics. Concerning funding, it is noted that the complexity associated with defining the case for funding resilience is difficult outside of the areas related to emergency-response funding. While top-level funding is made available at a congressional level for resilience funding/building efforts, it is often outside of areas related to design engineering activities. However, some recent positive moves have been made to address this apparent historical imbalance from a planning and design engineering perspective.

Concerning metrics, ADOT is currently focused on developing appropriate resilience metrics for agency-wide activities together with the Texas Transportation Institute Center for Advancing Research in Transportation Emissions, Energy, and Health (CARTEEH). CARTEEH is a Tier-1 center, funded by the U.S. Department of Transportation's Office of the Secretary for Research and Technology (OST-R), under the University Transportation Centers (UTC) program. Examples include resilience return on investment, resilience cost-benefit analysis, number of resilience activities conducted, total lane mile assessed for resilience, number of structures assessed for resilience, etc. These were expected to be finalized by the end of 2021 with significant benefits from a planning perspective to define/quantify agency-focused resilience activities.

Policy & Concept

ADOT defines resilience as found in FHWA Order 5520 – "anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions."[13]

ADOT's resilience program details may be accessed via the program's dedicated website [3]. At a Resilience Program level, it is focused on the management of assets (e.g., bridges, culverts, pavements, and roadside vegetation/stabilization) concerning the extreme weather-climate risk of intense precipitation, system flooding, wildfires, wildfire-induced floods, drought-related dust storms, rockfall incidents, slope failures, and measurable climate trends (especially as it relates to precipitation and direct effects of increased surface temperatures) by regions or specific segments emphasized as critical to contribute to the safety of the traveling public, improve weather and natural hazard risk management, and improve the long term life cycle planning of transportation infrastructure.

ADOT considers that "incorporating natural hazard, weather-related considerations, and resilience into how agencies plan and execute their Transportation System Management and Operations (TSMO) and maintenance programs helps the agency become more resilient to unanticipated shocks to the system. Adjustments to TSMO and maintenance programs - ranging from minor to major changes - can help minimize the current and future risks to TSMO and maintenance, and most importantly, safety to the traveling public."[14]

Policy implementation represents the 'holy grail.' ADOT planned to work with Government relations groups comprehensively in 2021 to provide education on activities in resilience capacity building from a state legislative approach, but this will need a high-level champion. Often support is developed as opposed to the policy. For example, Arizona has no state resilience policy but rather a resilience definition and an "implementation of the TAMP."

Leadership and Institutional Capacity

In some regards, barriers within ADOT to implementation have arisen by underestimating the appetite to adopt resilience across the agency and underestimating the willingness for individual practitioners to help. There have been no leadership barriers. Indeed, champions for adoption exist across the agency, for example, with the state engineers' office eagerly awaiting the 2021/22 resilience plan. Funding has been made available, for example, in upgrading the frame of an agency-level business case approach. There has been a willingness to champion and adopt new/advanced approaches where applicable, e.g., the case was made with leadership and approved by leadership for building asset class probabilistic risk-based methodologies. Overall, from the perspective of Leadership and Institutional Capacity, there have been no barriers, whereby the agency recognized at an early stage from agency-level planning through project development that better identifying, understanding, mitigating weather and natural hazard risks, and enhancing resilience were in their best interest in achieving the ADOT vision.

[13] https://www.fhwa.dot.gov/legsregs/directives/orders/5520.cfm [Accessed June 16, 2021]
[14] https://azdot.gov/business/environmental-planning/programs/sustainable-transportation/resilience-program/resilience [Accessed June 16, 2021]

Collaboration

ADOT communicates resilience approaches to develop consensus with both internal and external entities. The challenge in this regard is crafting a messaging structure that applies to a broad range of participants.

- Internally
- Specific internal collaborations facilitate the process, including the Asset Management Working Group. Resilience-based activities are built into the asset management plan. The group "supports the implementation of the TAMP, including developing performance measures and state targets to be reviewed for approval by the steering committee; identifying and prioritizing risks to ADOT's transportation infrastructure; recommending changes to policies, procedures, and processes to improve transportation asset management at ADOT; ensuring together to accomplish the development and maintenance." Detailing the breadth of participation is the membership of the group, listed here[15]: Transportation Asset Management, Facilitator
- FHWA Arizona -Division Representative
- Assistant Director for Transportation Systems Management and Operations Division
- Assistant Director for Infrastructure Delivery and Operations Division
- Deputy State Engineer – Operations
- Deputy State Engineer – Design
- Federal Aid Administrator – Financial Management Services
- Chief Economist – Financial Management

Consensus building before initiation of the working group is a vital activity, so the participants are well versed in the arguments and ready/willing to participate in discussions around and promote resilience-related activities.

Participation includes the Deputy Senior State Engineer and group level and director level participation from planning, asset management, TSMO, etc. TSMO participation has facilitated the development of tools and protocols, e.g., incorporating resilience into district-level emergency operations plans.

Furthermore, the breadth of services offered by different DOTs was discussed. For example, ADOT has an aeronautics group; as a result, ADOT manages airports for the State and is the federal funding portal for 175 municipal airports in the State. The Director and Deputy Director of Aeronautics are starting this year on resilience activities purely as a planning activity in terms of funding authorization activities.

Systems Operation should also be considered a part of the discussion and a possible champion for resilience-based activities. Accordingly, ADOT is looking to focus on growing resilience-based planning activities from a systems operation perspective.

[15] ADOT. (2021). Arizona DOT Transportation Asset Management Plan, Phoenix, AZ. Accessed July 7, 2022, from, https://azdot.gov/sites/default/files/2019/08/Transportation-Asset-Management-Plan.pdf

- Externally

ADOT interacts with the external organization in the context of resilience-related activities, such as MPOs and Councils of Government (COG). This also includes bringing resilience to the State's counties and regional flood control entities, especially through large-area drainage planning studies. Furthermore, ADOT plays an active role in collaborating with AASHTO, FHWA, and TRB. At a national level, ADOT led one of six pilot projects focused on "evaluating the linkage between asset management, LCP, risk, extreme weather, and measurable climate trends."[16] This project, built upon the ADOT Extreme Weather Vulnerability Assessment, assessed the vulnerability of transportation infrastructure to extreme weather and climate trends specific to Arizona.[17] ADOT developed a "multi-stakeholder decision-making framework – including planning, asset management, design, construction, maintenance, and operations – to cost-effectively enhance the resilience of Arizona's transportation system to extreme weather and climate risks."[18]

Resource Availability

Recent scans of state DOTs and MPOs have revealed common challenges to incorporating resilience into planning, including a lack of tools and resources. ADOT has expressed a similar need for increasing some of these resources.

- Data

From a resilience perspective, ADOT has found the central warehousing of data to be a 'game changer' in the use of data and management. A resource compendium has been established by ADOT via a resilience GIS database using ArcGIS. This way, base layer mapping in the agency was combined with traffic data and incident data in addition to the ADOT climate modeling mapping needs information, USGS, NOAA, National Weather Service, Forest Service, Dept. of Interior, etc. The platform developed applies to project development and consideration/analysis of over 30,000 lane miles in the system from a planning standpoint of 'areas of interest.' To minimize uncertainty from a planning perspective, it is essential that such data sets are regularly monitored, updated, and validated. ADOT considers the TAMP, with its requirement for regular updating, to be an excellent facilitator in this regard.

ADOT is passionate about the 'elephant in the room' to better address life cycle planning and long-term management of available resources in considering/tackling climate change effects, which is data! Data and human resources must be made available to facilitate, for example, interactions between planners, academia, resource agencies, and state climatologists to develop climate-based data inventory for use in planning and design. But how can this best be done? It will require the necessary people/resources to do this.

ADOT has just started its 3rd climate data effort with North Carolina State University; however, data storage/management facilities are proving an issue. ADOT does not have computer resources to work with the types of data sets produced. ADOT did 2015 and 2018 studies on collecting and using climate

[16] ADOT, "Asset Management, Extreme Weather and Proxy Indicators Pilot Project" Arizona Department of Transportation, March 2020. https://azdot.gov/sites/default/files/media/2020/03/ADOT-Asset-Management-Infrastructure-Resilience-Study-Report%20Final-2020.pdf [Accessed June 14, 2021]
[17] ADOT, "Extreme Weather Vulnerability Assessment" January 2015. https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/2013-2015_pilots/arizona/arizonafinal.pdf [Accessed June 13, 2021]
[18] ibid

data. All data was mapped in GIS, i.e., two time series from 19 different climate models were mapped in GIS.

One possible solution discussed is subdividing the country into manageable parts with similar climatic conditions. For example, ADOT already interacts with 6 states on advancing hydrology and hydraulic engineering, partnering with FHWA and USGS.

- Funding

ADOT considers that funding is easier to secure for resilience assessment at the project level. It is not as easy to define how the Federal Aid program can assist in planning. However, a part of the regional transportation planning budget mechanism can be assigned to facilitate resilience assessment from the Federal Aid program. A key issue is who has control over different developments and who has control over funding associated with those developments.

Risk and Resilience Assessment (RnR)

ADOT follows the risk framework in the FHWA document entitled, 'Incorporating Risk Management into TAMPs.[19] It details the consideration of risk and risk management provided in the TAMP.[20] The applied framework includes five components namely (i) Establish Context, (ii) Risk Identification, (iii) Risk Analysis, (iv) Risk Evaluation, and (v) Manage Risks. Risk types considered include Agency, Financial, Program, Asset, Project, and Activity. Risk registers are maintained whereby the likelihood and impact of various risks are assessed and ranked. While the TAMP focuses on bridges and pavements, the risk analysis considered other families of assets on the National Highway System and State Highway System. In total, 27 risks were identified in the TAMP, of which 16 are very high in priority. The TAMP proposes mitigation actions for high-priority risks, including those due to extreme weather.

Furthermore, 6 of 27 risk register items are resilience-based and are connected to/correlated with 6 others. So, a significant portion of the risk register has some resilience as a contributing factor. Overall, resilience fits comfortably within the risk-based approach. ADOT prepared a Preliminary Study of Climate Adaptation for the Statewide Transportation System in Arizona in 2013[21] and an Extreme Weather Vulnerability Assessment in 2015. [22]

Currently, quantitative probabilistic approaches to resilience quantification are under development by ADOT. They offer considerable promise for rational consideration of the effects of planning and design strategies and decisions. Fragility curves represent the system functionality over time.[23] Functionality curves describe system performance before, during, and after a hazardous event. ADOT's probabilistic

[19] FHWA, 'Incorporating Risk Management Into Transportation Asset Management Plans', https://www.fhwa.dot.gov/asset/pubs/incorporating_rm.pdf [Accessed June 12, 2021]
[20] ADOT, "Transportation Asset Management Plan" Arizona Department of Transportation, June 2019
[21] ADOT, " Preliminary Study of Climate Adaptation for the Statewide Transportation System in Arizona", March 2013. https://apps.azdot.gov/files/ADOTLibrary/publications/project_reports/pdf/az696.pdf [Accessed June 15, 2021]
[22] ADOT, "Extreme Weather Vulnerability Assessment" January 2015. https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/2013-2015_pilots/arizona/arizonafinal.pdf [Accessed June 13, 2021]
[23] Solomos, G. and Caverzan, A. (2014) Review on resilience in literature and standards for critical built-infrastructure. doi: 10.2788/872668.

framework shows promise in facilitating quantification of impact from planning and design decisions and strategies on the resilience of infrastructural elements or networks.

Currently, ADOT is conducting studies to assess planning and design options from a resilience enhancement perspective, such as the State Route 80 San Pedro River Bridge and the Interstate 10 Gila River Crossing, Figure 53.[24]

Figure 53. San Pedro Bridge over the Gila River, SR 80, Arizona

Challenges to incorporating qualitative and quantitative methods related to the funding and building a programming level argument for what should be risk unit activity and who should perform risk and recovery activities within the state agency.

The main successes of having methodologies to incorporate RnR approaches include (i) having the ability to speak at the asset class level (which is a more comfortable planning level conversation) and (ii) for planners to make decisions on how funding should be spent, i.e., on what activity e.g., future growth or preservation.

ADOT has protocols and procedures in place to monitor and track the impact of measures taken at a project level to enhance resilience. This includes monitoring instances where a risk-informed decision was taken not to incorporate resilience enhancement measures. ADOT stressed the importance of incorporating appropriate ongoing monitoring into developed frameworks to assess the efficacy of measures taken to enhance resilience.

- Criticality and Hazard Assessment

The purpose of ADOT's Asset Management Extreme Weather and Proxy Indicators Pilot Project, published in March 2020 [4], was to '(i) develop lifecycle planning methods that consider the effects of natural hazards and extreme weather conditions on transportation assets, (ii) establish analytical procedures that provide a risk-based approach for identifying assets and locations with a high likelihood of being impacted, (iii) develop a flexible, scalable, risk-based GIS-based resilience database and real-time information dashboard that links transportation asset management, natural hazard and weather, climate impacts, and ADOT infrastructure resilience efforts, and (iv) identify actions to improve overall

[24] https://i10bridgeproject.com [Accessed June 16, 2021]

infrastructure resilience linkages, especially for the most vulnerable assets or classes of assets eligible for FHWA TAMP reporting.' The pilot integrated extensive internal and external sources of data to identify and synthesize risks and hazards in the ADOT system. The approach adopted in the pilot is illustrated in Figure 54.

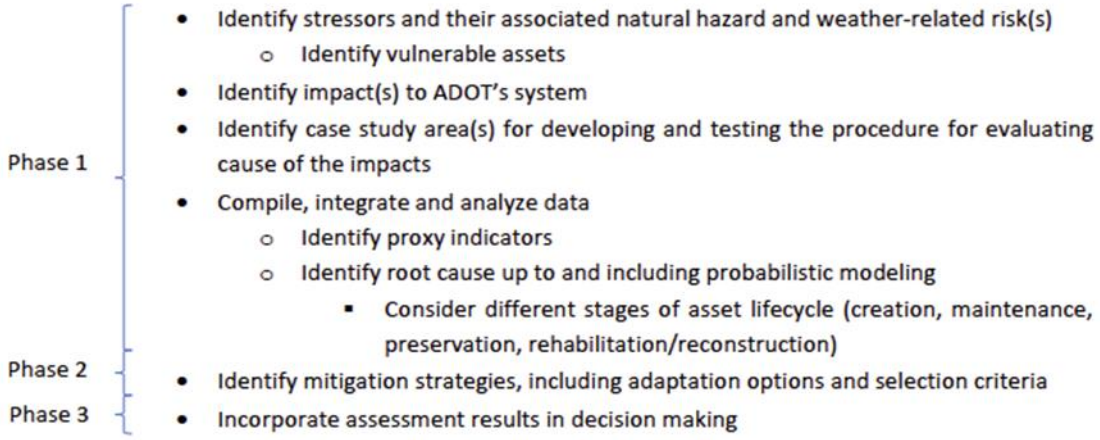


Figure 54. ADOT's Pilot Project Approach [4]

- Vulnerability Assessment

ADOT prepared a Preliminary Study of Climate Adaptation for the Statewide Transportation System in Arizona in 2013 [12] and an Extreme Weather Vulnerability Assessment in 2015.[25] In the 2015 assessment, ADOT leveraged the FHWA Vulnerability Assessment Framework, Figure 55.[26]

[25] ADOT, "Extreme Weather Vulnerability Assessment" January 2015. https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/2013-2015_pilots/arizona/arizonafinal.pdf [Accessed June 13, 2021]77

[26] https://www.fhwa.dot.gov/environment/sustainability/resilience/index.cfm [Accessed June 18, 2021]

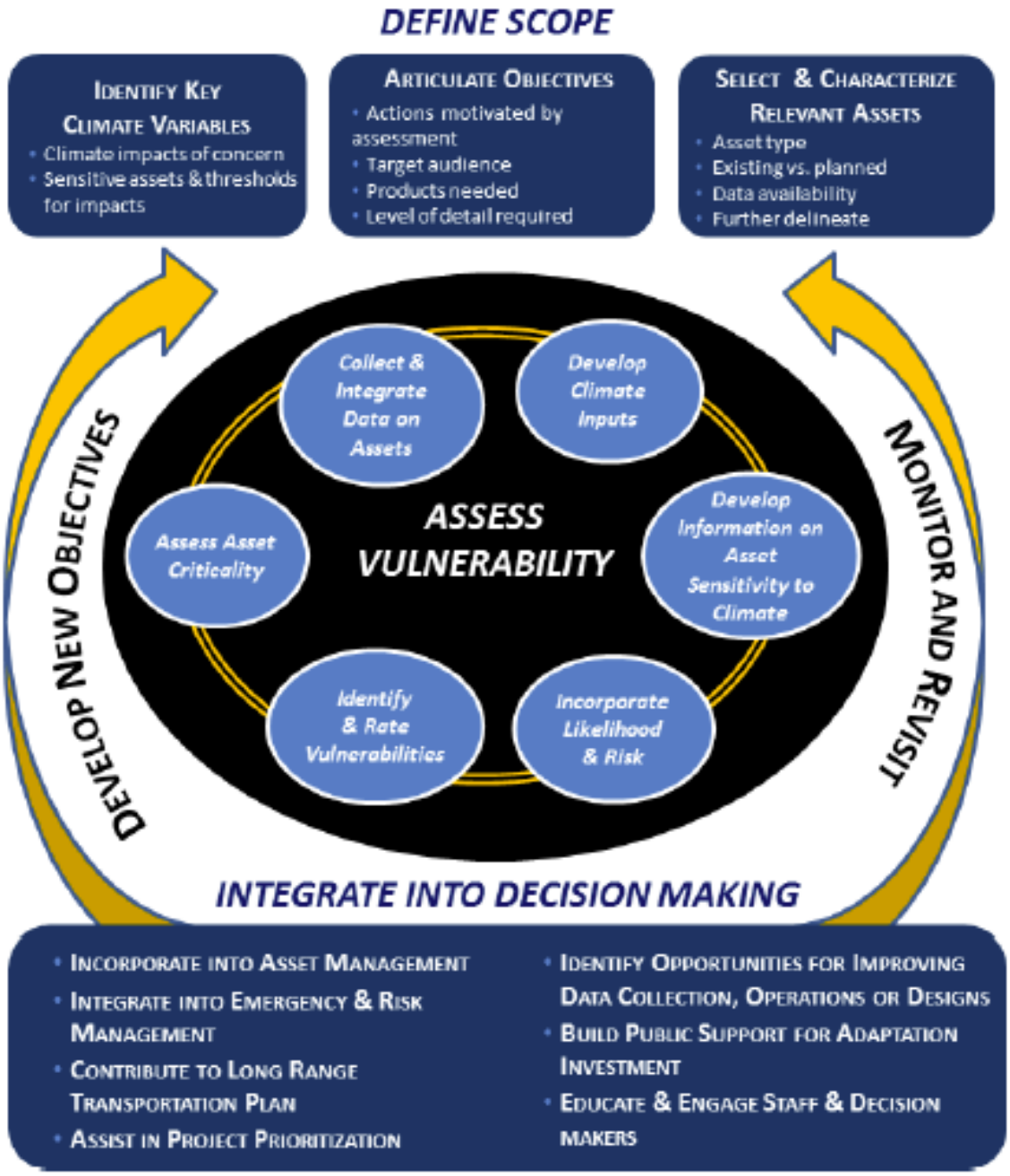


Figure 55. FHWA Vulnerability Assessment Framework[27]

Information was gathered on potential extreme weather impacts, climate data, transportation assets, and land cover characteristics (e.g., watersheds, vegetation, etc.). The datasets were then integrated with conducting a high-level vulnerability assessment. Stakeholder input and feedback were central to the process. The study was a part of the FHWA Climate Change Resilience Pilot Program. ADOT's goal was/is "the development of a multi-stakeholder decision-making framework - including planning, asset

[27] https://www.fhwa.dot.gov/environment/sustainability/resilience/index.cfm [Accessed June 18, 2021]

management, design, construction, maintenance, and operations – to cost-effectively enhance the resilience of Arizona's transportation system to extreme weather risks."

- Identification of Resilience Improvement Strategies

Since 2010, ADOT has developed 8-10 tools, to facilitate the assessment/quantification of resilience and the benefits of resilience enhancement from a planning perspective. Examples include tools to identify the necessary steps for resilience planning and include the benefits of incorporation into planning activities such as the 5-year plan. ADOT has, for example, (i) a resilience financial hierarchy model, (ii) a planning/screening tool, (iii) an end-to-end engineering process tool, (iv) a climate influence model, etc. Overall, an excellent 'toolbox' has been developed to be utilized in resilience assessment and planning, which facilitates the development of financial justification approaches and consideration of sustainability criteria in a 'total systems approach.'

In discussion, it was felt that long-proven program-level prioritization methodologies which provide for annual project prioritization could (and perhaps should) include resilience as a factor for consideration. It was felt that ADOT could, in some sense, serve as an intermediary (via the planning group) and offer resilience considerations to parties (external – municipalities, contributing authorities, etc.) involved in the planning exercise to develop prioritization strategies.

- Resilience Metrics

ADOT has established resilience metrics that are data-driven and tracked through resilience building software tools, e.g., dollars spent, number of screened activities, asset types, State Route vs. Interstate, etc. For example, metrics are employed in the economic justification for project building. ADOT has to date, completed 10 resilience-building efforts. By way of example: the 24-hour precipitation design threshold and scour critical status were selected as sensitivity metrics in ADOT's Asset Management, Extreme Weather, and Proxy Indicators Pilot Project.[28]

Professional Training and Development

ADOT does not offer specific training now. However, two initiatives were planned for the Fall of 2021: (i) an online/desktop training session for project managers on sustainable development for project development and (ii) a resilience training day.

Public Outreach & Communication

ADOT engages in extensive public outreach and communication via the ADOT News webpage.[29] ADOT has a robust system to inform the public of all things related to natural hazards. In addition, the webpage has been used to communicate several resilience-enhancing initiatives to the public, including relating awards for sustainable infrastructure and resilience-enhancing projects.

Final Thought

We concluded our discussion by **asking ADOT's NEPA Assignment, Innovative Programs, Major Studies Senior Project Manager**, 'How long do you think it would take an agency to incorporate resilience into

[28] ADOT, "Asset Management, Extreme Weather and Proxy Indicators Pilot Project" Arizona Department of Transportation, March 2020. https://azdot.gov/sites/default/files/media/2020/03/ADOT-Asset-Management-Infrastructure-Resilience-Study-Report%20Final-2020.pdf [Accessed June 14, 2021]
[29] https://azdot.gov/adot-news?page=1 [Accessed 18th June 2021]

planning?' He felt that based on his experience and on the fact that the Transportation Bill in development would be a significant lever in the process, a period of 5-7 years seemed 'about right.' ADOT began the process in 2011 and, in 2015, had a Resilience Program. He was very optimistic about the future as he felt there is a plethora of federal guidelines, tools, and suggestions were available. He closed our discussion by suggesting, 'It is not complicated, it is very manageable.'

DEEP DIVE CASE STUDY SUMMARY

Colorado Department of Transportation

Introduction

This document summarizes the deep-dive interview conducted with the Colorado Department of Transportation (CDOT) in support of Task 3 of NCHRP Project 08-129. An extended phone interview was held with the Resilience Program Manager, on Monday, June 1, 2021. Follow-up emails were exchanged with key CDOT staff members to obtain further information. The topics discussed included the incorporation of resilience approaches into Plans and Programs, Policies and Concepts, Leadership, and Institutional Capacity, Internal and External Collaboration, Resource Availability, Risk and Resilience Assessment (RnR), Identification of Resilience Improvement Strategies, Professional Training and Development, and Public Outreach/Communications which are discussed in the following sections.

Case Study Participants

- Risk and Resilience Program Manager
- Freight Office Manager
- Performance and Asset Management Branch Manager
- Transportation Asset Management Program Manager
- Division of Emergency Management Plans Officer
- Multimodal Planning Branch Manager

Agency Overview

CDOT maintains over 23,000 lane miles and over 3,400 bridges. Transportation planning is coordinated by the Multimodal Planning Branch within the Division of Transportation Development (DTD), in collaboration with the 5 CDOT Engineering Regions. In addition, DTD coordinates closely with the Division of Transit and Rail and the Office of Emergency Management (see Figure 56).

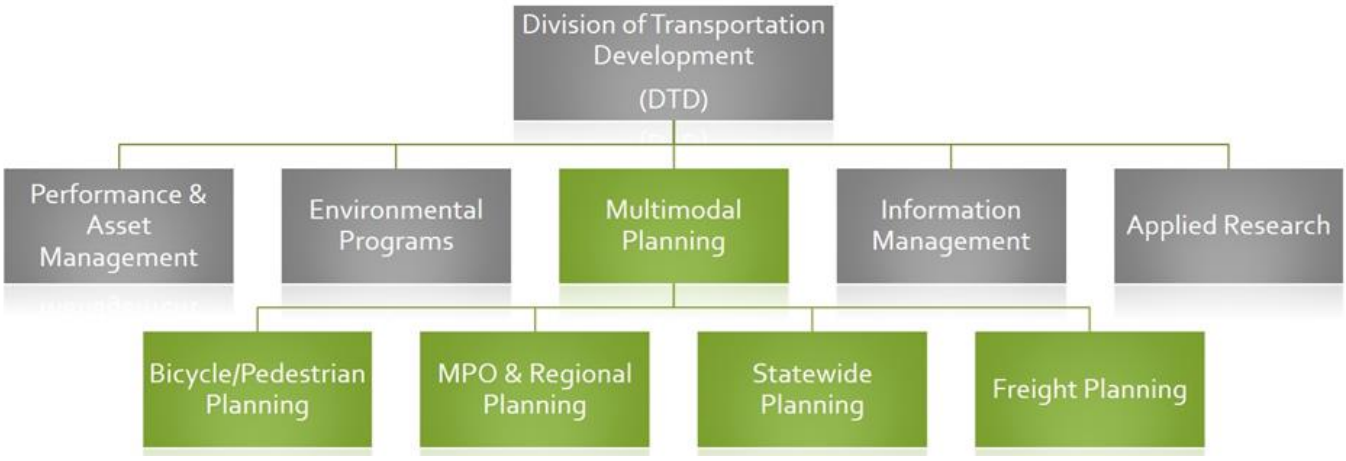


Figure 56. CDOT Organizational Chart

CDOT's mission is "To provide the best multi-modal transportation system for Colorado that most effectively moves people, goods, and information."[30]

The historic September 2013 flood (see Figure 57) caused over $700 million in damages to transportation infrastructure, including severe damage to local roads and local access bridges. This event inspired CDOT to aggressively investigate how to make their system more resilient to extreme weather and natural hazards. The CDOT Resiliency Program currently operates under the Performance and Asset Management Program. In 2017, the Resiliency Program completed a risk and resilience (RnR) assessment of the I-70 corridor under the auspices of the FHWA. This effort was followed by developing a guide and tool for conducting quantitative RnR assessments and benefit-cost analysis, completed in 2019. CDOT continues its efforts to integrate resiliency concepts into every aspect of the agency's day-to-day business. The Resiliency Program is developing 5 case studies to demonstrate integrating resilience with project prioritization and selection, scoping, environmental studies, asset management, and operations and maintenance. Finally, CDOT is adding an appendix to the Long-Range Statewide Transportation Plan (LRTP) to address resiliency. CDOT highlighted that its LRTP is multi-modal in scope.

[30] CDOT, "About CDOT," [Online]. Available: https://www.codot.gov/about/mission-and-vision.html. [Accessed 2 June 2021].

Figure 57. US 34 2013 Flood Damage

Key Findings

- Dedicated resiliency program
- Conduced FHWA-supported RnR assessment
- Developed RnR guide and tool
- Now drafting case studies, demonstrating the integration of resilience into planning, environmental, OM, asset management, and project development
- Has established a resilience policy
- Has mechanisms for internal and external collaboration
- Challenges include funding, staffing, performance metrics, and training
- Developed methodologies for identifying threats, evaluating vulnerabilities, and conducting quantitative risk assessments
- The criticality model's redundancy metric is being optimized with travel demand modeling
- Testing project prioritization tool based on resilience as a factor

Plans and Programs

CDOT incorporates resiliency into its multi-modal, Long-Range Transportation Plan (LRTP), Statewide Transportation Improvement Program, Transportation Improvement Program (TIPs), TAMPs, Freight Plans, and Emergency Response Plans at different levels (see Table 33). Projects addressed by the LRTP were evaluated to see if they were located on critical routes by CDOT's criticality measure. CDOT is augmenting the LRTP with a "Resiliency Appendix" that will provide links to various tools to help staff identify risks from natural hazards, quantify those risks, and assess the benefit versus cost of mitigating to improve resiliency.

Table 33 - CDOT Resilience Incorporation

Transportation Plan/Program	How is Resilience Included
TAMP	Goals, performance measures, and definition
LRTP	Project prioritization
TIP	Project prioritization
STIP	Project prioritization
Freight	Enhanced response to disruptions
Emergency Response	Continuity of Operations (COOP) contingencies

Projects identified in the LRTP become part of the TIP and STIP. CDOT is currently developing a scoring tool to facilitate project selection based on how well a project addresses risks to the transportation system. The tool's scoring system uses an interactive web mapping tool that allows a project sponsor to view different threats across the State, the criticality of the roadway system to assess whether there are known risks at a project site and to evaluate whether there is a return on investment in mitigating known risks. Projects that identify a hazard and include a mitigation plan will score higher with the new tool. Appendix E (December 2020), Corridor Profiles, from the Statewide Transportation Plan 2045 (August 2020), indicates whether a planned project for a given corridor includes a resiliency component. Example resiliency components include drainage improvements, rockfall mitigation, flood mitigation, etc.[31]

Multi-Objective Decision Analysis Scoring System

Resiliency is one of the factors in CDOT's Multi-Objective Decision Analysis scoring system that the agency employs to identify investment priorities for the agency's risk-based asset management plan. Currently, criticality is used as the primary measure of resiliency in the MODA system, but CDOT plans to add additional factors. In addition, CDOT is developing a process and procedure for identifying twice damaged assets in the STIP and assessing what can be done in those locations to mitigate future risks.

TAMP

Published in 2013, CDOT's TAMP includes a section dedicated to risk and resilience. The section describes the CDOT Risk Register, explaining how the Department identifies and scores threats. In addition, the TAMP describes emerging processes to address twice-damaged assets and provides an overview of resilience efforts, such as CDOT's Interstate 70 Risk and Resilience Pilot project. Since the publication of the TAMP, the Department has undertaken a case study to develop processes and procedures for identifying assets in the STIP that have been damaged more than once. This project also has refined

[31] CDOT, "Statewide Transportation Plan Appendix E - Corridor Plans," Colorado Department of Transportation (CDOT), Denver, CO, 2020.

processes for assessing whether actions can be done in these locations to mitigate future risks, in compliance with FHWA's "Part 667" requirements. Separately, CDOT also is continuing to explore incorporating Multi-Objective Decision Analysis, including resilience metrics, into its asset management systems, which helps prioritize asset management projects.

Freight Planning

In addition, CDOT works closely with its Freight Advisory Council (FAC) to develop freight plans. The Colorado Freight Plan reinforces the national goals stipulated in the FAST Act. One of the stated goals in the Freight Plan is to "improve the safety, security, efficiency, and resiliency of freight transportation in rural and urban areas."[32] Putting resilience into practice, FAC developed a GIS tool using data from their Oversize/Overweight (OSOW) permitting system to identify vulnerabilities on freight routes that are causing detours or preventing safe and efficient routing. With a resilience-focused mindset, CDOT can prioritize freight infrastructure investments that offer benefits. With this tool, CDOT was able to fund a bridge repair on a weight-restricted structure by highlighting the issues that forced detours caused 125+ miles of additional travel per trip, increased the risk of wide loads, increased the risk to the traveling public, and the deterioration of roadways not designed for heavy truck traffic. Currently, the same principles are being used to prioritize the timber structure repair program. Understanding routing challenges for OSOW loads is an excellent exercise to understand weaknesses in the system's resiliency.

Emergency Operations Planning

Like the Freight Plan, CDOT's Emergency Operations Plan and Regional Operational Operations Plans focus on returning the transportation system to a pre-incident operational level. In addition, each CDOT Region, Division, and departmental Offices contribute to the agency's Continuity of Operations Plan (COOP). The COOP outlines contingencies to identify alternate work locations (including home), alerting staff, etc. Externally, the Colorado Department of Public Safety guides the statewide COOP lead; but CDOT also coordinates with other State agency COOP program managers on issues and solutions they have encountered. For example, CDOT's Division of Emergency Management Officer regularly communicates with FEMA Region VIII's COOP program manager to exchange ideas.

The COOP helps identify locations where repeated incidents occur, thus, assisting CDOT with its reporting obligations under 23 CFR Part 667 (Periodic Evaluation of Facilities Repeatedly Requiring Repair and Reconstruction Due to Emergency Events).

CDOT Threat and Hazard Identification and Risk Assessment

The CDOT Threat and Hazard Identification and Risk Assessment (THIRA) document has been updated to address 46 different threats and hazards that could impact transportation in Colorado. The Office of Emergency Management (draws on a variety of sources to identify those hazards that put the transportation system at risk, including CDOT's OTIS, the National Weather Service, CDOT's Road Weather Information System (RWIS), Department of Natural Resources (DNR) Colorado Water Conservation Board's flood threat bulletin and fire burn area, DNR's Avalanche Information Center, Department of Public Safety Colorado Information Analysis Center, US Geological Survey's Flood Inundation Mapping Program, and Metro Area Urban Drainage and Flood Control District. A recent example of leveraging GIS data to keep essential functions running was the 2020 Grizzly Creek wildfire in Glenwood Canyon, where CDOT was forced to vacate the Hanging Lakes Traffic Operations Center. CDOT

[32] CDOT, "Colorado Freight Plan," Colorado Department of Transportation (CDOT), Denver, 2019.

staff accessed the National Wildfire Coordinating Group's *InciWeb* online mapping tool to identify a safe place to relocate and continue monitoring traffic operations.

While CDOT has made great progress in growing its resilience program, some challenges and barriers remain. For example, CDOT still has some gaps in its asset data, especially small culverts. Also, while riverine flooding is a major threat, FEMA flood maps do not provide full coverage for all CDOT's impacted roadways. Additionally, CDOT's resilience program could benefit from additional funding, metrics for resilience, better climate change data, specialized training, and a broader understating agency-wide of the concept of resilience. The resilience program has identified these 5 gaps:

- Lack of funding
- Lack of Staff
- Lack of knowledge and skills
- Lack of metrics
- Lack of reliable climate change data

Resilience Incorporation in Planning – Key Factors

Policy and Concept

On November 15, 2018, the Colorado Transportation Commission issued Policy Directive (PD) 1905.0, "Building Resilience into Transportation Infrastructure and Operations." This policy extends efforts to encourage resilience activities initiated after the catastrophic 2013 flood. The Directive requires CDOT to take proactive steps to manage risk to Colorado's highway infrastructure from the threat of floods, rockslides, avalanches, and other natural and man-made hazards. CDOT recognizes the advantages of having a resiliency policy in place:

- Solidifies CDOT's commitment to resiliency
- Formally establishes the resiliency program with CDOT executive support
- Defines resiliency and establishes staff responsibilities
- Promotes the development of tools, metrics, and performance goals for risk and resiliency
- Currently, CDOT is in the beginning stages of developing resilience goals and targets.

Leadership and Institutional Capacity

CDOT has benefited from a solid history of support and champions for resilience across the agency – from regional transportation directors to the asset management branch. A challenge for CDOT is maintaining its dedication to resilience into the future. The resilience program exists to carry out the goals of PD 1905.0, i.e., to promote incorporating resiliency into all aspects of CDOT's day-to-day business. Currently, it is staffed by one part-time position but has assistance from a standing Working Group and Executive Oversight Committee. In addition, the CDOT Resilience Office has provided Executive Staff with copies of a recent publication by the Transportation Research Board, *NCHRP Research Report 976: Resilience Primer for Transportation Executives* (2021).[33] CDOT highlighted that continued leadership support is key to establishing a resilient culture and maintaining the momentum in implementing resilience initiatives.

[33] D. Matherly, J. Mobley, P. Bye, J. McDonald, W. Ankner, K. Kim, E. Yamashita, P. Murray-Tuite, A. Pande, J. Renne and B. Wolshon, *NCHRP Research Report 976: Resilience Primer for Transportation Executives*, Transportation Research Board, Washington, DC, 2021.

Collaboration

Transportation agencies must nurture both internal and external collaboration to efficiently focus resilience efforts and investments, especially where areas of responsibility are shared. CDOT has mechanisms in place for both internal and external collaboration.

- Internal

The CDOT resiliency program consults with the Working Group and the Executive Oversight Committee. The Working Group consists of a broad spectrum of specialties, including hydrologists, project engineers, planners, asset managers, and maintenance supervisors. Similarly, the Executive Oversight Committee includes staff from Maintenance, the Executive Office, the Chief Engineer, the Director of Planning, Regional Directors, Safety, and the Operations Group. The FHWA-sponsored I-70 corridor RnR pilot study was an example of a collaboration between the Working Group and the Executive Oversight Committee.

- External

CDOT works with the Colorado Resiliency Office, the Statewide Transportation Advisory Committee (STAC), and Statewide MPO Committee. The Colorado Governor's office established the Colorado resiliency office (CRO) to promote cross-departmental improvements in the State's resiliency. The CRO Working Group consists of representatives from every statewide Department.

In addition, CDOT maintains a close relationship with the 15 Transportation Planning Regions around the State through the STAC, and with the State's five MPOs. For example, the Denver MPO assists the CDOT resilience program with developing the project scoring tool discussed earlier. Besides statewide agencies, CDOT collaborates with national transportation organizations, such as FHWA and AASTHO, as well as international organizations. CDOT has actively promoted the business case for resilience, both statewide and nationally, with a resiliency planning fact sheet that explains the financial benefits of proactively making pre-disaster investments.

One area where external collaboration could be improved is through interagency agreements between CDOT and organizations that play a role in emergency response. For example, a pre-incident arrangement between CDOT and the U.S. Forestry Service could facilitate access to the land threatened by wildfire.

Resource Availability

Recent scans of state DOTs and MPOs have revealed common challenges to incorporating resilience into planning, including a lack of tools and resources. CDOT has expressed a similar need for increasing some of these resources.

- Data

CDOT's Online Transportation Information System (OTIS), also known as C-Plan, hosts a wealth of spatial and attribute data, including traffic data, asset conditions, and design characteristics. CDOT has accumulated a reliable asset data inventory, including replacement cost, life cycle cost, condition state, and linear referenced location data. All this data is easily shared both inter-and intra-agency through OTIS. In addition, OTIS offers visualization tools. The OTIS portal hosts straight line diagrams to display selected highway characteristics and a map view for viewing transportation data. Publicly available hazard maps are referenced in the CDOT Risk Assessment Procedures Manual. Continuing gaps include precise data on small culverts, floodplain mapping for streams outside of The National Flood Hazard Layer and downscaled climate data.

- ### Funding

Since 2013, CDOT has financed projects to recover from flood and rockfall events with FHWA emergency repair funds. However, CDOT does not have a dedicated funding source for resilience.

- ### Staff and Knowledge Transfer

Currently, CDOT has only one person staffing its resilience program. Much other staff is engaged in resiliency efforts through the standing Working Group and Executive Oversight Committee. CDOT will hold a conference in the fall where resilience training will be provided to staff representing a wide cross-section of the organization.

Risk and Resilience Assessments

In 2017, CDOT completed a risk assessment of I-70 as part of an FHWA-sponsored RnR pilot study. This study considered a variety of threats, natural and manmade, including avalanche, landslide, rockfall, flood, scour, wildfire, and vehicle bridge strikes. The study employed a data-driven, quantitative approach. Select models for flood and rockfall were revised and became the basis for CDOT's RnR Manual. Completed in 2020, the RnR Manual gives detailed instructions on conducting a quantitative risk assessment for flood, rockfall, and post-fire debris flow. The manual was supplemented with a spreadsheet tool to facilitate performing the computations. CDOT intends to test its quantitative risk analysis with a statewide assessment of its culverts.

Section 7 of CDOT's 2013 Risk-Based Asset Management Plan addressed three levels of risk – agency, programmatic, and project/asset level risk. In 2013, CDOT held a workshop with the Risk Task Force and subject matter experts to compile a list of risks and populate a risk register that assigns a relative risk to each risk category under the three levels. CDOT's Risk Management website hosts hyperlinks to the Risk Workbook, a spreadsheet tool for helping transportation planners identify risk and conduct a qualitative risk analysis for projects.

- ### Criticality Assessment

As part of the 2017 I-70 corridor RnR pilot study, CDOT developed a multi-criterion model to assign a relative criticality score, on a scale of 1-to-5 (low to high criticality) to transportation assets. The Working Group settled on 6 criteria that embrace the concept of the Triple Bottom Line, demonstrating social, economic, and environmental responsibility: AADT, AASHTO functional classification, freight revenue ($), tourism revenue ($), the University of South Carolina's social vulnerability index (SoVI®), and redundancy, a topological metric based on several alternative routes available to a traveler (see Figure 58).

CDOT is working to improve its criticality model by replacing the redundancy factor with optimized alternate route calculations derived from travel demand modeling (see Figure 59). In addition, CDOT has expressed an interest in need for additional resilience metrics that consider climate change.

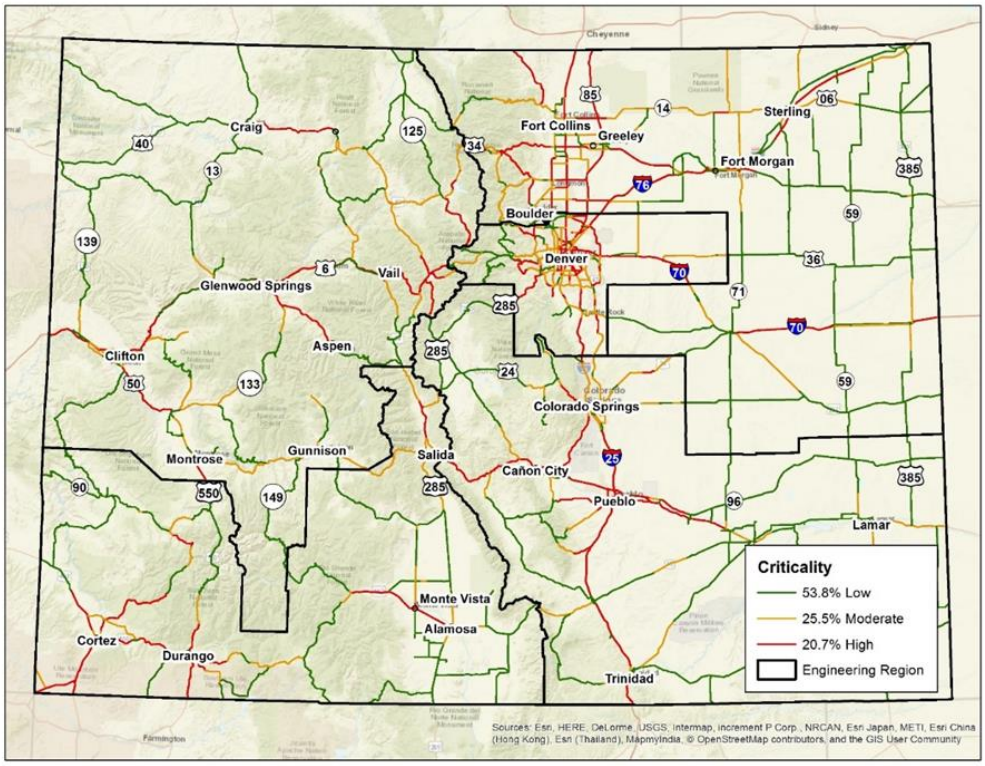


Figure 58. CDOT Criticality Map

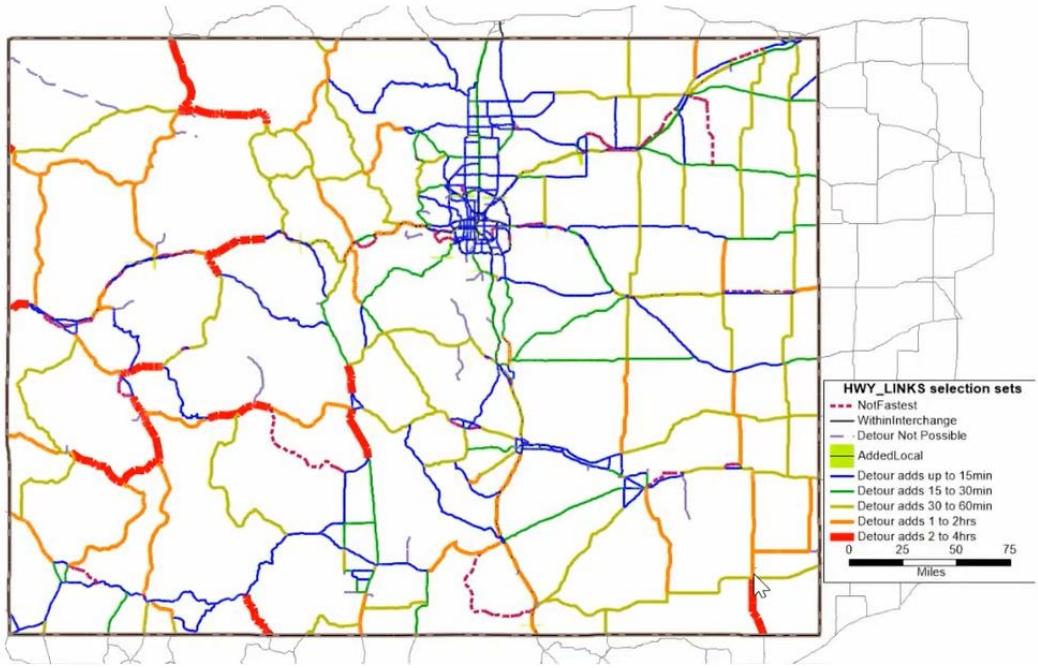


Figure 59. CDOT Detour Length Map

- ### Hazard and Threat Assessment

CDOT has identified its primary natural threats as riverine flooding, rockfall, avalanche, and post-fire debris flow. CDOT employs a variety of tools to conduct risk assessments, including ESRI's ArcGIS software, the RAMCAP framework, and CDOT's own Excel quantitative risk assessment tool. CDOT's GIS staff deployed the publicly available CDOT Asset Resiliency Mapping Application, enabling visualization of floodplains, wildfire perimeters, landslide footprints, and geohazard event data (see Figure 60).

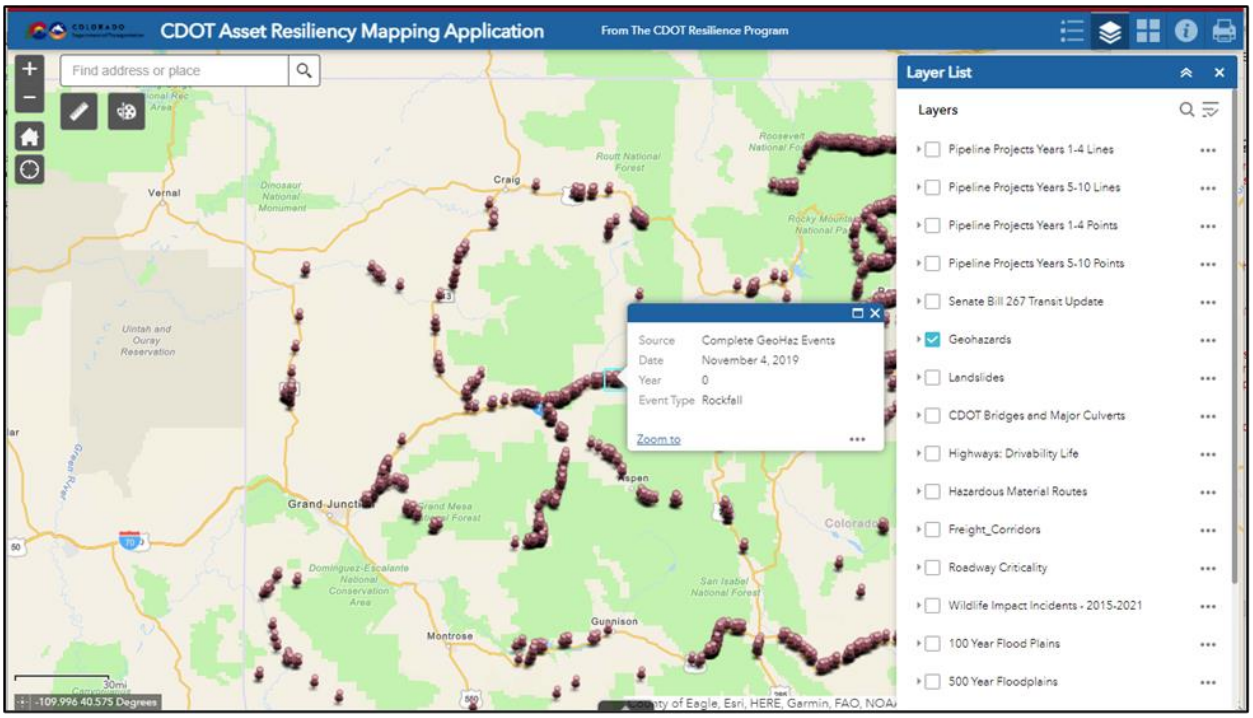


Figure 60. CDOT Asset Resiliency Mapping Application

- ### Vulnerabilities

In developing the RnR Manual, the CDOT Working Group assembled SMEs from Staff Hydraulics, Staff Bridge, the Geohazards Program, Maintenance, and Materials, to identify those factors contributing to asset failure when subjected to a given stress. For example, factors likely contributing to flood damage to pavement loss include topography, pavement condition, and embankment erodibility. In addition, the SME panel developed multi-criterion vulnerability tables for bridges, roadways, and culverts for flood, rockfall, and post-fire debris flow.

- ### Identification of Resilience Improvement Strategies

As discussed earlier, CDOT has completed a draft spreadsheet version of a project scoring tool with an online software version to follow. The tool evaluates whether a project contributes to resilience. The completed tool will be an online, web mapping application, giving project sponsors a bird's eye view of the threats in their region. The tool also aids in benefit-cost analysis. Factors contributing to a project's resilience score include funding source, asset criticality, asset vulnerability, project design, and benefit-cost ratio. A project can earn as much as 10 points for resilience, to be added to a total score based on additional criteria (e.g., safety, reliability, mobility). A project that contributes to resilience will more likely get funded than one that does not.

Improvement strategies can be based on environmental, risk, and economic factors. CDOT's draft geohazards technical plan explains project selection for mitigating geohazards is based on input from regional maintenance personnel, geology, climate, slope, and traffic data to rank geohazards in terms of severity.

Besides environmental factors, transportation planners must consider economic analysis. The RnR Manual gives examples of how to conduct benefit-cost analysis for alternative mitigation options. In addition, the FHWA's TEACR Program funded 9 case studies that explored how transportation agencies have incorporated climate change considerations into project selection and design.[34] CDOT participated in the TEACR program, implementing a study of a culvert crossing US-34 between Estes Park and Loveland, Colorado. The research team employed downscaled climate data and the US Army Corps of Engineers HEC-RAS software to evaluate existing culvert design versus projected future flows given various climate scenarios.[35]

- Resilience Metrics

As part of the efforts to create a unique resilience metric, CDOT tested the development of a Level of Resilience (LOR) Index for Colorado DOT, using example data from the 2017 I-70 Risk and Resilience Pilot (Figure 61). The annual risk to natural threats for CDOT assets along I-70 was aggregated

by 1-mile segments and binned into 5 quantiles. In addition, CDOT assets were assigned a relative criticality score—low, medium, or high. The intersection of criticality score and quantile risk with a matrix determined the LOR ranking on a scale from A, high resilience, to E, low resilience. This new resiliency metric could aid planners in the same manner as safety metrics do when identifying issues during the corridor planning process. For example, the LOR is used during the environmental process, Planning and Environmental Linkage Studies, or during the National Environmental Policy Act process, where areas of high risk are identified, and potential mitigation alternatives are analyzed their corresponding economic analysis justify their use. A key challenge to implementing the LOR, however, is the extensive resources required to do a statewide risk assessment necessary to generate the metric.

Professional Training and Development

CDOT is developing a resiliency training program to cross-train as many as 300 to 400 staff from across the agency. A 3-day conference was scheduled for Fall 2021. The conference will consist of a 45-minute discussion at the executive level and a 2-hour session in the afternoon to train staff on CDOT's quantitative risk assessment tool and the accompanying guide.

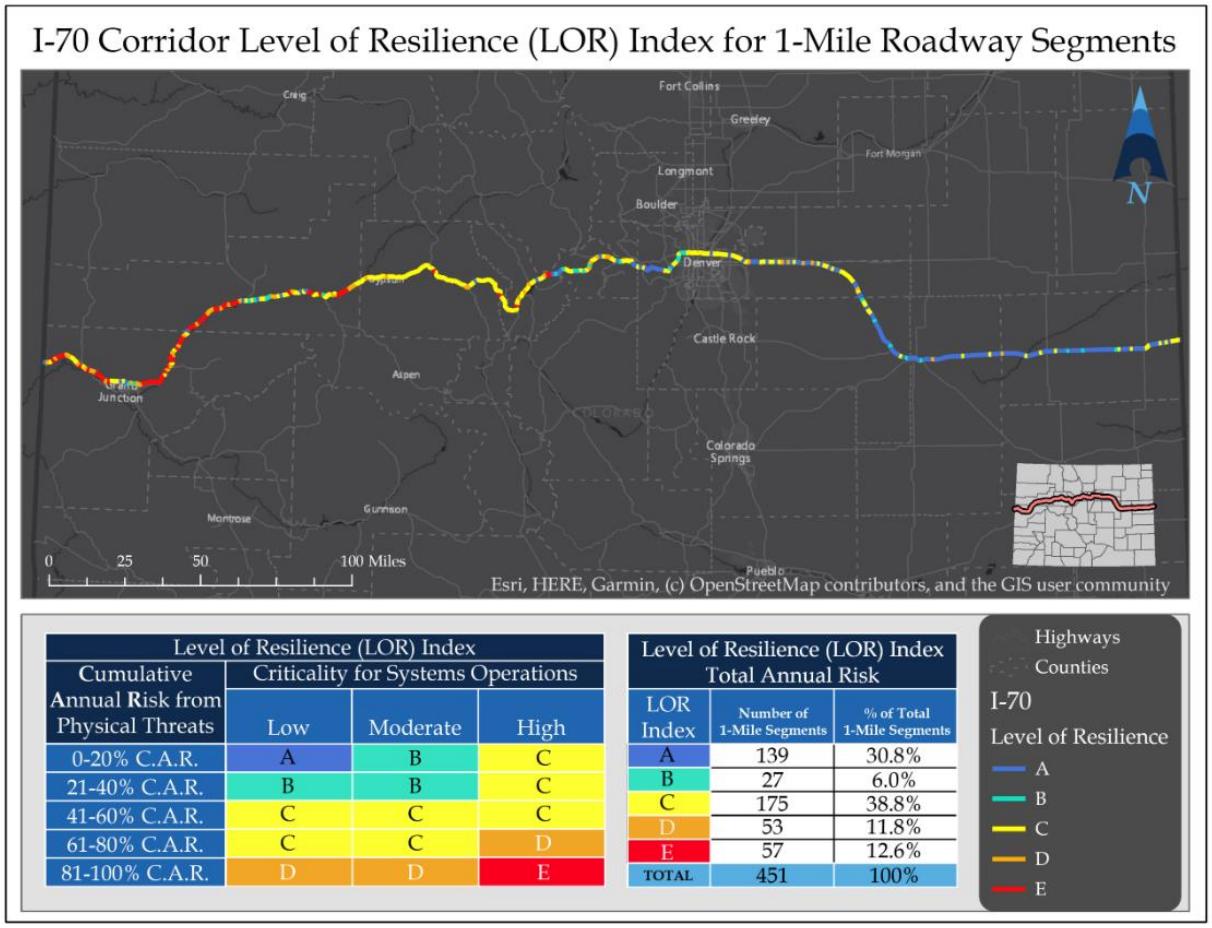
Public Outreach/Communication

While CDOT has not yet engaged in extensive public outreach or communication concerning resilience in transportation, CDOT has a robust system to inform the public of any road closures. Public Outreach/Communication. In addition, CDOT hosts a website dedicated to its resilience program. The

[34] A. Choate, B. Dix, B. Rodehorst, A. Wong, W. Jaglom, J. Keller, J. Lennon, C. Dorney, R. Kuchibhotla, J. Mallela, S. Sadasivam and S. Douglass, "Synthesis of Approaches for Addressing Resilience in Project Development," United States department of Transportation Federal Highway Administration, Washington, D.C., 2017.
[35] FHWA, "TEACR Engineering Assessment. Wildfire and Precipitation Impacts to a Culvert: US 34 at Canyon Cove Lane, Colorado," U.S. Department of Transportation Federal Highway Administration, Washington, D.C., 2017.

website explains the resilience program and contains links to the CDOT RnR Procedures Guidebook and quantitative risk assessment spreadsheet tool.

Figure 61. I-70 Corridor Level of Resilience Index for 1-Mile Roadway Segments



Level of Resilience (LOR) Index			
Cumulative Annual Risk from Physical Threats	Criticality for Systems Operations		
	Low	Moderate	High
0-20% C.A.R.	A	B	C
21-40% C.A.R.	B	B	C
41-60% C.A.R.	C	C	C
61-80% C.A.R.	C	C	D
81-100% C.A.R.	D	D	E

Level of Resilience (LOR) Index Total Annual Risk		
LOR Index	Number of 1-Mile Segments	% of Total 1-Mile Segments
A	139	30.8%
B	27	6.0%
C	175	38.8%
D	53	11.8%
E	57	12.6%
TOTAL	451	100%

Highways
Counties
I-70
Level of Resilience
A
B
C
D
E

DEEP DIVE CASE STUDY SUMMARY

Florida Department of Transportation

Introduction

This document summarizes the deep-dive interview conducted with the Florida Department of Transportation (FDOT), in support of Task 3 of NCHRP Project 08-129. An exhaustive list of questions was sent over to FDOT members, and they responded with their answers. An extended phone interview was scheduled for a follow-up and deeper dive into their response. The virtual interview was held with multiple staff from different agency areas and offices on Tuesday, June 15, 2021. Follow-up emails were exchanged with key FDOT staff members to obtain further information. The topics discussed included the incorporation of Resilience approaches into Plans and Programs, Policies and Concepts, Leadership, and Institutional Capacity, Internal and External Collaboration, Resource Availability, Risk and Resilience Assessment (RnR), Identification of Resilience Improvement Strategies, Professional Training and Development, and Public Outreach/Communications which are discussed in the following sections.

Case Study Participants

- Statewide Community Planning Coordinator/Office of Policy Planning
- Office of Policy Planning Director
- Intergovernmental Program Administrator
- State Drainage Engineer
- Emergency Coordination Officer
- Pavement Design Engineer
- Strategic Intermodal System (SIS) Planning Manager
- Transportation Planner and SIS Contract Manager

Key Findings

After visiting with the Florida Department of Transportation (FDOT), it is clear they have developed strong resilience initiatives and are constantly working to advance resiliency efforts to keep the State and its people safe. With the signing of the Resiliency of State Transportation Infrastructure Policy in April of 2020 by FDOT Secretary Thibault, resilience has continued to be pushed to the forefront. In addition, the Department has been excelling in multiple areas that showcase its integration of resilience into its agency systems and culture. Their role in resiliency can be seen through communication, collaboration, leadership, resources, risk and resilience assessments, training and development, and policy.

Key Highlights

- Dedicated Resilience program and team
- Established a resilience policy and definition
- Integrates resilience into policy, tools, and guideline development
- Key support from leadership and staff
- Actively collaborates internally and externally
- Developed successful methodologies and tools for identifying threats and conducting risk assessments

FDOT is incorporating resilience into statewide planning efforts, including the Florida Transportation Plan and TAMP. They provide resources like the Resilience Primer that establishes a framework, best practices, a resiliency toolbox for fellow agencies, and information for the community to stay up to date and involved in resilience efforts. Leadership shows support through funding, constant communication, and interest in all aspects of the resilience process. In addition, FDOT provides training to staff and support for research showcasing a buy-in to their own agency's abilities.

FDOT's mission is to provide "a safe transportation system that ensures the mobility of people and goods, enhances economic prosperity and preserves the quality of our environment and communities."[36] To improve safety, enhance mobility, and inspire innovation, FDOT hopes to serve the people of Florida with a transportation network that is well planned, supportive of economic growth, and congestion and fatality-free. Through resources for agency staff and community members to fund and support ongoing and future efforts, FDOT is advancing resiliency daily in Florida. They are actively developing tools to assess hazards and threats while managing current infrastructure assets already being impacted. Resilience at FDOT is ingrained in roles and projects to ensure the state creates a more sustainable and effective future for its residents.

With over 21 million residents, the State of Florida is constantly looking ahead to improve resilience efforts and support its communities.[37] The Office of Policy Planning **is instrumental in integrating resiliency strategies within transportation planning. An in-depth organization chart of this office and key members can be found in Appendix A.** According to the 2014 Annual Report[38], the Department has over 6,500 employees, seven districts, the central office, and Florida's Turnpike Enterprise. FDOT is decentralized, so each district is managed by a District Secretary and varies in structure but has the same major divisions of administration, planning, production, and operations. FDOT maintains 123,104-line miles of public roads, 12,130 line miles of the State Highway System, 4,344 line miles of Strategic Intermodal System, and 7,007 bridges.[39]

The Central Office of Policy Planning monitors and reports on the transportation system's performance across the Department. The performance management policy, effective in 2016, requires the linkage of performance measures to planning and programming decision-making, which helps inform decisions and provides essential feedback.[40]

Committed to an open government, FDOT provides its residents with information on the Department and its operations through online access and public meetings.

FDOT incorporates resiliency into various statewide and district-level transportation plans, including:

- Metropolitan Transportation Plans (MTP)
- Long-Range Statewide Transportation Plans (LRTP)

[36] FDOT, "About FDOT," [Online]. Available: https://www.fdot.gov/agencyresources/aboutfdot.shtm.
[37] U. Government, "Census.gov," [Online]. Available: https://www.census.gov/quickfacts/FL.
[38] FDOT, "2014-2015 Annual Report," [Online]. Available: https://www.fdot.gov/docs/default-source/traffic/its/projects_deploy/annualreports/AR-FY2014-15.pdf.
[39] FDOT, "Fast Facts," [Online]. Available: https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/planning/fastfactsdce18ce94ae1462e927016f398c543b3.pdf?sfvrsn=29ef5de8_8.
[40] FDOT, "Performance Management Policy," [Online]. Available: https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/content/planning/performance/000- 525-052.pdf?sfvrsn=edbcfe0f_0.

- Transportation Improvement Programs (TIP/STIP)
- (TAMP)
- Freight Plans
- Port Plans
- Seaports Plan
- Aviation Office

FDOT integrates resilience into all its different transportation plans, as well as "resilience-related research projects, studies such as the Strategic Intermodal System Resilience Planning Study." The incorporation of resilience is evident throughout FDOT's long-range and modal plans, work program, asset management plan, research efforts, and internal resources.

To assist in incorporating resilience into all of Florida's MPO Long Range Transportation Plan (LRTP), FDOT developed the Resilience Quick Guide, which outlines the steps to consider while creating an LRTP.[41] This guide identifies various opportunities to incorporate resilience into each process step, as seen in Figure 62.

Figure 62. Figure 1. LRTP Planning Steps – FDOT Resilience Quick Guide [6]

Their statewide plan, the Florida Transportation Plan (FTP), is an overarching plan that guides Florida's transportation future and is updated every five years. The process includes working with a Resilience Subcommittee of Transportation Partners and resilience experts to identify resilience strategies. This plan considers the following areas of resilience: weather, environmental changes, economic shifts, and operational disruptions. By placing resilience as an objective over the next five years, FDOT tries to incorporate and focus on increasing infrastructure resilience and addressing known and unexpected opportunities and risks. [42] They also have created a webpage designated to the FTP that provides updates and resources, explaining why resilience matters and how Florida can prepare and recover from disruptions.

In FDOT's TAMP, they set the stage for resilience by including it as one of the principal objectives of the plan and foundation pillars for performance measures of asset management. Their goal is to, "Reduce the

[41] FDOT, "Resilience Quick Guide," [Online]. Available: https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/planning/policy/resilience/2020-01-29_fdot-resilience-quick-start-guide_final.pdf?sfvrsn=31d65da4_2.
[42] FDOT, "FTP," [Online]. Available: http://floridatransportationplan.com/policyelement2020.pdf.

vulnerability and increase the resilience of critical infrastructure to the impacts of extreme weather and events".[43]

For example, when FDOT's assets are damaged or destroyed due to storm events like hurricanes, a mitigation strategy like hardening the asset is chosen. This will enhance its resilience by developing natural buffers, building protection, updating design standards, or improving existing strategies.

Florida is almost entirely surrounded by water, leaving it open to various natural disasters that impact essential infrastructure. Past damages and the indication of more frequent storm events creates a sense of urgency to adapt and protect against what will keep happening. Incorporating resilience directly into transportation plans and throughout the agency showcases the importance of being more resilient. These initiatives help to help and information to decision-makers, partner agencies, MPOs, local governments, and others about incorporating resilience. In addition, incorporating resilient efforts into the various transportation plans and research projects creates increased reliability and safety. FDOT expressed that having a resilience definition is "extremely helpful" as it is a way to provide a focus for the Department and bring a consistent message across all districts and divisions within FDOT.

Policy and Concept

Major drivers to incorporating resilience into transportation plans and throughout the agency include state and federal regulations and economic and safety benefits to the state and its communities. Federal Regulation 23 CFR 450.306(b) requires MPOs to "improve the resiliency and reliability of the transportation system and reduce or mitigate stormwater impacts of surface transportation" through their LRTPs .[44] FHWA Order 5520 establishes a policy on preparedness and resilience to climate change and extreme weather events. This allows them to integrate consideration of states' adaptation responses into the delivery and stewardship of the Federal-aid and Federal Lands Highway programs.[45] The State of Florida has enacted its own set of statutes and policies including Florida Statute 186.0079(3) which states, "The Executive Office of the Governor shall prepare a proposed state comprehensive plan which provides long-range guidance for the orderly social, economic, and physical growth of the state".[46] To ensure coastal management, Florida Statute 163.3178 intends, "…local government comprehensive plans restrict development activities where such activities would damage or destroy coastal resources…".[47] Florida has also established a statewide system to facilitate the transport and distribution of essentials in commerce to ensure the economic resilience of communities impacted by disasters, as stated in Florida Statute 252.359.[48]

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[43] FDOT, "TAMP," [Online]. Available: https://tamptemplate.org/wp- content/uploads/tamps/028_floridadot.pdf.
[44] "Cornell Law," [Online]. Available: https://www.law.cornell.edu/cfr/text/23/450.306
[45] FHWA, "Order 5520," [Online]. Available: https://www.fhwa.dot.gov/legsregs/directives/orders/5520.cfm
[46] F. Statutes. [Online]. Available: http://www.leg.state.fl.us/statutes/index.cfm?mode=View%20Statutes&SubMenu=1&App_mode=Display_Statute&Search_String=163.3178&URL=0100-0199/0163/Sections/0163.3178.html
[47] F. Statutes. [Online]. Available: http://www.leg.state.fl.us/statutes/index.cfm?mode=View%20Statutes&SubMenu=1&App_mode=Display_Statute&Search_String=163.3178&URL=0100-0199/0163/Sections/0163.3178.html.
[48] F. Statute. [Online]. Available: http://www.leg.state.fl.us/statutes/index.cfm?mode=View%20Statutes&SubMenu=1&App_mode=Display_Statute&Search_String=252.359&URL=0200-0299/0252/Sections/0252.359.html.

Resiliency of State Transportation Infrastructure Policy

In April 2020, FDOT Secretary signed Policy 000-525-053, the Resiliency of State Transportation Infrastructure Policy. The policy states the Department must consider the resiliency of the State's transportation system to support the "safety, mobility, quality of life, and economic prosperity of Florida and preserve the quality of our environment and communities".[49] This policy ensures FDOT will continue identifying risks and resiliency, emphasizing sea-level rise, flooding, and storms, assessing potential impacts, and employing strategies to avoid, mitigate, or eliminate impacts.

These efforts will be conducted through the various long-range and modal plans, work programs, research efforts, and various guidelines available. When developing the policy, a distinct challenge arose. It was difficult to fully incorporate blanket agency resilience policies at the district or project level since FDOT is decentralized. The varying priorities throughout each district created an added layer in the development. In the end, FDOT recognizes the importance of having a resilience policy. Having an established resilience definition, as defined in the policy as, "the ability of the transportation system to adapt to changing conditions and prepare for, withstand, and recover from disruption", allows consistent messaging and incorporation of resilience at every level. It sets the tone in the Department that resilience is something we recognize and integrate throughout.[50]

No Formal Definition of Risk or Resilience

FDOT does not differentiate between risk and resilience assessment; they use the terms interchangeably. In their Asset Management plan, they identify risk, and it is framed as risk and as they go on to reference ways to mitigate risk, that is referred to as resilience. Overall, while not stated, the ultimate differing factors for risk and resilience for FDOT depend on the purpose and context it is being used. They do believe, though, that separate definitions and clarification of the two could help. FDOT anticipates the Planning Department would clarify the two and has been pulling together definitions to help get clarity for staff to use moving forward.

In addition to having a policy and definitions, a strong Resilience Planning Framework can be essential for a state DOT. FDOT explained the key to a good framework covers a broad definition of resilience while looking at all aspects of the agency's business. It identifies roles, responsibilities, and partnerships and ensures that work done in planning can be used in other areas of the agency's work, including project implementation. Resilience planning should look at trends and new issues/opportunities and identify potential focus areas. Resilience in planning should also provide the coordination and communication framework for conversations throughout the agency. FDOT has not formally developed a Resilience Planning Framework, but they are in the process of doing so. Until that framework becomes official within the agency, they will continue to look at specific risks, establish an action plan, and ensure work toward implementation.

Leadership and Institutional Capacity

FDOT has agency leadership support to help incorporate resilience approaches into all agency functions. Leadership is very supportive of furthering resiliency strategies within transportation planning, shown

[49] [Online]. Available: https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/planning/policy/resilience/resiliency_policy_000-525-053.pdf?sfvrsn=4dae64fd_2.
[50] "FTP TM 1," [Online]. Available: http://floridatransportationplan.com/pdf/FDOT-SIS_ResiliencePhaseI-TechMemo_wApp_8-22-18.pdf.

through providing funding for resiliency efforts, participation in discussions and meetings, making presentations, and coordinating and collaborating within FDOT and externally with other agencies. FDOT leadership helps secure resiliency funding, allowing for projects like risk assessments to be pursued and implemented. These efforts showcase their interest and initiative to stay up to date and involved. Staff states leadership is, "interested in what we have to say... and works to educate themselves along with us to continue moving resiliency forward with the agency."

Their constant engagement and willingness to be involved create future success by emphasizing resilience in FDOT business and with internal staff and external partners.

Along with leadership support, FDOT also has an institutional mechanism to help coordinate resilience efforts through working groups. For example, the Central Office working group meets quarterly to focus on what decisions need to be made and appropriately give direction. They also have a network of resilience contacts within the FDOT Central and District offices. The goal is to hold a statewide working group to hear from even more people and receive information on initiatives around the State.

Resilience efforts are continuously being incorporated and focused on as a piece of the project, but funding for it is included in the main scope of work. FDOT has started to look at additional opportunities to fund resilience-related portions of projects, but they do not know exactly where the future is headed.

Additional staff time and funding have been added to specific projects specifically for resilience work, but they integrate the efforts into regular business. Since Florida is prone to various natural storm events, there are ways to obtain separate funding for resilience efforts. FDOT works with those agencies to procure additional funding in other ways to ensure resilience is being fully integrated and utilized in all FDOT projects.

Agency culture is important, and at FDOT, there are champions focused on incorporating resilience into the agency culture at the leadership and staff levels. The roles evolved over time and organically, for the most part, instilling a level of awareness and effort to institutionalize resilience within. Agency champions include but are not limited to, people in the roles of Assistant Secretary for Strategic Development, Chief Planning, Director of the Office of Policy Planning, Manager of the Systems Implementation Office, and other staff within those offices. In addition, there are planning staff at FDOT Districts who work closely and coordinate with those in Central Office. These positions are essential for successfully incorporating resilience as they are the most influential roles. They can drive policy and change, integrating and institutionalizing the process; they are the activators for FDOT.

Collaboration

FDOT communicates resilience approaches in planning both internally and externally. State agencies, federal agencies, regional and local agencies, environmental partners, and transportation partners are among those FDOT collaborates.

- Internal

  Internally, the central office works with all other district offices, some routinely and some on a varying basis, including Engineering & Operations (Design, Construction, Maintenance, Emergency Management, Environmental Management, etc.), and the Office of General Counsel. Communication includes during the quarterly working group meetings and informally when comments or concerns arise. The advantages of collaborating with other internal groups include helping to understand what various FDOT offices and programs are doing related to resilience. In

addition, the open door for all divisions to see what each other is working on allows for sharing of ideas and information. It also helps to develop consistency in the messaging across the board. There are some challenges for staff internally, though. Due to staff across the agency being interested in resilience in addition to their original work set, time and workload are seen as a day-to-day challenge within the office. Also, resilience efforts are already being done but are not highlighted under resilience. This means some pieces must be revamped to show the resilience efforts more explicitly, which takes away from the already limited staff time.

FDOT is constantly nurturing a culture of innovation, though, always working on process enhancements and improvements to manage the competing interests and allow for success in the workplace.

- External

  External collaboration is made up of fellow state agencies, including:

  - Florida Department of Environmental Protection (FDEP)
  - Florida Department of Economic Opportunity (FDEO)
  - Florida Department of Agriculture and Consumer Services (FDACS)
  - Florida Division of Emergency Management (FDEM)
  - FHWA
  - NOAA
  - MPOs
  - Regional Planning Councils (RPCs)
  - Regional Resilience Compacts
  - Local governments
  - Water management districts
  - Environmental partners
  - Transportation partners

Externally, collaboration allows for sharing information and data that might not have been available before, identification of potential opportunities for joint implementation between agencies, cost-sharing, and help problem-solving. FDOT has collaborated with MPOs to provide resources on incorporating resilience into their LRTPs and has hosted a peer exchange for them alongside FHWA. The biggest challenge, though, is combining the different goals and missions when working together to benefit all parties and successfully achieve the overall initiative.

FDOT is continually trying to improve collaboration, both internally and externally, through their working groups and network of resilience contacts to identify what needs are there to be fully successful. Further problem solving and planning early will hopefully enhance future FDOT collaboration efforts. The most effective communication channels and strategies FDOT identified were meetings, peer exchanges, webinars, personal communication, and engagement in planning efforts of other agencies, including U.S. Army Corps of Engineers, FDEP, regional organizations, and local governments. Additionally, they are beginning to plan a statewide resilience meeting for all State staff, hopefully improving communication and initiative implementation. FDOT would like to ensure all the programs are in the loop and actively working and contributing to resilience efforts. When collaborating with other agencies, FDOT learns what they are doing so they can use their tools, information, projects, and examples to assist in determining

how to best work with them. The goal is to work alongside partners while also meeting the needs and goals of the Department.

Resource Availability

- Funding

For FDOT, funding for resilience is built into the project planning and is not budgeted as a separate line item. They see resilience as part of every project, not an individual item with a different budget. There is additional funding through other agencies FDOT can sometimes receive in addition to the original project budget, but often that is dependent on state legislation. Federal grant opportunities can be helpful but take time and money to produce and apply for. FDOT feels with the funding available, they have enough to incorporate necessary resilience approaches.

- Data

FDOT also has processes to collect data to conduct risk and resilience analysis like an ongoing project to assess MPO resilience planning and data needs (JF). FDOT also has several other research projects underway related to developing a resilience index, incorporating non-stationarity, and expanding the Sea Level Scenario Sketch Planning Tool for project-level analysis. The Sketch Planning Tool provides data for Florida counties affected by sea-level rise (SLR) and is updated periodically to include revised projections and new data. In addition, the Strategic Intermodal System (SIS) Resilience Planning Study provides vulnerability information for SIS facilities for additional hazards.

These tools are used for planning purposes and to show the hazards and vulnerabilities. They are just a few of the resources FDOT has in place. The Department also looks at an environmental screen tool, slosh models, SLR, precipitation, and other models.

Additional datasets and tools that could benefit FDOT would focus on operational costs and mitigation efforts. FDOT is continuously evaluating ways to improve its existing tools. While there are various challenges, overall, FDOT explains you do not always know what you are missing when you do not have it. They are currently working on identifying the data needs and availability through research projects, sometimes it is a collaborative effort with other state offices to ensure using credible sources and identifying all data and needs.

The most beneficial data sources FDOT has found include: (1) work currently being done by the University of Florida for resilience planning, and (2) storm surge and lidar-related data from the Florida Division of Emergency Management that was very beneficial in the SIS hazards analysis, as well as a review of storm surge, impacts to the statewide evacuation network. Other data sources for the vulnerability assessment were also beneficial, like the NOAA drought monitor, Florida DEP Subsidence Incident Reports, Southern Wildfire Risk Assessment, and FGDL. This data helps identify infrastructure and services potentially vulnerable to a variety of hazards. It is most frequently included in transportation plans for projects with an identified vulnerability (e.g., a resilience improvement to a proposed project).

- Staff and Knowledge Transfer

Another necessary resource to incorporate resilience into transportation planning is staff availability and overall time. For example, FDOT uses a lot of consultants and has an extensive transportation data section in the Central and other District offices. In addition, when operating outside agencies, they

thoroughly review and meet internally to ensure the most successful people are assisting them with their resilience initiatives.

Risk and Resilience Assessments

FDOT performs risk assessments, typically in the form of vulnerability assessments to address the extent of assets being impacted, and resilience assessments, typically done by consultants. The terms are used interchangeably within FDOT. They are done quantitatively and are typically a mix of probabilistic and deterministic approaches. RnR performance metrics can be found in the FTP Policy Element. They are not being used to make decisions yet, but the long-term goal for FDOT is to determine key performance indicators. However, there has not been much movement past conception since data limitations have hindered their ability to know what will be practical or helpful.

- Criticality Assessment

In their TAMP, FDOT does not identify specific assets or corridors but discusses risks at the agency, program, and asset levels and how they mitigate them. They also discuss the annual Pavement Condition Surveys (PCS), which monitor and report on the performance and condition of pavements on the state highway system. The data collected goes into the Pavement Management System (PMS) for analysis to assist with project selection. In addition, the Department has a bridge inspection program to assess the condition of bridges. This information feeds into the AASHTOWare Bridge Management Software (BrM) for processing. The Department also has a policy that a structure is programmed for corrective action within six years of being identified as structurally deficient or weight restricted. FDOT also inspects bridges to determine criticality and uses resilience index research to identify critical linkages related to hurricane hazards. There is constant forward progress in identifying their critical assets, but challenges reside in their resilience practices, not all being developed enough to utilize performance indicators effectively.

- Hazard and Threat Assessment

To improve system continuity and recovery, FDOT has protocols and tools to stay prepared and responsive for immediate recovery and assessment of damages. Protocols are implemented as part of their standard workings, including major debriefs with stakeholders that generate lessons learned and eventually policy and procedure guidelines. An example of this can be seen by FDOT mitigating power outages at service plazas, causing major impacts to visitors by installing generators. This keeps facilities open and lessens the impact caused. FDOT also utilizes tools they have developed like the Sea Level Scenario Sketch Planning tool to identify flooding, storm surge, and sea-level rise. The key hazards in Florida that the Department deals with are water-related. Additional hazards are identified based on stakeholder input from the Environmental Partners Working Group and FTP Implementation Committee, and hazards of most relevance or likelihood as specified in the State's Hazard Mitigation Strategy/Plan.

The Florida Transportation Plan, which makes up FDOT's LRTP, focuses on four areas of resilience, weather, environmental changes, economic shifts, and operational disruptions, to identify and address possible threats and mitigation strategies. In addition, FDOT utilizes publicly available software and tools they have developed to strategize and mitigate against the threats and hazards.

- Vulnerabilities

FDOT performs vulnerability assessments to address the extent of assets being impacted. They follow the FHWA Vulnerability Assessment and Adaptation Framework with modifications based on elements most

important to FDOT. In some cases, like for the SIS, they developed their methodology, as seen in Figure 63 below.

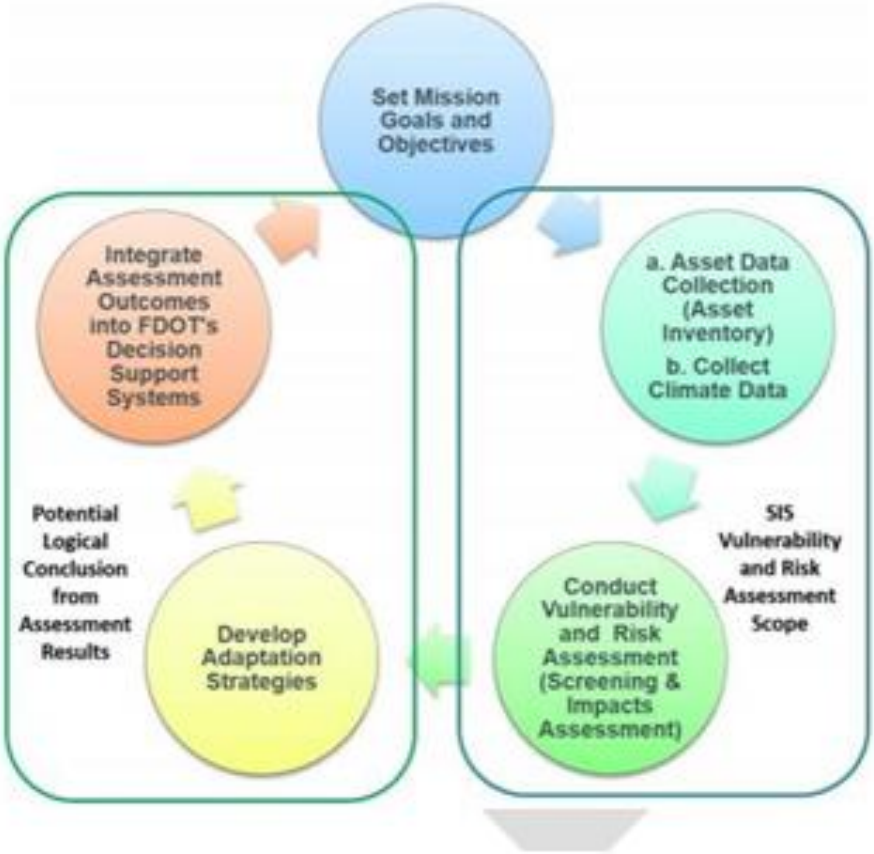


Figure 63. Proposed Framework for SIS Vulnerability and Risk Assessment[51]

FDOT estimates vulnerability through various resources like geospatial tools (ArcGIS), which are used to compare transportation infrastructure for areas affected by a hazard to identify potentially vulnerable assets. The hazard data may be obtained from climate or storm surge models, historical trends when projections are unavailable, and field data supplied by operations and maintenance personnel. The vulnerability may be estimated based on inundation level or other similar ratings.

Identification of Resilience Improvement

- Strategies

FDOT does not yet have a process to identify and prioritize resilience improvement strategies. However, their SIS Action Plan is currently in draft form and will assist in helping to identify and prioritize strategies.

- Resilience Metrics

[51] "Cornell Law," [Online]. Available: https://www.law.cornell.edu/cfr/text/23/450.306.

FDOT does not have a formal process for measuring the performance of resilience improvement strategies. FDOT notes the lack of failure is a positive measure and is constantly improving based on the results of every past event.

Professional Training and Development

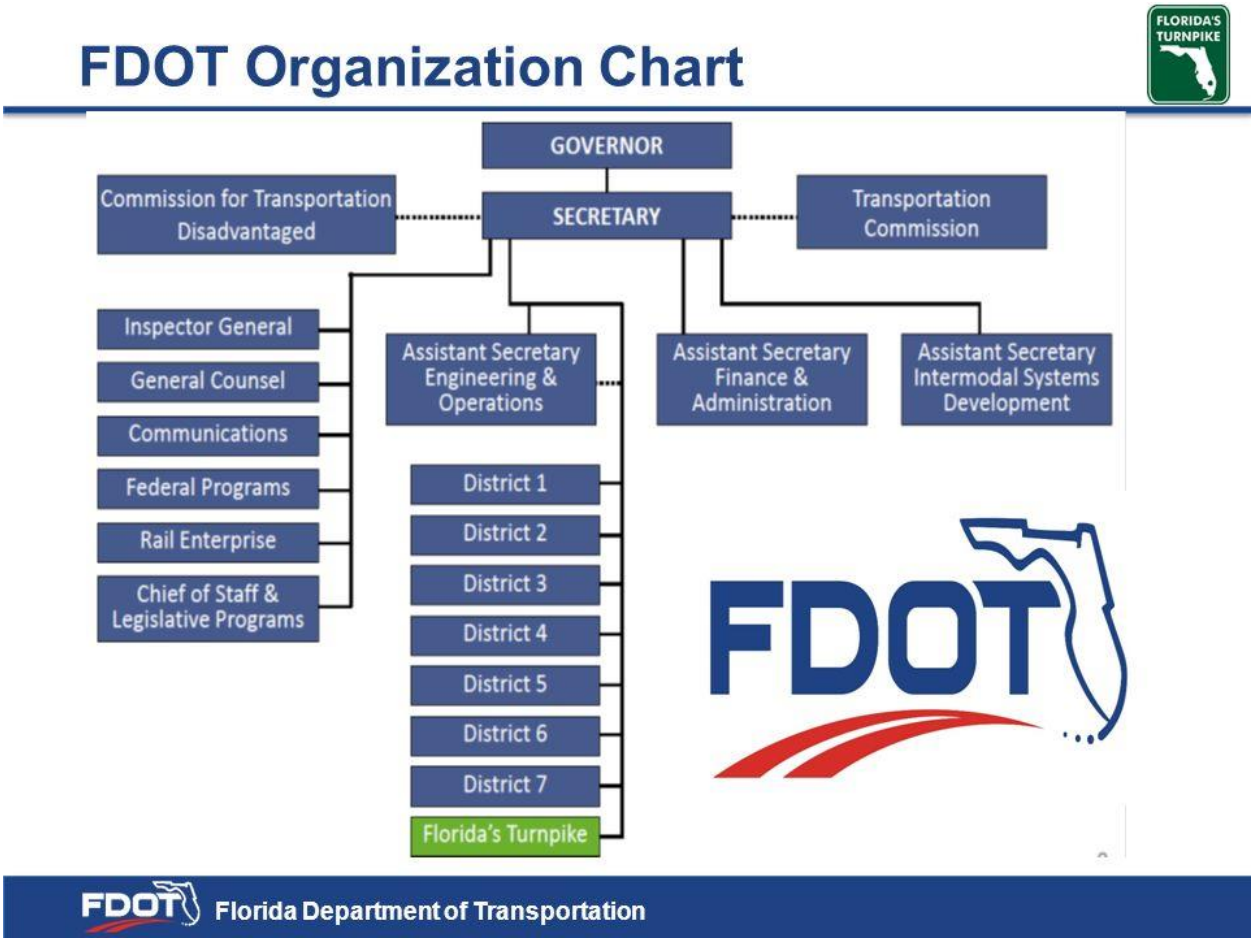
FDOT is always seeking new information and ways to share it with more staff. This allows them to spread necessary knowledge on significant efforts, like incorporating resilience into planning, to as many people as possible. They have also conducted training on tools like the updated Sea Level Scenario Sketch Planning Tool. In addition, they inform staff throughout the agency about resilience-related training and professional development webinars and resources.

Other than webinars, FDOT staff states they have not provided other specific training to share information. Regarding the emergency response and management program, FDOT adds resilient mitigation strategies. Staff incorporates updated plans into design and manuals to ensure lessons are learned after experiences. This helps the agency keep building back better and ensures they are prepared for future events allowing for continuous improvement.

Public Outreach and Communication

FDOT has coordinators, both management and staff level, to convey to agency staff what is occurring concerning resilience-oriented projects and programs. In addition, they send out information through the Working Group and the agency-wide list of contacts. There are currently no strategies for communicating resilience initiatives with the public, but FDOT responds to requests from public leaders throughout the State.

FDOT successfully uses multi-agency communications systems and protocols during emergency response/management actions. They use FEMA protocol and good communication techniques during emergency responses. There is a lot of collaboration with the Division of Emergency Management, which oversees FEMA projects with resilience, which has led to success stories of key infrastructure around the State. FDOT has not yet developed communication resilience program strategies, but they are under development as part of their resiliency policy implementation. The public can find out more information through FDOT's dedicated Resilience page. The website explains the resilience efforts in place and links to additional helpful information.


FDOT Organization Chart
FLORIDA'S TURNPIKE
GOVERNOR
SECRETARY
Commission for Transportation Disadvantaged
Transportation Commission
Inspector General
General Counsel
Communications
Federal Programs
Rail Enterprise
Chief of Staff & Legislative Programs
Assistant Secretary Engineering & Operations
Assistant Secretary Finance & Administration
Assistant Secretary Intermodal Systems Development
District 1
District 2
District 3
District 4
District 5
District 6
District 7
Florida's Turnpike
FDOT
FDOT Florida Department of Transportation

DEEP DIVE CASE STUDY SUMMARY

Minnesota Department of Transportation

Introduction

This document summarizes the deep-dive interview conducted with the Minnesota Department of Transportation (MnDOT), supporting Task 3 of NCHRP Project 08-129. An exhaustive list of questions was sent over to MnDOT members, who responded with their answers. An extended phone interview was scheduled for a follow-up and deeper dive into their response. The virtual interview was held with multiple people from different areas on Wednesday, June 23rd, 2021. The topics discussed included the incorporation of resilience approaches into Plans and Programs, Policies and Concepts, Leadership, and Institutional Capacity, Internal and External Collaboration, Resource Availability, Risk and Resilience Assessment (RnR), Identification of Resilience Improvement Strategies, Professional Training and Development, and Public Outreach/Communications which are discussed in the following sections.

Key Findings

After visiting with the Minnesota Department of Transportation (MnDOT), it is clear they have developed strong resilience initiatives and are constantly working to advance resiliency efforts to keep the citizens of Minnesota safe. Being a land of extremes, with key multimodal assets, MnDOT is constantly dealing with various threats to its system. While there is no established resilience policy, MnDOT has a Statewide Multi-Modal Plan that integrates resilience and incorporates resilience in standard practices to increase resiliency efforts holistically. In addition, the Department has been excelling in multiple areas that showcase its integration of resilience into its agency systems and culture. Their efforts and activities in resiliency can be seen through communication, collaboration, leadership, resources, risk and resilience assessments, training and development, and policy.

Resilience planning at MnDOT is a developing process intended to be "broader than climate consideration only", but comprehensive of all potential resilience concepts.[52] They are incorporating resilience into various statewide planning efforts, including the Statewide Multi-Modal Plan and their TAMP. They provide resources like the "Transportation Resilience: Current Practices and Opportunities" for MnDOT that establishes a framework, best practices, and gaps and opportunities as well as an annual sustainability report for the community to stay up to date and involved in resilience efforts.[53] Leadership shows support by funding resilience research and actively supporting the resilience advisory team. MnDOT provides resiliency training to staff as well as support for research showcasing their own agency's abilities.

[52] MnDOT, "Transportation Resilience Report," [Online]. Available: http://www.dot.state.mn.us/sustainability/docs/resilience-report-2020.pdf.
[53] MnDOT, "Annual Sustainability Report," [Online]. Available: https://www.dot.state.mn.us/sustainability/docs/2019-sustainability-report.pdf.

Agency Overview

MnDOT's mission is to, "Plan, build, operate and maintain a safe, accessible, efficient and reliable multimodal transportation system that connects people to destinations and markets throughout the state, regionally and around the world".[54] Resilience planning at MnDOT is a developing process and intended to be broader than climate consideration only, but comprehensive of all potential resilience concepts. They define system resilience in their 20-Year SMTP as, "…reducing vulnerability and ensuring redundancy and reliability to meet essential travel needs. The transportation system is vulnerable to threats, such as severe weather, acts of terrorism, and cyber-attacks. Advanced preparation, mitigation and adaptation to threats and risks, helps to ensure the people and goods can continue to travel during emergencies.[55] In 2011, Minnesota created the 50-year Minnesota GO Vision, a collaborative vision supportive of the State's quality of life and economy that has since been built upon to shape their vision further. In addition, MnDOT has established principles to guide future policy and investment decisions including:

- Leverage public investments to achieve multiple purposes,
- Ensure accessibility,
- Build to a maintainable scale,
- Ensure regional connections,
- Integrate safety,
- Emphasize reliable and predictable options,
- Strategically fix the system, and
- Use partnerships.

With the goal to create transportation networks and services to support Minnesota's quality of life and economy, MnDOT hopes to serve the people of Minnesota with a transportation network that is safe, convenient, efficient, and an effective movement of people and goods. Minnesota's multimodal transportation system maximizes the health of people, the environment, and economy.[56] They have developed a steering committee and risk register that assess hazards and threats and actively work on mitigation strategies to combat impacts on infrastructure assets. Resilience at MnDOT is ingrained throughout the agency, incorporating resilience in all plans and initiatives to ensure the State creates a more sustainable and effective future for its residents.

With over 5.5 million residents, the State of Minnesota is always looking ahead to improve resilience efforts and support its communities.[57] The Office of Sustainability and Public Health (OSPH) is essential in implementing resilience throughout the agency. It is led by the Assistant Commissioner for Sustainability and Public Health, and others who report to him including Jeffrey Meek, the Sustainability Coordinator, Principal Sustainability Planner, Principal Transportation and Public Health Planner, and the Sustainability

[54] MnDOT, "Vision," [Online]. Available: http://www.dot.state.mn.us/vision/.
[55] MnDOT, "SMTP," [Online]. Available: https://www.minnesotago.org/application/files/7414/8642/7717/SMTP_Plan_Final_Jan2017_small.pdf.
[56] MnDOT, "SMTP," [Online]. Available: https://www.minnesotago.org/application/files/7414/8642/7717/SMTP_Plan_Final_Jan2017_small.pdf.
[57] MnDOT, "Demographics," [Online]. Available: https://mn.gov/admin/demography/data-by-topic/population-data/our-estimates/.

Planner.[58] They report to the Deputy Commissioner and Chief Engineer, who reports to the Commissioner of MnDOT. MnDOT is divided into eight regional district areas, seven Greater Minnesota districts, and one Minneapolis/St. Paul Metropolitan district. Day-to-day operations are primarily managed at the district level.[59] MnDOT maintains 142,914 line miles of streets, roads, and highways, 4,485 track miles of Freight Rail, Commuter and Intercity Passenger Rail lines, and more than 4,000 miles of Designated Trails Invalid source specified..[60]

The SPH develops and coordinates the Department's sustainability and public health activities and leads efforts across the State.[61] MnDOT provides its residents with information on the Department and its operations regarding sustainability and public health through online access.

Plans and Programs

MnDOT incorporates resiliency into various statewide and district-level transportation plans, including Statewide Multimodal Transportation Plan (SMTP), TAM, Freight Plans (statewide and district), Statewide Pedestrian Plan, Statewide Aviation Plan, Statewide Port Plan, Statewide Transit Plan, Emergency Response Plans (ERPs), and State Highway Investment Plan (MnSHIP). Table 34 summarizes how MnDOT incorporates Resilience into its transportation plans and programs.

MnDOT also integrates resilience into current and completed resilience-related research projects, such as the Flash Flood Vulnerability and Adaptation Assessment Pilot Project, Extreme Flood Vulnerability Analysis, and Slope Vulnerability Assessments.[62] In addition, the incorporation of resilience is evident throughout MnDOT's transportation plans, asset management plans, research efforts, and internal resources. To assist in incorporating resilience into their plans, MnDOT utilizes the framework guidance in their SMTP and guidance from their Transportation Resilience: Current Practices and Opportunities for MnDOT document.

Their 20-year Statewide Multi-Modal Transportation Plan (SMTP) is an overarching plan that guides Minnesota's transportation future and is updated every four years, per state and federal law.[63]

[58] MnDOT, "Sustainability Team," [Online]. Available: http://www.dot.state.mn.us/sustainability/docs/osph-workplan-2021.pdf.

[59] MnDOT, "MnDOT Districts," [Online]. Available: https://www.dot.state.mn.us/information/districts.html.
[60] MnDOT, "SMTP," [Online]. Available: https://www.minnesotago.org/application/files/7414/8642/7717/SMTP_Plan_Final_Jan2017_small.pdf.
[61] MnDOT, "Sustainability Team," [Online]. Available: http://www.dot.state.mn.us/sustainability/docs/osph-workplan-2021.pdf.
[62] MnDOT, "Resilience in Research," [Online]. Available: http://www.dot.state.mn.us/sustainability/climate-resilience.html.
[63] MnDOT, "SMTP," [Online]. Available: https://www.minnesotago.org/application/files/7414/8642/7717/SMTP_Plan_Final_Jan2017_small.pdf.

It is part of the Minnesota GO Vision plans, with the first SMTP adopted in 2012. The plan evaluates the entire transportation system and focuses on five objectives:

Open decision-making,

- Transportation safety,
- Critical connections,
- System stewardship, and
- Healthy communities.

Table 34. How FDOT integrates resilience into planning

Transportation Plan/Program	How is Resilience Included
SMTP	Definition, goals and objectives
TAMP	Goals and objectives, use of metrics
Freight	Goals and objectives, use of metrics
Statewide Pedestrian	Goals and objectives, use of metrics
Statewide Aviation	Goals and objectives, use of metrics
Statewide Port	Goals and objectives
ERPs	Goals and objectives
MnSHIP	Goals and objectives

SMTP identifies guidance and priorities for the whole transportation system by providing a framework for statewide transportation plans. Implementation of these initiatives is guided by transportation, local, regional, state, tribal, federal, and private sector and non-profit partners.[64] The process includes outlining what residents of Minnesota want their transportation system to do, understanding where the system currently is and its key trends, detailing public engagement opportunities, and creating objectives and implementing a work plan to integrate them. By identifying resilience as an objective for the next 20 years, MnDOT expresses the importance of incorporating resilience in all aspects of its agency. In MnDOT's TAMP, they set the stage for resilience by emphasizing how acknowledging risk and understanding risk can help improve agency and infrastructure resiliency. The goal of the TAMP is to serve as an "accountability and communication tool".[65] It is a planning tool to help MnDOT further evaluate risks, develop mitigation strategies, analyze life cycle costs, establish asset condition performance measures and targets, and develop investment strategies.

A land of extremes, Minnesota is heavily affected by climate change, as seen in its extreme weather events like increased rainfall and flooding events. Climate change exposes the state to higher temperatures that cause issues like facility operations, impacted ecosystems, air pollution, human health, and agricultural changes.[66] These threats stress the system and amplify the need for resilience incorporation. Minnesota has climate goals, supportive leadership, and a strong history of looking at risk and incorporating resilience. Their stance on resiliency helps to provide to decision-makers, partner agencies, MPOs, local governments, and others about incorporating resilience. Incorporating resilient efforts into the various transportation plans and research projects creates increased reliability and safety.

[64] MnDOT, "SMTP," [Online]. Available: https://www.minnesotago.org/application/files/7414/8642/7717/SMTP_Plan_Final_Jan2017_small.pdf.
[65] MnDOT, "TAMP," [Online]. Available: https://www.dot.state.mn.us/assetmanagement/pdf/tamp/tamp.pdf.
[66] EPA, "MnDOT climate change," [Online]. Available: https://www.epa.gov/sites/production/files/2016-09/documents/climate-change-mn.pdf

Resilience Incorporation in Planning – Key Factors

Policy and Concept

Major drivers to incorporating resilience into transportation plans and throughout the agency include state and federal regulations and economic and safety benefits to the state and its communities. FHWA Order 5520 establishes a policy on preparedness and resilience to climate change and extreme weather events. This allows them to integrate consideration of states adaptation responses into the delivery and stewardship of the Federal-aid and Federal Lands Highway programs.[67] The State of Minnesota has enacted Statute 174.01, which outlines the creation of MnDOT and its roles as a transportation agency.[68] The Next Generation Energy Act (2007), established the goal of reducing Greenhouse Gas (GHG) emissions over the next 50 years.[69]

Challenges they have experienced include uncertainty beyond what their design engineers are comfortable working with and confusion of how resilience is defined. In an attempt to mitigate these barriers, MnDOT developed a definition for system resilience that can be found in their SMTP. However, until the full concept of resilience is understood, "a definition won't be the answer".

MnDOT performs risk and resilience assessments, used interchangeably, at different planning levels. They have identified that some risks are directly related to resilience, and some are not, but typically they do not call them resilience assessments. Key MnDOT explained that in the OSHP, they look at system-wide issues and consider resilience assessment as an asset having a specific issue, which would be another office's role. Assessments are done internally, and MnDOT tracks the inventory and condition of assets with ArcGIS and Excel to create a risk matrix.

For state DOTs, having a solid resilience planning framework can be essential. MnDOT has implemented a Risk Management Framework that focuses on risks associated with achieving specific performance outcomes.[70] MnDOT identifies the importance of having a system that tracks asset inventory and conditions and processes that make tradeoffs between assets. This allows the state to look into trends, new issues, and potential focus areas.

Leadership and Institutional Capacity

MnDOT has leadership support for the incorporation of resilience approaches into agency functions. This can be seen through their enterprise risk management process that looks at high-level risks and a resilience advisory team. Leadership supports continuing MnDOT's resilience efforts, as highlighted by their efforts to help fund resilience research and support various pilot resilience efforts. They also support additions to the OSHP team and create dedicated positions within it to work on resilience. While there is no specific program solely for resilience, OSHP works to elevate sustainability and public health needs. Within the division, specific positions focus on resilience, climate change, and asset management. The Resilience Advisory Team appears to be a key component for successfully incorporating resilience planning within MnDOT. The team consists of a dozen people invited to meet every other month and talk about the most pressing topics impacting the state pertaining to risk, resiliency, climate change, and

[67] FHWA, "Order 5520," [Online]. Available: https://www.fhwa.dot.gov/legsregs/directives/orders/5520.cfm
[68] Revisor, "MnDOT statute," [Online]. Available: https://www.revisor.mn.gov/statutes/cite/174.01.
[69] Minnesota, "Law of MN," [Online]. Available: https://www.revisor.mn.gov/data/revisor/slaws/2007/0/136.pdf
70 MnDOT, "TAMP," [Online]. Available: https://www.dot.state.mn.us/assetmanagement/pdf/tamp/tamp.pdf.

other topics. In addition, some key staff are agency champions for helping elevate resilience issues to the executive level.

Along with leadership support, MnDOT has an informal strategy for institutionalizing system resilience into staff roles. Through their staff leads and resilience advisory team, MnDOT works to assist staff in incorporating resilience into their roles. In addition, MnDOT is currently working on a report that outlines a proposed approach to institutionalizing the process.

A major issue MnDOT faces is increased precipitation across the state, which can be very expensive to mitigate and creates environmental issues. Weather is a common topic for Team MnDOT and is constantly discussed between staff and leadership. MnDOT considers water a part of its identity and has rooted resilience into that, bringing all the issues arising from it to the forefront. As a result, they believe the agency is elevating and focusing on the most pressing issues. Fortunately, MnDOT is a well-resourced and staffed team, so they can communicate and mitigate what is most important. They also have strong working relationships with other state agencies that help identify and mitigate risks when needed.

Collaboration

MnDOT communicates resilience approaches in transportation planning both internally and externally. States, federal, regional, and local agencies, as well as environmental, tribal, private sector and non-profit, and transportation partners, are among those MnDOT collaborates with.

- Internal

Internally, MnDOT collaborates with other groups within the agency regarding resilience initiatives including the Office of Transportation System Management (OTSM), Office of Environmental Stewardship (OES), Office of Emergency Management (OEM), Office of (OCC), and others as needed. The various groups collaborate and work effectively to achieve the state's goals by sharing information and resources. The advantages of collaborating with other internal groups include creating more open and candid conversations and providing detailed insights into how things work internally. For the planning process, they have been able to work across the agency and have better integration, coming up with newer and broader ideas. Everyone is on board culturally with what the Agency wants to achieve in terms of resilience. Some challenges include the complicated nature of incorporating resilience throughout the system. Key MnDOT staff noted that once details and specifics are shared and communicated, it can get complex really fast. For example, MnDOT hasn't settled on their true risk tolerance regarding resilience. Also, debates arise that add to the complexity such as, "is a plan really needed", "can we afford to do a risk assessment", "what's the right level of risk we are willing to tolerate", etc. There are a lot of assets and systems that need to be in place to avoid looking at individual infrastructures. In addition, staff is excited about thinking more holistically about resilience, but often it is beyond their role to think that far ahead in the conversation. MnDOT is fostering a culture of resilience, though, always working on improvements and advancements to manage competing interests and allow for success in the workplace.

- External

External collaboration is made up of fellow state agencies, including Invalid source specified.:

- Minnesota Department of Employment and Economic Development (MDEED),
- Minnesota Department of Agriculture (MDA),

- Minnesota Department of Public Safety (MDPS),
- Minnesota Pollution Control Agency (MPCA),
- Minnesota Department of Natural Resources (MDNR),
- Minnesota Environmental Quality Board (MEQB),
- FHWA,
- FTA,
- EPA,
- USGS,
- NOAA
- MPOs,
- Regional Development Organizations, and
- Local governments.

Externally, collaboration allows for sharing information and data that might not have been available before, identifying potential opportunities for joint implementation between agencies, cost-sharing, and help problem-solving and mitigating risks. MnDOT participates in an Interagency Climate Adaptation Team with 20 other agencies every month. This allows MnDOT to share resilience strategies and resources beyond their agency while gaining access to information from others. The Department is also involved with peer exchanges with other states and MPOs for resilience corridors but has stated there is not much collaboration. The biggest challenge is ensuring both agencies benefit and successfully achieve their original goal. MnDOT has ideas to initiate further collaboration, discussing a possible tiered system.

Resource Availability

- Funding

MnDOT does not allocate a separate budget to incorporate resilience into planning. They have discussed including separate funding as part of the 20-year Highway Investment Plan, but it has not yet been incorporated. Currently, they look at resilience as part of the investment strategy when developing mid-range plans and not as a separate line item. Resilience is seen as being part of every project. They receive research funding with the help of leadership support, but MnDOT staff believes more funding would help implement resilience approaches.

- Data

MnDOT also utilizes various data sets and tools to support resilience-based practices including asset life cycle cost, asset condition, and asset deterioration curves/models. These are used on varying levels based on the specific asset. To collect data needed for conducting risk and resilience analysis, MnDOT does not use anything specific. Still, they have underlining data systems, like the transportation data management system and Excel for risk matrices. While there are no specific tools, they use the systems to track inventory and conditions of assets to ongoing projects. They do have the data they need to get the job done but having better data on previous extreme events would benefit MnDOT and flush out robust data sets to measure resilience and track the frequency of damages and closures.

MnDOT has found the most valuable data for them to evaluate resiliency in the areas of flooding and how that historical data can help them predict and anticipate rainfall/flooding in the future. Other information includes what the DOT owns and its condition, capacities for hydraulics, and having it all easily accessible and the training necessary to understand it. One requirement is to look at locations MnDOT has used Emergency Relief funds to help inform if they have repeat damage. MnDOT wants to expand it

throughout the state and put it all in one database for decision-making. MnDOT acknowledges they don't have an extremely robust resilience index, but it is an area of growth for them, and they are looking to improve it.

Regarding data collection and analysis improvements, MnDOT notes progress in tracking climate impacts and ways to measure the change in resilience would be helpful. In addition, knowing key information about major assets would allow them to fix and prepare them for future impacts. When collaborating with other agencies, MnDOT collects data using a fairly robust geospatial sharing site between state agencies. They use climate data from the State Climate Office and use publicly available data from USGS and NOAA.

- Staff and Knowledge Transfer

In terms of staffing, MnDOT is in a good place with the number of staff but giving staff more time to dedicate to resilience projects like qualitative vulnerability assessments would be beneficial.

Risk and Resilience Assessments

MnDOT performs risk and resilience assessments at different planning levels, including enterprise, project, asset, and financial. Therefore, the terms are used interchangeably and are typically performed internally.

- Criticality Assessment

Regarding having a process to identify critical assets and corridors, MnDOT states it depends on how you define critical. For users, they do, but specifically for resilience they do not yet have one. They use an asset matric system that includes a tiering exercise of their assets to prioritize and identify them. First, they do interstates, National Highway Systems, and then non-National Highway Systems. MnDOT has a list of the biggest and most critical bridges in the state based on several criteria, including AADT. They look at corridors system-wide and place them into tiers based on how critical the asset is. There is not a specific tool they use other than excel, where they create a large workbook to work out of.

For some assets without a process, a challenge is deciding which ones should be prioritized. Key MnDOT staff discuss the relation community resilience plays into asset resilience and the influence of what the community wants. Something can play into what is chosen, but the DOT can't afford to upscale and address all of the issues so there has to be a way to pick and choose which ones do. This is part of the continual improvement they are working towards.

- Hazard and Threat Assessment

MnDOT utilizes an Enterprise Risk Management Steering Committee to improve system continuity and recovery to identify threats that might affect their transportation system. They look at key risks that might impact the entire transportation system and put together climate risks and annual reviews on how to mitigate them over the next few years. They also have financial and asset risk processes that assist in identifying hazards and threats. MnDOT expressed that some of what they identified could apply to other states, as they learned from other states. They note they have learned a lot and can use what they have found as examples for others with good communication.

MnDOT identifies and understands which hazards and vulnerabilities threaten their system through Asset Management Plans (TAMP), Freight Plans, Statewide Pedestrian Plan, Statewide Aviation Plan, Statewide Port Plan, Emergency Response Plans (ERPs), and State Highway Investment Plan (MnSHIP). They are

currently trying to identify climate risks through a new GIS algorithm that would run statewide and give a better idea of what areas are vulnerable and at-risk. All assets in their TAMP go through a formal risk process using a risk register. MnDOT also utilizes publicly available software and tools, like the online ESRI GIS database, to strategize and mitigate against threats and hazards.

- Vulnerabilities

MnDOT conducts flood and slope vulnerability modeling, as well as an analysis of emergency relief locations with repeat damage. They are done quantitatively and are typically a mix of probabilistic and deterministic, depending on the project. MnDOT does not have any official resilience metrics but does have several metrics that indirectly relate to resilience (e.g., culvert inspections and conditions). There are some targeted measures taken but nothing full-scale. Two areas they want to learn more about are an investment in infrastructure that increases resilience and tracking asset climate vulnerability through the GIS algorithm they are creating. MnDOT focuses on incorporating resilience into existing metrics instead of creating new ones.

MnDOT estimates vulnerability through the documentation on slope and flood vulnerability models. The challenges residing with estimating vulnerabilities are showcased in how new the field is. Increasing the resilience of transportation infrastructure is such a relatively new area, so it requires time, research, and funding to advance and develop.

- Identification of Resilience Improvement Strategies

Currently, MnDOT has strategies and processes to implement selected strategies for resilience improvement for their Asset Management Plan (TAMP), Statewide Pedestrian Plan and Statewide Port Plan. There is no formal process to implement resilience strategies, but they are looking at risk reduction related to resilience. For measuring the performance of the resilience improvement strategies, MnDOT has developed strategies or uses tools in their Asset Management Plan (TAMP), Freight Plans, and Statewide Aviation Plan.

MnDOT is trying to build a database of what is being done for the risks, like a resilience tool kit, to help normalize resilience into project development. It is an area constantly being worked on to give project managers more tools to make better decisions. MnDOT sees the need for a broader strategy but is still discussing what that would look like.

- Resilience Metrics

MnDOT has established metrics to estimate system resilience. They are used in MnDOT's Asset Management Plans (TAMP), Freight Plans, Statewide Pedestrian Plan, and Statewide Aviation Plan.

Professional Training and Development

MnDOT is always interested in new information, data, and guidelines on adaptation strategies to share with staff. The current staff, though, has a lot of local expertise. Therefore, the Department does not explicitly provide resilience-related training and professional development opportunities for staff in different functional areas, but sometimes they provide resources on related topics like AOP. The training and development opportunities allow staff to continue learning and be involved in other aspects of the job.

MnDOT's Emergency Management section provides emergency response and management program training. In addition, they have developed plans such as the:

- MnDOT Emergency Operations Plan (EOP),
- MnDOT Business Impact Analysis (BIA),
- Continuity of Operations Plan (COOP), and
- MnDOT Radiological Emergency Plan (REP).

These plans come from an all-hazards perspective and help to assure and safeguard "Minnesota's critical transportation infrastructure from acts of terrorism, natural and manmade disasters, and a multitude of other emergency situations."[71]

Overall challenges regarding professional capacity include retaining and attracting the right level of people. Many counties and cities pay a higher rate than MnDOT can, so some divisions lack redundancy, leading to a small workforce. Also, support training and development are not as built out or incorporated as they should be throughout the agency. There are constraints and concerns, but MnDOT has done an excellent job of making rotation programs to get more well-rounded employees. Also, in this day and age, there is a new opportunity with teleworking being available, allowing staff to be based all over the state. It also opens up the spectrum for where MnDOT can look for a variety of specialists they may need.

Public Outreach and Communication

MnDOT has its Resilience Advisory Team, STSC, and an annual sustainability report to convey to agency staff what is occurring concerning resilience-oriented projects and programs. The Team discusses the most pressing topics at their meetings that need to be brought to the Agency's attention. For the public, the Department utilizes its website and the annual sustainability report to communicate resilience initiatives. The report allows the community to see MnDOT's four key focus areas, which include[72]:

- Reduce transportation sector GHG emissions,
- Promote agency sustainability,
- Improve resilience of the transportation system, and
- Promote public health.

MnDOT effectively uses multi-agency communications systems and protocols during emergency response/management actions. They use FEMA protocol and good communication techniques during emergency responses. MnDOT has a thoughtful and comprehensive public outreach, and communications effort that provides information dissemination during major disruptions and incidents and information exchanged during an agency's effort to implement a resilience program. Their Emergency Management section has developed plans like the Emergency Operations Plan (EOP) that explains the appropriate measures. The public can learn more about emergency response measures by contacting the MnDOT Emergency Management department.

[71] MnDOT, "Maintenance Manual," [Online]. Available: https://www.dot.state.mn.us/maintenance/pdf/manual/chapter7emergency.pdf.
[72] MnDOT, "Maintenance Manual," [Online]. Available: https://www.dot.state.mn.us/maintenance/pdf/manual/chapter7emergency.pdf.

APPENDIX F – INDUSTRY ENGAGEMENT

Overview

The research team conducted a 3-hour virtual workshop called "Strategy Validation Industry Workshop", on December 15, 2021, at 2:00 pm (EST). The workshop was hosted through the Zoom online meeting platform and consisted of a short presentation by the research team followed by polling questions using Mentimeter as a polling tool. Attendees were encouraged to participate using the Zoom chat function or by unmuting themselves to provide comments and feedback.

Purpose

The workshop's purpose was to receive feedback from state DOT (Department of Transportation) professionals to validate and enhance proposed strategies and tasks/actions for incorporating resilience into transportation planning. In addition, the input will be used to refine the guide.

Invitation and Registration

Invitation to the Workshop was distributed to a broad variety of communities through email. As part of the invitation, a link to a Wufoo registration site is provided to track attendees to the workshop (see Appendix 1 for example of email invitation). People interested in participating in the workshop were able to use the link provided in the email to register and provide their contact information and background (see Appendix 2 for Wufoo Workshop register). The workshop had 41 individual registrants on the Wufoo site.

Following registration on the Wufoo site, registrants received a calendar invitation with details to access the Zoom Platform the day of the event followed by an annotated agenda and read-ahead material with information about the project and the purpose of the workshop (see Appendix 3 for read-ahead material).

A total of 34 people participated in the workshop. Most of the attendees were primarily employees of state DOTs from multiple disciplines such as planning, operations, and maintenance (O&M), engineering and design, safety, etc., with some representation from TRB (Transportation Research Board), FHWA (Federal Highway Administration), MPOs (Metropolitan Planning Organizations), and universities. Figure provides a representation of the geographical distribution of the Workshop participants. A total of 18 states plus the District of Columbia, Maricopa County, Arizona, and the New Jersey Transportation Planning Authority, were represented.

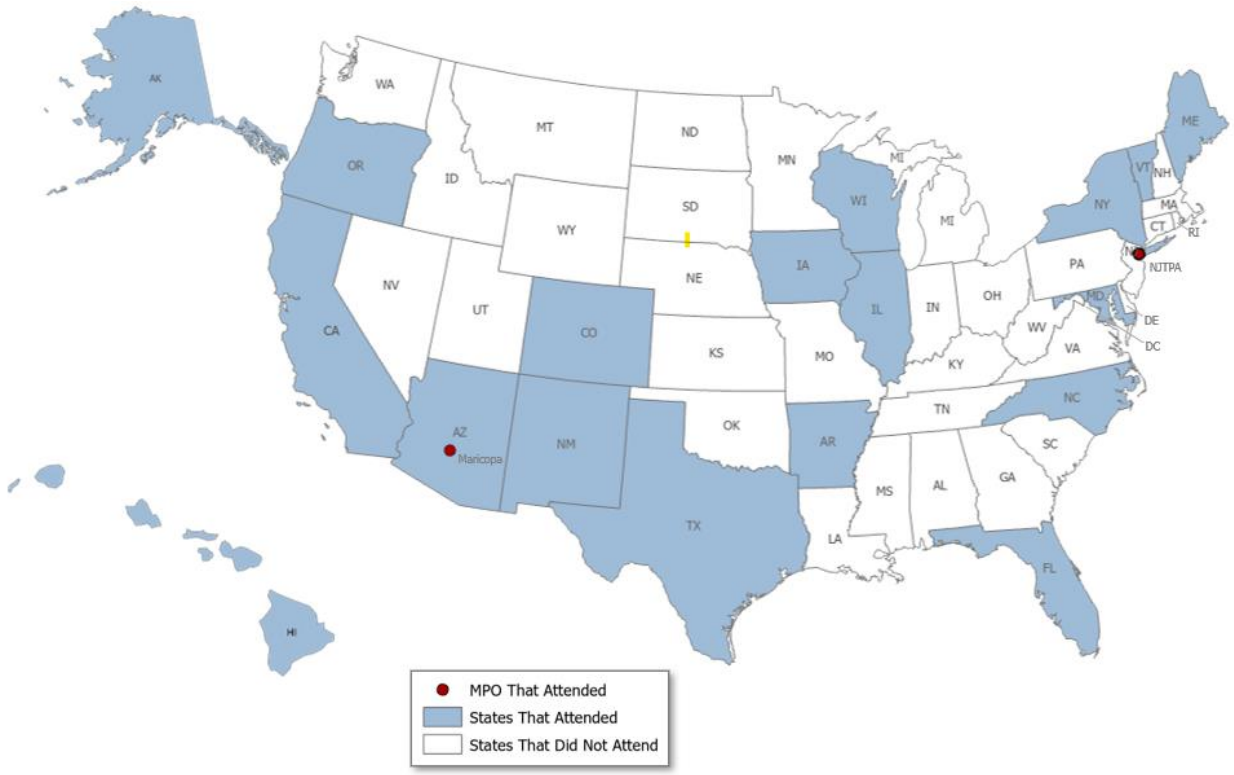


Figure 64

Figure 64. Map of Spacial Distribution of Work Workship Attendees

Content and Logistics

The content of the workshop included participants and research team introductions, overview of the project objective, review of project accomplishments to date, guide components, workshop overview, polling questions, discussions, and next steps.

The guide's key components include the 6 Key Building Blocks or strategies for incorporating resilience into planning, the roadmap, and the Capability Maturity Framework (CMF). The workshop focused on presenting and soliciting feedback on tasks/actions proposed to support the 6 Key Building Blocks or strategies. The 6 strategies are:

4. Leadership and Agency Structure
5. Capacity and Competency
6. Collaboration and Communication
7. Resource Requirements
8. Risk and Resilience Assessment
9. Business Processes

The 6 strategies were subdivided into sub-strategies when appropriate. A total of 71 task/actions were proposed to support the strategies/sub-strategies and to be validated and discussed with the Workshop participants. For a complete breakdown, see Table 35. The complete list of tasks is included in Appendix 3, Read Ahead.

Table 35. Breakdown of Strategies and Number of Supporting Tasks

Resilience Strategy	Sub-Strategy	Number of Tasks
Leadership and Agency Structure	Leadership	6
	Agency Structure	5
Capacity and Competency	--	7
Collaboration and Communication	Collaboration	5
	Communication	3
Resource Requirements	Staffing	3
	Data Management	6
	Tools and Technology	6
	Funding	4
Risk and Resilience Assessments	--	16
Business Processes	--	10

The tasks were presented during the workshop via a PowerPoint slide show. Tasks were grouped and presented by strategy. Following the presentation of all the tasks for a given strategy, the workshop participants were asked to log into Mentimeter and vote on the importance of each task/action on a scale from 1 (strongly disagree) to 5 (strongly agree) using the slider widget. After voting on a set of tasks, the participants were able to see the polling results and were given the opportunity to ask questions and provide feedback. This cycle was repeated until all the tasks for all 6 strategies were presented.

Polling Overview

Through the series of polls related to each of the strategies, valuable feedback was collected regarding the importance of the proposed tasks/actions and how they might be improved.

Key Takeaways

Some of the key takeaways from the discussions that followed each poll include:

- Making the business case for resilience for the executive leadership is crucial.
- Establishing a dedicated resilience organization within the agency may not be realistic; therefore, it is more important to foster a culture of resilience throughout the agency.

- Resilience should be integrated at program level.
- Policy directives are useful for promoting resilience initiatives.
- Historical data capture for supporting risk and resilience model development is a challenge because of the bias towards only recording large events. There needs to be a process for capturing data pertaining to small events.
- Agencies should conduct after action reviews following events to capture lessons learned.
- Qualitative assessments may still be useful, especially at the planning level.
- The guidelines should include case studies that highlight best practices.

Polling Questions

Below are the questions and responses corresponding to each of the six Key Building Blocks identified by the research team.

Strategy/Building Block 1: Leadership & Agency Structure

This segment presented tasks to support the strategy for encouraging leadership and agency structure actions. Leadership is the art of motivating staff. Leadership endorsement of resilience initiatives is key to successfully incorporating resilience into agency goals, programs, and business processes. A total of 24 participants voted on tasks related to leadership (see Figure 655).

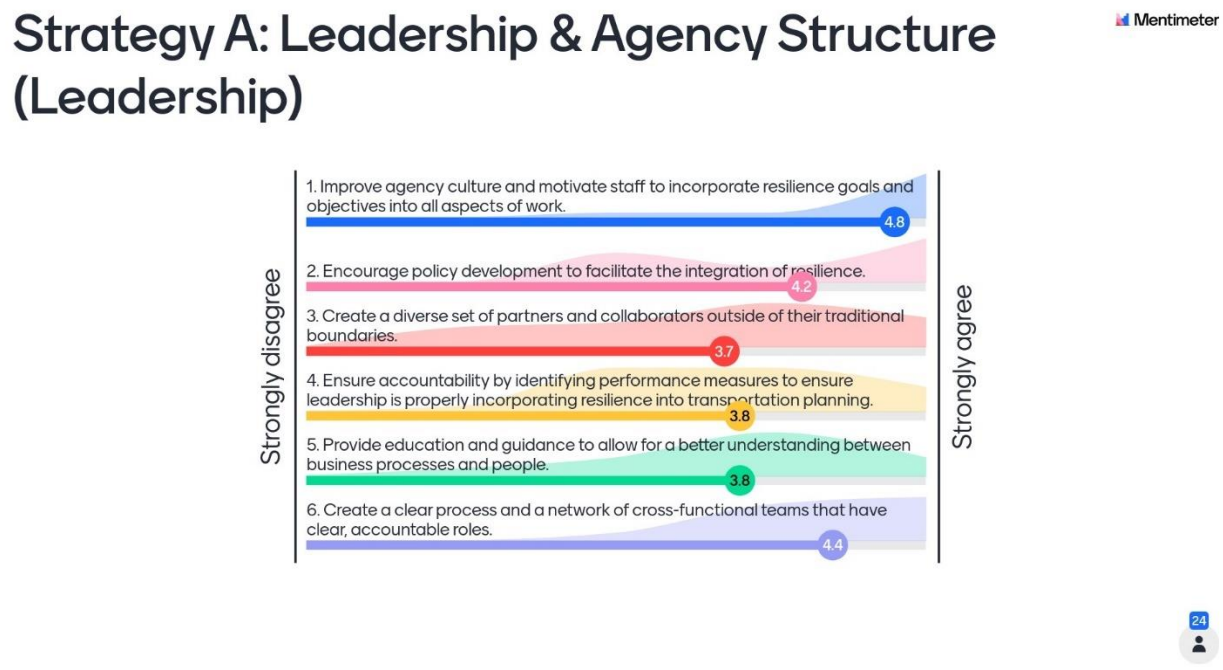


Figure 65. Polling Results - Leadership

The most popular task for leadership was task #1, "Improve agency culture and motivate staff to incorporate resilience goals and objectives into all aspects of work", with an average score of 4.8. The least popular task was task #3, "Create a diverse set of partners and collaborator outside of their traditional boundaries." Following the voting, one DOT representative indicated that his vote was not based on whether a task is important but whether it is a function of leadership. The research team responded that participants should vote on each task with both approaches in mind: 1) relative

importance and 2) whether the proposed task is representative of the strategy at hand. The research team further suggested that a task needs to be a core function of leadership but also needs to be helpful in promoting resiliency within the agency. Another state DOT representative mentioned that the tasks can be hierarchically related, i.e., one might need to be implemented prior to implementing another. Key take-aways from the conversation on leadership are that agencies absolutely need resilience champions, leadership buy-in (at state DOT level and above), and funding.

Next, the discussion turned to barriers to implementing tasks related to leadership. One participant pointed out that timing is key. Incorporating resilience into planning is a long-term project and cannot be accomplished in fits and starts. Common barriers mentioned included: 1) failure to recognize resilience as a priority, 2) personnel turnover within leadership, and 3) restrictions on resources. Finally, one participant stressed the need to make the business case for resilience and another brought up the value of incorporating resilience goals into policy directives.

The second set of tasks under leadership and agency structure focused on agency structure. Agency structure is reflected by the organizational chart – who reports to who and who is responsible for what.

A total of 22 responded to this poll. Polling on tasks related to agency structure revealed that the most popular task was task #5, "Develop operational and strategic goals and objectives around resilience that are aligned with agency performance" while task #1, "Restructure the organization to allow for a more resilience focused agency", was least popular (see Error! Reference source not found.66).

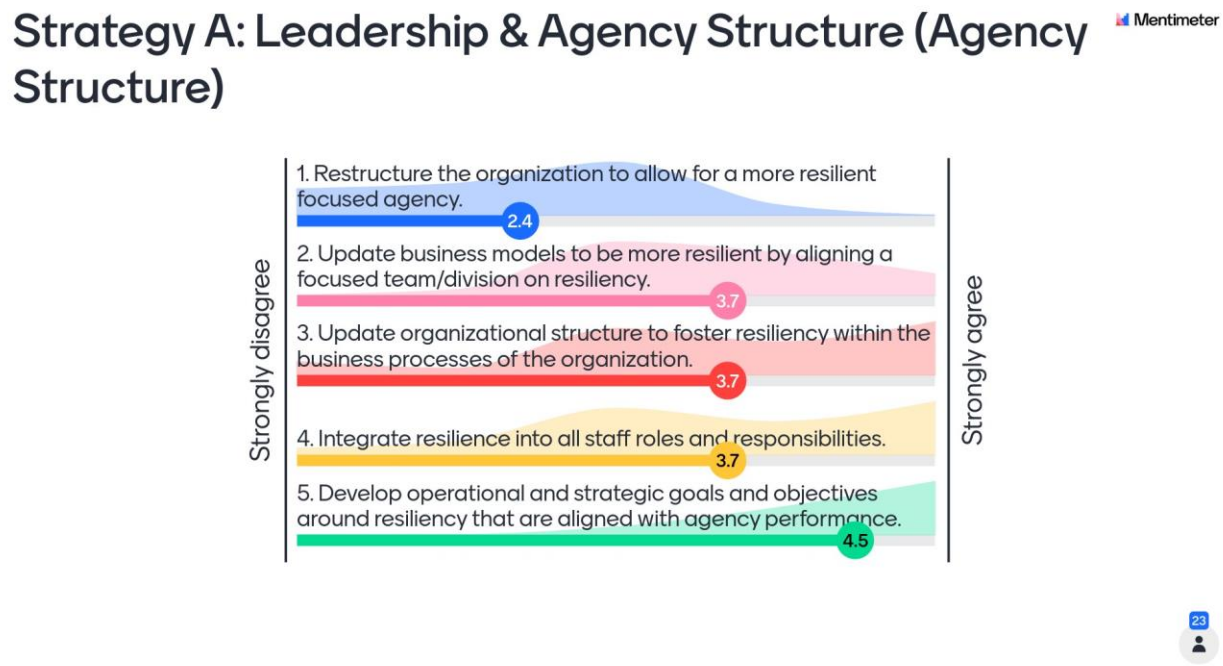


Figure 66. Polling Results - Agency Structure

Key points made during the discussion included:

- Transportation agencies might need a chief sustainability officer, at the director or deputy director level, to take charge of resiliency initiatives.

- Dedicating one or two people to taking responsibility for resiliency initiatives might not be enough. Agencies need to embrace a resilience culture.
- Some DOTs are too small to create a dedicated resilience organization.
- Competing priorities are a barrier to adopting resilience initiatives.
- Another barrier is politics. For example, not everyone is on board with planning for impacts that may not materialize until well into the future, such as climate change.
- Transportation agencies need the federal government to make changes to design standards. Engineers rely on design manuals and guidelines. Resilience needs to be incorporated into that information.

Strategy/Building Block 2: Capacity and Competency

This segment was devoted to addressing tasks intended to help raise the maturity of an agency's capacity and competency to incorporate resilience into planning. A total of 22 participants responded to this poll. The most popular task was task #7, "Foster an agency wide culture which demonstrates dedicated support for resilience efforts, collaboration, coordination, and rewards" and the least popular was task #6, "Recognize and foster conservatorship of agency corporate knowledge." (See Figure 69**Error! Reference source not found.**).

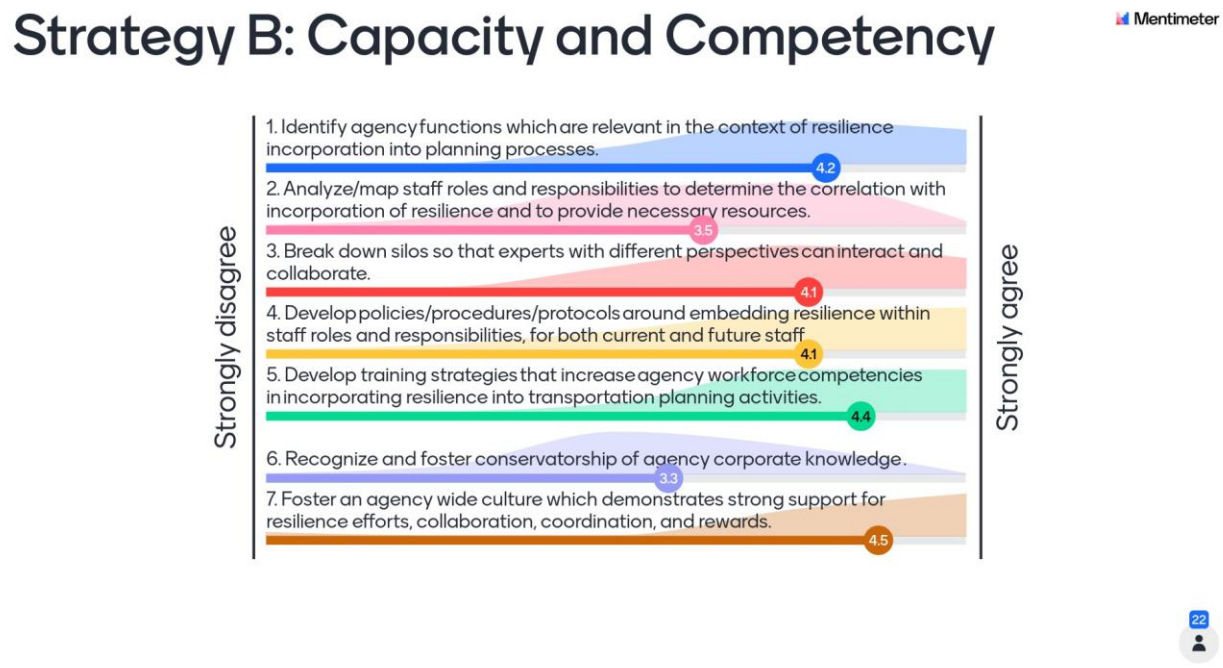


Figure 67. Polling Results - Resource Requirements (Capacity and Competency)

Key points made during the discussion included:

- Agencies need information on the Resiliency Improvement Plan.
- After-action reviews after events are important to capture what went wrong and create improvement plans and a database.
- The problem with task #2, "Analyze/map staff roles and responsibilities to determine the correlation with incorporation of resilience and to provide necessary resources", is staff turnover.

- The problem with task #6, "Recognize and foster conservatorship of agency corporate knowledge", is that by the time knowledge is documented it is likely obsolete. Change occurs too rapidly.
- Perhaps the real failing is the lack of a system in place to document knowledge.
- Agencies need ways to track the progress of resilience initiatives: metrics, gap assessment, key performance indicators, etc.
- Agencies need strategies for identifying high risk hazard areas to help with project prioritization.
- Agencies need to consider not only natural hazards but other emerging threats as well, such as cyber. Along similar lines, agencies should identify their target hazards before capacity building.

Strategy/Building Block 3: Collaboration and Communication

This segment topic focused on communication and collaboration efforts exercised by the agency (both internally and externally) for incorporating risk and resiliency into their planning efforts and what strategies are in place and to what level are they followed through on.

A total of 24 participants responded to this poll (see Figure 68. Polling Results - Collaboration and Communication). The most popular task was task #2, "Identify intra-agency stakeholders and develop collaborative strategies", while the least popular was task #4, "Identify and develop collaboration strategies between private and public sectors".

Figure 68. Polling Results - Collaboration and Communication

Key discussion points include:

- Agencies should use after-action reviews to identify gaps and what research is needed for disaster recovery, but after-action reviews might become politically influenced or sensitive. Therefore, a key issue is how these reviews will be used and who is responsible.

Strategy/Building Block 4: Resource Requirements

This segment topic focused on the agency's resources, or lack of resources, for incorporating risk and resiliency into their planning efforts and what resources are available and required. The first resource requirement to be addressed was staffing. Twenty-two participants participated in this poll (see Figure 69). There were only three tasks associated with this strategy, with task #3 being the most popular, "Develop training programs for professional development and skill enhancement," while task #2, "Develop an effective knowledge management program to preserve and disseminate institutional knowledge" the least popular.

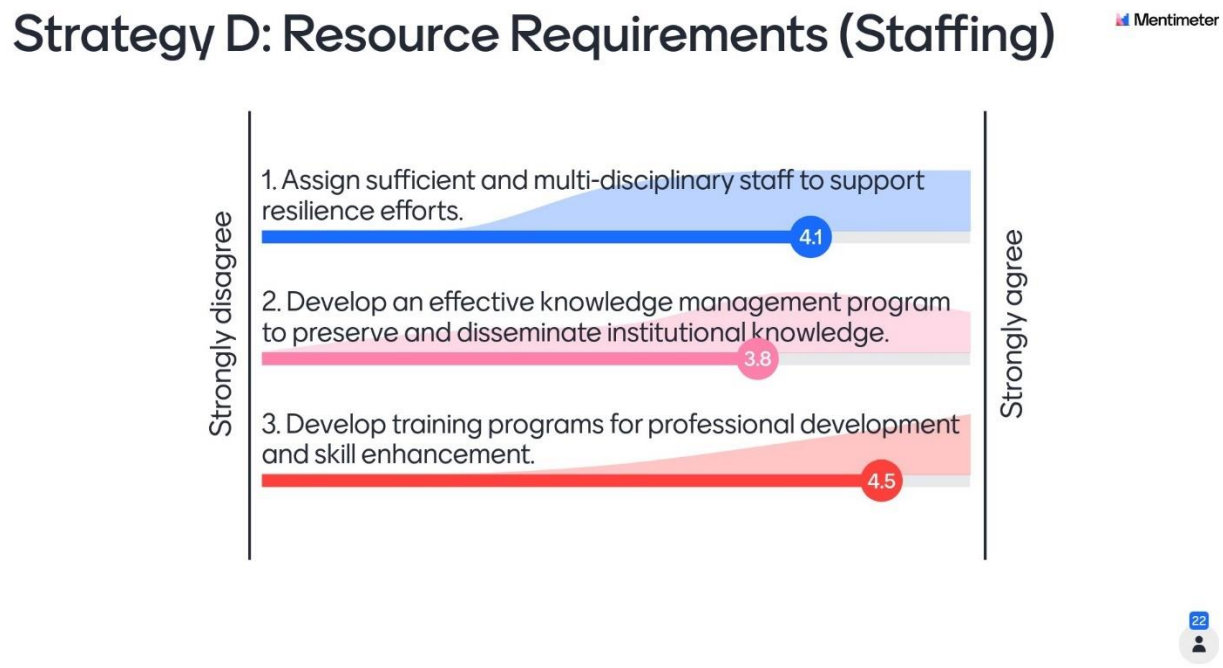


Figure 69. Polling Results - Resource Requirements (Staffing)

Key points of discussion included:

- A problem with assigning specific staff responsibility for resilience gives other staff members an excuse to say, "It's not their job."
- Some agencies do not have the capacity ("bandwidth") to address resilience.
- If a person is assigned the responsibility for administering resilience programs, it may need to be a high-level administrative position.
- Some state DOTs do not have a dedicated resilience program but a multi-discipline approach – resilience is spread across the agency, disciplines, and functional areas. For example, North Carolina has an interagency team that meets monthly to coordinate. Executive leadership is needed to help implement resilience from planning to operations.
- Having policy directives supporting resilience programs and executive leadership support is helpful.

- The aftermath of a disaster can provide momentum for fortifying a resilience program and opportunities to enhance the system's resilience.
- Expertise within an agency can become siloed. As a result, different pockets of expertise remain insular. An example is cybersecurity.

This segment addressed tasks designed to help agencies find funding mechanisms. A total of 21 participants responded to the poll (see **Error! Reference source not found.**). The most popular task was task #4, "Develop a business case for resilience to justify resilience initiatives." At the same time, the least favorite is task #2, "Assign a specific budget from transportation planning or projects to support resilience efforts".

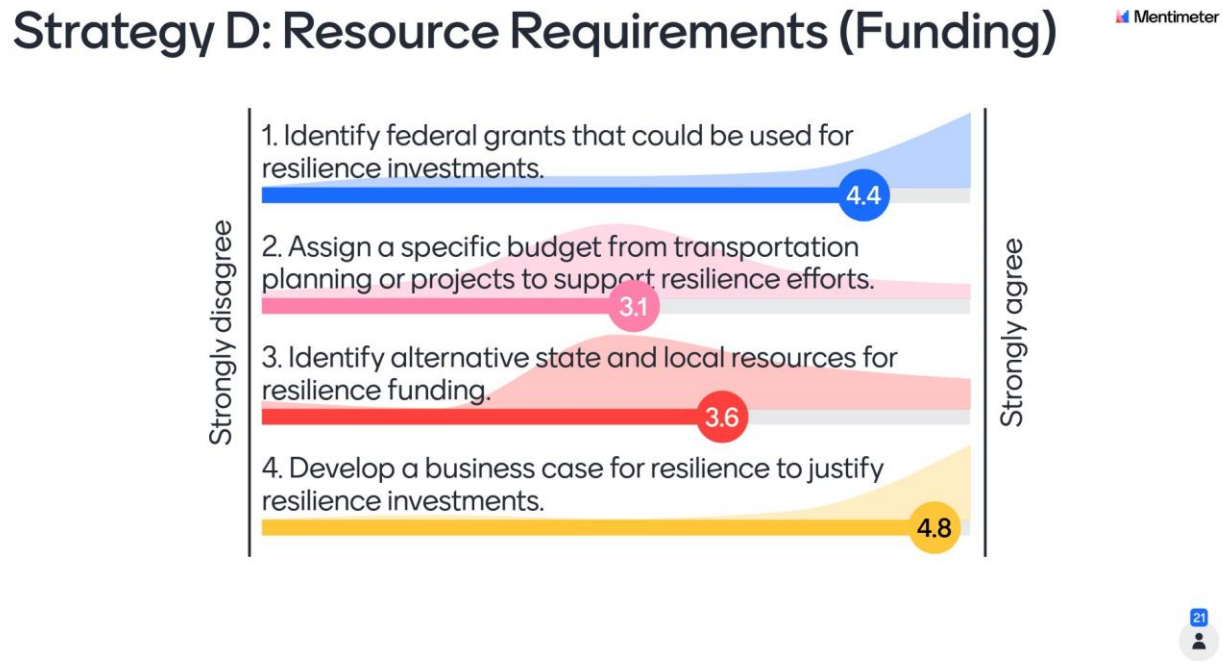


Figure 70. Polling Results - Resource Requirements (Funding)

Key discussion points included:

- The participants seemed unanimous in recognizing that making the business case for resilience is especially important. It was recommended that resilience should be included in the criteria used to prioritize projects.
- There is a need for a research problem statement to address benefit-cost analysis for the environmental permitting process.
- The research team noted an active NCHRP project that addresses making the business case for resilience, NCHRP 20-127.

This segment addressed the systems needed to collect, store, and curate the data required for risk and resilience assessment. A total of 18 participants responded to this poll (

Figure 71). The most popular task was task #3, "Develop and implement a formal data collection process for historical damage/maintenance data." In contrast, tasks #5 and #6 were the least popular, "Configure tracking systems to create metrics" and "Identify means to gather better data at lower cost," respectively.

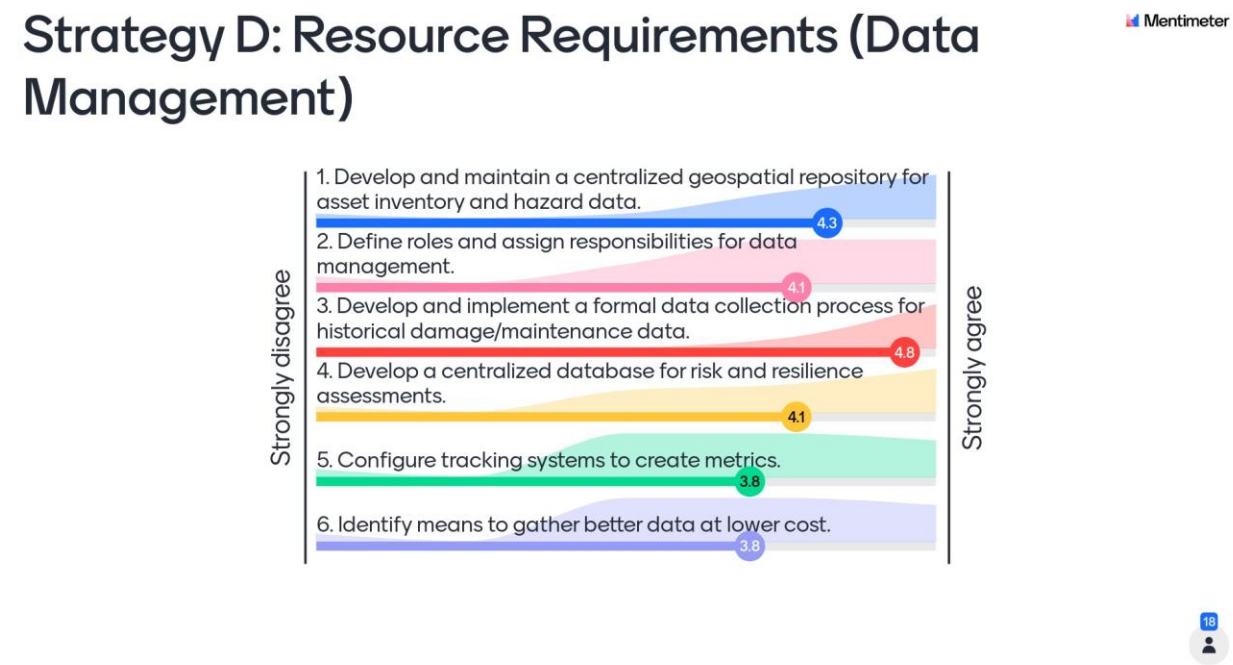


Figure 71. Polling Results - Resource Requirements (Data Management)

Key discussion points included:

- One MPO highlighted its online GIS (Geographical Information Systems) mapping application, which enables users to visualize flood projects, road closures, and information.
- DOTs should not wait to acquire the perfect data set. Instead, analysis can begin with data on hand for initial planning.
- Data used for section 667, "twice damaged assets," is heavily biased because a threshold must be exceeded to get an event to qualify for a grant.
- When recording data, maintenance personnel do not usually correlate damage with a cause or specific event.
- Damage data that is recorded tends to be biased towards larger events. There is a process gap because data will not likely be collected for small events.

This segment was concerned with the tools and technology needed to conduct risk and resilience assessments and economic analyses. A total of 21 participants responded to the poll (**Error! Reference source not found.**). The most popular task was task #5, "Employ cost-benefit analysis tools to support investment decisions in resilience." In contrast, the least popular was task #4, "Employ travel demand modeling tools to support risk and resilience assessments."

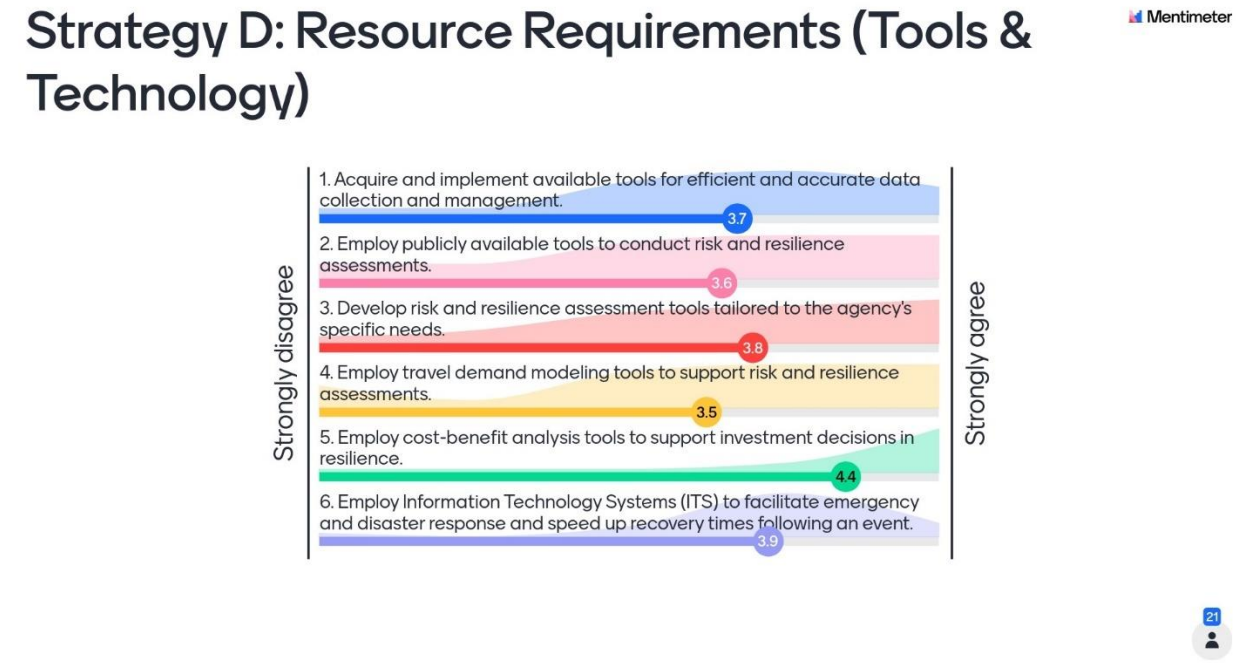


Figure 72. Polling Results - Resource Requirements (Tools & Technology)

Key discussion points include:

- One DOT stated that using big data and data mining for different natural hazard scenarios is unlikely if 1) the DOT must pay for the data set and 2) the DOT does not understand or have confidence in the data set.
- DOTs need to emphasize the need for better integration of engineering with climate science at the planning level and the need for data-rich tools.
- There are gaps in available data, especially floodplain data for stream reaches not covered by FEMA flood maps.
- DOTs must share and build off each other's efforts rather than re-invent the wheel.
- Resilience initiatives should be pushed at the program rather than the project level.

NOTE: Some discussion points in this section were related to other strategies.

Strategy/Building Block 5: Risk and Resilience Assessments

This section addressed the methodologies and components of risk and resilience assessments. There was a total of 16 proposed tasks, divided into two groups. A total of 20 participants responded to a poll covering the first 8 tasks (see **Error! Reference source not found.**). Task #5 and task #8 tied for most popular, "Characterize threats and hazards to identify potential problem areas" and "Conduct vulnerability assessments to identify assets/areas susceptible to identified threats/hazards," respectively. The least popular task was task #3, "Assign responsibility for risk and resilience assessments."

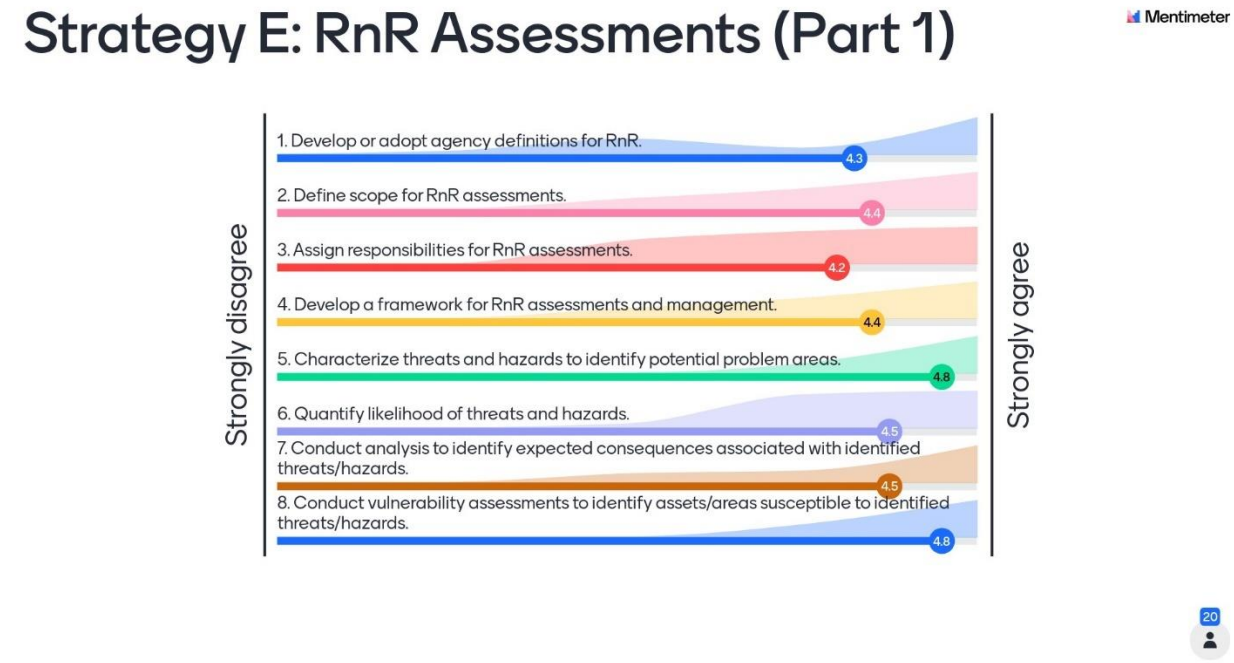


Figure 73: Polling Results - RnR Assessments (Part 1)

Nineteen participants responded to the poll covering the second set of risk and resilience assessment-related tasks (see Error! Reference source not found.). The most popular task was task #13, "Identify resilience improvement strategies," while the least popular was task #10, "Characterize and incorporate the uncertainty of RnR analysis."

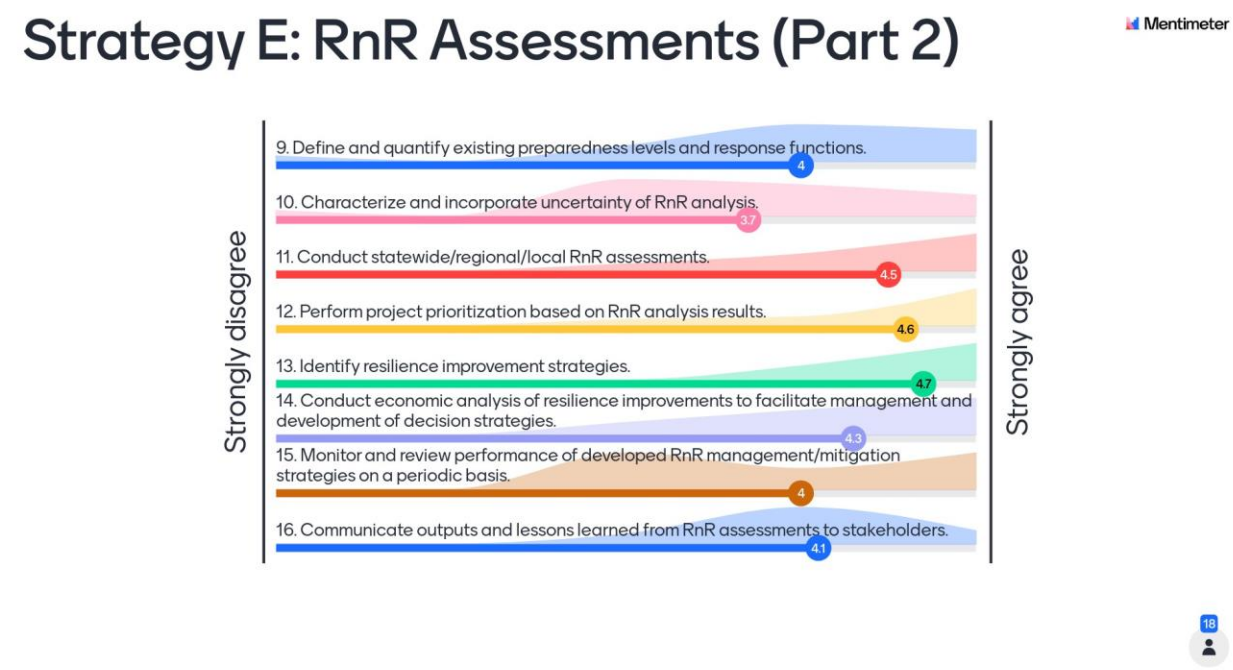


Figure 74. Polling Results - RnR Assessments (Part 2)

Key discussion points included:

- Developing a definition of resilience is difficult. Therefore, it might be better to begin doing assessments and create an agency definition later.
- One DOT noted that their agency adopted a definition for resilience developed by the State and applying that definition to DOT-specific issues is difficult.
- Other DOTs agreed. There is no need to waste time arguing over definitions, or on which hazards to focus. What is essential is determined by leadership.
- The research team noted a correlation between resilience and its impact on sustainability.
- Qualitative assessments can still have value as an initial screening tool at the planning level. However, more robust methods may be suitable for the project level. Whether a qualitative, quantitative, deterministic, or probabilistic approach is taken depends upon the need.
- Quantitative approaches facilitate prioritizing risks.
- Connecting system-level assessments to project-level assessments is essential.

Strategy/Building Block 6: Business Processes

This section addressed business processes as an overarching strategy to elevate resilience within an agency. Business process-related tasks were divided into two groups of 5. A total of 17 participants responded to the first poll (**Error! Reference source not found.**). The most popular task was task #5, "Incorporate statewide/regional/local RnR evaluation to identify most vulnerable parts of the system for potential project solution." In contrast, the least popular task was task #3, "Perform state of review to establish current resilience initiatives by other agencies."

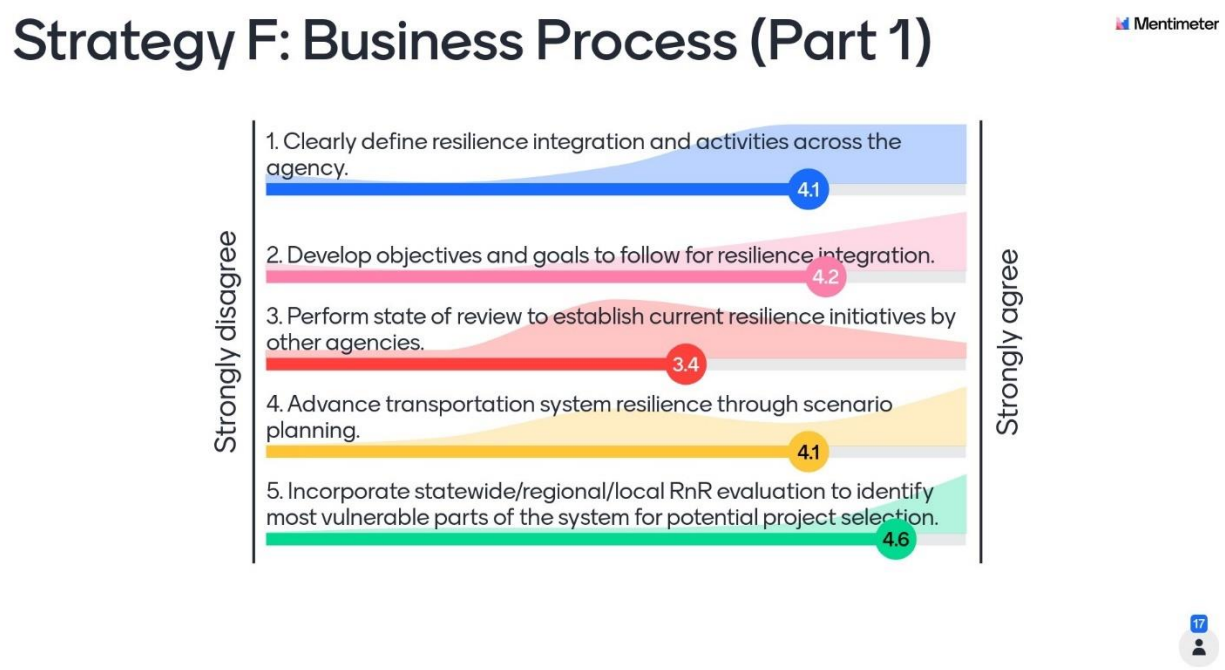


Figure 75. Polling Results - Business Processes (Part 1)

A total of 16 respondents responded to the poll covering the second set of business process-related tasks. The most popular task was task #10, "Provide guidance documents to ensure an understanding of resilience activities across the agency". In contrast, task #6 was the least popular, "Conduct risk and resilience screening of the entire state project inventory during the initial planning phase before selecting final projects for planning" (See Error! Reference source not found.).

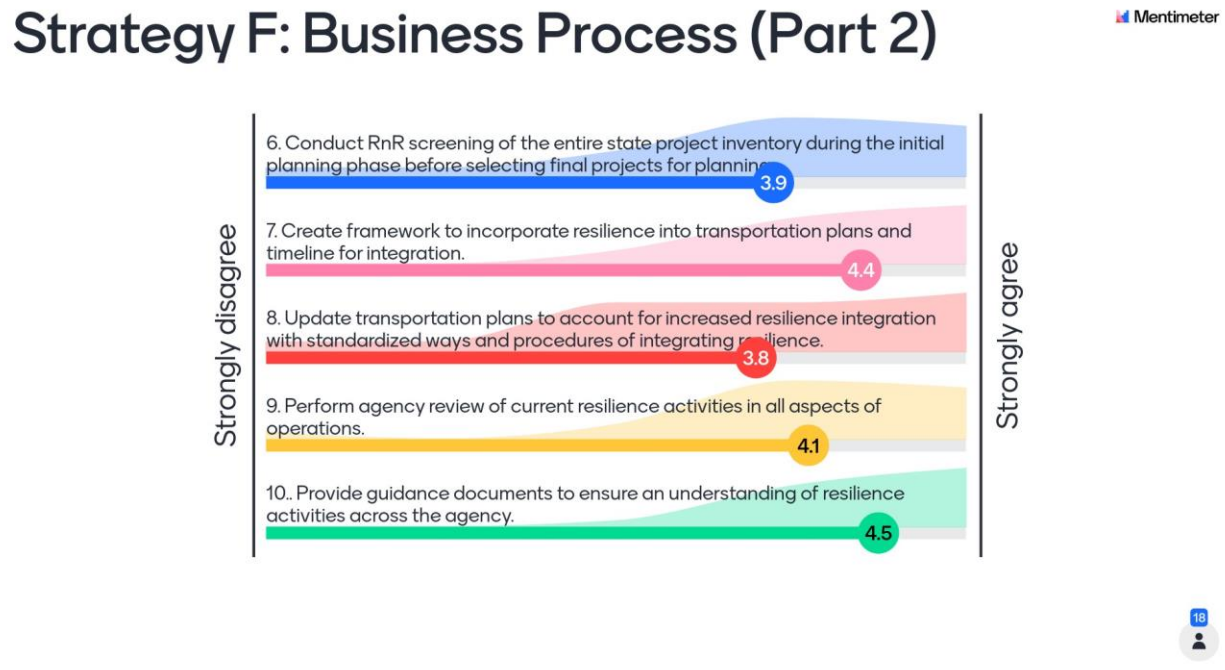


Figure 76. Polling Results - Business Processes (Part 2)

Key discussion points included:

- One DOT pointed out that a missing business process is an integration with maintenance and data. What is the business process for gathering the agency's data?
- A system is needed to document issues as they happen.

Closing Questions

Finally, the participants were asked to give an assessment of the tasks overall, grading the functions according to a qualitative scale, from "Love it" to "Hate it" (Figure 77). A total of 15 participants responded, unanimously voting, "Love it!".

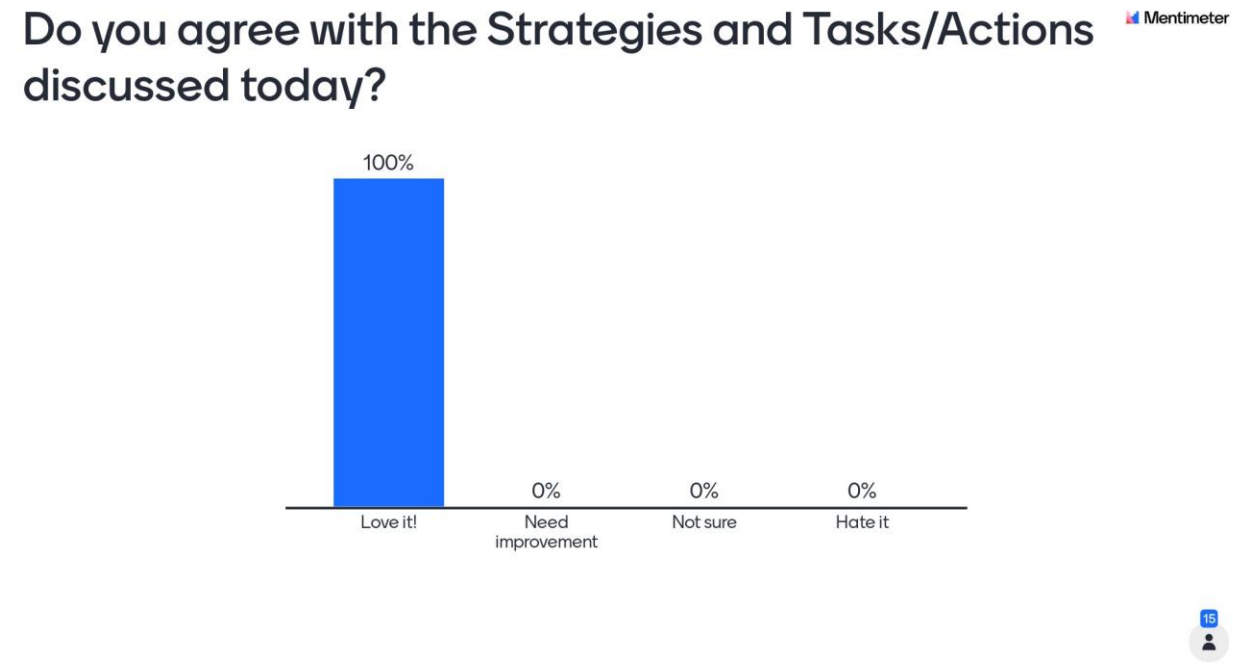


Figure 77. Polling Results – Do You Agree with the Strategies & Tasks Presented?

In closing, the participants were asked to make comments or suggestions for the guide. A total of 18 participants responded (see **Error! Reference source not found.**8 and Figure 79. **Polling Results (b) – Provide Final Comments or Suggestions**

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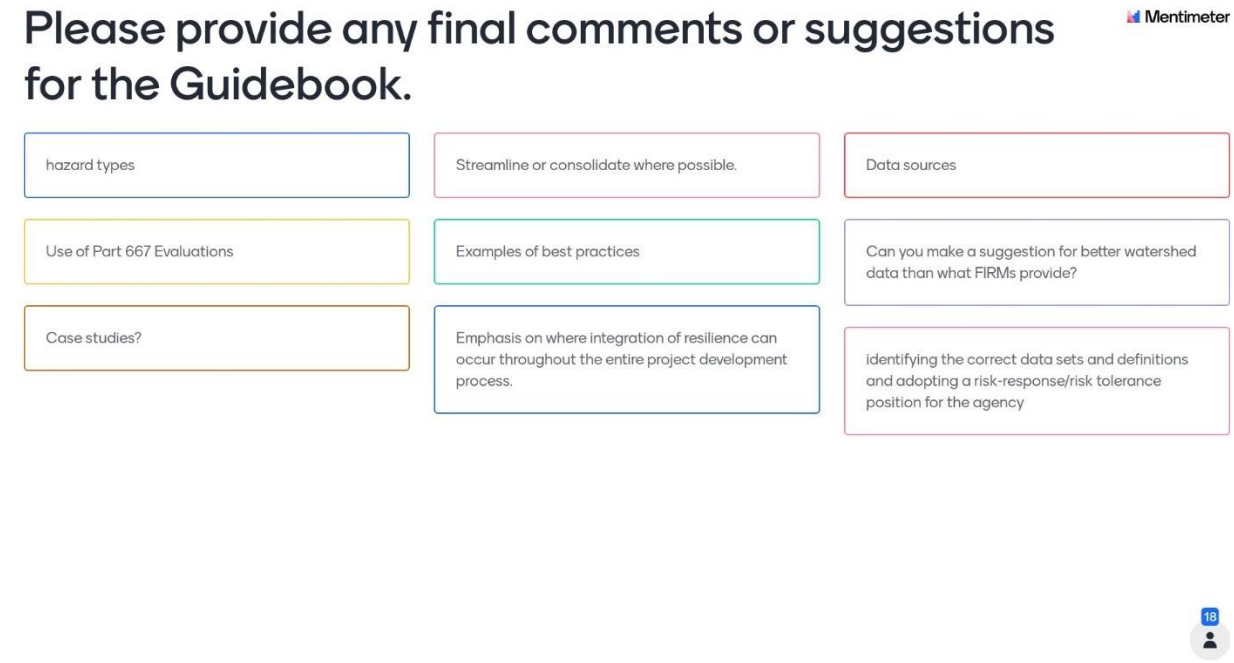

Figure 78. Polling Results (a) – Provide Final Comments or Suggestions

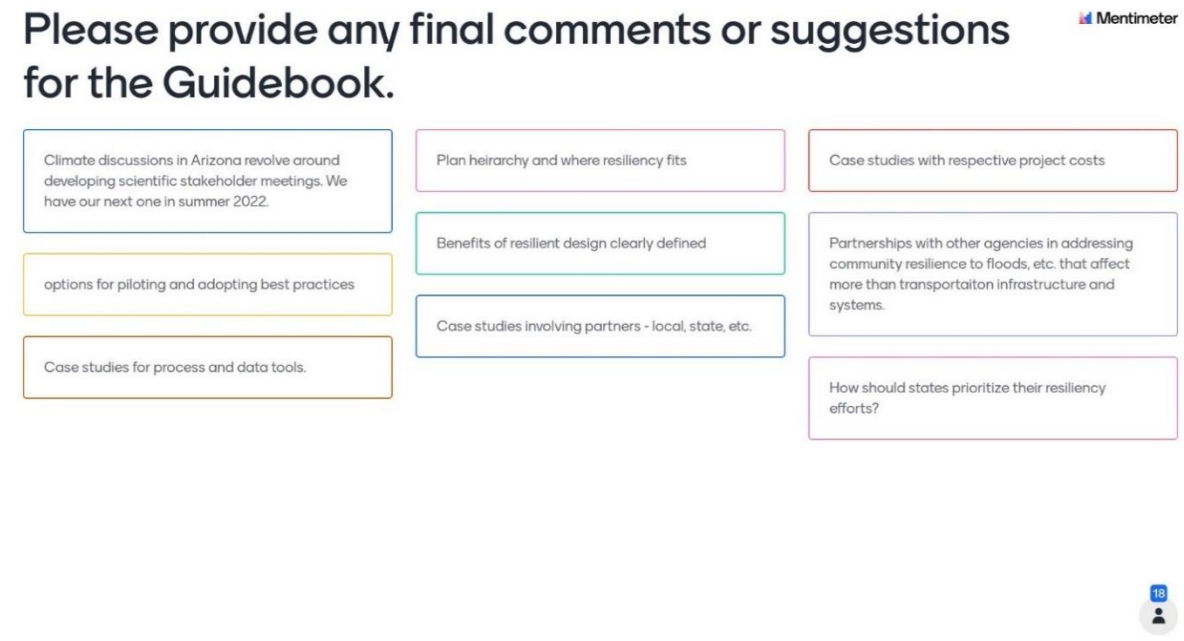

Figure 79. Polling Results (b) – Provide Final Comments or Suggestions

Here is the total list of 18 comments as provided by the participants regarding their final comments of suggestions for the guide:

- Hazard types

- Streamline or consolidate where possible
- Data sources
- Use of Part 667 Evaluations
- Examples of best practices
- Can you suggest better watershed data than what FIRMS provides?
- Case studies?
- Emphasis on where integration of resilience can occur throughout the entire project development process.
- Identifying the correct data sets and definitions and adopting a risk-response/risk tolerance position for the agency.
- Climate discussions in Arizona revolve around developing scientific stakeholder meetings. We have our next one in the summer of 2022.
- Plan hierarchy and where resiliency fits.
- Case studies with respective project costs.
- Options for piloting and adopting best practices.
- The benefits of the resilient design are clearly defined.
- Partnerships with other agencies in addressing community resilience to floods affect more than transportation infrastructure and systems.
- Case studies for process and data tools.
- Case studies involving partners – local, State, etc.
- How should states prioritize their resiliency efforts?

Email Workshop Invitation

Dear ……,

The research team for the NCHRP 08-129 – *Incorporating Resilience into Planning* would like to invite you to participate in a virtual Industry Workshop to help us validate the roadmap and strategies needed to incorporate Resilience into Transportation Planning.

After the passing of the new *Infrastructure Investment and Jobs Act* (IIJA) requiring that USDOT establishes a risk and system resilience assessment intergovernmental process, now more than ever, state DOT need information on how to incorporate resilience into their decision-making process and activities.

The main objective of the NCHRP 08-129 project is to develop a guide on how transportation agencies can integrate resiliency planning into decision-making. The guide will include:

- Identification of data sources and gaps as well as analytical tools and techniques to facilitate proactive and effective resilience planning
- Identification of obstacles to incorporating resilience into state DOT transportation planning and decision-making
- Identify how state DOTs integrate and share resilience planning procedures with other agencies/modes
- Effective roadmap to help transportation agencies incorporate resilience efforts and approaches into transportation planning
- Key Building Blocks to advance resilience efforts in transportation planning
- Capability Maturity Framework to measure agency maturity level and needs for incorporating resilience into transportation planning
- The process of integrating resilience planning into existing institutional practices

Workshop Details

When: December 15, 2:00 pm – 5:00 pm ET.

Where: Invitations with details will be sent to registered participants. **Please save the date!**

How: Please REGISTER **by November 26**. If you feel there is someone else in your agency that would be a good fit for this workshop, please let us know, and we can send an invitation.

Once again, thank you for helping advance the incorporation of Resilience in Transportation Planning.

If you have any questions, please don't hesitate to contact me.

Best regards,
Maria
(PI for NCHRP 08-129)

Wufoo Attendee Registration Page

NCHRP 08-129 Industry Workshop

The NCHRP 08-129 project is developing a Guidebook to help transportation agencies to incorporate Resilience into Transportation Planning. The objective of this Workshop is to obtain feedback from practitioners to validate the Roadmap and strategies developed during this research project.

Name

Last Name

Affiliation

Title

Department

Phone Number

– ### –

email

Please explain your interest in participating in the Industry Workshop.

Submit

Read-Ahead Material

Read-ahead Material for

NCHRP 08-129 Industry Workshop

Validation of Strategies/Actions for Incorporating Resilience in Transportation Planning

Background

The aftermath of such disasters as Hurricane Katrina and the September 11 Trade Center Bombing, as well as the resulting regulatory drivers such as MAP-21, FAST Act, and the new Infrastructure Investment and Jobs Act (IIJA) have compelled transportation agencies to consider resilience when developing their transportation plans and programs. Unanticipated adverse events result in disruptions that impede a transportation agency's primary mission of providing mobility to the traveling public. Therefore, transportation agencies need to plan and prepare for the unexpected. Incorporating resilience into planning enables a transportation agency to be proactive. Research has shown that for every dollar invested in resilience 6 dollars are saved. Thus, benefits of incorporating resilience into planning include improved reliability, safety, shorter recovery times following disruptions, and economic losses avoided thanks to pre-planned investments.

Project Objective

This research project aims to develop a guide to help state DOTs and other transportation agencies integrate resilience concepts into transportation planning efforts. Phase I of this project included researching the State of the practice through literature review and stakeholder engagement and identifying gaps and needs in incorporating resilience into planning. Phase II consisted of developing the guide and implementation and communication materials.

Workshop Objectives

The workshop's main objective is to validate the proposed strategies and tasks to be developed and utilized in the guide to help state DOTs incorporate resilience into transportation planning.

The core elements to be discussed at the workshop include:

- Key Building Blocks/Strategies
- Tasks associated with Key Building Blocks/Strategies

- Key Building Blocks/Strategies

Error! Reference source not found. illustrates the six Key Building Blocks/Strategies required for effective integration. Description of each of the Key Building Blocks/Strategies are provided below.

Figure 80. Key Building Blocks/Strategies for Effective Integration of Resilience into Planning

A. Leadership and Agency Structure

Leadership and Agency Structure is part of the key building blocks for the successful incorporation of resilience into transportation planning. Leadership and Agency Structure considers the organizational structure of an institution and the level of support and endorsement by leadership. Agency structure determines how the roles, power, and responsibilities are assigned, controlled, and coordinated and how information flows between the different levels of management. Leadership is the art of motivating staff toward achieving a common goal, directing the entire agency toward strategies to move the agency's broader goals forward. Agency leadership helps to support and progress toward integrating resilience strategies within transportation planning and helps to modify its organizational structure and policies to facilitate the integration of resilience. The needs and goals of individual departments and functions are incorporated into Agency strategy to ensure the long-term success of resilience integration into planning and create a resilience understanding and culture.

B. Capacity and Competency

Transportation agencies need the right capacity and competency to effectively integrate resilient strategies within transportation planning. This refers to the people managing the organization's resilience effort and those doing the work of incorporating resilience strategies throughout transportation planning. Employees have the skills and training to understand and support their roles in incorporating resilience. In addition, expectations and incentives for employees and groups should be tied to effectively integrating resilience within planning. Agency leadership must show strong support for resilience efforts and motivate staff to participate. Staffing needs should be regularly evaluated to ensure that new roles are created, and existing roles are modified to support evolving requirements within resilient

strategies/practices, and mitigation techniques. Furthermore, it is important that knowledge retention tools and succession planning are woven into Agency policy and structure.

C. Collaboration and Communication

Collaboration and communication with different internal groups within a transportation Agency (e.g., planning, operations, emergency response, asset management, engineering, maintenance, etc.) and with other agencies (e.g., MPOs, transit agencies, freight agencies, utility owners and operators, etc.), stakeholders and the public, are key factors to implement resilience within an Agency, into transportation planning. Creating these relationships and collaboration processes helps to identify the different problems and needs in different agencies and the community and helps develop resilience strategies and plans to make more effective and sustainable decisions in the long term.

D. Resource Requirements

Providing adequate, appropriate, and timely resources is vital in developing and succeeding in efforts to incorporate resilience into planning activities. Often shared challenges exist around the collection/provision of reliable data and its management via information and communication technology (ICT) systems, flexible programming, provision/development of appropriate analysis tools, funding, and staffing. To facilitate incorporating resilience into planning activities, relevant data sources, computing facilities, funding, and human resources are made available in an appropriate and timely manner. Here there is room for considerable innovation to be applied to maximize the potential of available resources. Furthermore, providing necessary and appropriate resources to facilitate professional training and development of current and future staff is vital in developing expertise and champions for resilience-related efforts/activities.

E. Risk and Resilience Assessments

Risk and Resilience (RnR) assessments are a key building block for incorporating resilience in transportation planning. RnR assessments are a critical responsibility/activity of and for DOTs. Different agencies conduct these assessments using different approaches and at different levels. However, the application of RnR assessments in transportation planning varies amongst agencies, with some employing the analysis at a project level but not necessarily in detailed planning activities. As an essential criterion, the scope and boundaries of the analysis should be identified and clearly defined. The outputs of the analysis can facilitate prioritization activities to be identified. To perform RnR analyses, it is necessary to understand asset and corridor vulnerabilities and to consider criticality in the face of relevant hazards and threats. Assessments may be performed in a qualitative or quantitative sense or as a combination of these depending upon the objective of the analysis, the scale considered, and the available information. Qualitative methods are typically more suited to the assessment of a network or system rather than an assessment of individual elements. They can be employed to provide information, identify high-level results, and facilitate comparative analysis. Quantitative tools can be beneficial as they provide an objective measure such that infrastructure components or networks may be analyzed in greater detail. However, this is commensurate with the level of effort required in the analysis. Quantitative analyses also have the advantage of quantifying and treating uncertainties in an appropriate context. The influence of uncertainty on the analysis results can be studied in detail and, where applicable, reduce the need to collect additional information. Key to both methodologies is the definition of appropriate thresholds against which the analysis outputs may be compared. This way, a range of actions can be considered and

prioritized from alternative perspectives, e.g., benefit-cost analysis. A significant benefit of quantitative assessments is the ability to rank alternative strategies in an objective sense subsequently.

F. Business Processes

A business process is a series of steps performed by a transportation agency team to achieve a goal. Each step in a business process denotes a task assigned to a team or staff member to ensure a tangible result. The business process within transportation planning ensures transportation plans, such as the Long-Range Transportation Plan, Mid-Range Plans, STIPs (Statewide Transportation Improvement Plan), Freight Plans, etc., provide some standardized ways and procedures of integrating resilience and that resilience is a component of the various planning documents within the agency. Therefore, business processes for resilience activities across the agency must be clearly defined, understood, and structured to incorporate resilience from a transportation planning perspective.

- Tasks

One of the objectives of the guide is to provide state DOTs with strategies and tasks that they can implement when creating an action plan to incorporate resilience into transportation planning. These tasks will be provided for each of the Key Building Blocks/Strategies helping agencies to increase their capability maturity in integrating resilience into their agencies and transportation planning. The initial tasks associated with each Key Building Block/Strategy are listed below.

A. Leadership and Agency Structure

Task No.	Description
Leadership	
1	Improve agency culture and motivate staff to incorporate resilience goals and objectives into all aspects of work
2	Encourage policy development to facilitate the integration of resilience
3	Create a diverse set of partners and collaborators outside of their traditional boundaries
4	Ensure accountability by identifying performance measures to track to ensure leadership is properly incorporating resilience into transportation planning
5	Provide education and information to allow for a better understanding between business processes and people
6	Create a clear process and a network of cross-functional teams that have clear, accountable roles
Agency Structure	
1	Restructure the organization to allow for a more resilient, focused agency

2	Update the business model to be more resilient by aligning a focused team/division on resiliency
3	Update organizational structure to foster resiliency within the business processes of the organization
4	Integrate resilience into all staff roles and responsibilities
5	Develop operational and strategic goals and objectives around resiliency that are aligned with agency performance

B. Capacity and Competency

Task No.	Description
1	Identify agency functions that are relevant in the context of resilience incorporation into planning processes
2	Analyze/map staff roles and responsibilities to determine the correlation with the incorporation of resilience and to provide the necessary scope and resources to facilitate integration
3	Break down silos so that experts with different perspectives can interact and collaborate
4	Develop policies/procedures/protocols around embedding resilience within staff roles and responsibilities for both current and future staff
5	Develop training strategies that increase agency workforce competencies in incorporating resilience into transportation planning activities/functions
6	Recognize and foster conservatorship of agency corporate knowledge
7	Foster an agency-wide culture, top-down and bottom-up, which demonstrates strong support for resilience efforts, collaboration and coordination and rewards the application of resilience-based initiatives in transportation planning activities

C. Collaboration and Communication

Task No.	Description
1	Establish a collaborative infrastructure and framework

2	Identify intra-agency stakeholders and develop collaboration strategies to further resilience efforts in multimodal transportation planning (e.g., the collaboration between planning, O&M, and engineering and design)
3	Identify inter-agency stakeholders and develop collaboration strategies to further resilience efforts in multimodal transportation planning (e.g., MPOs, transit agencies, cities, underrepresented communities, environmental groups, etc.)
4	Identify and develop resilience collaboration strategies between private and public sectors to further resilience efforts
5	Develop collaboration strategies between multi-sectors to identify dependencies and to further resilience efforts (e.g., energy, water, etc.)
6	Identify and develop shared goals and a mission statement to support resilience initiatives.
7	Develop a communication plan for resilience initiatives
8	Increase stakeholder engagement through the planning process (internal, external, and public)

D. Resource Requirements

Task No.	Description
Staffing	
1	Assign sufficient and multi-disciplinary staff to support resilience efforts
2	Develop an effective knowledge management (KM) program to preserve and disseminate institutional knowledge
Data Management	
3	Develop and maintain a centralized geospatial repository for asset inventory and hazard data
4	Develop and implement a formal data collection process for historical and infrastructure damage and repair, operational disruptions, safety, maintenance, and emergency data
5	Develop a centralized database for risk and resilience assessments
6	Configure tracking systems to create metrics
7	Identify means to gather better data at a lower cost

Tools and Technology	
8	Acquire and implement available tools for efficient and accurate data collection and management
9	Employ publicly available tools to conduct risk and resilience assessments
10	Develop risk and resilience assessment tools tailored to the agency's specific needs
11	Employ travel demand modeling tools to support risk and resilience assessments
12	Employ cost-benefit analysis tools to support investment decisions in resilience
13	Employ ITS to facilitate emergency and disaster response and speed up recovery times following an event
Funding	
14	Identify federal grants that could be used for resilience investments
15	Assign a particular budget from transportation planning or projects to support Resilience efforts
16	Identify alternative State and local resources for resilience funding
17	Develop a business case for resilience to justify resilience investments

E. Risk and Resilience (RnR) Assessment

Task No.	Description
1	Develop or adopt agency definitions for RnR
2	Define scope for RnR assessments (e.g., context, objectives and targets/metrics)
3	Assign responsibilities for RnR assessments
4	Develop a framework for RnR assessments and Management
5	Characterize Threats & Hazards (e.g., flooding, earthquake, extreme heat, pandemic, cyber security, climate change, etc.) to identify potential problems
6	Characterize Threats & Hazards (e.g., flooding, earthquake, extreme heat, pandemic, cyber security, etc.) to identify potential problems
7	Quantify the likelihood of threats and hazards

8	Conduct analysis to define and identify expected consequences (e.g., financial, environmental, societal, etc.) associated with identified threats and hazards
9	Conduct vulnerability assessments to identify what assets/areas are more susceptible to the identified threats and hazards
10	Define and quantify existing preparedness level and response functions
11	Characterize and incorporate uncertainty
13	Conduct RnR assessment (Qualitative, Semi-Quantitative, Quantitative, Deterministic/Probabilistic) to identify potential assets/areas that need resilience improvements
14	Perform project prioritization based on RnR analysis results
15	Identify resilience improvement strategies (e.g., multimodal solutions, infrastructure enhancement, emergency response plans, etc.)
16	Conduct economic analysis of resilience improvements (e.g., BCA) to facilitate management and development of decision strategies to reduce risk and enhance resilience
17	Monitor and review performance of developed RnR management/mitigation strategies periodically
18	Communicate outputs and lessons learned from RnR assessments to stakeholders

F. Business Process

Task No.	Description
1	Clearly define resilience integration and activities across the Agency
2	Develop objectives and goals to follow for resilience integration
3	Perform State of review to establish current resilience initiatives by other agencies
4	Include Resilience in Scenario planning
5	Incorporate RnR assessments as part of the screening process for the entire state project inventory during the earlier planning phase for project selection
6	Incorporate RnR assessment for project selection to be considered for the state project inventory.

7	Create a framework to incorporate resilience in transportation plans (e.g., STIP, LRTP (Long Range Transportation Plan), freight, multimodal plans, ER (Emergency Repair) plans, etc.) and a timeline for integration
8	Update transportation plans to account for increased resilient integration with standardized ways and procedures of integrating resilience within the agency (best practice)
9	Perform agency review of current resilience activities in all aspects of operations, as those activities can be reviewed and understood as it relates to transportation planning
10	Provide guideline documents to ensure an understanding of resilience activities across the agency (standard of operations procedure)

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