National Operations Center of Excellence

NOCoE Best Practices: Resiliency in Operations

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Concepts

INTRODUCTION

Resiliency of the transportation system has many facets that affect Transportation Systems Management and Operations (TSMO) in both asset development and implementation as well as execution of activities to respond and mitigate events. The term resiliency can be defined in a number of different ways depending on the type of organization and affected communities. In the transportation field there are two definitions that in combination capture the variety of elements to be considered:

- FHWA defines resilience as, "the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions."
- AASHTO defines resilience as, "the ability to prepare and plan for, absorb, recover from, or more successfully adapt to adverse events."

Resilience can be applied to large or unexpected but widespread events, such as weather and natural disasters, and can also be more narrowly focused toward specific events or projects.[1] At the most basic level resiliency is about the planning and actions an agency can take before, during, and after different types of adverse events that affect infrastructure and technology assets, processes, organization and workforce.

FRAMEWORK

The U.S. Department of Homeland Security provides the framework shown in Table 1 to organize the different aspects of resiliency.

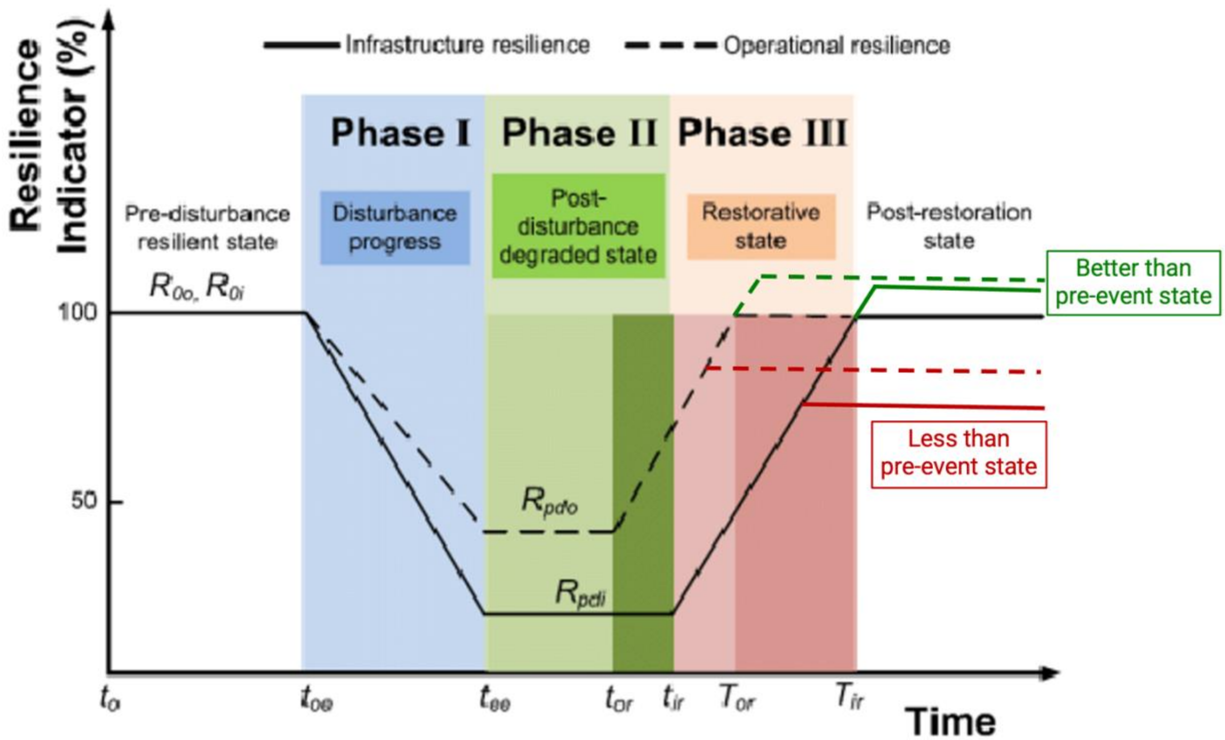
Table 1. Key Discriminators Used to Develop Consolidated Resilience Definitions

		Discrete Options			
Key Discriminators	**Goal**	Maintain Continuity of Function	Graceful Degradation	Recovery of Function to Desired Level in Designated Time	Inhibit Basic State of Change
	Event Cycle	Before Event	During Event	Post Event	
	Approach	Outcome-Based		Process-Based	

Source: U.S. Department of Homeland Security, *Risk and Resilience: Exploring the Relationship*, 2011.

[1] *See, e.g.*, FHWA Order 5520 and 23 U.S.C.§ 101(a)(24).

The typical performance of the transportation system degrades when a disturbance event happens resulting in reduced performance to some minimum level for both operations and infrastructure. Operations and infrastructure may degrade at different rates and reach different minimum levels of resiliency and at that minimum level for some period of time. The responsible agency or agencies react, and the performance eventually recovers to some level, in some cases the original level, in other cases to a state of performance less than the pre-event state or alternatively a better state. A resilient system makes the area between normal performance and valley created by the reduction and recovery of performance as small as possible.



Source: Moradiamani, Ali & Jalili, Mahdi, "Power Grids as Complex Networks: Resilience and Reliability Analysis," *IEEE Access*, 2021 pg. 1-1. Annotated (Licensed by CC BY 4.0).

Figure 1. Resilience Trapezoid Reduction and Recovery.

Resiliency can be used as a core component to organize TSMO program delivery to lessen potential impacts to the roadway network before they occur and to reduce the time to restore full operation. This benefits transportation agencies, the business community, and the traveling public.

Some elements of resiliency used by agencies as foundational practices were initially developed almost 25 years ago and refined from application and by experience over time.

Managing the impacts of both acute and chronic hazards requires a fundamental shift from isolated responses to a coordinated, systemic approach. Because modern threats are rarely contained, regional variations often mean that a single localized event can trigger a cascading crisis across multiple jurisdictions. To combat this, agencies must move away from treating operational resilience as a standalone objective and instead embed it as a cross-cutting practice fueled by inter-organizational collaboration, flexibility, and robust public communication. However, current execution remains uneven; while some agencies prioritize immediate tactical response, others focus on long-term planning, with implementation largely dictated by risk, resource availability, and local expertise.

Nowhere is this need for integration more critical than in transportation, where agencies face a diverse spectrum of weather, environmental, and intended and unintended incidents.

Industry groups, including the U.S. DOT, the National Research Council, and AASHTO's Special Committee on Transportation underscore that resilience engineering in TSMO is still in its formative stages. To mature these practices, their key recommendations urge leaders to invest heavily in resilient infrastructure, operationalize resilience into daily workflows, and establish tools, models, and standards to mitigate systemic vulnerabilities. Central to this strategic shift is the implementation of a quadrennial review of transportation infrastructure, ensuring that forecasting, planning, and community relationships continuously adapt to evolving multi-hazard landscapes.

More information on specific tactics for approaching resiliency as applicable to TSMO strategies and operations is available on NOCoE's website. In addition, AASHTO's *Transportation Operations Manual* (TOM) includes several sections of chapters on managing adverse weather and cybersecurity events:

- Chapter 20: Event Management Tactics
  - 20.2: Emergency Transportation Operations for Disasters
  - 20.3: Road Weather Management
- Chapter 29: Technology Trends
  - 29.2: Cybersecurity

Resiliency and Risk Preparedness:

Historically, the concepts of resiliency, sustainability, and adaptation have often been discussed together. Today, the focus is increasingly shifting toward understanding and preparing for a broad range of both short and long term risks, including severe weather, environmental disruptions, and physical or cyber security threats.

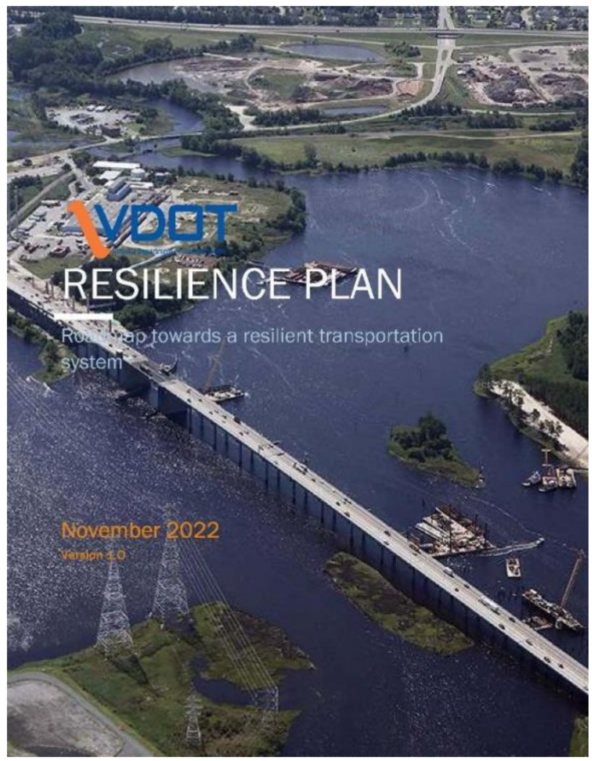
Resiliency work centers on anticipating potential events, assessing their impacts, and developing strategies that improve outcomes before, during, and after disruptions occur. This approach emphasizes the use of data, trends, and risk-based planning to inform practical actions that strengthen preparedness and recovery capabilities.

By concentrating on measurable hazards and operational risks, organizations can maintain focus on building resilience rather than becoming sidetracked by debates over the causes of those risks. This enables more productive conversations about how to reduce vulnerabilities, enhance readiness, and support communities, infrastructure, and operations in the face of an uncertain future.

Planning

GOALS AND OBJECTIVES

To be able to build a meaningful response mechanism for different types of potential events requires advance planning. State, county, and city transportation departments are advancing structural changes in how they safeguard essential travel corridors in response to adverse events. While agencies that need to address extreme weather-related events like hurricanes, tornados, heavy snowfall, and fire have been leaders in resiliency planning, recent federal grant program(s) have created in initiatives around the country in agencies of all sizes for planning, infrastructure improvements, at-risk coastal areas, and evacuation routes. (even with FHWA PROTECT grant program being placed in review status in February 2025).



Leading DOTs are formalizing resilience plans as standalone documents or incorporated into comprehensive transportation resiliency improvement plans. Both approaches integrate weather forecasting, infrastructure engineering, data analytics, and interagency protocols into a unified strategy. By evaluating risks and impacts at the systems level, state and local planners ensure that the transportation network remains durable, adaptable, and capable of maintaining economic and community lifelines through unexpected disruptions.

When planning for infrastructure resilience, transportation departments are shifting from historical weather data to forward-looking, probabilistic climate modeling. Engineering standards are being modified to create infrastructure that can withstand forecast changes in precipitation rates and intensity, severe flooding, wildfires, and high and low temperatures. State and county engineers are taking this planning level information into improvement plans to widen culverts, retrofit bridges, elevate low-lying corridors above 100-year flood lines, and using environmental solutions, such as bioswales and engineered wetlands to naturally mitigate stormwater runoff to address these challenges.

In the area of transportation technology, resilience relies on real-time situational awareness and predictive maintenance. DOTs are integrating road weather information systems that pair cameras with automated pavement and structural sensors to continuously feed weather data back to their traffic management centers. During an active event, this technology ecosystem allows system operators to track evolving hazards such as flash floods or buckling pavement, and to then communicate detour information to public safety agencies, dynamic message signs, and public navigation apps.

Operational resiliency bridges the gap between infrastructure and real-time crisis execution through flexible, cross-cutting collaboration that includes not only agencies' staff, but also proactive relationships with community stakeholders. Traffic disruptions do not stop at jurisdictional borders, e.g., a county road closure can paralyze a city grid or overwhelm a state highway. Resilience planning therefore emphasizes joint training and tabletop exercises, pre-established incident command structures, and shared resource pools between state DOTs, county public works, municipal utilities, and emergency management agencies. Operationally, this translates into predefined trigger points for deploying clearing crews as well as staging emergency traffic-control equipment along key evacuation routes. Organizing after-action reviews helps to refine response protocols after every major incident and to provide recurring feedback into agency resiliency planning.

Another aspect of operational resiliency are the DOT organization and workforce themselves. Can different parts of the organization and its staff elements function independently from one another during an event? How are responsibilities and organization of authority different during an event when elements could be compromised or is access limited? How is the work force cycled through shifts to avoid fatigue in the short term of the response and long(er) term of recovery?

While cybersecurity is not the focus of this report, information technologies that support transportation operations and infrastructure are coming under increased threat from adverse actors. Many agencies have moved to cloud-based data services, decentralized systems, and archived recovery backup to ensure that critical software networks remain operational even if a physical headquarters is physically compromised, loses power, or suffers a cyberattack. However, there remains a substantial group of agencies working toward solutions that mitigate risk in the area of resilience.

As an example, Virginia DOT clearly places the department's resiliency plan within the context of its overall mission by stating risk and intended actions:

> *The mission of the Virginia Department of Transportation (VDOT or Department) is to plan, deliver, operate, and maintain a transportation system that is safe, enables the easy movement of people and goods, enhances the economy, and improves the quality of life. Shifting environmental conditions, however, threaten the ability of Virginia's transportation network to safely and efficiently move people and goods. Consequently, the Department is faced with the* ***challenge of identifying resilience needs and developing specific strategies to anticipate, prepare for and mitigate events that put the transportation network at risk of disruption and deterioration****, while ensuring that network improvements do not undermine other climate resilience strategies or put more people at risk.*

By connecting resiliency to the core aspects of the department's mission to meet the safety, movement, economic and quality of life goals as part of the agency long-range planning process, VDOT places the topic at the forefront of considerations of all features of service delivery. Their plan identifies six core objectives to focus the response to the resiliency challenge(s):

1. Promote data driven decisions
2. Engage and partner with stakeholders
3. Identify at-risk infrastructure and prioritize needs
4. Identify resilience measures
5. Utilized feasibility and effectiveness analyses
6. Incorporate resilience into current funding policies

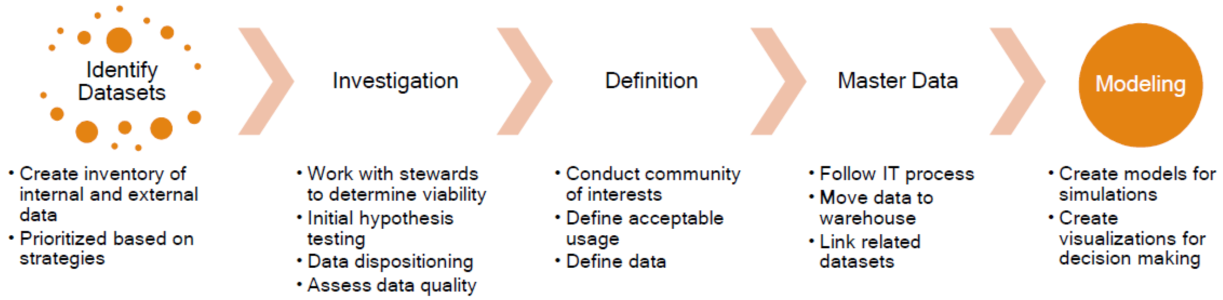
The objectives lead to subordinate strategies to meet their resiliency needs. As a result, their resiliency frame is formalized throughout agency functions of transportation planning, project development, delivery, operations, maintenance, and asset management.

ASSESSMENTS / NEEDS IDENTIFICATION

State DOTs and Metropolitan Planning Organizations (MPOs), use assessments to evaluate their system vulnerability to resilience-related risks. Assessments are designed to determine where a jurisdiction stands in relation to their resilience journey and to help to define what short, mid, and long term actions need to be taken and the operating/capital funding to support them. While some of these reviews evaluate trends in extreme weather hazards across entire transportation networks, others are highly targeted, focusing on specific vulnerabilities like flash flooding risks for bridges and culverts or the impact to roadway pavement due to excessive heat. For agencies that have not yet launched systematic assessments, alternate collaborative methods like scenario planning and stakeholder workshops are being used to map out how future development patterns intersect with evolving environmental risks.

The first element of the assessment process is to define the applicable internal and external data resources and datasets to support decision-making. Relevant datasets include information regarding environmental conditions, weather, climatic stress factors, geography, hazards, threats, system asset types and attributes, asset conditions, critical access, user populations, and vulnerability. Each should be evaluated and leveraged as appropriate to inform appropriate use cases and applications as well as to inform what gaps may exist and where there are needs for new data sources or additional research.

VDOT, for example, uses a defined process to move from data identification to master datasets to use as inputs to simulation modeling and visualizations for decision-making (See Figure 2). For each step in the process the agency defines success measures to understand progress on their implementation strategies.

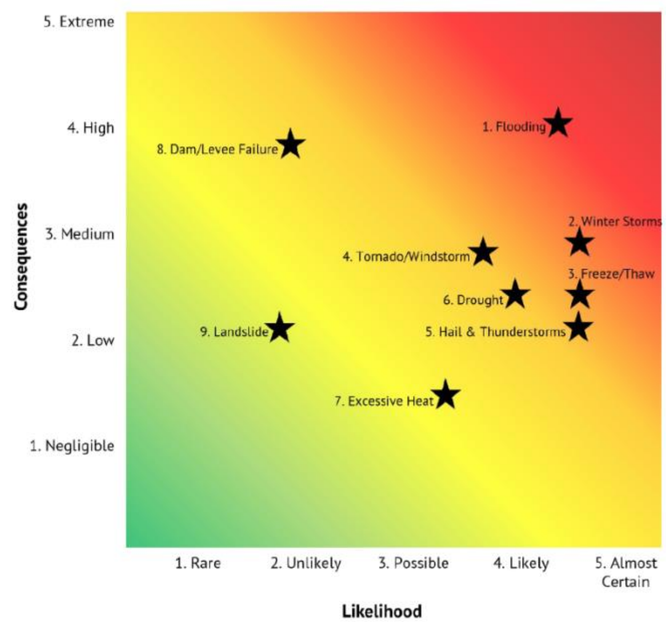


Source: *VDOT Resilience Plan: Roadmap Towards a Resilient Transportation System*, November 2022, pg. 15.

Figure 2. Data Mastering Process as Input to Modeling.

In order to determine whether and to what extent resilience measures are necessary is tied to asset, process, or organizational vulnerabilities. Agencies approach this issue using risk-based screening to identify needs to be addressed in their improvement plan.

Iowa DOT uses a matrix of consequence multiplied by likelihood to create a risk score (see Figure 3 and Table 1) created by the agency's Resiliency Working Group work to evaluate and prioritize natural hazards through a risk-based assessment using various data resources available to the agency. This information is further developed as hazard profiles for each category of events incorporating a description and the impacts to the transportation system.



Source: *Iowa DOT Resilience Improvement Plan*, 2024, pg. 38.

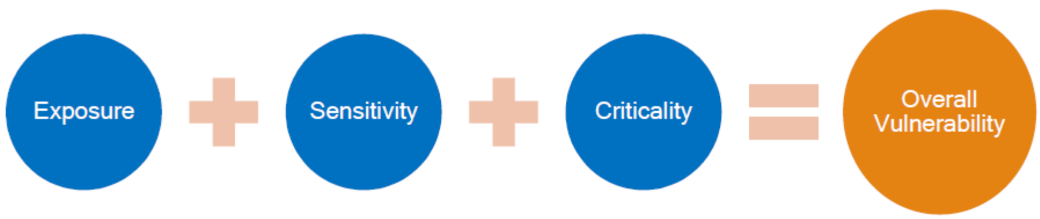
Figure 3. Risk Prioritization Matrix.

VDOT employs a methodology that combines exposure, sensitivity, and criticality to determine the overall vulnerability of an infrastructure asset. The agency first applies this risk-based screening approach to new and other specific target projects to determine the vulnerability and extent of resiliency measures necessary. The next steps are to expand assessments to existing infrastructure and to integrate the methodology into the department processes and business practices.

Table 2. Risk Prioritization Scores and Preferred Mitigation Methods.

Tier	Hazard	Likelihood	Consequence	Risk	Preferred mitigation methods
Tier 1	Flooding	4.02	3.94	15.83	Take proactive steps to mitigate the risks of these hazards
	Winter Storms	4.27	2.88	12.28	
	Freeze/Thaw	4.23	2.38	10.04	
Tier 2	Tornado/ Windstorm	3.31	2.77	9.18	Have strategies in place to quickly react when these events occur
	Hail & Thunderstorms	4.23	2.02	8.55	
	Drought	3.6	2.33	8.41	
Tier 3	Excessive Heat	3.69	1.69	6.22	Monitor and conduct prevention activities as appropriate
	Dam/Levee Failure	1.58	3.71	5.87	
	Landslide	1.42	2.02	2.86	

Source: *Iowa DOT Resilience Improvement Plan*, 2024, pg. 39.



Source: *VDOT Resilience Plan: Roadmap Towards a Resilient Transportation System,* November 2022, pg. 21.

Figure 4. Contributing Factors to Asset Vulnerability.

PERFORMANCE METRICS

Various performance metrics and targets are used by transportation agencies to track progress toward their resiliency objectives over time and are often tied to existing safety, system preservation, or environmental stewardship goals. The metrics can be characterized by 1) completion of an action within a specific strategy within an objective or 2) the percentage of an asset type that meets resiliency criteria; some common examples include:

- On-schedule completion of routine culvert inspections,
- Percentage of compliance on erosion and sediment control ratings
- Total number of roadway and centerline lane miles of new or upgraded facilities built with grade above 100-year floodplain
- Assessing the volume-capacity ratios and conditions of existing roadways under normal vs. event conditions
- Number of MPOs and local communities with resiliency plans

- Setting explicit targets, such as ensuring 90% of strategic facilities can accommodate a 100-year flood or 60% for a 200-year flood.
- Acres of wetlands or wildlife habitat restored,
- Quantifying the volume of litter and debris cleared from storm drains to prevent localized roadway flooding.
- Concentration of housing and employment located in FEMA flood zones
- Wildland-urban intermix areas prone to wildfires
- Projects that integrate stormwater management improvements

Coastal and regional tracking metrics can include monitoring the number of local communities that have successfully established environmental adaptation plans. Some agencies merge overall system reliability with resilience by tracking operational metrics, aiming to maintain traffic volume-capacity ratios below one, lowering the total percentage of roadways classified in "poor" condition or "critical backlog," and successfully reducing regional commute times.

Implementation

BACKGROUND

State, MPOs, and local jurisdictions take related approaches to incorporating resiliency into their jurisdictions' capital improvement plans. Resilience strategies are formalized by aligning regional projects with state and federal planning mandates which are the precursors to funding opportunities. At the state and regional level transportation-focused improvements are incorporated into the transportation improvement plan (i.e., STIP or RTIP). Because funding is finite, agencies deploy risk-based asset management tools to score infrastructure based on its criticality and vulnerability, prioritizing life-safety routes, and evacuation corridors for structural hardening. Projects are added to the improvement programs based on a variety of project evaluation and ranking systems that prioritize the use of limited funding to the most effective opportunities. Resiliency elements are cross cutting and fiscal resources to support implementation may be available through other state agencies with missions focused on the environment, conservation, agriculture, wetlands, coastal programs along with supporting federal funding from agencies outside U.S. DOT.

STRATEGIES

In addition to tracking performance over time, agencies have been adding specific resilience-related evaluation criteria to prioritize and select upcoming transportation projects for funding. These criteria primarily evaluate whether a proposed project is located within a vulnerable hazard zone such as a FEMA 100-year floodplain or a wildfire susceptible suburban/urban area, or whether a design actively mitigates risks like stormwater runoff. Another aspect considered is baseline design criteria to qualify for funding such as control and mitigation stormwater during design, construction, and long-term post-construction operations before they can even qualify for funding. Agencies are shaping their prioritization of resilience projects around systemic adaptation, structural fortification, and emergency response capabilities. Project scoring systems are explicitly weighted to favor strategies that protect critical economic and logistics assets.

For example, the Boston Region MPO awards priority points to projects that update facilities to seismic design standards, protect vulnerable freight networks, or improve overall emergency response functionality. Other regional planning organizations award extra points to designs that offer network redundancy or enhance emergency mobility for critical assets. At the state level, Hawaii DOT determines its strategic priorities by collaborating with stakeholders and assigns significant weight to system preservation, environmental sustainability, and long-term hazard mitigation goals during their project selection process. By officially prioritizing long-term resilience relative to all-hazards mitigation, these agencies ensure that funding is structurally directed toward infrastructure projects that reduce infrastructure vulnerability.

Other strategic approaches for projects to enter the operating budget or TIP include scheduling vulnerable infrastructure for increased routine maintenance and requiring projects in coastal areas to incorporate resilient design elements or updating older facilities to meet modern seismic design standards. From a system-wide reliability perspective, strategies are being chosen that provide network redundancy, enhance overall mobility around critical facilities during extreme events, and improve long-term winter maintenance capabilities.

Agencies are implementing resiliency solutions through a variety of methods by creating processes to prioritize projects as well as taking advantage of different funding opportunities. Although federal funding programs changes with each administration, the determination of effectiveness in meeting transportation agencies' various programmatic objectives serves as a substantial basis for future funding opportunities. A few examples follow.

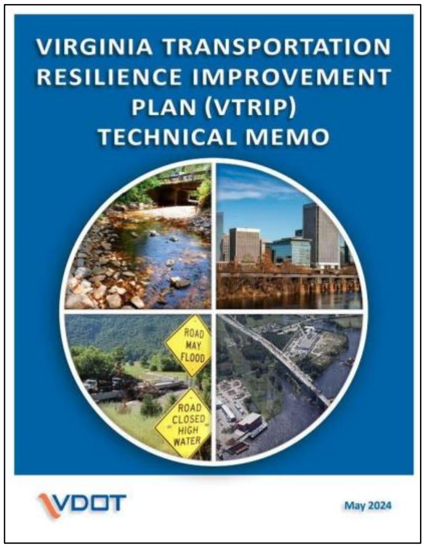
FHWA Resilience and Durability to Extreme Weather Pilot Program

FHWA's pilot program supported agencies to integrate resilience and durability into agency practices, assessed the vulnerability and risk of transportation projects using available tools, and implemented a resilience solution.

> ***Utah Department of Transportation (UDOT):*** The agency developed model based approach to enterprise risk and resilience. The7-step Asset Risk Management Process can estimate annual risk by threat and by asset, then the resilience findings are incorporated into existing management programs including statewide, corridor, and project planning. UDOT developed metrics and thresholds to incorporate annual risk information into its existing processes. Threats included in the analysis are flooding, wildfires, and earthquakes.
>
> ***Mid-America Regional Council (MARC):*** MARC analyzed risks and potential mitigation strategies associated with flooding and stream stability in the Blue River Watershed and their effects on transportation infrastructure in Kansas City metropolitan area. The *Little Blue River Watershed Flood Risk and Ecosystem Restoration Project General Investigation Study* draft report also addresses resilience considerations in development of the *Metropolitan Transportation Plan* and the *Blue River Watershed Plan*.

Florida DOT: Removal of roadway-blocking debris, restoration of traffic signals, and overseeing detours for longer-term closures are essential to support emergency response, restoration of transportation services, and economic recovery. Initially developed by District 3 in the Florida panhandle area for the 2020 hurricane season, the Electronic Signals and Traffic Operations Response Management (**eSTORM**) system provides traffic signal status fields with pictures to existing databases and enhanced the mobile app with drop-down menu selections to input data directly. This upgraded efforts for traffic control and detours through connected portable traffic signals, cameras, and changeable message signs which communicate with the regional TMC.

As a result of the initial success, the eSTORM app and dashboards are now a statewide storm management tool and available to other states with a traffic signal database built on an ArcGIS platform.



Virginia DOT: The agency's Resilience Plan recognizes the impact of "shifting environmental conditions that may hamper the transportation network" and calls for two dozen actions in the areas of network monitoring, forecasting, mitigation, and adaptation to render Virginia's network more resilient. The subsequent *Virginia Transportation Resilience Improvement Plan (VTRIP) Technical Memo* documents VDOTs work to integrate resiliency implementation into the overall state TIP (VTrans) prior to its next update cycle by aligning the long-range planning process and resilience planning as well as coordinating with the strategies in the *Commonwealth of Virginia Hazard Mitigation Plan* (COVA HMP) and the *Coastal Resilience Master Plan*. The memoranda provides specific actions and timeline toward implementing the strategies in the plan and actions necessary.

VDOT has implemented various regulations, codes, and standards related to transportation resilience and sustainability complementing key federal regulations and guidelines. The agency has initiated risk-based assessments of assets and systems to determine their vulnerability to various hazards and events along with community engagement for local area planning.

Resilience can tie into transportation planning processes (including the development of long - range plans, TIPs, TAMPs, or environmental reviews):

VDOT is exploring whether to use the agency's SMART SCALE scoring system which prioritizes transportation projects based on objective, outcome-based metrics, can support integration of resilience initiatives to ensure projects contributing to infrastructure resilience receive appropriate funding and attention. This approach ensures a more effective allocation of resources towards projects that not only meet immediate transportation needs but also contributes to long-term sustainability and resilience of Virginia's transportation infrastructure.

The agency recognizes that the resiliency improvement plan and supporting funding allocation needs to evolve over time as implementation of earlier strategies in the process are complete and the implications better known. In the meantime, the department plans to focus on incorporating resilience into existing funding streams programs to implement high benefit, cost-effective measures.

Iowa DOT: The agency takes a comprehensive approach as a "toolbox" in the *Resilience Improvement Plan* that identifies three types of implementation elements to mitigate hazards tied to resilience: strategies, countermeasures, and research. This can be both typical roadway improvements and natural infrastructure improvements (e.g., native plantings and bioretention).

The plan also includes reference to coordination with other state plans and implementation resources including: *2023-2032 Iowa Transportation Asset Management Plan*, *Iowa State Freight Plan*, *Iowa Drought Plan*, *State Hazard Mitigation Plan*. Many of the ideas listed in Iowa's Resiliency Toolbox benefit the operation of the transportation system beyond mitigation of the specific hazards for which they are listed. For example, shoulder improvements play a safety role by allowing roadway users space to recover from departing their lane and, in addition, may mitigate the impact flowing water has on the roadway. Iowa DOT's perspective is to increase consideration of improvements that jointly benefit multiple goals of the agency mission to keeping users safe on the system as a core aspect of their stewardship of the transportation system.

Practice

PURPOSE

Beyond coursework and training to expand knowledge, skills, and abilities of the workforce, practicing response and recovery for unanticipated incidents or severe weather events is essential for transportation departments. The execution of emergency plans relies heavily on organizational experience and seamless interagency coordination that cannot be established for the first time during a crisis. When an impending natural event (e.g., hurricane, wildfire, etc.) or sudden blizzard, flash flood, or unexpected infrastructure failure occurs, the speed at which debris is cleared, detours are established, and emergency corridors are opened directly impacts public safety and economic continuity. Routine training exercises and simulations allow personnel to iron out logistical bottlenecks, test the limits of equipment, and build trusting working relationships with external first responders under low-stakes conditions. Proactive preparation transforms abstract emergency plans and procedures into operational action, reducing response times, minimizing infrastructure downtime, and saving lives when an event occurs without warning.

To improve the resiliency and response to events Incident Command System (ICS) training, tabletop exercises, performing after action reviews support DOT workforce and improve coordinated response efforts. Integrating the three provides for the continuous improvement of processes supporting preparation, execution, and refinement that is vital for building long-term transportation system resilience. This enables DOTs to shift from a reactive posture to a proactive culture, ensuring that infrastructure, technology, and personnel can withstand disruptions and that not only the DOT can rapidly recover, the transportation system can as well.

TABLETOP EXERCISES

With its origination in military wargaming in the 1800's the concept of table exercises moved into civil defense and emergency management organizations in the 1950's and the U.S. Tabletop exercises provide a low-stakes environment to stress-test theoretical response strategies against complex, evolving hazards. Because these exercises are role playing and discussion-based, they allow DOTs to test agency staff's approach to high-consequence, multi-hazard threats in a completely safe environment. Teams can make mistakes, evaluate alternative operational choices, and refine their strategies without risking public safety or incurring substantial operational costs. At the national level, the Department of Homeland Security's Cybersecurity and Infrastructure Security Agency offers customizable tabletop exercise packages. In addition, state emergency management agencies (e.g., Illinois, Tennessee, etc.) offer different packages as well to state and local agencies.

Pre-incident tabletop exercises are a structured simulation where key personnel from law enforcement, fire and rescue, EMS, transportation, utilities, and private industry meet to talk through their roles and responses during a hypothetical emergency scenario. Led by a facilitator, participants are presented with an evolving, realistic crisis such as a cyberattack on a traffic management center, a hazardous material spill on a major highway, or a category-4 hurricane approaching a coastal transportation network. Rather than deploying physical assets or field personnel, participants use their agency's existing emergency response plans, Standard Operating Procedures (SOPs), and resource lists to work through how they would react step-by-step.

Source: FHWA.

The exercise typically uses a two- or three-dimensional representation of the roadway environment (e.g., aerial maps and photographs) and props (e.g., toy cars) representing different resources. The benefit of scenario training is that participants can stop at any time and question other responders about their actions. More recently, the conduct of tabletop exercises/scenarios can be supported through commercially available virtual incident simulation software (Incident Commander™, developed by the National Institute of Justice, is one example of a virtual training tool). Using three-dimensional, multiplayer computer gaming simulation technology allows participating staff to enhance response performance for a variety of large-scale incidents.

Tabletop exercises serve as a crucial component of practicing and directly reinforcing an agency's ability to handle unexpected events in several ways. A paper emergency plan can look perfect until it is put under pressure. A tabletop exercise forces agencies to answer tough logistical questions potentially revealing plan vulnerabilities and gaps. During a fast-moving crisis, overlapping responsibilities can breed chaos. A tabletop exercise gathers representatives from city, county, and state DOTs alongside emergency management, police, fire, and utility providers, forcing them to explicitly define who commands specific decisions. This helps to clarify roles and establishes jurisdictional boundaries. In addition, they build interagency relationships before the crisis by building trust and familiarity, ensuring smoother communication when a real event occurs. Another aspect of tabletop exercises is that they can text communications protocols facilitators will routinely introduce as unexpected updates to the scenario, such as a localized cellular outage or an influx of misinformation on social media. This forces the agency's public information officers and technical teams to test how they would verify facts and disseminate critical safety alerts to the public under pressure.

INCIDENT COMMAND SYSTEM

Source: FHWA.

The Incident Command System (ICS) is a standardized, on-scene emergency management framework designed to allow responders from multiple agencies including DOTs to blend seamlessly into an integrated unified and predictable common management structure in a crisis situation. Originally developed in the 1970s following a series of devastating wildfires in California, ICS eliminates communication barriers and jurisdictional friction by establishing a clear chain of command, common terminology, and manageable spans of control. Whether applied to a localized traffic incident or a massive natural disaster, as an objectives-based system ICS scales dynamically to organize comprehensive resource management of personnel, facilities, equipment, and communications under a single, unified command structure. The ability of all responders to communicate clearly and effectively through ICS is at the heart of the National Incident Management System (NIMS) required by the Federal Emergency Management Agency (FEMA) for the management of all hazards.

Transportation agencies play a critical and multi-faceted role within this framework, particularly during incidents that impact or rely on public infrastructure. Because emergencies frequently disrupt mobility, DOTs, transit authorities, and public works are integrated directly into the ICS structure within the Operations, Logistics, or Planning sections. Their primary responsibility is to manage the transportation network, which includes establishing detour routes, clearing debris from evacuation corridors, providing real-time traffic updates to the public, and deploying heavy machinery to support first responders. All core aspects of the response and recovery elements of resilience.

Additionally, transportation personnel often serve as vital logistical backbones during large-scale operations. Transit agencies can mobilize fleets of buses for mass evacuations or utilize public vehicles to transport emergency personnel and supplies to staging areas. By actively participating in the unified command structure under the ICS, transportation officials ensure that traffic management strategies align perfectly with emergency management, law enforcement, and fire rescue operations, ultimately securing the incident space while maintaining the vital movement of people and goods away from danger. Employing ICS improves response timeliness and recovery duration for an event.

FHWA offers ICS training courses and the *Simplified Guide to the Incident Command System for Transportation Professionals* specifically tailored for highway and transportation audiences. FEMA provides the standard NIMS and ICS curriculum (including ICS-100 through ICS-400) for public and private sector officials.

AFTER ACTION REVIEWS

An After-Action Review is a structured, collaborative assessment conducted after an incident, emergency operation, or planned event to evaluate performance; capture lessons learned and identify areas for improvement. The after action review process captures critical ground truths and data, converting information from the operation into permanent structural upgrades and updated emergency protocols. Originally pioneered by the military and now standard across emergency management, the AAR process brings together responders, stakeholders, and leadership to answer four core questions:

- What was supposed to happen?
- What actually happened?
- What went well, or poorly?
- Why did it happen?
- What can be improved upon next time?

Source: FHWA.

Rather than serving as a tool for assigning blame, the main goal of an effective after action review focuses on operational facts to constructively critique the procedures used, decisions made, systemic gaps, and successful strategies to determine an improvement plan to refine future readiness documented in an after action report (e.g., by restructuring the procedures, adding extra resources, etc.). Transportation agencies play a pivotal role in the after action review process because the success of almost any major emergency response is inherently tied to the performance of the transportation network. Following multi-agency incidents such as a major hazardous material spill, a severe weather event, or a mass evacuation, DOTs, transit authorities, and traffic management centers provide critical data-driven insights. They contribute telemetry data, traffic camera footage, infrastructure damage assessments, and timelines of debris clearance or detour implementation. This quantitative data grounds the review in objective facts, helping the entire command structure understand exactly how traffic flow, road closures, and public transit disruptions impacted the overall timeline of the response. Ideally, after-action reviews/debriefings should occur immediately after the incident has been cleared to ensure that details and procedures of the response effort are not forgotten.

Beyond providing data, transportation personnel actively shape future emergency strategies during these reviews by identifying systemic vulnerabilities in infrastructure and communication. For instance, a transportation agency might highlight how a bottleneck on an evacuation route delayed an emergency vehicle, leading to recommendations for pre-staged towing assets or updated contraflow plans in the future. They also evaluate how effectively their internal communication channels linked with law enforcement and fire rescue under the Incident Command System. By embedding their unique operational perspective into the final Improvement Plan, transportation agencies ensure that future disaster responses feature more resilient infrastructure, faster route clearance, and tighter interagency coordination.

From the national perspective FEMA frames after action reviews as part of the *National Continuous Improvement Guidance* within the *Preparedness Toolkit*. Chapter 2 of the Guidance focuses on preparing for and conducting the after action review process. In addition, there is a substantial amount of resources available on after action reviews associated with Traffic Incident Management (TIM) which can be scalable to larger events from FHWA in the form of educational resources, webinars, and focused toolkits like the *Multidisciplinary TIM After-Action Reviews/Debriefings* and from the Emergency Responder Safety Institute online courses such as *After Action Review for Roadway Incidents* for multi-agency, roadway-focused debriefs. Further State agencies provide procedures and sample templates (e.g., the *Colorado TIM Team Toolkit*, The Virginia Statewide Traffic Incident Management Committee's resource library, as well as other many other states' examples).

Resources

RESOURCE LIST

AASHTO Transportation Operations Manual (TOM)

- Chapter 20: Event Management Tactics
  - 20.2: Emergency Transportation Operations for Disasters
  - 20.3: Road Weather Management
- Chapter 29: Technology Trends
  - 29.2: Cybersecurity

AASHTO Committee Transportation System Security and Resilience Resource List

General All Hazards and Emergency Management Reports

- *U.S. DOT Resilience Coalition White Paper* (2 April 2024)
- *Understanding Transportation Resilience: A 2016-2018 Roadmap* (January 2017)
- *Managing Catastrophic Transportation Emergencies: A Guide for Transportation Executives* (September 2015)
- *Fundamental Capabilities of Effective All-Hazards Infrastructure Protection, Resilience, and Emergency Management for State Departments of Transportation* (September 2015)

Five 'Fundamentals' Reports

- NCHRP Report 525, Surface Transportation Security Vol. 14, Security 101: A Physical Security Primer for Transportation Agencies (2009)
- NCHRP Report 525, Surface Transportation Security Vol. 15, Costing Asset Protection: An All-Hazards Guide for Transportation Agencies (CAPTA) (2009)
- NCHRP Report 525, Surface Transportation Security Vol. 16, A Guide to Emergency Response Planning at State Transportation Agencies (2010)
- NCHRP Report 645, Blast-Resistant Highway Bridges: Design and Detailing Guidelines (2010)
- TCRP Report 86 / NCHRP Report 525, Surface Transportation Security Vol. 8, Continuity of Operations (COOP) Planning Guidelines for Transportation Agencies (2005)

Federal Highway Administration

- Resilience Publications webpage (updated 9 September 2025)
- *Resilience Pilots* (updated: 28 February 2025)

Federal Highway Administration (continued)

- *Climate Change Adaptation Guide for Transportation Systems Management, Operations, and Maintenance* (FHWA-HOP-15-026)
- *Risk-Based Transportation Asset Management* publications webpage (updated: 4 April 2024)
- *Integrating Resilience into the Transportation Planning Process White Paper on Literature Review Findings* (May 2018)
- *Vulnerability Assessment and Adaptation Framework* and Adaptation Clearinghouse summary.
- PROTECT Transportation Grant Program (accessed January 2026)
- *Tabletop Exercise Instructions For Planned Events and Unplanned Incidents/Emergencies* (November 2007) and generic exercise slide deck.
- *Building Resilient Transportation Infrastructure* in U.S. DOT Momentum edition 1, November 2022
- Nature-Based Solutions for Coastal Highway Resilience: An Implementation Guide (August 2019)

States

- **Colorado** - FHWA. *Integrating Resilience into Agency Operations: Colorado Department of Transportation*. Report No. FHWA-HEP-21-037. Washington, DC: Federal Highway Administration, 2021.
- **Iowa DOT -** *Resilience Improvement Plan*, Des Moines, IA, Iowa DOT, 2024.
- **Nevada** - SRI International. *Nevada's Plan for Recovery & Resilience*. Carson City, NV: Nevada Governor's Office of Economic Development, 2020.
- **Texas** - Bathgate, Kyle, Jingran Sun, et al. *Creating a Resilient Port System in Texas: Assessing and Mitigating Extreme Weather Events – Final Report*, Report Number: FHWA/TX-22/0-7055-1. Austin, TX, Center for Transportation Research, The University of Texas at Austin, 2022.
- **Utah DOT**- *Asset Risk Management Process*, Salt Lake City, UT, Utah DOT, June 2020.
- **Virginia DOT**. *Resilience Plan: Roadmap Towards a Resilient Transportation System*. Richmond, VA, Virginia Department of Transportation, 2022.
- **Virginia DOT**. *Virginia Transportation Resilience Improvement Plan (VTRIP) Technical Memo*. Richmond, VA, Virginia Department of Transportation, May 2024.

National Cooperative Highway Research Program

- Dorney, Chris, Michael Flood, et al. *Deploying Transportation Resilience Practices in State DOTs*, NCHRP Web-Only Document 293. Washington, DC: The National Academies Press, 2021.
- Duncan, Chandler, Harris, J., et al. *Strategies for Incorporating Resilience into Transportation Networks*. NCHRP Research Report 1118. Washington, DC: The National Academies Press, 2024.
- Flannery, Aimee, Maria A. Pena, and Jessica Manns. *Resilience in Transportation Planning, Engineering, Management, Policy, and Administration*, NCHRP Synthesis 527.

Washington, DC: The National Academies Press, 2018.

- National Academies of Sciences, Engineering, and Medicine. *Transportation Resilience: Adaptation to Climate Change*, Proceedings of a Symposium, June 16-17, 2016, Brussels, Belgium. Washington, DC: The National Academies Press, 2016.
- E-Circular 226: Transportation System Resilience: Preparation, Recovery, and Adaptation (September 2016)
- Dorney, Chris, Michael Flood, et al. *Mainstreaming System Resilience Concepts into Transportation Agencies: A Guide*, NCHRP Report 970. Washington, DC: The National Academies Press, 2021.
- *Building and Measuring Community Resilience: Actions for Communities and the Gulf Research Program* (2019)
- TCRP Web-Only Document 70: *Improving the Resilience of Transit Systems Threatened by Natural Disasters*
- Joseph L. Schofer et al. *Investing in Transportation Resilience: A Framework for Informed Choices*, Special Report 340. Washington, DC: The National Academies Press, 2021.

National Resilience Reports

American Planning Association

- Planning Resilient Infrastructure

National Association of Development Organizations

- Integrating Economic Resilience in Performance-Based Transportation Planning
- Planning for Transportation Together: Collaborating to Address Transportation and Economic Resilience

Environmental Protection Agency

- Smart Growth Strategies for Disaster Resilience and Recovery updated on July 14, 2025
- Brechwald, D., Chakoas, A., et al. *Regional Resilience Toolkit – 5 Steps to Build Large Scale Resilience to Natural Disasters*. Washington, DC: Environmental Protection Agency, 2019.

NOAA

- *U.S. Climate Resilience Toolkit*

DHS / CISA

- CISA Tabletop Exercise Packages
- *National Infrastructure Protection Plan* (NIPP). Washington, DC: Department of Homeland Security, 2013.
- *NIPP Supplement Tool: Incorporating Resilience into Critical Infrastructure Projects*. Washington, DC: Department of Homeland Security, 2020.
- *Executing a Critical Infrastructure Risk Management Approach*. Washington, DC: Department of Homeland Security, 2020.