Texas Department of Transportation

Texas Statewide Transportation Resilience Plan

September 2025

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Acronyms and Abbreviations

°F	Degrees Fahrenheit
BCA	Benefit Cost Analysis
BRIC	Building Resilient Infrastructure and Communities
CAT	Cooperative Automated Transportation
CCTV	Closed Circuit Television
CPT	Corridor Prioritization Tool
DMS	Dynamic Messaging Sign
DOT	Department of Transportation
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIRM	Flood Insurance Rate Map
HMGP	Hazard Mitigation Grant Program
IIJA	Infrastructure Investment and Jobs Act
ITS	Intelligent Transportation System
I	Interstate
MPO	Metropolitan Planning Organization
NBI	National Bridge Inventory
NCEI	National Centers for Enviornmental Information
NOAA	National Oceanic and Atmospheric Administration
PROTECT	Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation
RIP	Resilience Improvement Plan
ROW	Right-of-Way
RPO	Rural Planning Organization
RSC	Resilience Steering Committee
SH	State Highway
SLRTP	Statewide Long-Range Transportation Plan
STRP	Statewide Transportation Resilience Plan
TAMP	Transportation Asset Management Plan
TCRMP	Texas Coastal Resiliency Master Plan
TMC	Traffic Management Center
TWDB	Texas Water Development Board
TxDOT	Texas Department of Transportation
TxWRAP	Texas Wildfire Risk Assessment Portal
TRIP	National Transportation Research Nonprofit
UPS	Uninterrupted Power Supply
UNDRR	United Nations Office for Disaster Risk Reduction
U.S.	United States
UTP	Unified Transportation Plan

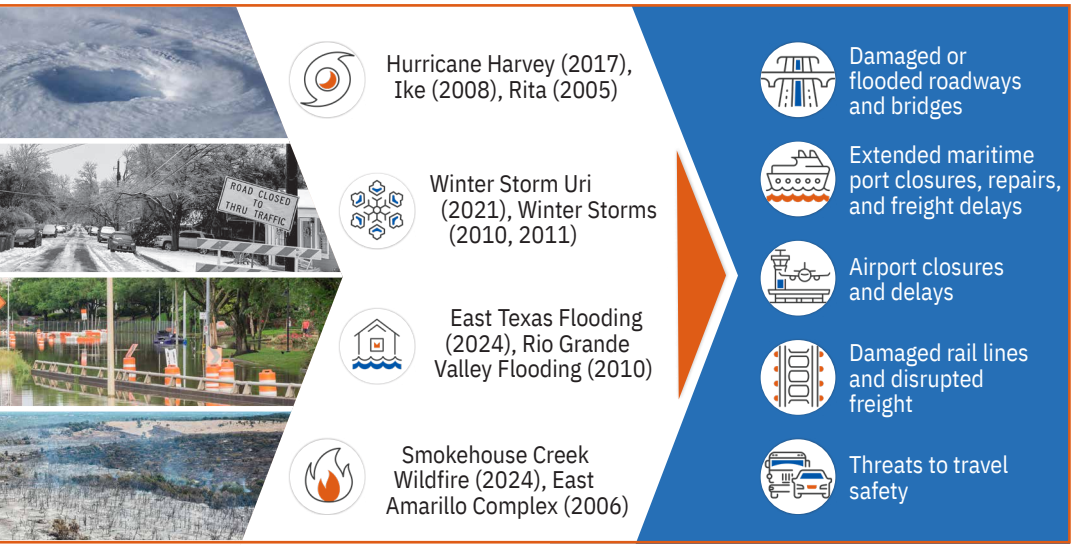
Executive Summary

Executive Summary

From the Gulf Coast to the Panhandle, the Texas multimodal transportation system – the largest in the United States – connects 30 million people to jobs, schools, homes, recreation, and services and transports $2.9 trillion worth of freight within the state and beyond each year. Its efficient operation is vital to Texas residents as well as to the Texas economy.

In recent years, the Texas transportation system has faced a growing number of disruptors, from hurricanes to winter storms, threatening its operations, public safety, and the Texas economy. These and other disruptors demonstrate the urgent need to plan for the Texas transportation network's long-term resilience.

Figure ES-1: Disruptors Occurring Between 2005 and 2024 and their Impacts on the Texas Transportation System



STRP Purpose

The Texas Department of Transportation (TxDOT) developed the Statewide Transportation Resilience Plan (STRP) to respond to these challenges and secure a resilient future for transportation infrastructure.

The STRP has established a planning framework TxDOT can use to assess resilience comprehensively across the statewide transportation network's most critical components. Developed in coordination with TxDOT divisions, districts, and external stakeholders, the STRP:

- **Identifies critical vulnerabilities and resilience strategies**
- **Guides projects and investments**
- **Proposes measures that can track system performance**

Resilience is the ability to support and maintain a **multimodal** transportation system that can **safely move people, goods, and services** during adverse conditions, and to be able to **anticipate, prepare** for, **adapt** to, withstand, respond to, and recover efficiently from both human and natural disasters and disruptions.

Why is TxDOT Planning for Resilience?

By anticipating and planning for future disruptors, **TxDOT can protect the transportation system** and in turn improve the quality of life for Texans and the Texas economy.

Resilience Planning Benefits:

Projected Trends for Extreme Weather Events Under a High-Emissions Extreme Weather Scenario

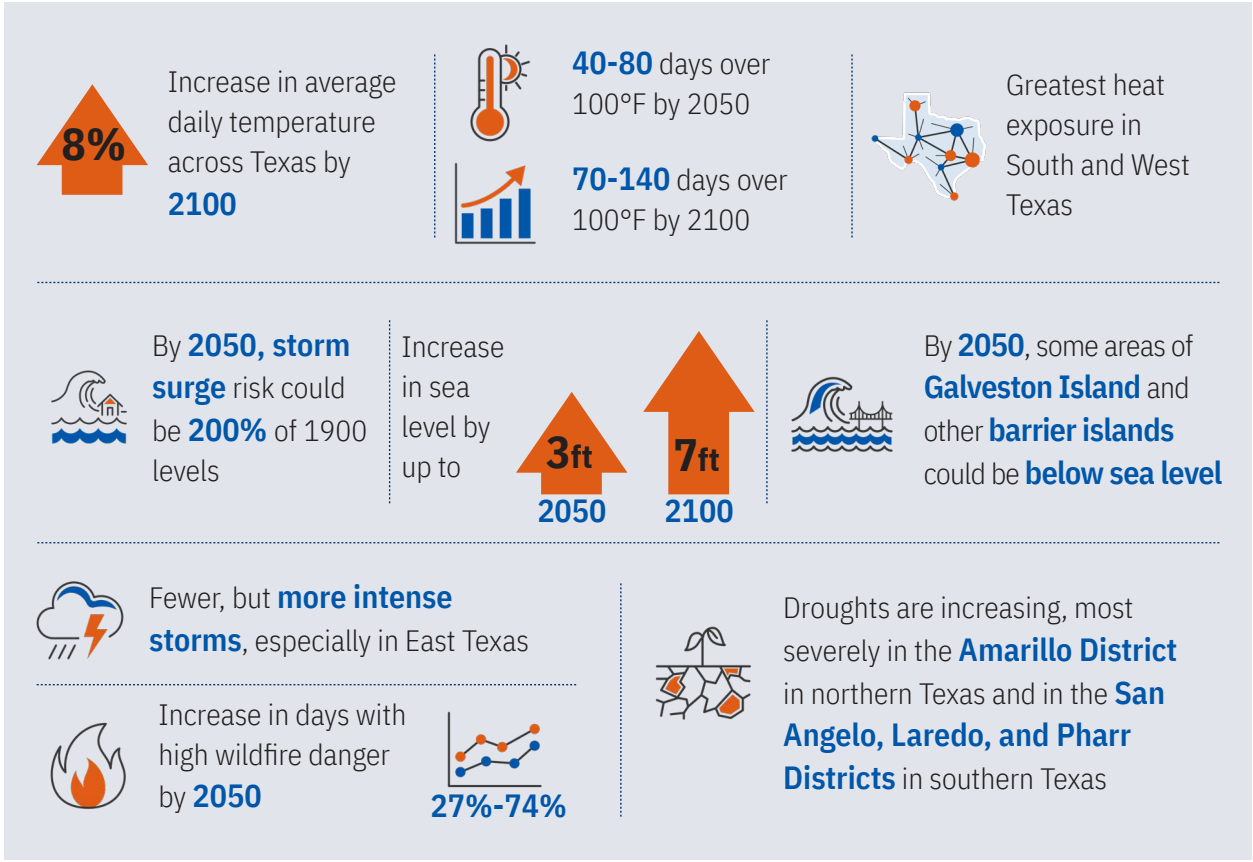


Figure ES-2: Projected Trends for Extreme Weather Events in Texas

What Does the STRP Do?

The STRP supports TxDOT in anticipating future impacts; building partnerships; saving costs; and strengthening safety, system performance, and connectivity across the transportation system.

- Defines resilience for the TxDOT context
- Establishes resilience goals and objectives for TxDOT
- Identifies critical transportation assets in the multimodal network
- Evaluates key vulnerabilities to extreme weather events and human-related disruptors
- Identifies strategies, projects, and performance measures
- Recommends funding and financing opportunities
- Advances implementation of resilience projects and strategies

The STRP Contains:

116 Strategies

- 14 policy strategies
- 23 program strategies
- 44 project strategies
- 35 information and technology strategies

7 Key Performance Measures

Track progress and monitor system resilience

696 Resilience Projects

Eligible for Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation (PROTECT) funding

14 Funding and Financing Opportunities

Federal opportunities and financing tools

The STRP and PROTECT Funding

The federal Infrastructure Investment and Jobs Act (IIJA) created the **PROTECT** Program to provide funding to improve surface transportation infrastructure's resilience to natural hazards. The PROTECT program allows states to develop a Resilience Improvement Plan (RIP) to receive up to a 10% reduction in the non-federal cost share for PROTECT projects. The STRP serves as the Texas RIP.

The STRP Meets PROTECT Requirements By:

- **Undertaking a systemic approach to multimodal transportation resilience**
- **Conducting a science-based vulnerability assessment for future extreme weather events**
- **Recommending a robust set of resilience strategies**
- **Incorporating findings into the Statewide Long-Range Transportation Plan (SLRTP)**

The STRP Achieves 10% Cost Savings

~$145 million
Average annual PROTECT funding allocated to Texas from fiscal year 2022 through 2026

20%
State funding match required by PROTECT

10%
Reduction in TxDOT's share of that match if all PROTECT requirements are met

Investment in resilience can be a significant cost savings for Texas:

Every dollar spent on risk reduction generates $15 in savings on post-disaster recovery.[1]

Resilience Challenges and Opportunities

The transportation network faces a range of challenges that can affect continuity of operations, connectivity, mobility, and asset resilience. The STRP provides opportunities for TxDOT to develop a systemic framework to address these challenges while supporting the SLRTP and agency-wide strategic goals.

Challenges:

More frequent and intense extreme weather events

Hurricanes, floods, and droughts leading to costly damage and delays

Human-made disruptors

Cyberattacks and border protests leading to disruptions

Bridge strikes

Trucks and ships hitting the underside of a bridge frequently leading to roadway and bridge (including maritime) closures

Data availability

Data used to track resilience not being available for the entire state

Lack of redundancy

No or long alternative routes existing for some critical roadways

Opportunities:

Improving network reliability and reducing travel delays

A more resilient transportation network can recover faster after a disruptor, reducing delay times

Improving freight resilience

Freight resilience is supported by a redundant, interconnected transportation system

Optimizing maintenance costs

Proactive planning for disruptors is less costly than repairing the damage after it occurs

Improving data and coordination

The STRP can enhance communication and data-sharing to improve resilience

Strengthening partnerships and enhancing community collaboration

Coordinated efforts to create a stronger, more stable transportation system

STRP Goals and Outcomes

The STRP supports the fulfillment of both the SLRTP goals and TxDOT's agency-wide operational goals.

STRP Goals

Strengthen strategic planning and design
through implementation of strategic measures, resilient designs, and proactive planning to ensure the sustained functionality and adaptability of vulnerable multimodal assets.

Ensure operational continuity
of transportation systems by employing resilient recovery and adaptive responses to facilitate the seamless movement of people and goods in the event of a disruption.

Improve adaptability at the organizational level
to ensure sustained performance through innovative solutions, continuous learning, and cross-functional collaboration.

Outcomes Supporting SLRTP Goals

- Improved safety
- Optimized maintenance budgets
- Extended asset lifespans
- Improved travel times and reliability
- Reduced downtime for repairs
- Increased investment efficiency
- Enhanced environmental and health benefits

Stakeholder Engagement

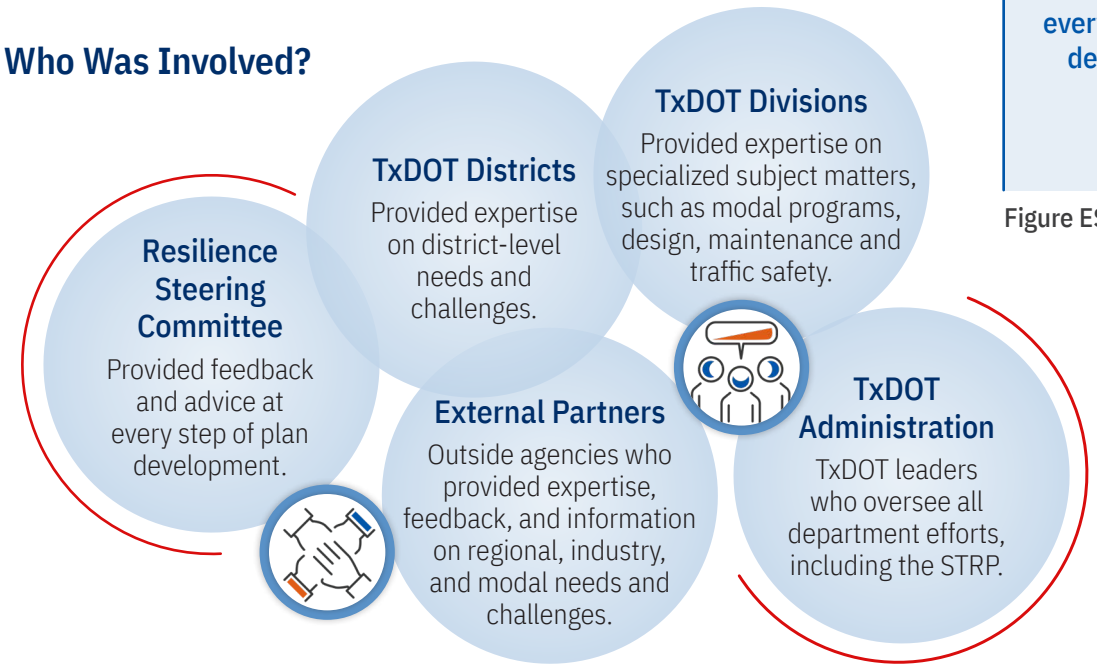
By engaging stakeholders, TxDOT ensures that the STRP reflects the state's diverse resilience needs and priorities. The engagement process has improved understanding of resilience challenges and priorities, collected data on resilience-related efforts, reviewed STRP study findings, and collaborated on strategy and performance measure development.

STRP Stakeholder Engagement

5 Resilience Steering Committee meetings	**8** stakeholder workshops attended by **200+** individuals from **100+** agencies	**40** stakeholder interviews
Key staff from TxDOT divisions and districts who championed the plan and provided guidance, feedback, and advice at every step of plan development.	Stakeholders form across the state brought together to integrate transportation priorities and needs representing Texas' unique geographies and regions into the STRP.	Strategic outreach to gain in-depth feedback from key experts on specific focus areas.

Figure ES-3: Stakeholder Engagement for the STRP

Who Was Involved?



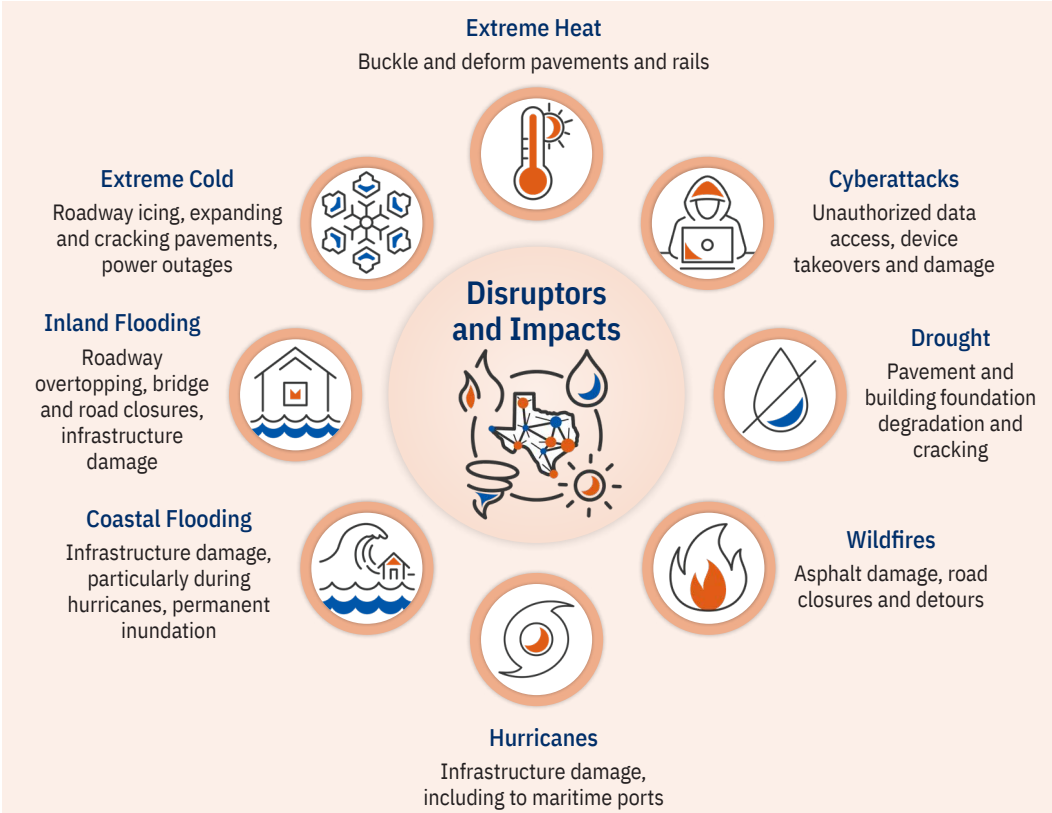
What's in the STRP?

The STRP evaluates the vulnerability of 10 asset types that are key components of the transportation system to future extreme weather events. Asset types with more than 1,000 segments or assets, including the roadway, bridge, and rail networks, were filtered to include only assets whose failure or disruption would have major impacts on the transportation network.

Figure ES-4: Assets Included in the STRP

The STRP evaluated each asset's vulnerabilities to extreme weather events. The STRP relied on input from TxDOT districts, divisions, and other stakeholders to select disruptors that have affected the transportation system in the past. These disruptors are projected to increase in severity and frequency in the coming decades, with worsening consequences for the transportation system.

Figure ES-5: Disruptors Included in the STRP



Vulnerability Assessment

The STRP identifies transportation assets that are highly vulnerable to key extreme weather events.

Roadways

Disruptors of primary concern:

Extreme Heat | Flooding | Wildfires

Highlights:

- Roadways in South and West Texas – especially the **Laredo District** – have high vulnerability to extreme heat
- Flexible (asphalt) pavements generally have higher vulnerabilities to flooding, wildfires, and extreme cold than rigid (concrete) pavements

Bridges and Culverts

Disruptors of primary concern:

Flooding | Hurricanes

Highlights:

- The **4,807** bridges and culverts in this study are most vulnerable to hurricanes and inland flooding
- By mid-century, **3 coastal bridges** in this study are projected to be inundated by sea level rise

ITS

Disruptors of primary concern:

Extreme Heat | Extreme Cold | Cyberattacks | Flooding

Highlights:

- **544** out of 4,463 ITS assets in this study (either dynamic messaging signs (DMS) or closed circuit television cameras (CCTV)) are highly vulnerable to inland flooding
- ITS assets are vulnerable to cyberattacks, which can lead to data breaches and unauthorized access to devices

Maintenance Facilities

Disruptors of primary concern:

Hurricanes | Flooding | Wildfires

Highlights:

- **19** out of 307 facilities in this study are highly vulnerable to inland flooding
- All maintenance facilities in the **Yoakum and Atlanta districts** have high vulnerability to wildfire

Border Crossings

Disruptors of primary concern:

Flooding

Highlights:

- Most border crossings cross the Rio Grande River, so they are in the **100-year** or **500-year floodplain** and have high or moderate vulnerability to inland flooding
- **6** out of 34 border crossings in this study have moderate vulnerability to wildfires

Maritime Ports

Disruptors of primary concern:

Highlights:

- **9** out of 20 ports in this study have high vulnerability to storm surge and 3 feet of sea level rise.
- **6 ports** have high vulnerability to multiple disruptors, including flooding from sea level rise, storm surge, and wildfires

Bike Lanes and Shared Use Paths

Disruptors of primary concern:

Highlights:

- **132 out of 475 miles** of bike lanes and shared use paths in this study have high vulnerability to inland flooding
- All **59 miles** of bike lanes and shared use paths in the Houston district have high vulnerability to hurricanes

Airports

Disruptors of primary concern:

Highlights:

- **25** out of 289 airports in this study have high vulnerability to inland flooding
- **9 airports** are highly vulnerable to extreme heat

Transit

Disruptors of primary concern:

Highlights:

- **6** transit centers and light rail stations and **17 miles** of light rail routes in Dallas are highly vulnerable to inland flooding
- Transit assets in Houston are highly vulnerable to hurricanes

Railways

Disruptors of primary concern:

Highlights:

- **Over 1,000 miles** of railway considered in this study have high vulnerability to inland flooding
- **226** of the 10,707 miles of railway in this study have high vulnerability to extreme heat

Considering the Cost of Inaction

Why analyze the cost of inaction?

Damage and disruption to Texas transportation assets have costs far beyond the direct repair and maintenance costs.

The STRP used a case study approach to estimate the costs of inaction for specific disruptor and asset combinations.

The analysis evaluated:

- Physical damages and repairs
- Field crew response and debris removal
- Costs to drivers because of delays and detours

Bridge closures can result in long detours

Roadways and Inland Flooding

$3.3 million

Costs for a 40-hour closure for a segment of I-20 in Odessa District

Bridges and Inland Flooding

$1 million–$2.2 million

Costs for repairing Judge Jodie Stavinoha Bridge in Houston District, requiring 12-40 hours of closure

ITS and Power Outages

$350 thousand

Costs of a 50-hour power outage at 10 key intersections in Lubbock

Maintenance Facilities and Flooding

$1.5 million

Costs of damages and operational disruptions for the Odessa District maintenance facility

* Results are rounded and shown in 2023 dollars.

$17.8 billion[2]

Cost of deteriorated roads each year for:

- Additional repairs
- Increased fuel consumption and tire wear
- Accelerated vehicle depreciation

$4.6 billion[3]

Cost of traffic delays on the 100 most congested road segments in Texas in 2023

Resilience Strategies

Based on the vulnerability assessment, the STRP developed resilience strategies that focus on the most vulnerable assets. The strategies encompass all asset types and disruptors and were designed to integrate easily with existing TxDOT plans and processes and achieve STRP goals.

Figure ES-6: Count of Resilience Strategies in Each Category

Strategies are categorized as:

Polices: Specific courses of action that, if adopted, will shape the way TxDOT approaches resilience.

Programs: A collection of initiatives or activities to enhance collaboration and system resilience.

Projects: Infrastructure improvements that improve the safety and efficiency of existing systems and prepare Texas for future disruptions.

Information and Technology Strategies: Studies and technology enhancements and improvements.

Strategies are also categorized by implementation timeframe:

Short-term (0 to 4 years) strategies may already be in place or require minimal funding or coordination to complete. Short-term strategies may require immediate action and contribute quickly to increased system resilience.

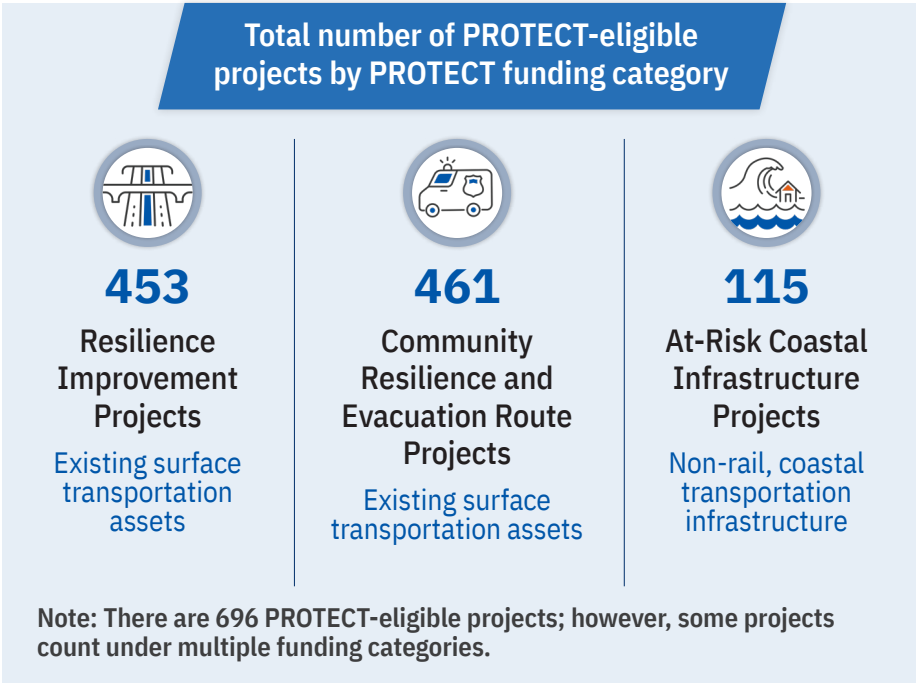
Medium-term (5 to 9 years) strategies may require additional planning, funding, or coordination to complete. TxDOT should begin working towards medium-term strategies as soon as possible, because the strategies may take several years to implement successfully.

Long-term (10+ years) strategies likely require the most significant planning, funding, and coordination to complete. TxDOT can work towards these strategies by establishing the necessary internal conditions (e.g., internal buy-in, funding sources), so that the strategies can be accomplished in the long-term.

Resilience Improvement Projects

To fulfill the RIP requirements for the PROTECT program, the STRP identified 696 existing TxDOT projects that may be eligible for PROTECT funding.

Figure ES-7: Total Number of PROTECT-eligible Projects by PROTECT Funding Category



Note: There are 696 PROTECT-eligible projects; however, some projects count under multiple funding categories.

Implementation

The STRP's success depends on timely implementation. The STRP is designed to be an actionable document, with a menu of funding and financing opportunities to support implementation and performance measures to track and monitor progress.

Funding and Financing

Planning for and implementing resilience strategies will be an ongoing and iterative process that may require TxDOT to consider new funding sources and financing options. Resilience strategies are intended to be part of the standard project scoring process; however, external funding and financing opportunities are available and could be considered to convert STRP strategies into implemented projects. Available funding opportunities include:

- Federal resilience, transportation, and security grants
- Access to funding through debt issuance
- Catastrophe and green bonds (designed specifically to raise capital for investments related to extreme weather events

If the cost of implementing a resilience strategy is significantly higher than typical costs, a cost-benefit analysis may be used to compare the cost of investing in a resilience project with the cost of damages from future disruptors.

Resilience Performance Measures

Performance measures are a key tool for TxDOT to monitor the transportation system's condition and performance. With input from TxDOT leadership, the RSC, and TxDOT divisions, the STRP team developed a set of seven key resilience-focused performance measures that apply to all transportation system assets.

Key Performance Measures

3 EXISTING PERFORMANCE MEASURES

- Percent of Bridges Inspected with A or B Condition Scores
- Average Facilities Condition Index Score
- Urban, Rural, and Truck Reliability Indexes

4 PROPOSED PERFORMANCE MEASURES

- Percent of Critical Assets Damaged Multiple Times because of Disruptors or Severe Weather Events
- Percent of Lane Miles with Alternate Routes
- Percent of Evacuation Routes in Good or Better Condition (Structure/Pavement Condition)[i] [4]
- Annual Incidents of Pavement Buckles because of Extreme Heat

i Pavement condition is determined by pavement distress (deterioration) and ride quality (smoothness).

Catalysts for Implementation

To achieve the STRP's goals, resilience strategies must transition from ideas and concepts to reality. Taking the following steps below will catalyze implementation and help TxDOT embed and prioritize resilience into operations, planning, and decision-making.

Incorporate resilience considerations into design

A Resilience Design and Construction Concepts Guide can embed resilience considerations into project design and delivery. The guide will safeguard TxDOT's infrastructure investments by incorporating the STRP's infrastructure strategies and accounting for projected future conditions in project design and construction.

Assess system redundancy and expand evacuation routes

Assessing redundancy and expanding evacuation routes can reduce bottlenecks, enhance TxDOT and first responders' ability to react quickly during emergencies, and provide safe evacuation for Texas' growing population.

Expand resilience engagement, partnership, and coordination

Engagement and coordination will enable stakeholders to share resources, learn from each other's expertise, and leverage strategic initiatives. TxDOT can play a key role in partnership building by leading regional resilience planning efforts and participating in multi-agency resilience working groups.

Develop and share resilience data and tools

A shared data resource for internal and external groups can support expanded coordination efforts and informed resilience planning.

Establish a funding and financing strategy

An effective funding strategy should consider investment scale and timing, identify opportunities to embed adaptation strategies within existing planned capital projects, match near-term strategies with current grant opportunities, establish partnerships and strategies for larger grants, and identify strategies that local partners can support.

Execute

Resilience is an iterative process, and executing short-term strategies creates momentum for medium- and long-term resilience improvements. Tracking resilience performance measures and implementing medium- and long-term strategies will improve safety and prevent damage-related costs far into the future.

1

Introduction to the Statewide Transportation Resilience Plan

1 Introduction to the Statewide Transportation Resilience Plan (STRP)

About the Statewide Transportation Resilience Plan

From the Gulf Coast to the Panhandle, the Texas multimodal transportation system – the largest in the United States – connects 30 million residents to jobs, schools, homes, recreation and services, and transports an estimated $2.9 trillion worth of freight within the state and beyond each year. In recent years, the Texas transportation system has faced a growing number of disruptors, from hurricanes to winter storms, threatening its operations, public safety, and the Texas economy. To respond to these challenges, the Texas Department of Transportation (TxDOT) developed the Statewide Transportation Resilience Plan (STRP) to secure a resilient future for the transportation system.

By establishing a planning framework, the STRP supports TxDOT in assessing its resilience comprehensively across the transportation system's most critical components. The STRP's goals are to identify the transportation system's critical vulnerabilities, develop strategies to address those vulnerabilities, guide projects and investments, and track system performance. Developed in coordination with TxDOT divisions, districts, and external stakeholders, the STRP aligns closely with TxDOT's long-range and strategic plans.

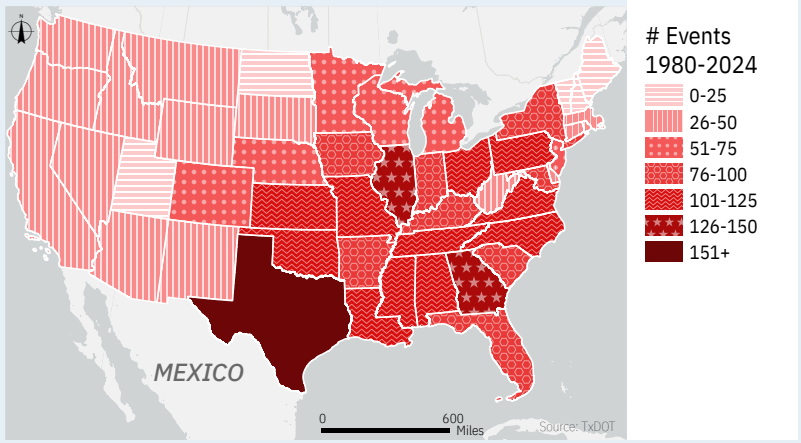
Texas experienced **188** extreme weather events, resulting in monetary losses each of at least **$1 billion** annually in inflation adjusted costs between 1980 and October 2024. This includes 19 droughts, nine floods, one freeze event, 126 severe storms, 15 tropical cyclones, seven wildfires, and 11 winter storms.[5]

Highlights

The Need for a Resilience Plan

The number of extreme weather events is growing rapidly in Texas (**Figure 1**). Between 2019 and 2024, Texas experienced an average of 12 extreme weather events with losses exceeding $1 billion per year, much higher than the state's annual average from 1980 to 2024 of four events per year.

Figure 1: Number of Extreme Weather Events with Damages Costing Over $1 Billion Each in the U.S. Between 1980 and 2024



The STRP is TxDOT's first statewide transportation-focused resilience plan. The STRP identifies the multimodal transportation system's key vulnerabilities to extreme weather events and develops a set of strategies to address these vulnerabilities.

It also supports the fulfillment of TxDOT's agency-wide goals to promote safety, deliver the right projects, optimize system performance, preserve assets, and foster stewardship.

Recent events — Hurricane Harvey (2017), Winter Storm Uri (2021), and wildfires, floods, and hurricanes as recently as summer 2024 — have damaged infrastructure and disrupted operations across highways, maritime ports, rail, and airports.[6]

The consequences have included higher repair and recovery costs than anticipated, with delays to the movement of people and goods, traffic crashes, disrupted access to critical facilities, and supply chain interruptions. Investment in system resilience can lead to significant cost savings: every dollar spent on risk reduction generates $15 in savings on post-disaster recovery.[7]

What's in the STRP?

The STRP provides a framework and acts as a cornerstone for resilience and adaptation planning at TxDOT. It defines resilience in the context of the transportation system and establishes TxDOT resilience goals and objectives. It also identifies critical transportation system assets and evaluates their vulnerabilities to disruptors including: extreme heat, extreme cold, inland and coastal flooding, hurricanes, wildfires, drought, and cyberattacks.

To address these vulnerabilities, the STRP outlines a set of resilience strategies, identifies existing projects that can incorporate these strategies, and recommends useful performance measures for tracking overall Texas transportation system resilience. The plan also highlights the economic consequences of inaction and identifies funding and financing resources to support implementation. The STRP enhances TxDOT's ability to anticipate future impacts; save costs; build partnerships; and strengthen connectivity, safety, and performance across the statewide transportation system.

What is Resilience?

Resilience for the STRP is the ability to support and maintain a **multimodal** transportation system that can **safely move people, goods, and services** during adverse conditions, and can **anticipate, prepare for, adapt to, withstand, respond to, and recover** quickly from human and natural disasters and disruptions.

Every **$1** spent on risk reduction generates **$15** in savings on post-disaster recovery.[8]

The STRP and PROTECT

The STRP fulfills the Promoting Resilient Operations for Transformative, Efficient and Cost-saving Transportation (PROTECT) program requirements for Resilience Improvement Plans (RIPs). As the RIP for Texas, the STRP will enable the state to access up to a 10% non-federal cost-share reduction for PROTECT fund use. Projects approved for a PROTECT discretionary grant and included in the RIP may qualify for a 10% reduction in the required non-federal cost share.

The STRP aligns with PROTECT requirements for a RIP by:

- **Undertaking a systemic approach to multimodal transportation resilience**
- **Conducting a science-based vulnerability assessment for future extreme weather events**
- **Recommending a robust set of resilience strategies**
- **Incorporating findings into the Statewide Long-range Transportation Plan (SLRTP)**

PROTECT Resilience Improvement Plan Requirement:

Requirement (B): The STRP goes beyond RIP requirements by including a detailed vulnerability assessment for 10 types of multimodal transportation assets. The STRP considers key hazards in the state hazard mitigation plan, including hurricanes, flooding, drought, and more.

A Comprehensive Assessment

The STRP provides a comprehensive vulnerability assessment focused on long-term trends in extreme heat, coastal flooding, and other extreme weather events over the next 30 years and extending to the year 2100. However, the STRP is not intended to address immediate impacts or emergency response. To facilitate prioritized implementation efforts, the STRP focuses on transportation assets that are the most critical to the transportation network, such as evacuation routes and roads that provide access to critical facilities (**Figures 2, 3,** and **4**). TxDOT also is developing a freight-focused resilience study that will expand upon the STRP's findings. The STRP does not include Texas' extensive pipeline network, mainly privately owned and which serves as an important part of the natural gas and petroleum freight transportation system.

Although not directly responsible for all transportation assets included in the STRP, TxDOT plays a key role in developing plans; coordinating and applying for federal funding; and working with metropolitan planning organizations, TxDOT districts, and other stakeholders across the state. TxDOT enhances the transportation network's overall resilience and functionality through ongoing collaboration.

Figure 2: Assets Included in the STRP

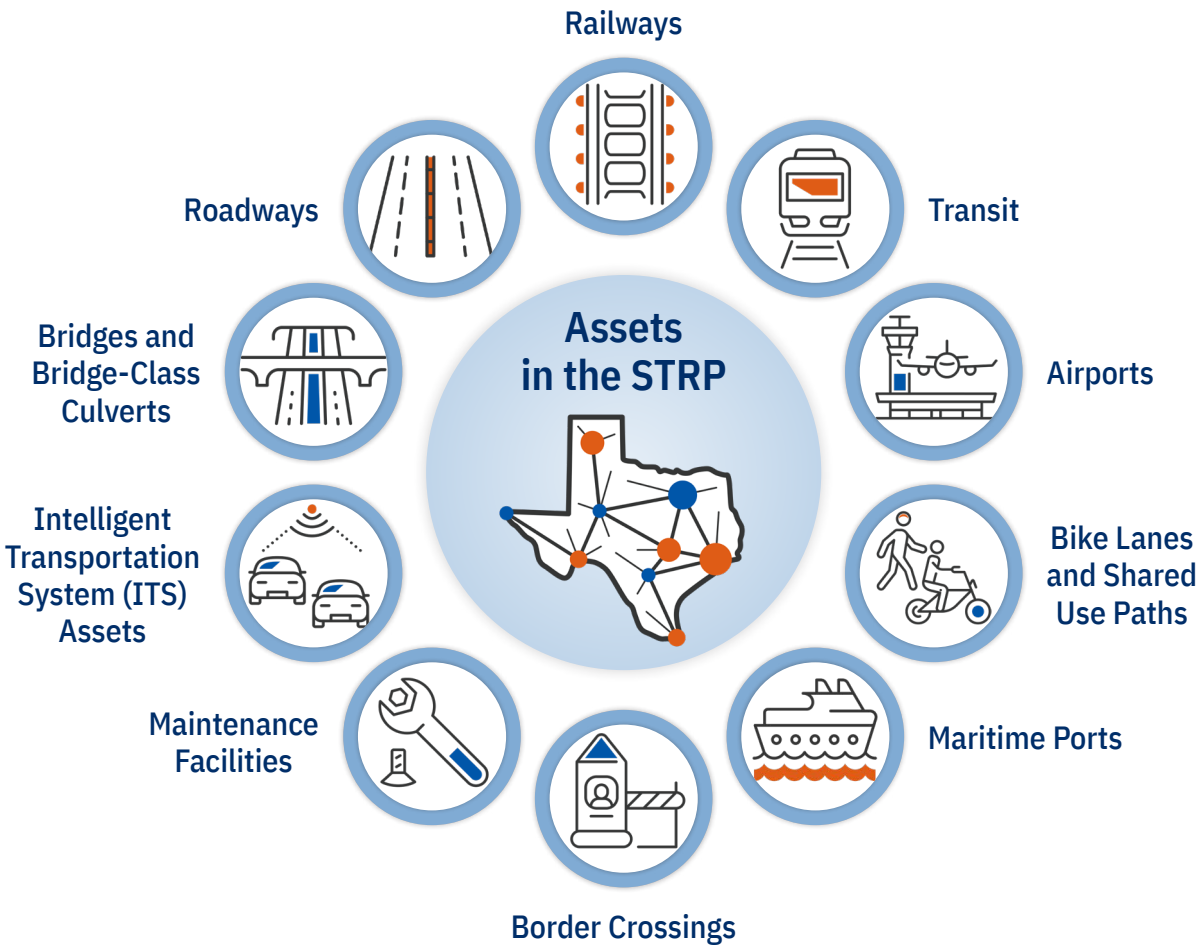


Figure 3: Technical Analysis Framework for the STRP

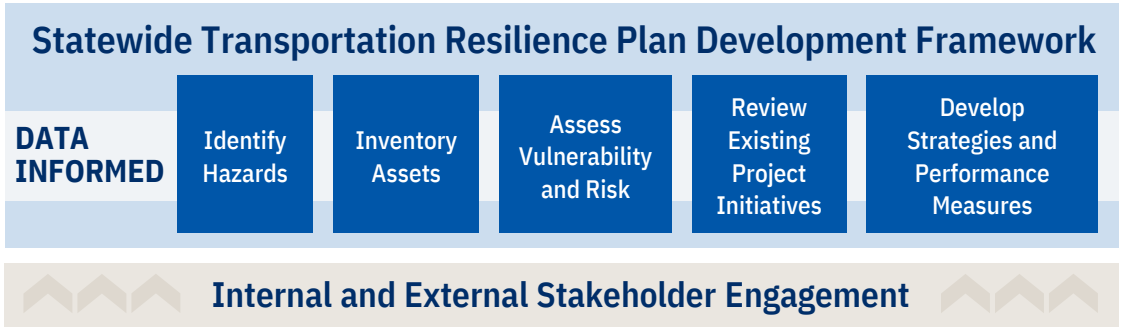
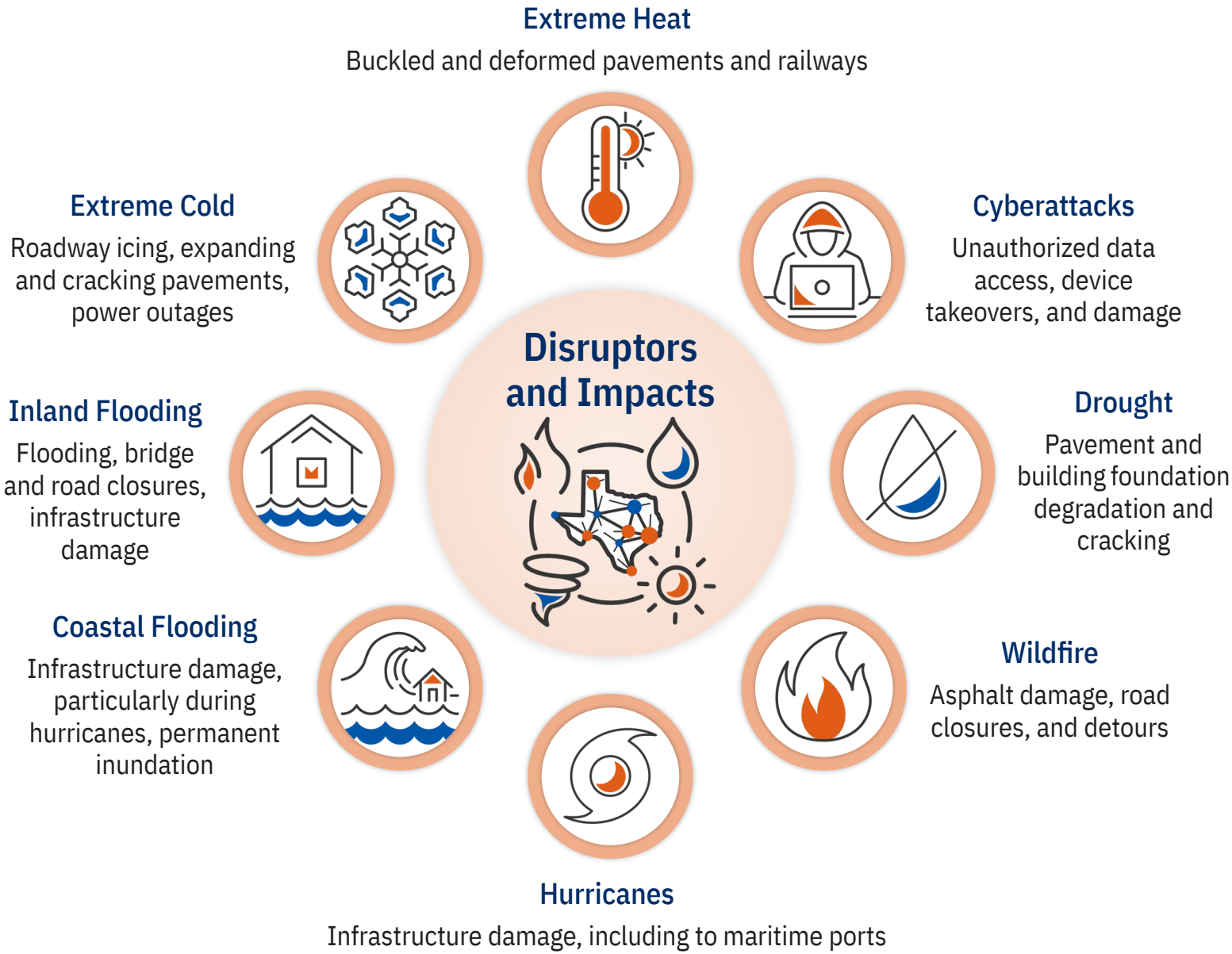


Figure 4: Extreme Weather Events and Human-Related Disruptors Included in the STRP



Extreme Events in Texas

Hurricane Harvey (2017): A Category 4 storm, this hurricane killed 103 people, cost $125 billion in damages, and required the largest disaster response effort in Texas history. Harvey flooded 80,000 homes, closed 23 maritime ports, and left 781 roads completely impassable in the days following the storm. Extended maritime closures because of repair and recovery efforts resulted in approximately $17.4 billion in economic damage.[11]

Extreme Drought (2011 to 2014): An extended drought from 2011 to 2014 caused $32 million in pavement degradation in Central and West Texas, where there is a high proportion of expansive soils that swell when wet and contract when dry. The City of Austin completely rebuilt a road that had an anticipated service life of 50 years after just 12 years, because of damage caused by contracting soils.[12]

Winter Storm Uri (2021): This historic winter storm led to widespread power outages that affected 4.5 million people. According to the Texas Comptroller of Public Accounts, power outages and road closures led to a 20% decrease in chemical and plastic exports, which made up 17% of all Texas exports the three months before the storm, and at least $600 million in agricultural losses.[13]

Smokehouse Creek Wildfire (2024): The largest wildfire in Texas history burned more than one million acres in three weeks before being contained. The fire closed highways; forced evacuations; killed thousands of cattle; and burned hundreds of ranches, farms, and homes in the Panhandle.[14]

Flash Flooding (2010 and 2024): Rio Grande Valley flooding in 2010 lasted for a month, closing international bridges and disrupting trade. In April 2024, record-breaking rainfall led the San Jacinto River to overflow, affecting large parts of East and Southeast Texas, including Harris County. In May 2024, flash flooding and hurricane-force winds led to four deaths, multiple road closures, and power outages for millions of people in Houston and Dallas.[15]

Challenges

The transportation network faces a range of challenges related to resilience. Among these are more frequent and intense extreme weather events and cyberattacks that can cause delays to freight and trade.

More Frequent and Intense Extreme Weather Events

Texas is already experiencing more frequent and damaging extreme weather events. Texas currently leads the nation in the number of high-cost weather events, including hurricanes, floods, and wildfires.[9] Over the past decade (2015 to 2024), Texas has experienced 103 weather events costing more than $1 billion in damages each, more than double the number of events costing more than $1 billion each in the decade prior (2005 to 2014). The increasing frequency and severity of these events is already leading to higher maintenance, repair, and replacement costs. In addition, the infrastructure damage, road closures, and power outages cause significant delays for travelers, first responders, and freight and shipping operations.

Disruptions to the freight system can have far-reaching impacts on recovery efforts that affect both the Texas and national economies. To withstand these impacts, transportation infrastructure will require updated designs, standards, and maintenance practices, such as elevated bridges, expanded culverts, and wildfire risk reduction through more frequent roadside vegetation management.

Human-Made Disruptors

Cyberattacks have become an increasing risk for the transportation system, as ITS devices play an important role in monitoring roadway conditions, providing real-time data, and coordinating transportation operations. These ITS assets are vulnerable to both extreme weather events and cyberattacks, with consequences including malfunctioning assets, data loss, pauses in freight operations, and malicious takeovers through hacking. Similarly, enhancing resilience at Texas' 34

land and rail border crossings is critical to ensure economic health. In 2019, an estimated 114 million tons of goods passed across the Texas-Mexico border.[10] Disruptions at border crossings result in costly delays for freight and people, with cascading costs for supply chains that can affect both the state and national economies.

Bridge Strikes

Bridge strikes are caused by oversized trucks and large ships not heeding warning signs and hitting the underside of bridges. This is a major concern for the Interstate (I) 20 corridor, among others. Bridge strikes can result in lane or road closures, the need for repairs, and cumulative deterioration of pavement and bridge conditions, especially for bridges that experience multiple strikes each year.

Data Availability

Because of the state's size, collecting accurate, reliable data on assets and disruptors is a challenge. For example, a project to map the 500-year floodplain currently is in development, meaning that some floodplain data was unavailable for the STRP. Additionally, data is continuously being updated based on advances in science.

Lack of Redundancy

Access to alternative routes is a challenge for many critical highways. In West Texas, closures due to disruptors often require long detours. Because these highways connect the oil and gas industries with shipping centers (maritime ports, railways) and refineries, road closures can delay oil and gas shipments, which can impact State and national economies. As Texas' population continues to increase, it is also important to consider adding redundancy along evacuation routes, particularly as hurricane seasons become more intense.

Opportunities

The STRP identifies opportunities for the transportation system to become more resilient to the challenges that are identified while supporting agency-wide goals. Through planning with resilience in mind, TxDOT can take advantage of the following opportunities:

Improving Network Reliability and Reducing Travel Delays

Resilience planning at a statewide level can provide the opportunity to reduce asset downtime and improve traffic flow. By prioritizing investments that address highly vulnerable assets, planning can reduce direct damage, improve reliability, and reduce delays. Resilience planning also supports the consideration of future, more extreme, disruptors during a project's design phase. For example, including upgraded culvert capacity during project design can decrease the likelihood of flooding and associated road closures after project completion.

Improving Freight Resilience

Improving system resilience can provide an opportunity to reduce delays for freight and shipping, particularly if project sponsors prioritize implementation for the Texas Highway Freight Network, maritime ports, railways, and border crossings. One example is designing rails to higher temperature thresholds to prevent rail buckling. Strengthening maritime ports against coastal flooding can reduce infrastructure damage, maritime port closures, and associated impacts on shipping. ITS and smart freight technologies can reduce wait times at maritime ports and border crossings and allow trucking companies to avoid transportation system pinch points.

Optimizing Maintenance Costs

Anticipating future disruptors in planning and implementation provides an opportunity to generate significant cost savings due to avoided costs for post-event clean-up, repairs, and recovery. The STRP's cost-of-inaction analysis confirms that investing in resilience can be more cost-effective than reactively paying for recovery. These savings become even greater when considering avoided costs for households and businesses.

Recovering Resiliently

Both scheduled maintenance and unplanned repairs can serve as an opportunity to incorporate resilience. They offer an opportunity to update asset design to accommodate projected long-term trends in extreme weather events. For example, repairs for flood-damaged roadways can incorporate higher foundations or improved drainage systems. If repairs and reconstruction continue to follow original specifications, this could lead to a repeated cycle of damage and recovery, rather than improved resilience.

Improving Data and Coordination

Enhancing data collection and coordination can improve response times and encourage collaboration on resilience solutions and strategies. In addition, strengthening the ITS network to both extreme weather events and cyber threats can increase the uptime of ITS devices, thus improving data availability and reliability. In turn, this can enable TxDOT and its traffic management centers to better coordinate and manage traffic flow and respond to emergencies, resulting in improved safety and recovery time.

Strengthening Partnerships and Enhancing Community Coordination

Extreme disruptors impact entire regions and can have comprehensive and long-reaching consequences, including in areas the disruptor did not physically impact. The transportation system connects regions and communities, linking, for example, the Permian Basin to the refineries and ports on the Gulf Coast. Fewer disruptions to transportation will better enable residents to access jobs, schools, and other necessities. Functioning local supply chains are critical to stock supermarkets, especially during disruptors or for post-disaster recovery. As such, coordination among jurisdictions and stakeholders is critical to connect communities across regions. TxDOT can play a key role in developing new and increasingly important collaborations among communities, resulting in strengthened partnerships that span jurisdictional boundaries and shared benefits for overall public health, the environment, and local economic vitality. Furthermore, coordination with local and regional agencies can advance nature-based solutions that may span jurisdictional boundaries, such as restoring wetlands.

Resilience Planning Benefits:

How to Use the STRP

The STRP introduces the key goals, challenges, and opportunities of resilience planning.

- **Chapter 1** introducing challenges and opportunities associated with transportation and explains how to use this plan
- **Chapter 2** describes its goals and how it aligns with other TxDOT planning efforts
- **Chapter 3** summarizes the stakeholder engagement process
- **Chapter 4** provides an overview of projected future trends for extreme weather events and their impacts on the transportation system
- **Chapter 5** presents the results of the vulnerability assessment, including identifying highly-vulnerable assets
- **Chapter 6** describes the cost-of-inaction assessment results
- **Chapter 7** presents resilience strategies and associated prioritization and project identification processes
- **Chapter 8** outlines STRP considerations for implementation, including funding and financing options, performance measures, and next steps

Groups and Suggested Uses

The STRP encourages the following groups to use this document to learn more about transportation system resilience planning:

TxDOT Leadership and State Officials: Understand key challenges, trends, and priorities for resilience planning for the multimodal transportation system and identify policy opportunities and strategic initiatives.

TxDOT Divisions and Districts: Explore long-term trends in extreme weather events and human-related disruptors, identify highly-vulnerable transportation asset types and incorporate findings into TxDOT planning, project development, funding, policies, design standards, and manuals.

Metropolitan Planning Organizations (MPOs), Rural Planning Organizations (RPOs), Cities and Counties: Review statewide findings, methodologies, strategies, and performance measures to align their regional and local resilience planning, including RIP development.

External Partner Agencies: Understand key extreme weather events, transportation vulnerabilities, and strategies to coordinate planning and project development. Outside agencies include other state departments of transportation (DOTs), MPOs, and maritime ports.

Public: Explore how Texas is likely to experience more extreme and frequent hurricanes, extreme heat, floods, droughts, and wildfires and likely impacts for transportation users.

Industry and Private Business: Identify key vulnerabilities related to extreme weather events for freight and shipping; incorporate findings into planning, investments, and operations; and explore partnership opportunities with TxDOT and other agencies to build resilience in transportation operations.

2

Plan Goals and Objectives

2 Plan Goals and Objectives

Plan Goals and Objectives

The STRP aims to define resilience in the TxDOT transportation planning context, assess potential impacts on transportation assets from extreme weather events, develop an implementation plan of strategies to reduce the potential impacts, and establish a process to consistently incorporate resilience into TxDOT planning processes. The STRP sets out three overarching goals and supporting objectives that align with goals from the SLRTP and other agency plans. The STRP also aligns closely with TxDOT's existing plans.

By planning for the transportation system's future resilience and recommending a set of implementation strategies, the STRP is creating the foundation to develop more resilient transportation assets and projects across the state, which can translate into improved safety for all users, reduced maintenance costs, longer asset lifespans, improved travel times and reliability (because of less downtime for repairs), more efficient investments, greater environmental and health benefits, and improved water quality and flood control (from stormwater improvements).

Highlights

The STRP exceeds the PROTECT program's requirements for RIPs and will help TxDOT maximize federal funds available for implementing resilience projects. Texas will receive an average of $145 million per year for efforts in transportation resilience from 2022 to 2026 as part of the PROTECT Formula Grant Program. By developing the STRP, Texas can lower its share of PROTECT funding costs for the formula program from 20% to 10%. Similarly, for the PROTECT Discretionary Grant Program, receiving entities may lower their share of funding costs by the same amount if the entity is a state (e.g., TxDOT) or MPO.

The STRP supports SLRTP goals:

STRP Goals	SLRTP Outcomes
Strengthen strategic planning and design	Improved safety
	Optimized maintenance budgets
	Extended asset lifespans
Ensure operational continuity	Improved travel times and reliability
	Reduced downtime for repairs
Improve adaptability at the organizational level	Increased investment efficiency
	Enhanced environmental and health benefits

Strengthen Strategic Planning and Design

Goal Description:

Enhance resilience through implementation of strategic measures, resilient designs, and proactive planning to ensure the sustained functionality and adaptability of vulnerable multimodal assets.

Objectives:	TxDOT SLRTP Goals Supported:
Reduce the vulnerabilities of critical transportation assets	Safety, Preservation, Mobility
Develop and implement resilient design and construction standards	Safety, Preservation, Mobility, Connectivity
Provide digital resources and mapping tools for statewide transportation resilience planning	Safety, Preservation, Mobility
Invest in green infrastructure and nature-based solutions	Safety, Preservation, Mobility, Connectivity, Stewardship

Ensure Operational Continuity

Goal Description:

Ensure the operational continuity of transportation systems by employing resilient recovery and adaptive responses to facilitate the seamless movement of people and goods in the event of a disruption.

Objectives:	TxDOT SLRTP Goals Supported:
Support post-disaster recovery planning	Safety, Preservation, Mobility, Connectivity, Economic Vitality, Stewardship
Reduce response time and recovery cost	Safety, Preservation, Mobility, Connectivity, Economic Vitality
Foster inter-agency partnerships for coordinated resilience planning, investment, and emergency response preparedness	Safety, Connectivity, Stewardship
Invest in alternative routes, modes, and backup systems	Preservation, Mobility, Connectivity, Economic Vitality, Stewardship
Improve supply chain resilience through investment in alternative modes of freight transit	Preservation, Mobility, Connectivity, Economic Vitality, Stewardship

Improve Organizational Adaptability

Goal Description:

Improve adaptability at the organizational level to ensure sustained performance through innovative solutions, continuous learning, and cross-functional collaboration.

Objectives:	TxDOT SLRTP Goals Supported:
Expand educational programs and community engagement on resilience initiatives	Preservation, Economic Vitality, Stewardship
Implement technology and mechanisms for ongoing monitoring and evaluation of resilience measures	Preservation, Mobility, Connectivity, Economic Vitality, Stewardship
Establish resilience governance structures and policies that enable decision makers to respond effectively to extreme weather events	Preservation, Stewardship

The STRP Supports TxDOT Plans

The STRP provides a framework for integrating resilience transportation planning, including asset management, funding mechanisms, corridor improvements, and freight planning (**Figure 5**). The STRP builds on adopted plans and plans in development by aligning goals, priorities, and strategies.

Figure 5: Common Resilience-Related Themes Shared Between the STRP and TxDOT's Existing Plans

Account for Resilience in Lifecycle Planning and Maintain, Preserve, and Improve Assets

- Statewide Long-Range Transportation Plan
- Texas-Mexico Border Transportation Master Plan
- Transportation Asset Management Plan
- Metropolitan Transportation Plans
- Statewide Multimodal Transit Plan
- Statewide Active Transportation Plan

Support Safety, Reliability, and Efficiency

- Statewide Long-Range Transportation Plan
- Texas-Mexico Border Transportation Master Plan
- Transportation Systems Management and Operations
- Metropolitan Transportation Plans
- Corridor Studies
- Texas Strategic Highway Safety Plan
- Cooperative Automated Transportation Strategic Plan

Improve Environmental Stewardship

- Statewide Long-Range Transportation Plan
- Texas-Mexico Border Transportation Master Plan
- Texas Freight Mobility Plan
- Metropolitan Transportation Plans
- Corridor Studies
- Texas Electric Vehicle Infrastructure Plan
- Texas Statewide Rail Plan

Statewide Transportation Resilience Plan

establishes a framework for resilience planning

Improve Network Resilience and Connectivity

- Texas-Mexico Border Transportation Master Plan
- Texas Freight Mobility Plan
- Corridor Studies
- Metropolitan Transportation Plans
- Texas Electric Vehicle Infrastructure Plan
- Freight Network Technology and Operations Plan
- Cooperative Automated Transportation Strategic Plan

Identify and Prioritize Resilience Strategies and Projects

- Statewide Long-Range Transportation Plan
- Unified Transportation Program
- Metropolitan Transportation Plans
- Texas Port Mission Plan
- Texas Airport System Plan
- Texas Statewide Rail Plan
- Statewide Multimodal Transit Plan
- Statewide Active Transportation Plan

Reduce Disruptions to Supply Chains

- Texas-Mexico Border Transportation Master Plan
- Texas Freight Mobility Plan
- Corridor Studies
- Freight Network Technology and Operations Plan
- Texas Port Mission Plan

Connecting Texas 2050 – Statewide Long-Range Transportation Plan

The latest version of *Connecting Texas 2050*, establishes the vision, goals, objectives, and strategic recommendations for the Texas multimodal transportation system through 2050. This plan guides the overall direction of planning and programming investments. The STRP and SLRTP teams coordinated closely during the development process for both plans to support alignment, with the SLRTP incorporating STRP findings as required by PROTECT.

Texas Delivers 2050: Texas Freight Mobility Plan[16]

Texas Delivers 2050 describes TxDOT's comprehensive strategy for a multimodal freight system to support economic growth through safe, efficient, resilient, and equitable movement of goods through 2050. The STRP supports the Texas Delivers 2050 goal of a connected and resilient freight network by assessing the vulnerability of critical freight network assets to a wide range of disruptors and developing targeted strategies.

Texas-Mexico Border Transportation Master Plan[17]

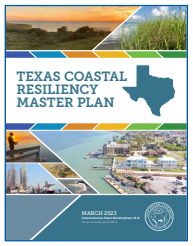
The *Texas-Mexico Border Transportation Master Plan* outlines long-range cross-border transportation policies, programs, and strategies for the efficient and safe movement of people and goods across the Texas-Mexico border and throughout the border region. The STRP assesses border crossings and critical transportation infrastructure's vulnerability and develops targeted resilience strategies in support of the plan's cross-border resilience goal.

Transportation Asset Management Plan[18]

The *Transportation Asset Management Plan* (TAMP) outlines a 10-year strategy for managing and maintaining the state's pavements and bridges and highlights resilience as one of TxDOT's existing risk management strategies. Updated regularly, the next edition of the TAMP may incorporate findings from the STRP when developing the strategy for managing pavements and bridges.

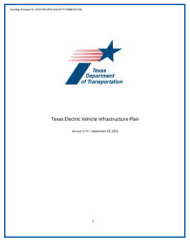
Unified Transportation Program[19]

Updated annually, the *Unified Transportation Program* (UTP) is a 10-year plan that provides a framework to select and fund priority transportation projects to develop or construct. The STRP team reviewed projects in the 2025 UTP, as listed on the TxDOT Project Tracker,[20] to identify projects that address resilience and therefore may be eligible for PROTECT funding (**Chapter 7**). Future UTPs could incorporate STRP findings by including resilience in project selection criteria and integrating resilience metrics into system performance measures.



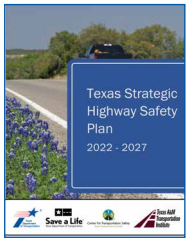
Texas Coastal Resiliency Master Plan[21]

The Texas General Land Office's *Texas Coastal Resiliency Master Plan* (TCRMP) outlines a comprehensive strategy to protect and enhance the Texas coast and its habitats, infrastructure, and communities through actions and projects to address vulnerabilities and promote economic growth, safety, and environmental health. The STRP used the 2023 edition's coastal flooding data, and the TCRMP informed the coastal resilience sections; in turn, STRP findings and strategies related to coastal resilience may be incorporated into the next TCRMP update.



Texas Electric Vehicle Infrastructure Plan[22]

The Texas Electric Vehicle Infrastructure Plan provides a framework that will enable current and future drivers of electric vehicles to travel confidently across the state and increase economic development, focusing on establishing a network of electric vehicle charging stations supported by a reliable electric grid. Alternative Fuel Corridors are included in the STRP assessment. In addition, the STRP supports the development of electric vehicle infrastructure as a more redundant fuel source.



Texas Strategic Highway Safety Plan[23]

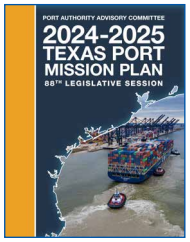
The *Texas Strategic Highway Safety Plan* aims to improve safety on state and local roadways. It recommends strategies and targets to reduce crash-related fatalities and injuries. The STRP supports improvements to the transportation system that will help achieve the plan's goal of zero fatalities and serious injuries on TxDOT roadways by 2050.

Freight Network Technology and Operations Plan[24]

The *Freight Network Technology and Operations Plan* provides a statewide blueprint for a technology-based freight safety and operations program, as recommended in the 2018 Freight Mobility Plan. The plan recommends several technology and operations investments on the Texas Multimodal Freight Network that align with recommendations in the STRP, such as improving advanced traveler information systems and dynamic route guidance.

Cooperative Automated Transportation Strategic Plan[25]

Cooperative Automated Transportation (CAT) technologies can improve safety and mobility while reducing the environmental impact of the transportation system. The *CAT Strategic Plan* identifies emerging CAT technologies and opportunities to maximize CAT benefits. The STRP supports the use of technologies such as CAT to improve safety, reduce congestion on critical routes, and improve transportation data.



Texas Port Mission Plan[26]

The *Texas Port Mission Plan* outlines maritime ports infrastructure and connectivity needs and identifies important maritime ports projects for investment. The plan emphasizes the need for maritime ports to be resilient in order to support the Texas economy and in connecting the state with outside resources during and after a disruptor. The STRP supports the plan by identifying investments in maritime ports infrastructure that will enhance the resilience of maritime ports to coastal hazards and supply chain impacts. The maritime ports in this plan were included in the STRP vulnerability assessment.

Texas Airport System Plan[27]

The *Texas Airport System Plan* aims to improve airport access and ensure timely development and maintenance of the airport system. The STRP increases airport resilience with recommendations for infrastructure investments that would maintain airport access roads, improve backup power, and enhance stormwater drainage.

Texas Statewide Rail Plan[28]

A functional freight and passenger railway system improves resilience by enhancing the statewide economy and improving safety and reducing emissions by reducing highway congestion. The STRP supports projects identified in the *Texas Statewide Rail Plan* that will enhance railway mobility, reliability, and resiliency, such as station stormwater and drainage improvements and the construction of additional tracks.

Statewide Multimodal Transit Plan[29]

The *Statewide Multimodal Transit Plan* identifies specific actions necessary to increase mobility and connectivity, support economic and population growth, and address congestion. The plan is informed by extensive public outreach and stakeholder engagement to identify how Texans use and value transit. The STRP supports the development of transit that is resilient to disruptors, enabling the expansion of transit systems that can meet the goals of this plan.

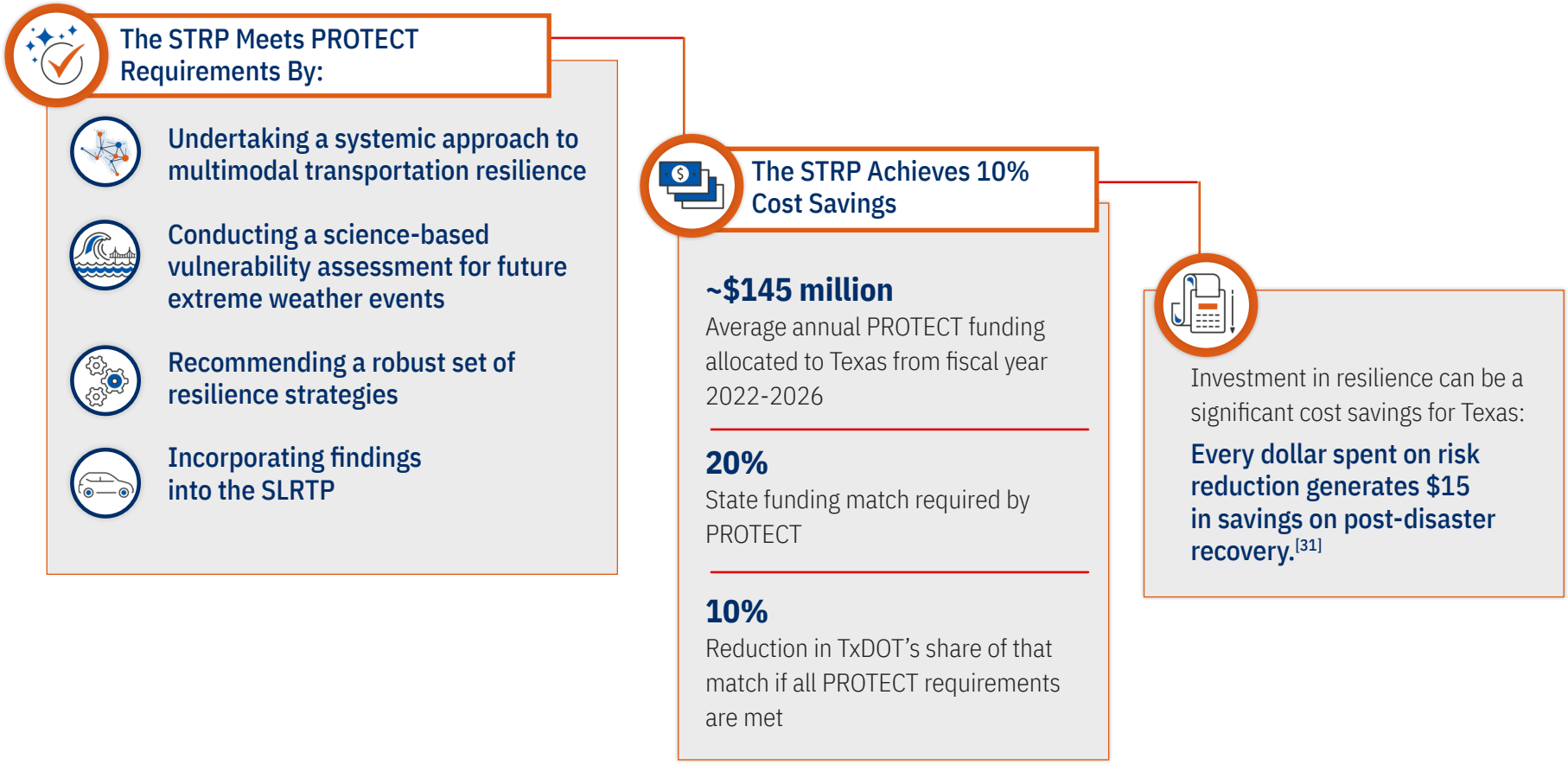
Statewide Active Transportation Plan[30]

The *Statewide Active Transportation Plan* establishes a vision for the future of active transportation (walking, biking, and rolling) through 2050. The STRP supports improvements to bike lanes and shared use paths that are resilient to extreme heat, flooding, and other disruptors that often prevent people from traveling using active transportation.

The STRP Supports Federal Programs

The 2021 Infrastructure Investment and Jobs Act (IIJA) is a comprehensive legislative package aimed at modernizing America's infrastructure. Within the IIJA, the PROTECT program provides funding for improving the resilience of surface transportation. At least 2% of the funding is required to be used for resilience planning activities, such as for development of a RIP. The STRP is TxDOT's RIP.

For fiscal years 2022 to 2026, PROTECT allocates an average of $145 million in formula funds annually for Texas, with a 20% state match. One of the STRP's benefits is that it allows Texas to reduce its cost share by 10%. To be eligible for the cost-share reduction, the RIP must meet requirements specified by the PROTECT program, and findings must be incorporated into the SLRTP. Throughout the plan, the STRP identifies the chapters that fulfill PROTECT's requirements for a RIP and identifies which requirements are fulfilled.



3

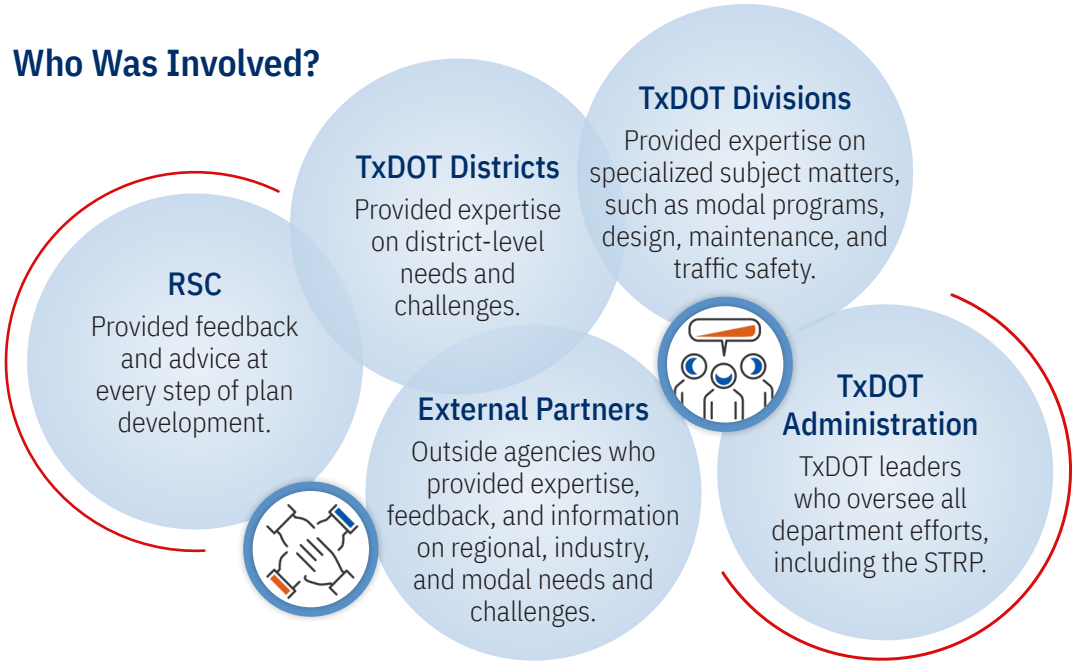
Stakeholder Engagement

3 Stakeholder Engagement

Stakeholder Engagement Overview

Stakeholder engagement was crucial to ensure that the STRP reflects the priorities and needs of Texas' diverse communities and industries. The stakeholder engagement process aimed to increase project awareness, collect data on transportation and resilience efforts, coordinate with ongoing local and State planning efforts, collaborate on strategy development, and validate results through feedback. The efforts consisted of meetings with the TxDOT Resilience Steering Committee (RSC), external stakeholder workshops, internal TxDOT coordination meetings and external stakeholder interviews. **Figure 6** shows the stakeholder engagement activities timeline.

Who Was Involved?



Highlights

Stakeholder Engagement Goals:

- Increase project awareness
- Identify data on transportation and resilience efforts
- Coordinate with ongoing local and state planning efforts
- Collaborate on strategy development
- Validate results through feedback

Stakeholder Engagement Activities:

- **Five** RSC meetings
- **Eight** Stakeholder workshops
- **15+** Internal TxDOT coordination meetings
- **40** External stakeholder interviews

Figure 6: Stakeholder Engagement Timeline

Resilience Steering Committee

The RSC provided internal coordination and engagement during the STRP's development. Members include key staff from Administration, 15 TxDOT divisions, and six districts, representing unique geographical areas across the state. The goal of the RSC meetings were to capture regional resilience issues, collect input on study deliverables, identify study champions, and facilitate connections with stakeholders to catalyze the STRP's implementation.

5 RSC Meetings attended by **80+** individuals across Administration, **15** divisions, and **6** districts

What We Heard from the RSC:

TxDOT's Role

- Encourage organizations to incorporate resilience strategies in planning.
- Provide guidance for enhancing resilience for on- and off-system assets.

Challenges and Concerns

- Aging infrastructure requires more maintenance and upkeep.
- Infrastructure damage and cascading impacts, such as freight delays, will increase economic costs.
- Coordinating among agencies is difficult.

Resilience Goals

- Identify and reinforce critical infrastructure vulnerabilities.
- Share data with other agencies and partners.
- Develop and maintain alternative transportation routes.

Performance Measures

- Track travel time and travel delays during disruptions.
- Evaluate redundancy in power supply and routes.

Strategy Inputs

- Ensure strategies improve long-term asset resilience without compromising performance.
- Transfer knowledge and data to cities and agencies.

Stakeholder Workshops

Stakeholder workshops aimed to identify transportation resilience priorities and needs through discussions with various transportation stakeholder groups about challenges across Texas.

8 workshops attended by **200+** individuals across **80+** partner agencies, **25** districts, and **3** divisions

What We Heard About Statewide Resilience:

Urban Areas

- Operations and emergency response are affected by power outages.
- Limited funding, staffing, and resources are available.
- Data-driven resilience policy recommendations are needed.
- Urban areas require network redundancy improvements.

Rural Areas

- Rural areas face challenges from undivided roads, heavy truck traffic, and cable cuts.
- Limited transit services impact evacuation capabilities in rural areas.
- Mobile mechanics and fuel trucks are needed during evacuations.
- Border crossing delays occur and limited broadband availability exists in rural areas.

Freight, Trade, and Border Transportation

- Alternative routes and robust security infrastructure are needed.
- Emergency response plans and agency coordination are necessary.

Railways, Maritime Ports, Waterways, and Airports

- Strengthening of critical infrastructure to withstand extreme weather is needed.
- Disaster relief programs and proactive infrastructure development is essential.
- Enhanced workforce training and regular vulnerability analyses are needed.
- Needs exist for rural expansion, technology optimization, and quick maritime ports access.

TxDOT Districts

- Backup power systems, power source redundancy, and elevated coastal highways should be considered.
- Effective inter-district and inter-agency coordination is needed during disruptive events.
- Districts require preparation for utility risks and extreme weather conditions.

MPOs

- Some MPOs are focused on at-risk assets and resilience performance measures.
- Regular maintenance is needed for evacuation routes serving critical facilities.
- MPOs require TxDOT's support for planning and data sharing.
- Some MPOs identify rising sea levels and increasing flood risks as major challenges.

External Stakeholder Interviews

Stakeholder interviews were part of strategic outreach geared toward gathering detailed information to inform different tasks throughout the study and understand resilience needs and priorities for various individual stakeholders, modes, and regions.

40 Interviews with

- **24** Government Agencies (5 Counties, 8 Government Agencies, 6 MPOs, 5 state DOTs)
- **3** Industry Associations
- **3** Ports
- **3** Railroads
- **2** Advocacy Groups
- **2** Private Industry
- **2** Research and Academic Institutions
- **1** Utility

What We Heard:

Disruptors

- Region-specific challenges include seismic activity, landslides, sinkholes, fog, wind and dust storms, and heavy truck traffic.
- Human-made disruptors such as construction, accidents and cybersecurity threats have caused significant infrastructure damage and community impacts.

Critical Assets

- Various assets, including roads, bridges, maritime ports, airports, rail networks, and pipelines, were identified as critical.
- Emergency response infrastructure, such as communication systems, shelters, and evacuation routes, were deemed critical for ensuring the safety and well-being of communities during disruptions.

Resilience Needs

- Needs included effective inter-agency communication; accurate and timely data; dedicated resilience funding, staff, and resources; and State-level guidance and performance metrics for resilience.
- Investments in hardening infrastructure, improving drainage systems, and implementing innovative technologies were suggested.

Future Vulnerabilities

- Anticipate more frequent and severe hurricanes, floods, wildfires, and extreme heat events.
- Significant investments are needed to combat future threats and vulnerabilities arising from electric grid failure.

Resilience Challenges

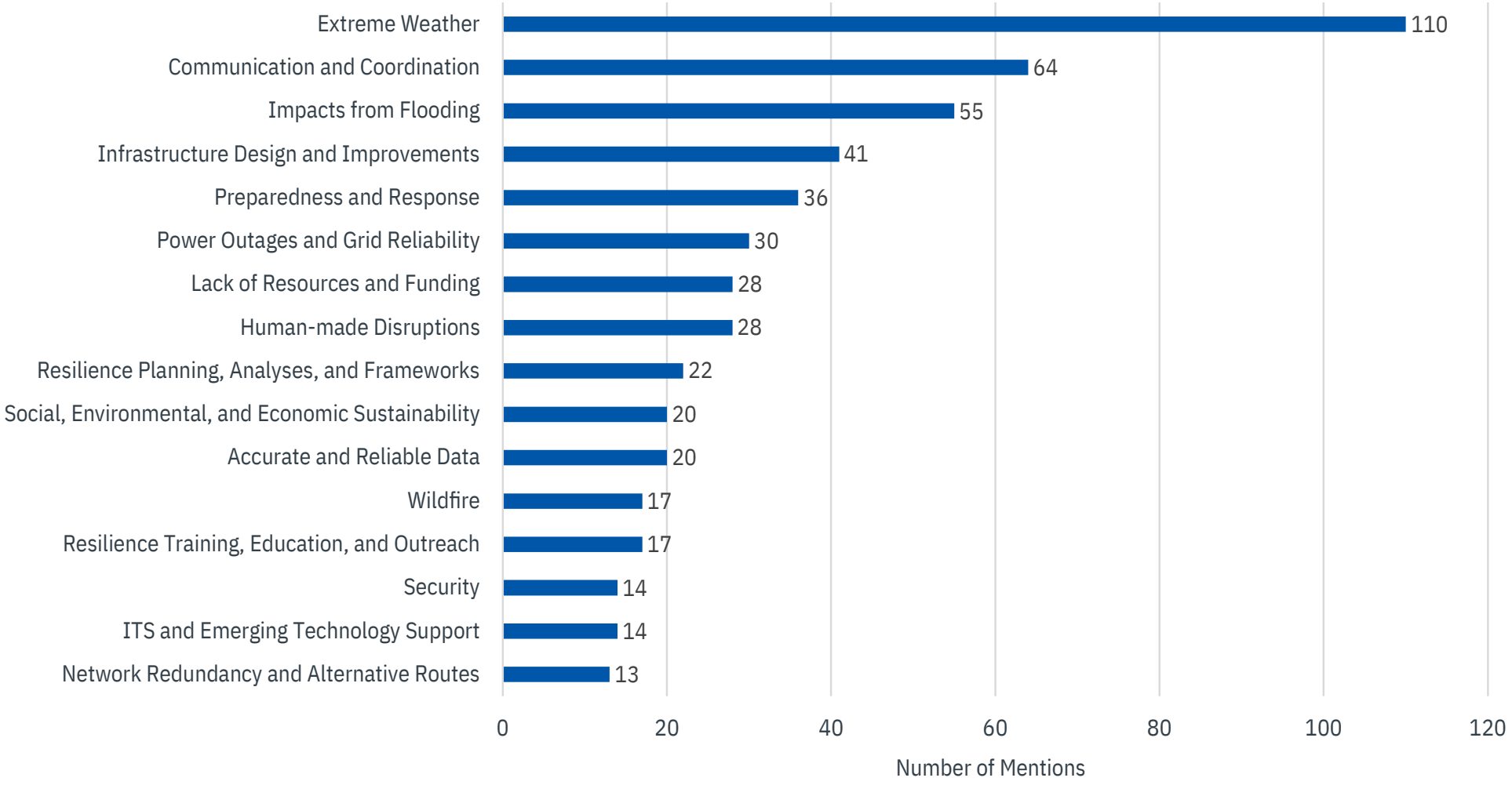
- Major challenges included post-storm debris and sedimentation, power outages, disrupted communication, and supply chain disruptions.
- Securing adequate funding and resources for resilience planning and implementation is a major challenge for many stakeholders.

Best Practices

- Engaging with local communities and stakeholders through outreach and education programs on resilience.
- Effective collaboration and partnerships through data sharing, standardizing emergency response protocols, and developing local resilience plan are crucial for successful resilience planning and response efforts.

Figure 7 summarizes the most common stakeholder needs, challenges, and priorities related to resilience across Texas, based on the number of mentions these and other topics generated during RSC meetings, stakeholder workshops, and external stakeholder interviews. The most common responses received were those related to challenges with extreme weather, communication and coordination, and flooding.

Figure 7: Most Common Needs, Challenges, and Priorities Heard from Stakeholder Engagement Activities



4

Extreme Weather Event Impacts on the Texas Transportation System

4 Extreme Weather Event Impacts on the Texas Transportation System

Overview of the Texas Multimodal Transportation System

The transportation system encompasses multiple modes that support the safe and efficient movement of people and freight. The system includes roadways, bridges and culverts, ITS assets, maintenance facilities, border crossings, maritime ports, bike lanes and shared use paths, airports, transit facilities and routes, and railways.

This vast transportation network includes more than 80,000 on-system centerline miles and nearly 200,000 lane miles of roadways,[33] over 57,000 bridges and bridge-class culverts, with more than 550 million vehicle miles traveled each day. To narrow the analysis and provide meaningful, actionable results, the STRP filtered the road, bridge, and rail networks to focus on assets whose failure or disruption would have significant impacts on the transportation network. The results of the filtering analysis are shown in **Table 1** and **Figures 8** through **11**. For example, hurricane evacuation route status was one of the filtering criteria, so the STRP includes all designated hurricane evacuation routes.[i]

i The criticality analysis considers key factors such as evacuation route status and energy corridor status, Texas Transportation Institute studies on criticality, and stakeholder input.

PROTECT Resilience Improvement Plan Requirement:

Requirement (A): The STRP considers a time horizon of 30 to 75 years to account for the desired life of assets and includes strategies and performance measures to guide TxDOT resilience efforts for immediate and long-range investments. This requirement is also fulfilled through content discussed in **Chapters 7** and **8**.

The STRP includes 10 transportation asset types, including surface transportation, aviation, and maritime assets. The STRP addresses the entire extent of the state.

Highlights

Under a high emissions scenario, Texas is projected to experience:[32]

- An 8 degree Fahrenheit (°F) increase in daily average temperatures by 2100
- 3 feet of sea level rise by 2050 and 7 feet by 2100
- Higher storm surge during hurricanes
- More days each year with high wildfire risk
- More intense droughts
- More severe rainfall and greater flood risk
- Fewer extremely cold days and more frequent heat waves

Key transportation impacts are anticipated to include:

- Asphalt buckling and blow ups, pavement washouts, cracking, and damage
- Damage from debris flow, scour, and high-water speeds
- Rail buckling, derailments, and train slow downs
- Maritime port damage, delaying freight and shipping
- Runway pavement damage and heat-related take-off challenges
- ITS device damage, power and communications failure, and loss of data
- Delays and closures because of rail buckling
- Power outages and flood damage, leading to delays and closures

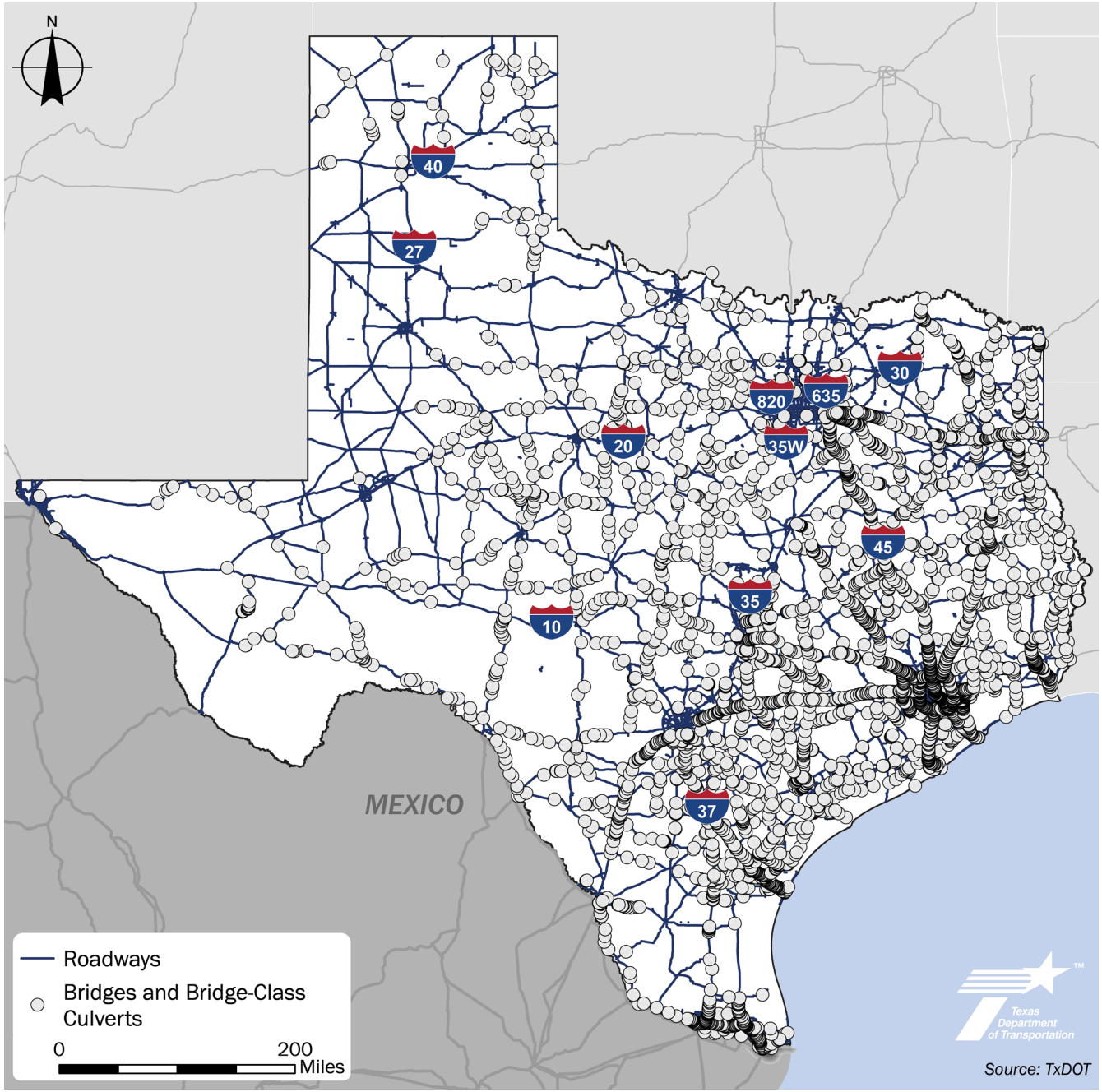
Table 1: Number of Critical Assets Included in the STRP

Asset Type	Number of Critical Assets in the STRP
Roads	33,400 miles
Bridges and Bridge-Class Culverts	4,807
ITS Assets	4,463 dynamic messaging signs (DMS) and closed circuit television (CCTV) cameras + 7 Traffic Management Centers (TMCs)
Maintenance Facilities	307
Border Crossings	28 land crossings and six rail crossings
Maritime Ports	20
Airports	289
Transit	146 stations 238 miles of light rail route 72 transit centers
Bike Lanes and Shared Use Paths	475 miles
Railways	10,707 miles

Roadways:
33,400 miles of roadways that are on the National Highway System, Texas Trunk System, Texas Freight Network, or National Highway Freight Network or that are Energy Sector Corridors, Evacuation Routes, Truck Routes, Hazardous Material Routes, or close to critical facilities and infrastructure

Bridges and Bridge-Class Culverts:
4,807 bridges and bridge-class culverts located on an evaluation route, within 100 to 200 feet of a critical roadway, or with a detour length greater than 10 miles

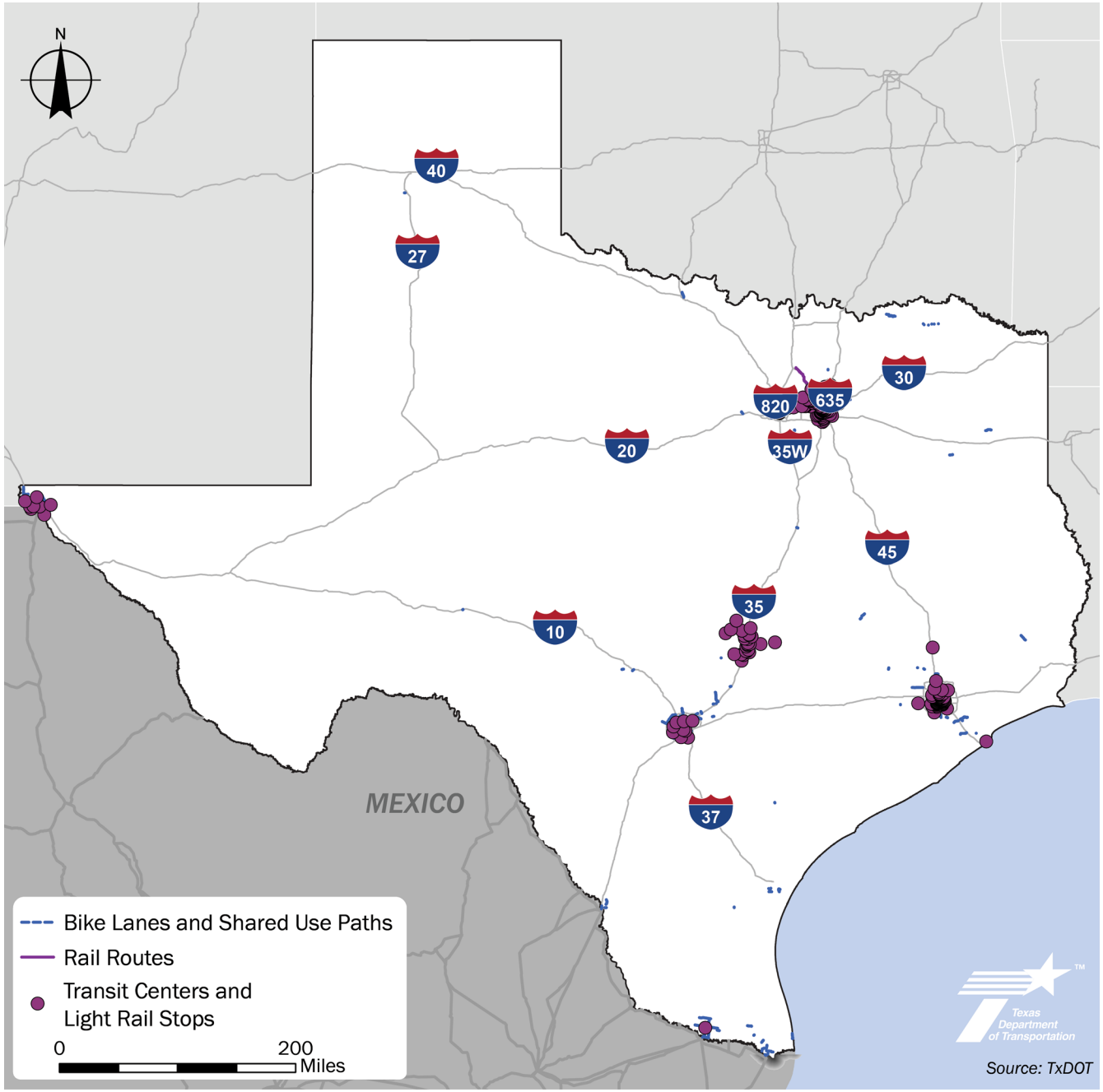
Figure 8: On-System Roadways, Bridges, and Bridge-Class Culverts Included in the STRP



Bike Lanes and Shared Use Paths:
475 miles of bike lanes and shared use paths concentrated in Houston, Dallas/Fort Worth, Austin, and San Antonio[i]

Transit:
146 light rail stations, 72 transit centers, and 234 miles of light rail routes in the Dallas, Austin, Houston, San Antonio, McAllen, Galveston, Conroe, and El Paso transit systems[ii]

Figure 9: Bike Lanes and Shared Use Paths, Transit Centers, and Light Rail Routes and Stops Included in the STRP



i Although there are over 5,000 miles of on-system sidewalks, only bike lanes and shared use paths — paths shared by pedestrians, bicyclists, and micromobility users — were considered in this analysis.

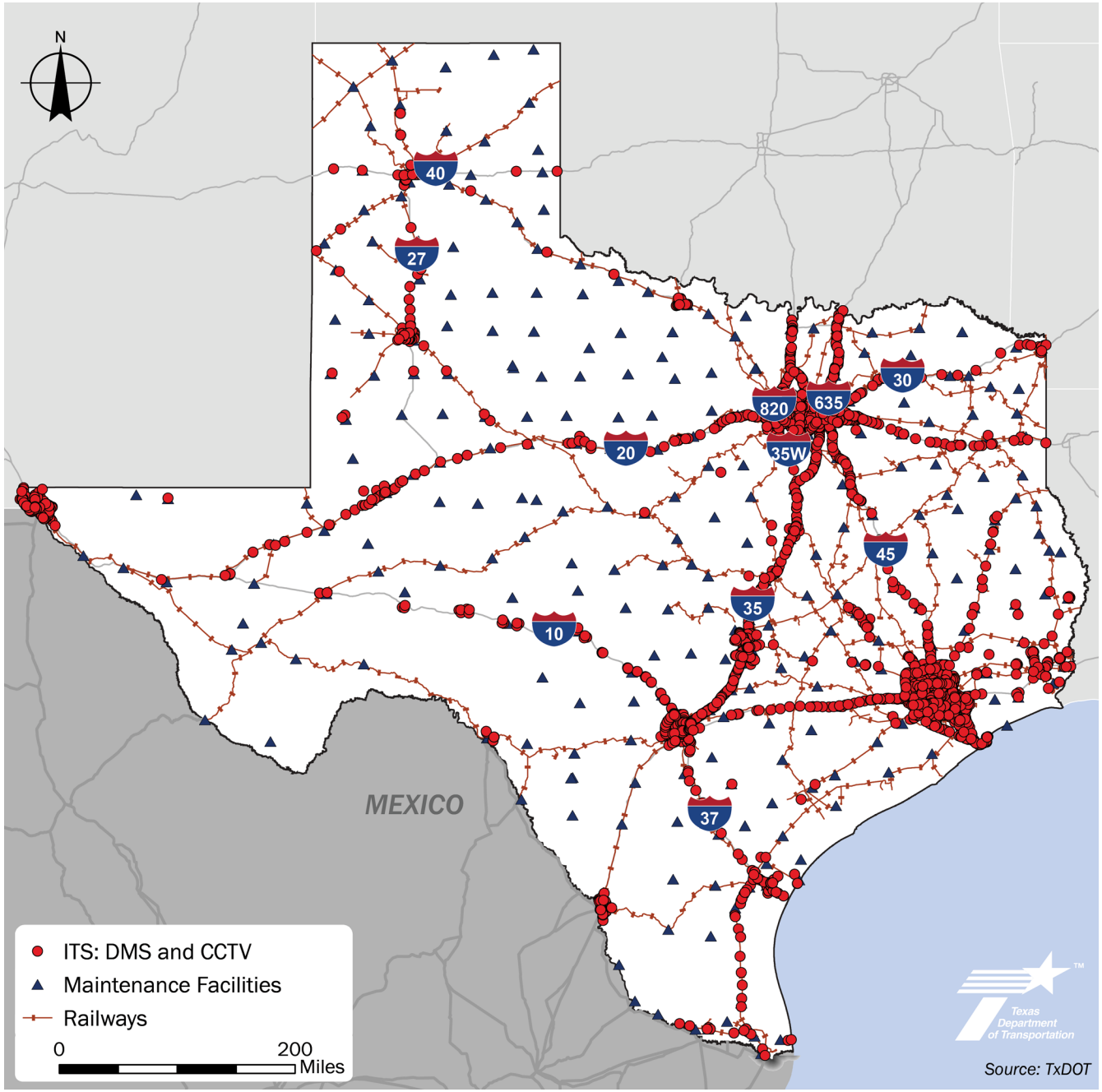
ii Bus transit assets are an important part of the Texas transportation system. To narrow the focus of the statewide assessment, the STRP only included fixed-in-place transit assets such as transit centers, light rail stops and light rail stations.

ITS Assets:
4,463 DMS and CCTV cameras, and seven TMCs

Maintenance Facilities:
307 administrative offices, workspaces, heavy equipment storage yards, vehicle storage bays, equipment maintenance shops, road maintenance material storage, and parking lots

Railways:
10,707 miles of active and main line railways

Figure 10: TxDOT ITS Assets, Maintenance Facilities, and Railways Included in the STRP

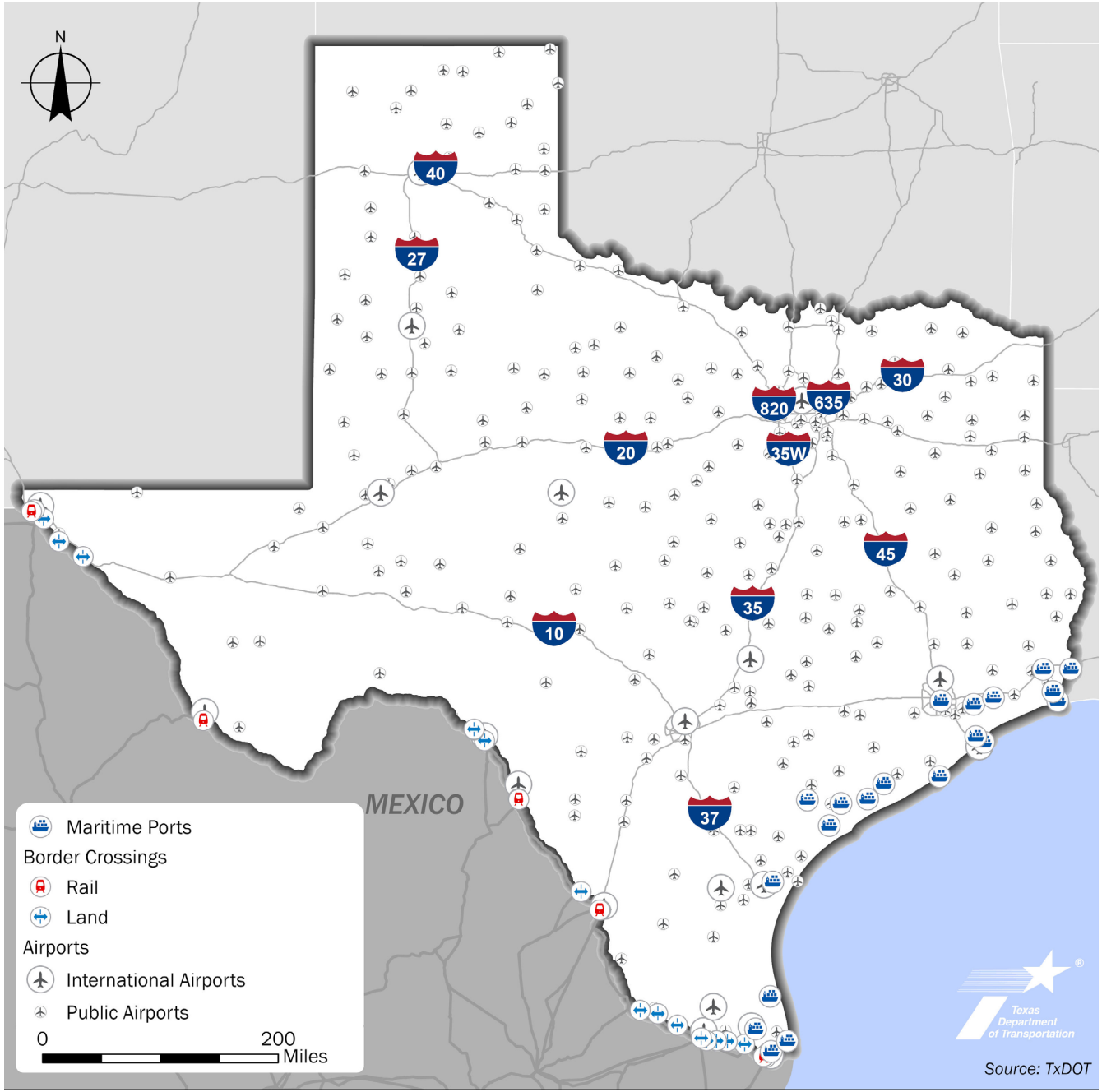


Border Crossings:
28 land and six rail border crossings

Maritime Ports:
20 active maritime ports

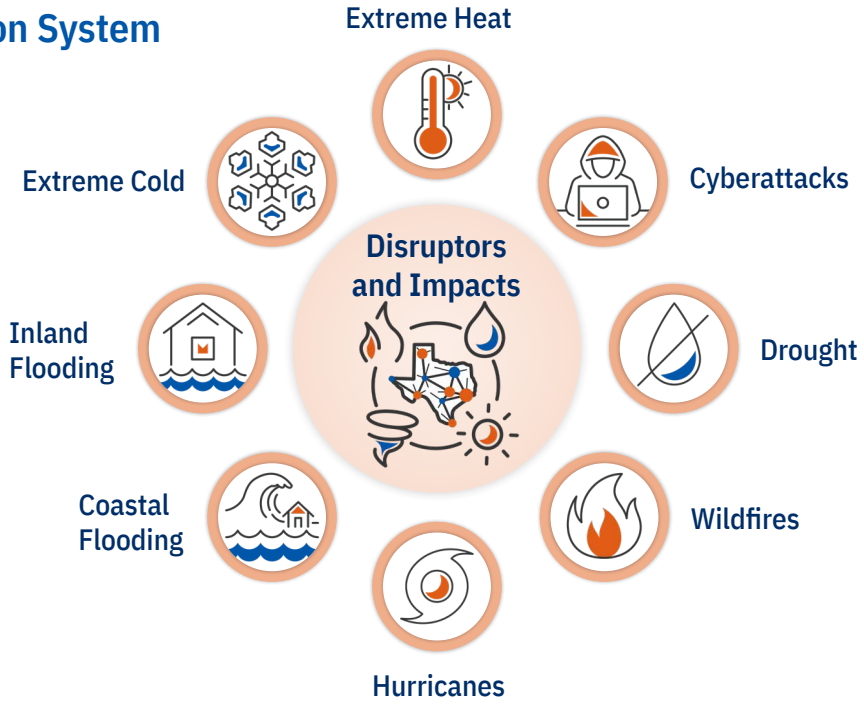
Airports:
289 public use airports

Figure 11: TxDOT Border Crossings, Maritime Ports, and Airports Included in the STRP



Extreme Weather Event Trends and Impacts on the Transportation System

The Texas transportation system already is experiencing challenges – including closures and increased maintenance and construction costs – associated with more frequent, severe disruptors. This section describes the natural and human-made disruptors identified in the STRP, including how these disruptors are projected to change by end-of-century based on a high-emissions, or "business-as-usual", scenario.



Texas is Getting Hotter

- By 2100, daily average temperatures are anticipated to increase 8° F across the state.[34]
- The number of days with triple-digit maximum temperatures has tripled since 1970.[35]
- Heat is the deadliest type of weather, killing more people annually than hurricanes.[36]
- South and West Texas typically experience the highest temperatures. Some cities inb these areas, including Del Rio, San Angelo, and Laredo, are projected to experience overb 100 days with temperatures over 100°F by 2050.[37]

The National Weather Service San Angelo warns residents to avoid their vehicles during a day with high temperatures.

Heat impacts on the transportation system

- Pavement deformations, buckling, and blowups, requiring higher roadway maintenance and repair costs.
- Railway bending and kinking, leading to train derailments or slower speeds that delay freight and passenger travel.
- Increased difficulty for airplane departures.
- Health risks, such as heat illness, when using active transportation (walking or biking) or public transportation.

Road buckling from extreme heat on US Highway 75 southbound in Denison, Texas. July 2016.
Source: KXII.

Winter Weather is Becoming More Extreme

- Although projected to become milder and more infrequent, winter storms and freezes can cause significant, short-term disruptions.
- Texas also experiences hail events with hail the size of golf balls, or in extreme cases, grapefruits (4 to 5 inches in diameter).[38][39]

Winter storm and ice impacts on the transportation system

- Expanding and cracking pavements from more frequent freeze-thaw cycles.
- Icing on roads leading to closures and crashes, disrupting freight and shipping, and requiring more de-icing chemicals that accelerate pavement deterioration.
- Lower accuracy of sensitive electronic devices, such as cameras and sensors.
- Power outages that disrupt railway operations, the ITS system, emergency response, border crossings, airport operations, and maritime port operations.
- Hail can damage vehicles, ITS assets, and other transportation infrastructure.

Snowy road in Texas with "Icy Conditions Exist" dynamic message sign.

Storms and Inland Flooding are Becoming More Intense

- The amount of rain each year is projected to decline slightly but storms will be heavier (have more rain).[40]
- Waterways, paved areas, and outdated drainage systems are vulnerable to more intense storms. As urban areas continue to expand, so will the area covered by impervious surfaces that cannot absorb water, increasing flood risks.[41]

Storm and inland flooding impacts on the transportation system

- Extreme precipitation and storms can overwhelm river, culvert, and stormwater infrastructure capacity, leading to flooding.
- Road and bridge closures from embankment failure, washouts, and debris.
- Damage to electronic devices and increased maintenance costs.

Sink hole in the road being fixed by a work crew.

Coastal Flooding is Exacerbated by Rising Seas and More Intense Tropical Storms[42]

- Texas has some of the highest rates of sea level rise in the country because of high subsidence (land sinking) from the historical extraction of groundwater, oil, and natural gas.[43] The Gulf Coast is likely to experience three feet of sea level rise by 2050 and up to seven feet of sea level rise by 2100, which would leave Galveston and other barrier islands below sea level.[44]
- Rising seas will exacerbate coastal flooding from storm surge, which refers to when strong winds from a storm push seawater onto shore and cause temporary flooding.

Sea level rise and storm surge impacts on the transportation system

- Sea level rise will result in permanent inundation of low-lying coastal areas, washing out roads, maritime ports, and other transportation assets.
- Higher average inundation during storms, leading to more building damage and higher costs.
- Increased maintenance and levee construction costs.
- Difficulty accessing transit stations, maritime ports, and maintenance facilities.
- Damage to building foundations and bridge substructures and road closures from toppled trees and debris.
- Delays at border crossings, airports, and maritime ports if power is lost.
- Increasingly high recovery costs for maritime ports.
- Reduced freeboard under bridges, potentially limiting larger vessels from passing underneath.

Figure 12: Projected Sea Level Rise at Coastal Bridges in Texas Visualized using the National Oceanic and Atmospheric Administration's (NOAA) Sea Level Rise Viewer

Current Conditions

Bridge to Surfside Beach, near Freeport

Rainbow Bridge in Beaumont

Three-feet of Sea Level Rise

Seven-feet of Sea Level Rise

Source: NOAA Office for Coastal Management. (n.d.) Digital Coast - Sea Level Rise Viewer. Accessed September 10, 2024. https://coast.noaa.gov/slr/#/layer/slr/7/-10593277.947125223/3357850.185955261/11/ satellite/2/0.8/2050/interHigh/midAccretion

Hurricane Harvey Flooding on I-69 in Humble, Texas. September 2017.
Photo credit: David J. Phillip / Associated Press

Stronger Hurricanes

- As oceans become warmer, hurricanes are projected to increase in overall intensity and rainfall amount.
- Although the total number of hurricanes is projected to remain steady or decrease slightly, the proportion of category 4 and 5 hurricanes is likely to increase.[45] Hurricanes are also expected to intensify more rapidly.
- Higher sea levels will increase storm surge damage from hurricanes.
- Hurricanes also may move more slowly, releasing a larger volume of rainfall over one location, thus increasing flood risks.[46]

Hurricane impacts on the transportation system

- Coastal flooding and storm surge can damage roads, bridges, maritime ports, maintenance facilities, and transit stations.
- High winds can damage ITS assets and maritime ports infrastructure.
- Intense rainfall during hurricanes also can lead to inland flooding, inundating roads and damaging bridges, leading to costly damages.

More Frequent and Intense Wildfires

- Higher temperatures dry out fuel and make it easier for wildfires to burn.
- Wildfire is most common in Central and East Texas and the Panhandle. However, wildfire risk is increasing rapidly in West Texas, particularly in late winter and early spring.[47]

Wildfire impacts on the transportation system

- Asphalt cracking, deformation, and melting.
- Unhealthy air quality.
- Reduced visibility and unsafe driving conditions.

North 207 Wildfire in Carson County. December 2021.
Source: Texas Forest Service

More Severe Droughts because of Higher Temperatures

- Higher temperatures increase the rate of soil evaporation, leading to more intense natural droughts.
- Summer evaporation losses in the next decade are projected to increase 7% compared to 2000 to 2018.[48] Increased evaporation rates can cause surface water supplies to dry up faster, exacerbating drought conditions.
- Much of the soil in Texas is expansive, meaning that it shrinks when dry and swells when wet. Drought can exacerbate the shrink-swell cycles of soils, leading to more intense impacts on infrastructure.

Drought impacts on the transportation system

- Shrinking and expanding soils beneath road surfaces and building foundations, resulting in degradation, cracking, and potholes.
- Shorter asset functional lives, requiring more frequent construction and maintenance.

Other Disruptors

Stakeholders engaged through the RSC, interviews, and workshops noted other disruptors that affect transportation resilience. In North and West Texas, dust storms – caused by high winds in a desert environment – can severely reduce visibility, causing travel delays. West Texas dust storms often require long detours. In coastal and West Texas, high winds can derail trains, damage ITS assets, and topple power lines. Stakeholders also noted tornadoes as a concern, which can damage roads, bridges, maintenance facilities, transit light rail stations, and ITS assets.

5 Vulnerability Assessment

5 Vulnerability Assessment

The vulnerability assessment identifies the relative vulnerability (minimal to high) of on-system assets to extreme weather event (**Figure 13**). Vulnerability is a combination of exposure, the presence of on-system assets in areas subject to disruptors,[i] and sensitivity, the degree to which an asset is damaged after exposure to a disruptor.

Though the vulnerability assessment findings largely focus on extreme weather events, cyberattacks also are identified as a critical vulnerability for ITS assets. Data breaches or malware attacks can lead to unauthorized messages being displayed on signage, sensitive information being accessed, and devices being shut down or damaged.

Results of the vulnerability assessment are presented below. The results are only for the subset of filtered on-system asset types selected for the STRP (refer to **Chapter 4**). The key findings of the vulnerability assessment focus on:

- Asset types with a large percentage of assets highly vulnerable to one disruptor
- Asset types in TxDOT districts with high vulnerability to multiple disruptors.

PROTECT Resilience Improvement Plan Requirements:

Requirement (C): An asset-based vulnerability assessment was conducted on critical assets, consistent with the Federal Highway Administration's (FHWA) Vulnerability and Adaptation Framework.

Requirement (D)(i): All designated evacuation routes were included in the STRP's vulnerability assessment. Evacuation route status also was used to prioritize assets for strategy development, with strategies and performance measures developed for evacuation routes, as described in **Chapter 7**.

Requirement (D)(v): The STRP employs publicly available, peer-reviewed datasets for extreme weather events, developed by NOAA and other sources.

Requirement (E)(vi): The STRP incorporates key input from stakeholders such as TxDOT districts, other State agencies, MPOs, maritime ports, and private industry and others. It also includes a cost-of-inaction assessment and funding and financing sources.

Highlights

Key Findings from the Vulnerability Assessment:

Assets along the coast, such as maritime ports and coastal roadways, are among the most vulnerable to multiple disruptors because they are exposed to sea level rise and hurricanes.

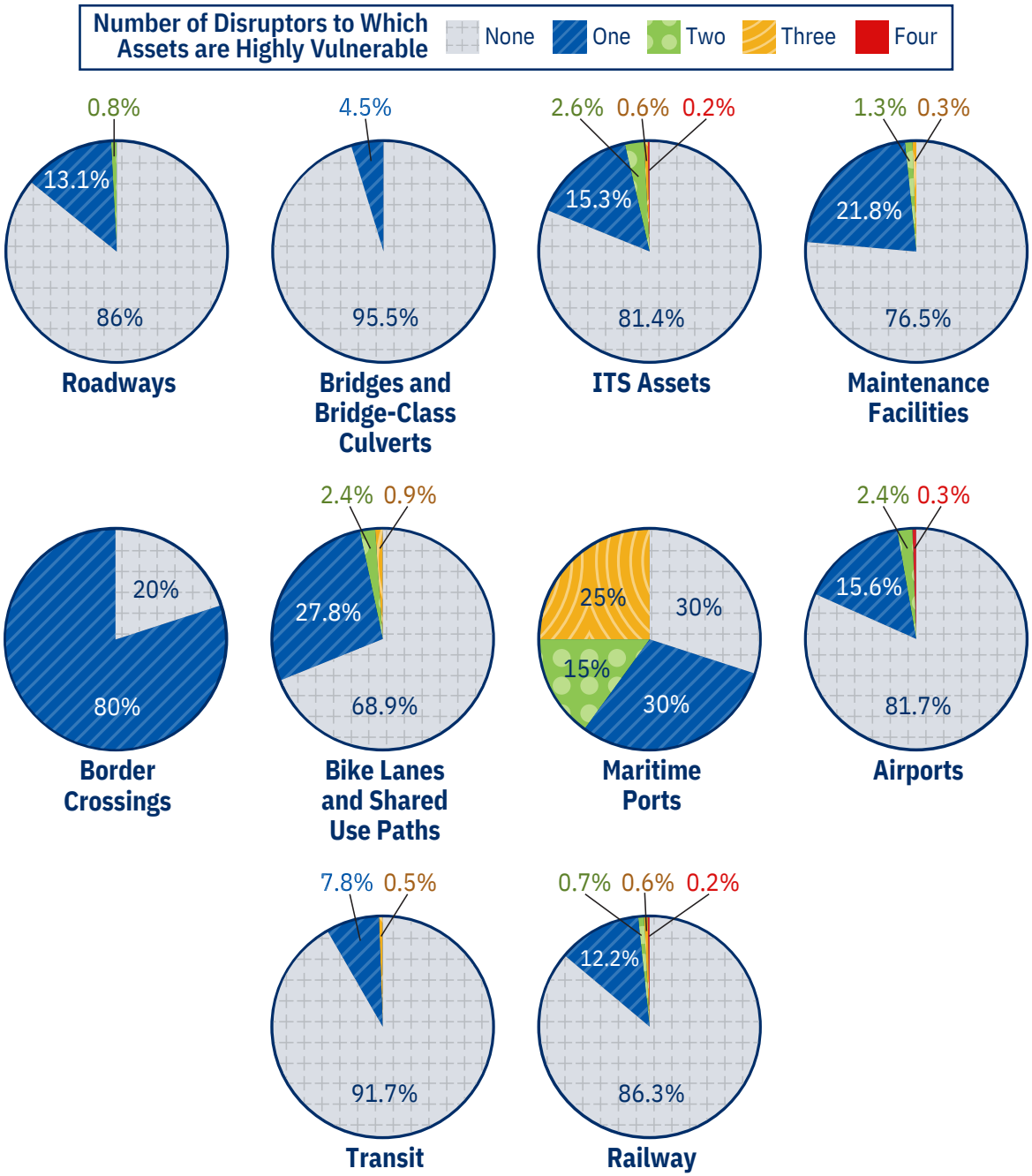
The Houston District has the largest number of assets with high vulnerability to most types of disruptors, including flooding and hurricanes.

More than half of all roadways have moderate or high vulnerability to extreme heat and wildfire.

ITS assets are increasingly vulnerable to cyberattacks, which can lead to systemwide malfunctioning and traffic delays.

i Exposure is determined by geospatially overlaying assets with projections for extreme weather events.

Figure 13: Proportion of Critical Assets in the STRP Highly Vulnerable to Multiple Disruptors by Assets Type



Roadways

Disruptors of primary concern: Extreme Heat, Flooding, Wildfire

Summary: Roadways with flexible (asphalt) or composite pavements (which make up 90% of roadways in the vulnerability assessment) have higher vulnerability to extreme cold, flooding, and wildfire than roadways with rigid (concrete) pavements. Roadways near the coast are highly vulnerable to storm surge, sea level rise, and hurricanes. Roadways in South and West Texas are more likely to be highly vulnerable to heat, and roadways in East Texas are more likely to be highly vulnerable to wildfire.

Key findings:

- 1,296 miles of roadways in South and West Texas have vulnerability to extreme heat. Of the roadways considered in this study with high vulnerability to extreme heat, over half (788 miles) are in the Laredo District.
- 690 miles of roadways have high vulnerability to inland flooding in the Odessa, San Angelo, and Lubbock districts.
- Of the 243 miles of roadways considered in this study with high vulnerability to hurricanes, 240 miles are in the Houston District.

Bridges and Bridge-Class Culverts

Disruptors of primary concern: Flooding, Hurricanes

Summary: Overall, the 4,807 bridges and bridge-class culverts in this study have fairly low vulnerability to most extreme weather events. However, they are most vulnerable to hurricanes and inland flooding. A strong correlation exists between bridge condition and vulnerability to disruptors (better condition means less vulnerability).

Key findings:

- Three coastal bridges (two in the Corpus Christi District and one in the Yoakum District) have high vulnerability to storm surge with seven feet of sea level rise – meaning they have decks that are projected to be inundated by 2100.[i]
- 215 TxDOT bridges considered in this study have high vulnerability to hurricanes, with a majority of these bridges located in the Houston and Beaumont districts.

i Only coastal bridges were analyzed for bridge deck overtopping. Neither statewide flood-depth data for inland flooding or comprehensive data on bridge deck heights were available at the time of the study.

ITS Assets

Disruptors of primary concern: Extreme Cold, Flooding, Extreme Heat, Cyberattacks

Summary: The approximately 4,470 ITS assets in this study are most vulnerable to extreme heat, inland flooding, and hurricanes. Their electronic components make them particularly sensitive to exposure to extreme temperatures and water. ITS assets also are threatened by cyberattacks, which can cause devices to break down or behave unlawfully.

Key findings:

- Approximately 90 ITS assets near the coast have high vulnerability to sea level rise, storm surge, and hurricanes.
- A total of 71 ITS assets considered in this study have high vulnerability to extreme heat.
- A total of 544 ITS assets that were considered in this study have high vulnerability to inland flooding. These assets are located in the Houston, Corpus Christi, Beaumont, and Pharr districts.

Maintenance Facilities

Disruptors of primary concern: Hurricanes, Flooding, Wildfire

Summary: The 307 maintenance facilities in this study consist of administrative offices, workspaces, heavy equipment storage yards, vehicle storage bays, equipment maintenance shops, road maintenance material storage, and parking lots. Maintenance facilities are most vulnerable to inland flooding, wildfire, and hurricanes.

Key Vulnerabilities:

- There are 19 facilities in this study with high vulnerability to inland flooding.
- Two facilities in this study have high vulnerability to seven feet of sea level rise, increasing to four facilities with storm surge with three and seven feet of sea level rise.
- All maintenance facilities in the Yoakum and Atlanta Districts have high vulnerability to wildfire.

Border Crossings

Disruptors of primary concern: Flooding, Cyberattacks

Summary: There are 28 land border crossings and six rail border crossings in the Pharr, Laredo, and El Paso districts. Border crossings are most vulnerable to inland flooding. Border crossings also can be vulnerable to cyberattacks, which can lead to unauthorized access to border control software and data breaches.

Key Vulnerabilities:

- All border crossings are over or adjacent to the Rio Grande, so they naturally lie in the 100 or 500-year floodplain, where they have moderate or high exposure to inland flooding. Thus, most border crossings (71%) have high vulnerability to inland flooding, and one has moderate vulnerability.
- Border control systems are vulnerable to cyberattacks, which can result in data breaches that allow malicious individuals or groups to gain access to confidential information.
- Six border crossings have moderate vulnerability to wildfire danger.

Maritime Ports

Disruptors of primary concern: Hurricanes, Coastal Flooding, Cyberattacks

Summary: The 20 maritime ports in this study are most vulnerable to coastal flooding hazards and hurricanes. Maritime port operations are vulnerable to cyberattacks, which can result in port disruptions, lost cargo, and financial losses with cascading economic impacts.

Key Vulnerabilities:

- Two maritime ports have high vulnerability to three feet of sea level rise, increasing to nine maritime ports with storm surge and three feet of sea level rise.
- Seven maritime port are vulnerable to permanent inundation from seven feet of sea level rise, increasing to 13 maritime ports with storm surge and seven feet of sea level rise.
- Six maritime ports have high vulnerability to coastal flooding, storm surge with three and seven feet of sea level rise, and wildfire.

Bike Lanes and Shared Use Paths

Disruptors of primary concern: Flooding, Extreme Heat, Wildfire

Summary: The Pharr District and the San Antonio District have the most bike lanes and shared use paths included in this study. The 475 miles of bike lanes and shared use paths in this study are most vulnerable to inland flooding, storm surge, extreme heat, and wildfire.

Key Vulnerabilities:

- Nine miles of bike lanes and shared use paths in this study have high vulnerability to extreme heat.
- A total of 132 miles of bike lanes and shared use paths in this study have high vulnerability to inland flooding.
- All 59 miles of bike lanes and shared use paths in the Houston District have high vulnerability to hurricanes.

Airports (Not TxDOT-Owned)

Disruptors of primary concern: Flooding, Extreme Heat, Wildfire

Summary: Generally, airports do not have high vulnerability to more than one extreme weather events, and 235 of the 289 airports do not have high vulnerability to any disruptors. Airport technological systems are vulnerable to cyberattacks, which can cause data breaches, financial losses, and flight disruptions.

Key Vulnerabilities:

- Nine airports in South Texas have high vulnerability to extreme heat.
- Exactly 25 airports included in this study have high vulnerability to inland flooding.
- Multiple (11) airports in this study have high vulnerability to hurricanes.

Transit (Light Rail Stops, Transit Centers, and Light Rail Routes) (Not TxDOT-Owned)

Disruptors of primary concern: Flooding, Hurricanes

Summary: Transit assets are most vulnerable to inland flooding and wildfire. This assessment is focused on physical transit assets and does not consider transit users. Transit users may be highly vulnerable to disruptors such as extreme heat, which could impact transit operations.

Key Vulnerabilities:

- Five transit centers and light rail stops and one mile of light rail route have high vulnerability to hurricanes, all in the Houston District.
- Six transit centers and light rail stops and 17 miles of light rail route in the Dallas District have high vulnerability to inland flooding.
- Six transit centers and light rail stops and one mile of light rail route in the Houston District have high vulnerability to inland flooding.

Railways (Not TxDOT-Owned)

Disruptors of primary concern: Flooding, Hurricanes, Extreme Heat, Drought

Summary: Approximately 1,469 miles of the 10,707 total miles of railways included in the study have high vulnerability to at least one disruptor. Railways have high vulnerability to all disruptors except extreme cold and wildfire.

Key Vulnerabilities:

- A total of 1,128 miles of railway included in this study have high vulnerability to inland flooding.
- Ten miles of railway considered in this study have high vulnerability to three feet of sea level rise, increasing to 49 miles with seven feet of sea level rise in the Corpus Christi, Houston, and Beaumont districts.
- Some 87 miles of railway considered in this study have high vulnerability to drought.

6

Cost-of-Inaction Case Study Analysis

6 Cost-of-Inaction Case Study Analysis

Disruption and damage to TxDOT's multimodal network can have cascading impacts on the state's economy. A May 2024 study noted that deteriorated roads cost motorists in Texas $17.8 billion a year from additional repairs, increased fuel consumption and tire wear, and accelerated vehicle depreciation.[49] Traffic delays cost an estimated $4.6 billion on the 100 most congested road sections in 2023.[50] More frequent disruptors will cause additional damage to the transportation system, exacerbating traffic delays, and driving costs up even more.

The STRP team conducted hypothetical case studies to illustrate the predictable and significant costs that could be incurred without resilience investment. The case studies evaluated a subset of combinations of disruptors and assets (e.g., a road segment with inland flooding), looking at the costs to TxDOT and potential costs to drivers from delays and detours.[i]

i Case study inputs, when feasible and applicable, are informed by TxDOT data on flood conditions and work order and contract costs from 2019 to 2023.

Highlights

Direct damages and delays from single events are estimated to amount in the millions of dollars. Estimated case study costs:[ii]

Roadways and Inland Flooding

- I-20 Segment, Odessa District: **$3.3 million** (40-hour closure)
- State Highway (SH) Segment, Waco District: **$900 thousand** (40-hour closure)

Bridges and Inland Flooding

- Judge Jodie Stavinoha Bridge, Houston District: **$1 million** (12-hour closure), **$2.2 million** (44-hour closure)

Maintenance Facility and Inland Flooding

- Inland Flooding at Odessa Headquarters and an Area Engineering and Maintenance Facility: **$1.5 million** (one foot of flooding)

Disruptor-Induced Power Outage

- Disruptor-induced Power Outage, City of Lubbock ITS System and Traffic Signals: **$350 thousand** (50-hour outage)

ii: Costs are estimates based on available data and methods and represent a hypothetical event. Costs are shown in 2023 dollars.

Roadways and Inland Flooding Costs

Inland flooding causes frequent and widespread disruption to the roadway network in Texas. Between 2019 and 2023, TxDOT's Highway Conditions Reporting System recorded 9,000 flood-related road conditions, of which 3,000 involved road closures. Heavy precipitation may lead to pavement and embankment failure and washouts, which can make roads unsafe and impassable. Debris removal and emergency response can be costly. During Hurricane Harvey, TxDOT's emergency response involved more than 4,000 employees working over 700,000 hours in the storm's aftermath.[51] The STRP team evaluated two roadway and inland flooding case studies, looking at the costs associated with closure of a segment of I-20 near the I-10 interchange in Odessa District and a segment of SH 174 in Waco District extending from Kopperl eastward just past the Brazos River. The analysis estimated costs of road damages, debris removal, response costs, and travel delay and detours to be $3.3 million for the I-20 segment and $900 thousand for the SH 174 segment (2023 dollars).[i]

Bridges and Inland Flooding Costs

Flooding can make bridges unsafe and/or impassable. During the 2015 Memorial Day floods, two bridges spanning the Blanco River collapsed.[52] In 2018, the RM 2900 bridge over the Llano River in Kingsland collapsed after a foot of rain caused a rapid rise in river water levels.[53] Reconstructing and replacing this two-lane bridge cost more than $30.5 million (adjusted to 2023 dollars).[54] Bridge closure can cause significant travel delays. When a 2005 flood event washed away a bridge span on I-20, traffic was detoured by 150 miles for a week-long period.[55] The STRP team estimated costs of inland flooding at the Judge Jodie Stavinoha Bridge on SH 99 in the Houston District crossing the Brazos River for a 100-year and 500-year flood event. These modeled scenarios had estimated costs of $1 million and $2.2 million in bridge damage, debris removal, response costs, and travel delay and detour costs (2023 dollars).[ii]

i Road damages and debris removal costs were evaluated using TxDOT data on work order and contractor costs and road conditions. Annual average daily traffic data, U.S. Department of Transportation (U.S. DOT) guidance on travel time and vehicle operating costs, and Federal Emergency Management Agency (FEMA) methods were used for informing delay and detour cost estimates.

ii Costs were evaluated using FEMA Benefit-Cost Analysis (BCA) methodology to quantify bridge damage, and the same data and methodology as the roadway case studies for debris removal, response costs, and travel delay.

Maintenance Facility and Inland Flooding Costs

TxDOT maintenance facilities typically house administrative offices, office work rooms, vehicle and equipment storage bays, and maintenance shops. During past flood events at maintenance facilities, costs were associated with damages to walls and floors, furniture, and mold remediation from water infiltration.[56] Depending on flood impact and duration, staff rescue and/or relocation costs also could be required. The STRP team estimated $1.5 million (2023 dollars) in structure and content damages and disruption and output losses to the Odessa District Headquarters and an Area Engineering and Maintenance Facility in the event of a 100-year storm.[iii]

ITS and Disruptor-Induced Power Outage

ITS assets play a vital role in supporting road safety, disseminating time-sensitive road information, and managing various parts of the transportation system. Particularly during emergencies, real-time visual information via CCTV and communication channels via DMS can be critical for emergency response and traffic management. In the last five years, Texas has faced two major winter storm-induced power outages - one during Winter Storm Uri in 2021 and the other during Winter Storm Mara in 2023. During Winter Storm Uri, the record-setting cold snap resulted in prolonged power outages in much of the state. At the peak of the incident, more than 4.5 million utility customers in Texas lost power. The STRP team estimated the costs of a power outage in the city of Lubbock and the cascading impacts of systemwide ITS functionality loss and downed traffic signals at 10 key intersections. The resulting response costs and travel delays are estimated to be $350 thousand (2023 dollars).[iv]

iii Costs were modeled for a scenario where the flood-depth is assumed to be a half foot at occupied structures impacted by a 100-year storm event in the FEMA's Flood Insurance Rate Map (FIRM). Structure and contents damages and disruption and output losses were evaluated using construction cost data from RSMeans, FEMA Hazus damage methods, and U.S. Army Corps of Engineers depth-damage curves.

iv Response costs were evaluated using TxDOT data on temporary traffic control measures and maintenance staff deployment to troubleshoot ITS assets and traffic signals. Travel delays were calculated by modelling traffic signal outage conditions and the delay it would cause drivers in added time required to cross affected intersections. Through the course of the 50-hour power outage scenario, the case study assumes that power will be restored to a percentage of assets throughout the duration.

7

Resilience Strategies

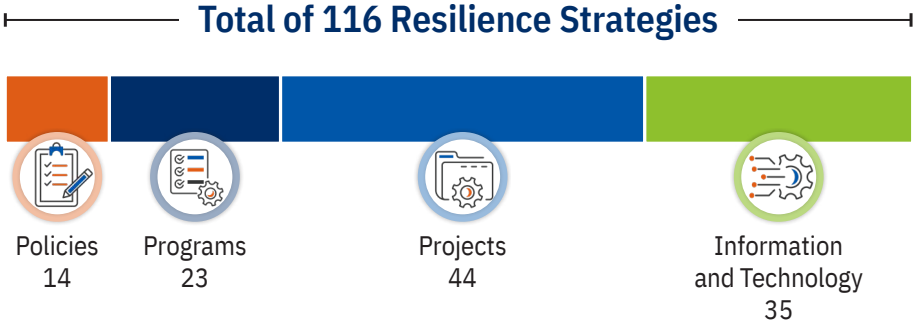
7 Resilience Strategies

The vulnerability assessment, cost-of-inaction assessment, and stakeholder input form the basis for identifying resilience strategies. The STRP team developed resilience strategies through a multi-step process that identified the disruptors to which each asset type is most vulnerable and then incorporated stakeholder validation to evaluate and refine them (**Figure 14**). The resilience strategies address all 10 asset types and eight disruptors, achieve STRP goals and objectives, and align with existing TxDOT plans and processes. Some strategies apply to the transportation system as a whole, and others are tailored to address a specific asset and disruptor combination, such as improving roadway resilience to flooding.

Resilience Strategies

The resilience strategies fall into one of four categories: **Policies**, **Programs**, **Projects**, or **Information and Technology**.

Figure 14: Number of Resilience Strategies by Category



The resilience strategies in this section focus on improvements that strengthen the transportation system's overall resilience and apply to all asset types and disruptors. The strategies also address disruptors of primary concern for each asset type (**Figure 15**), as identified by the STRP team based on the results from the vulnerability assessment, if the asset is on or near an evacuation route, and if the asset is close to a critical roadway or part of a key network. The strategies are organized by the recommended timeframe for implementation: short-term (0 to 4 years), medium-term (5 to 9 years), or long-term (10+ years) and by category, and show the STRP goal that each strategy supports.

Resilience strategies may be implemented individually or in tandem with each other. Strategies that TxDOT is already implementing or considering are summarized in **Table 2**. For large corridor projects exposed to multiple extreme weather events, broader policy and program strategies should be considered before project strategies. Project strategies, which often address a specific vulnerability to one disruptor, should be identified based on site-specific context.

Highlights

The **116** resilience strategies presented in this chapter are sorted into one of the following categories:

Policies are specific courses of action that, if adopted, will shape the way TxDOT approaches resilience.

Programs are a collection of initiatives or activities to enhance collaboration and system resilience.

Projects include infrastructure improvements that improve the safety and efficiency of existing systems and prepare Texas for future disruptions.

Information and Technology strategies include research studies and technology enhancements and improvements.

PROTECT Resilience Improvement Plan Requirements:

Requirement (D)(iii) and (E)(iii): The STRP develops strategies to increase the resilience of transportation assets, including natural infrastructure and nature-based solutions. The STRP recommends performance measures to enable TxDOT to track and monitor its resilience-related planning, implementation, and investments.

Requirement (D)(iv): The STRP team developed an asset prioritization process to determine resilience strategies for the highest priority assets. The STRP team also identified planned projects that can support resilience. Additionally, the STRP provides recommendations for funding and financing resources.

Requirement (E)(i): The STRP provides a set of strategies and performance measures that will increase the ability of TxDOT, TxDOT districts, and MPOs to prepare for and respond more effectively to extreme weather events.

Requirement (E)(ii): The STRP identifies codes, standards, policies, and manuals that should be updated to incorporate resilience considerations.

Figure 15: Number of Recommended Resilience Strategies for Each Asset Type

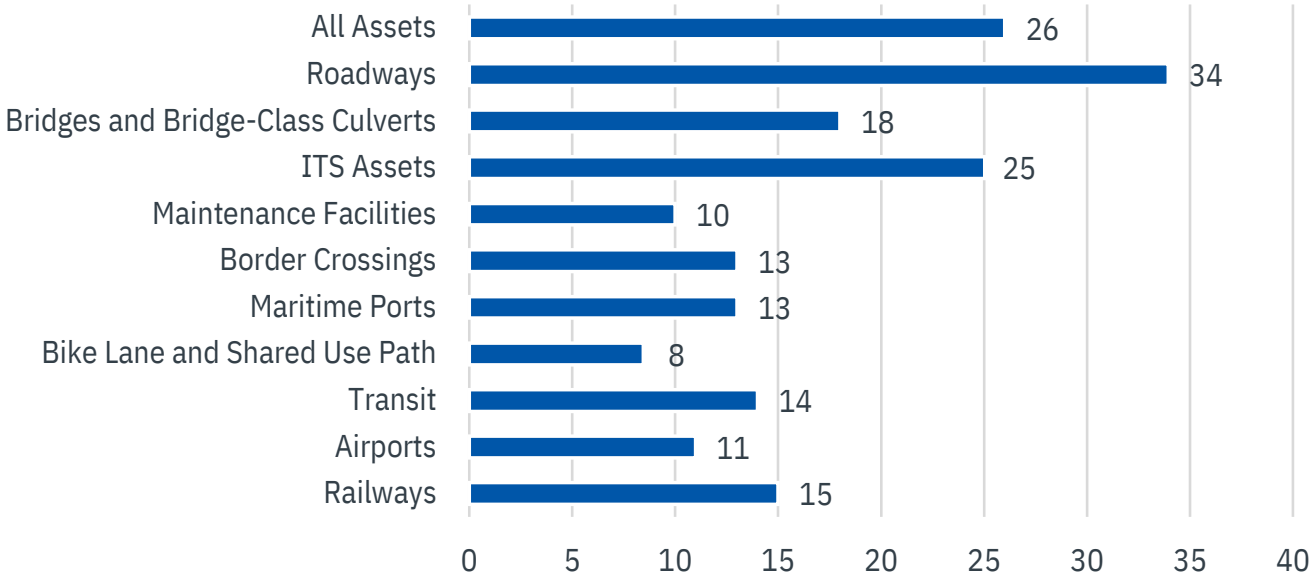
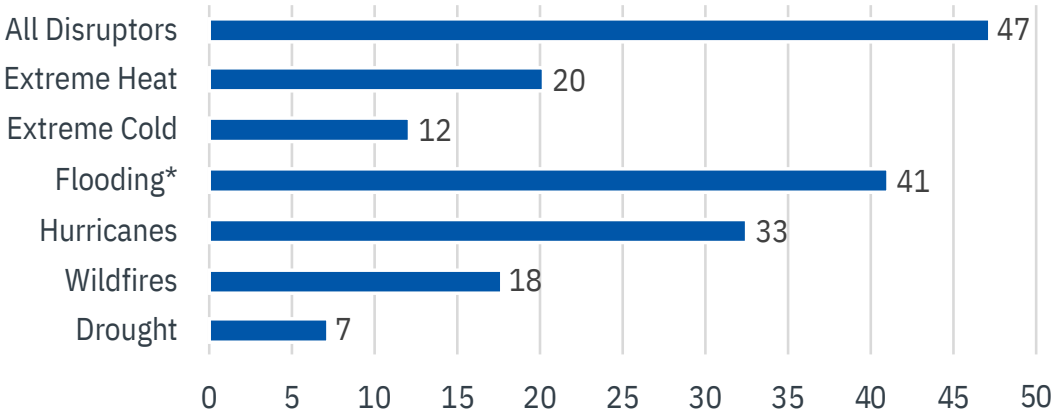


Figure 16: Number of Recommended Resilience Strategies for Each Extreme Weather Event



* Strategies for inland flooding and coastal flooding are combined because approaches to address flooding are similar, if not the same

Continued and/or Existing Efforts at TxDOT

Table 2: Continued and/or Existing Efforts at TxDOT

Strategy	Category	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Update TxDOT's Departmental Materials Specifications (DMS) to incorporate more resilient material requirements.	Policy	✓		
Update TxDOT's Roadway Design Manual, Hydraulic Design Manual, and Bridge Design Manual to incorporate projections for extreme weather events.	Policy	✓		
Enhance coordination with emergency services, such as the Texas Department of Emergency Management, Texas Public Utility Commission, and local emergency service authorities.	Policy		✓	✓
Continue meeting with cross-departmental stakeholders through the RSC to coordinate and streamline resiliency efforts at TxDOT.	Policy		✓	✓
Develop an ITS Emergency Response Plan that includes training on how to strengthen ITS infrastructure in response to disruptors and to leverage stakeholder partnerships.	Policy		✓	✓
Establish designated resilience funding at the state level by leveraging various funding sources to ensure a reliable funding stream that is not solely dependent on federal resources. As a starting point, consider creating a dedicated funding category within the UTP for resilience or sustainability-related projects.	Policy			✓
Continue to stagger maintenance and construction schedules to ensure travel redundancy.	Program		✓	
Continue to develop resources and materials that effectively communicate with non-English speakers in emergency and evacuation situations.	Program			✓
Expand TMC support to adjacent districts and increase staffing to ensure continuous operative capacity.	Program		✓	
Update the STRP periodically as data improves, resilience and adaptation solutions evolve, and TxDOT's infrastructure changes.	Program	✓	✓	✓
Prevent scour of roads and bridges in the floodplain or that are projected to be exposed to coastal flooding through armoring, bank stabilization, and river training.	Project	✓		
Implement shoreline stabilization techniques to address coastal scour.	Project	✓		

Table 2: Continued and/or Existing Efforts at TxDOT (continued)

Strategy	Category	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Continue to install uninterrupted power supply (UPS) (backup power) to cameras and traffic signals at critical locations.	Project	✓		
Ensure proper insulation of ITS cabinets, particularly in areas where extreme heat, freezing temperatures, or flooding is expected. This may include equipping cabinets with effective temperature control devices or installing higher rated cabinets. Flood protective need to include corrosion-resistant materials and sealing ground-mounted ITS cabinets.	Project	✓	✓	
Install a flood detection and early warning system to provide critical real-time information to help TxDOT respond quickly to hurricanes, flash floods, and severe storms.	Project	✓		
Upgrade culverts in areas projected to experience flooding to accommodate future peak flows.	Project	✓		
Evaluate the performance of bridges and culverts that are identified as having moderate or high vulnerability to prioritize bridges for upgrades.	Project	✓		
Install flood barriers to keep flood waters off roadways and runways.	Project	✓		
Equip facilities with cooling systems to reduce temperatures.	Project	✓		
Adjust the structural design of pavements, bridges, and railways to sustain higher temperatures and more intense heat waves.	Project	✓		
Harden electric and utility infrastructure to better withstand strong winds.	Project	✓		
Strategically install vibration dampers on ITS assets, focusing on assets along evacuation routes.	Project	✓	✓	
Invest in backup power generators at maintenance facilities, transit centers, maritime ports, and airports that provide electricity for at least 48 hours.	Project	✓	✓	
Elevate all TxDOT electrical equipment above projected flood heights to prevent damage.	Project	✓	✓	
Upgrade medians to handle higher precipitation volumes.	Project	✓		
Use fire-resistant materials for the construction and maintenance of buildings and infrastructure in areas with high wildfire vulnerability or areas that have experienced increases in wildfire activity in the past decade.	Project	✓		

Table 2: Continued and/or Existing Efforts at TxDOT (continued)

Strategy	Category	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Stabilize severely burned areas inside TxDOT right-of-ways (ROWs) to prevent erosion and sedimentation.	Project	✓		
Ensure components of ITS assets and lighting structures are resistant to strong winds.	Project	✓	✓	
Elevate roadway, railway, transit, and bridge assets in the floodplain above projected flood heights, particularly on evacuation routes.	Project	✓		
Consider drought and fire-resistant landscaping, including shade trees, along highways and bike lanes and shared use paths. Vegetation can reduce erosion and sedimentation on/around pathways, while providing shade can enable use during heat waves.	Project	✓	✓	
Conduct proactive vegetation management in areas projected to have large increases in the number of days with high wildfire danger.	Project	✓		
Establish central warehouses in each TxDOT district to store stabilization and de-icing materials for rapid deployment.	Project	✓	✓	
Develop dashboards or portals to share critical ITS data with stakeholders to improve coordination and communication time.	Information and Technology	✓	✓	
Incorporate resilience metrics for extreme weather events in TxDOT's Corridor Prioritization Tool (CPT) and Pavement Analyst tools.	Information and Technology	✓	✓	
Research regional plant species that improve resilience inside TxDOT ROW.	Information and Technology	✓		✓
Develop ITS architecture.	Information and Technology	✓		

Table 2: Continued and/or Existing Efforts at TxDOT (continued)

Strategy	Category	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Conduct cybersecurity vulnerability analyses of ITS networks along the critical roadway network to improve resiliency.	Information and Technology	✓		
Create an inventory of culverts and stormwater drainage networks and conditions.	Information and Technology	✓		✓
Develop a robust inventory of all transportation infrastructure that includes (at a minimum) elevation and condition information.	Information and Technology	✓		
Develop degradation models to analyze the degradation or response of transportation infrastructure to extreme weather events.	Information and Technology	✓		
Research feasibility of nature-based strategies to reduce wave runup and address coastal erosion.	Information and Technology	✓		

Short-Term Strategies (0 to 4 Years)

Short-term strategies are those that may already be in place or require minimal funding or coordination to complete. These strategies may require immediate action and quickly can enhance system resilience (**Tables 3, 4, 5,** and **6**). The general timeframe for these strategies to be initiated within 4 years.

Table 3: Short-Term Recommended Policy Resilience Strategies

Short-Term Policy Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Establish emergency standby contracts for extreme event response.		✓	
Incorporate resilience needs into TxDOT's current investment processes and programs and identify potential funding streams to support resilience project implementation.			✓
Coordinate with flood control districts to implement additional flood control measures (e.g. planting trees and vegetation) in TxDOT project areas prone to flooding.		✓	✓
Ensure staffing levels can meet increased maintenance needs and provide complete support during disruptor events.		✓	✓

Table 4: Short-Term Recommended Program Resilience Strategies

Short-Term Program Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Form a Resilience Working Group with partner agencies and municipalities.		✓	✓
Use the Texas Wildfire Risk Assessment Portal (TxWRAP) and coordinate with the Forest Service to improve communication of wildfire danger.		✓	
Develop a benefit-cost analysis methodology that compares the economic costs of not addressing resiliency concerns to the cost of resilience enhancements. Use the results of the analysis to prioritize high risk assets.		✓	✓

Table 4: Short-Term Recommended Program Resilience Strategies (continued)

Short-Term Program Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Implement the triage strategy to prioritize asset response. This involves 1) addressing major issues to critical infrastructure in advance of a natural disaster, 2) coordinating with other agencies to provide routes to critical facilities during a disruptor, and 3) developing and practicing plans for restoring service.		✓	
Proactively assess evacuation routes to evaluate needs and develop additional routes if necessary.		✓	
Work with emergency response providers to integrate ITS data into plans and communication protocols.		✓	
Develop a staffing plan for ITS maintenance.		✓	✓
Procure and stage critical equipment, such as personal protective equipment, generators, and medical supplies, before disruptor events.		✓	
Implement policies that minimize transit user exposure to extreme heat and other weather-related disruptors.		✓	✓
Establish a protocol to relocate locomotives and trackside electronic equipment before flooding conditions may occur.	✓	✓	
Establish a consistent protocol for assessing damage following extreme storms, hurricanes, and other disruptors.		✓	✓

Table 5: Short-Term Recommended Project Resilience Strategies

Short-Term Project Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Treat metal components of assets to resist corrosion because of increased salinity exposure.	✓		
Strengthen bridge elements to withstand more powerful winds and storm surges. This may mean replacing shallow foundations with deeper foundations, replacing older columns and piers with newer ones, and upgrading materials.	✓	✓	
Develop median breaks or crossovers on evacuation routes to support roadways and manage high traffic volumes temporarily.	✓	✓	

Table 5: Short-Term Recommended Project Resilience Strategies (continued)

Short-Term Project Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Dredge deeper channels to absorb sediment during a storm or hurricane.	✓		
Equip critical ITS assets with a quick-connect panel to ensure that backup generator or power equipment can be connected easily to the device.	✓		
Strengthen railway infrastructure to withstand high winds. This may involve using stronger materials, reinforcing existing structures, and implementing wind-resistant designs.	✓		

Table 6: Short-Term Recommended Information and Technology Resilience Strategies

Short-Term Information and Technology Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Create a data clearinghouse and resilience and adaptation project status tracker that allows local agencies and other TxDOT partners to access adaptation and resilience information.		✓	✓
Develop an interactive data repository and dashboard where local governments can upload and access emergency response and other resilience data.		✓	✓
Identify existing resilience-related performance measures and establish additional performance measures for ITS assets.		✓	
Develop ITS asset management, a communications network, and strategic, operations, and emergency plans. As part of the emergency plan, include periodic TMC emergency exercises to test the effectiveness of current emergency response capabilities.		✓	✓
Conduct a study to evaluate the redundancy of the roadway network, including identification of alternative routes for vulnerable roadways to increase redundancy.	✓		
Conduct feasibility studies on cool pavement materials for a variety of roadway types.	✓		
Conduct additional asset-level energy analysis and testing at TxDOT facilities.	✓	✓	

Table 6: Short-Term Recommended Information and Technology Resilience Strategies (continued)

Short-Term Information and Technology Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Encourage maritime port authorities to use resilience assessment tools.			✓
Display maritime port emergency notifications on DMS signs along routes leading to affected maritime ports.		✓	
Conduct a digital twin resiliency study to simulate the impact of extreme weather events, corridor growth, and urbanization in critical transportation arteries (refer to the North Carolina DOT US-74 Resiliency Study for an example).	✓	✓	

Medium-Term (5 to 9 Years) Strategies

Medium-term strategies are those that may require additional planning, funding, or coordination to complete. TxDOT should begin working towards medium-term strategies (**Tables 7, 8, 9,** and **10**) as soon as possible, because the strategies may take several years to implement successfully.

Table 7: Medium-Term Recommended Policy Resilience Strategies

Medium-Term Policy Resilience Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Establish protocols to assess when flooded pavements can be reopened.		✓	✓
Encourage maritime port authorities to improve communications with trucking companies.		✓	✓
Develop agency-wide sea level rise guidance.	✓	✓	✓

Table 8: Medium-Term Recommended Program Resilience Strategies

Medium-Term Program Resilience Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Increase pavement monitoring in areas projected to experience more frequent and severe droughts.	✓	✓	
Help MPOs and RPOs evaluate the performance of pavements and bridges outside TxDOT responsibility.		✓	
Establish a communication and coordination protocol with local entities to streamline communication during construction projects.		✓	✓
Expand the scope of future vulnerability assessments to include additional asset types and considerations, including fleet vehicle conditions.[57]	✓		
Work with the Texas Broadband Development Office to expand fiber connectivity for ITS assets.	✓	✓	
Develop a prioritized list of critical assets and infrastructure components for maritime ports, airports, and maintenance facilities for restoration after a disruptor event.		✓	

Table 9: Medium-Term Recommended Project Resilience Strategies

Medium-Term Project Resilience Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Widen roadways that serve as key evacuation routes, focusing on areas where bottlenecks have occurred historically or where projected traffic volumes during an evacuation will exceed the current carrying capacity of the roadway.	✓	✓	
Upgrade supportive elements of roadways (subgrade and shoulder) to handle higher precipitation volumes across all TxDOT roadway projects.	✓		
Ensure power sources along roadways are connected to backup power.	✓	✓	
Implement bridge substructure resilience improvements such as encasements, foundation retrofits, and carbon fiber reinforced polymer wrapping to strengthen highly vulnerable bridges.	✓		
Improve and maintain pavement and bridge conditions at border crossings.	✓		

Table 9: Medium-Term Recommended Project Resilience Strategies (continued)

Medium-Term Project Resilience Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Assess and improve drainage around critical transit light rail stations and routes.	✓	✓	
Design new transit stations with features adapted to extreme weather events.	✓	✓	
Replace wood railway ties with concrete ties.	✓		
Consider projected temperature extremes in design and construction of railways.	✓		
Pilot innovative rail-fastening enhancements that have greater heat resistance.	✓		
Encourage and support railways and transit agencies in proactively preparing for winter weather by assembling snow throwers, installing scraper shoes on trains, and expanding use of rail heaters.	✓	✓	

Table 10: Medium-Term Recommended Information and Technology Resilience Strategies

Medium-Term Information and Technology Resilience Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Research flood impacts on pavement structure and identify measures from the suite of infrastructure strategies that could address these impacts.	✓		
Refine the vulnerability analysis for bridges and inland flooding based on deck heights and projected flood depths.	✓		
Establish a central Network Operations Center to monitor and maintain communication network of all ITS assets.		✓	✓
Conduct pilot culvert vulnerability assessments.	✓		
Update the vulnerability analysis for inland flooding to include the complete 500-year floodplain from the Texas Water Development Board's Floodplain Quilt.	✓		
Enhance smart border infrastructure to enhance the reliability and efficiency of border control systems as well as to bolster the security and mobility of goods and services.		✓	✓

Table 10: Medium-Term Recommended Information and Technology Resilience Strategies (continued)

Medium-Term Information and Technology Resilience Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Conduct research on opportunities to replace pavements to help manage stormwater, including green infrastructure and best management practices suitable for installation on TxDOT property.	✓		
Perform a feasibility study to assess the potential for on-site renewable energy generation and storage.	✓		
Evaluate bridge structural designs to identify designs that can withstand stronger storm surge and water flow.	✓		
Deploy smart freight connector technology.		✓	✓
Conduct a study to determine whether low-lying maritime port roads, transit centers, railways tracks, and maritime port infrastructure should be elevated based on projected sea level rise.	✓		
Implement a network analysis for the coastal freight network to identify critical and vulnerable maritime ports, airports, and railway stations.	✓		
Conduct a study on the impact and consequences of past wildfires on the State roadway network.	✓	✓	
Evaluate TxDOT's planning and prioritization processes for freight to identify bottlenecks and other physical constraints.		✓	✓
Adjust digital maps (e.g. Waze, Google Maps, and Apple Maps) to guide users to the best available evacuation route during an emergency.	✓	✓	
Explore opportunities for connecting TxDOT facility irrigation systems to recycled water lines.	✓		

Long-Term Strategies (10+ years)

Long-term strategies are those that are likely to require the most significant planning, funding, or coordination to complete (**Tables 11** and **12**). TxDOT can work towards these strategies by establishing the necessary internal conditions, such as internal buy-in and funding sources, so that the strategies can be accomplished in the long-term.

Table 11: Long-Term Recommended Program Resilience Strategies

Long-Term Program Resilience Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Expand TMC monitoring efforts.		✓	
Prioritize resilience measure implementation and post-disaster recovery/response efforts on roads serving critical energy facilities to support power generation systems.		✓	

Table 12: Long-Term Recommended Project Resilience Strategies

Long-Term Project Resilience Strategies	Strengthen Strategic Planning and Design	Ensure Operational Continuity	Improve Organizational Adaptability
Improve wind resistance in TxDOT-owned facilities and buildings by using reinforced concrete, adding lightning protection systems to roofs, placing all electric equipment in penthouses, using reinforced cast-in-place concrete, and using windows and shutters approved for hurricane-force winds.	✓		
Re-tamp railway track ballast to increase ballast density and reduce chances of thermal misalignment.	✓		
Construct separate bike lanes and shared use paths that can incorporate more tree shading and cool pavements.	✓	✓	
Replace dark rooftops on maintenance facilities, transit stations, and airport buildings with lighter-colored materials.	✓		
Improve monitoring systems with early warning indicators on bridges and culverts to identify vulnerabilities caused by weather-related disruptive events, such as extreme rainfall and heavy river flows.	✓		

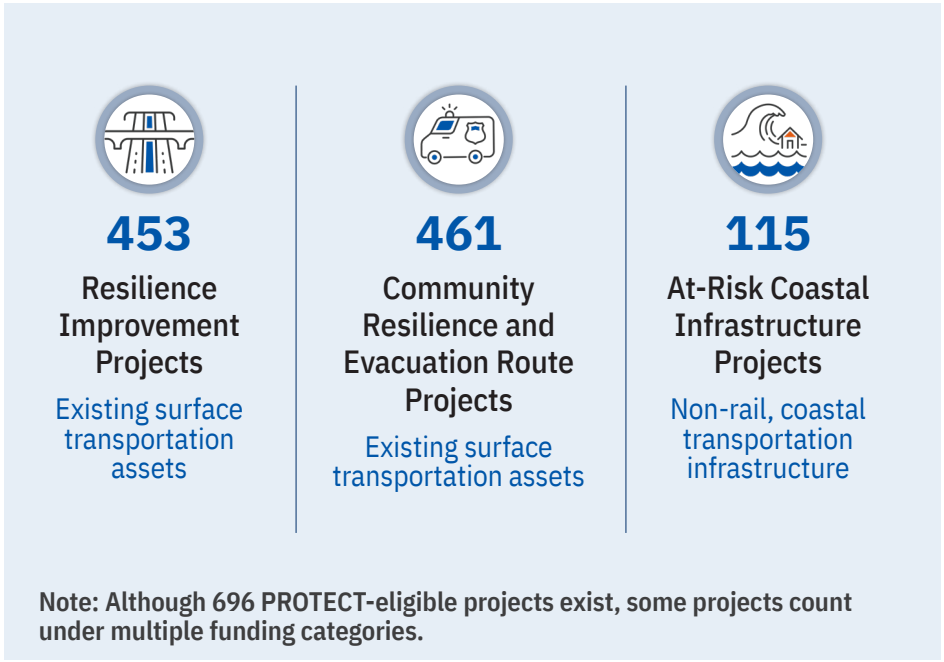
Resilience Improvement Project Identification

To meet Resilience Improvement Plan requirements, the STRP team searched existing plans and the UTP to identify currently planned projects potentially eligible for PROTECT funding (**Figure 17**). The final eligibility will be determined by FHWA. The resulting list includes a total of 696 resilience-related projects that fall under one or more of the following categories: resilience improvement projects, community resilience and evacuation route projects, and at-risk coastal infrastructure projects. The selected projects are programmed through 2029, to align with the PROTECT funding window. These projects include bridge upgrades, resurfacing, shoreline protection, evacuation route improvements, and preventive maintenance.

Resilience Improvement Projects were identified from:

- 2025 UTP
- Texas Delivers 2050
- 2023-2026 Statewide Transportation Improvement Program
- Permian Basin Freight Trade Transportation Plan
- Pharr District Long-Range Plan
- Presidio Freight and Trade Transportation Plan
- Texas-Mexico Border Transportation Master Plan
- 2024-2025 Texas Port Mission Plan
- Rio Grande Valley Regional Freight and Trade Plan
- US 90 Texas Corridor Study
- US 82 Texas Corridor Study

Figure 17: Total Number of PROTECT-Eligible Projects by PROTECT Funding Category



Note: Although 696 PROTECT-eligible projects exist, some projects count under multiple funding categories.

8 Implementation

8 Implementation

Funding and Financing Resilience

Planning for and implementing infrastructure and non-infrastructure adaptation strategies will be an ongoing, resource-intensive process. Resilience strategies are intended to be part of the standard project scoring process; however, external funding and financing opportunities are available and could be considered to convert STRP strategies into implemented projects. These sources may include grant opportunities, financing opportunities, and revenue-generating tools. If the cost of implementing a resilience strategy is significantly higher than typical costs, a cost-benefit analysis may be used to compare the cost of investing in a resilience project with the cost of damages from future disruptors.

Grant Opportunities

Multiple federal grant programs currently are applicable to TxDOT's priority strategies, several of which are listed by subject area below. In many cases, awards from federal grants must be accompanied by local match from receiving entities. Administering agencies are listed in parentheses.

Adaptation and resilience grants sometimes require the submission of applications on an annual deadline, while others may be pursued only following a Presidential Major Disaster Declaration.

- **PROTECT Discretionary and Formula Grant Program (United States Department of Transportation [U.S. DOT]):** Funding to ensure surface transportation resilience to natural hazards through planning activities, resilience improvements, community resilience and evacuation routes, and at-risk coastal infrastructure. Award amount dependent on project type (i.e., planning or construction).
- **Hazard Mitigation Grant Program (HMGP) (FEMA):** Funding for hazard mitigation projects that reduce risk from disasters and natural hazards, including wildfires, drought, hurricanes, earthquakes, extreme heat, and increased flooding to foster greater community resilience.

Highlights

This chapter provides information to convert the STRP from a plan into actions.

Funding and financing:

- High-priority federal grants
- Financing tools
- Revenue generation tools

Key Resilience Performance Indicators help TxDOT establish targets, evaluate progress, and report metrics to inform project planning, prioritization, and investments.

An implementation roadmap for the resilience strategies outlined in **Chapter 7**.

- **Pre-Disaster Mitigation Program (FEMA):** Funding to plan for and implement sustainable, cost-effective measures designed to reduce the risk to individuals and property from future natural hazards, while also reducing reliance on federal funding from future disasters.
- **Community Development Block Grant – Disaster Recovery and Mitigation (U.S. Department of Housing and Urban Development):** Disaster Recovery grants rebuild areas after a Presidential Major Disaster Declaration has been issued. Mitigation grants fund activities that mitigate disaster risk, reduce future losses and damage, and increase disaster resilience.

Transportation grants provide large-scale funding for projects in the transportation sector. The grants listed below explicitly mention funds that can be used for resilience and adaptation initiatives:

- **Metropolitan and Statewide Planning and Non-Metropolitan Transportation Planning Grants 5303, 5304, and 5305 (Federal Transit Administration):** Funding and procedural requirements for multimodal transportation planning in metropolitan areas and states.
- **Better Utilizing Investments to Leverage Development (BUILD) program:** Funding for critical freight and passenger transportation infrastructure projects.
- **Strengthening Mobility and Revolutionizing Transportation Grants (U.S. DOT):** Funding for eligible public sector agencies to conduct demonstration projects that are on advanced smart community technologies and systems to improve transportation efficiency and safety.

Factors to Consider for Developing Funding Strategies

Timing

The amount of time needed to secure the funding source relative to the project schedule.

Feasibility

The likelihood of receiving approval, whether it be from the federal government (grants) or voters (revenue generating tools, like a tax).

Administrative Complexity

The degree to which funding and financing tools may be implemented with TxDOT's existing resources, and/or may be implemented directly by TxDOT. This includes resources needed to oversee grant applications and administration, as well as resources needed to implement and provide ongoing support for financing and revenue generating tools.

Funding Amount or Revenue-Generating Potential

The range of funds or revenue (i.e., new taxes or bonds) that each funding source can generate and the volatility of the funding source.

Long-term Sustainability

The future availability of each funding source.

Funding Flexibility

The funding's requirements and restrictions.

Security grants fund projects that are intended to mitigate or rebuild from human-made disruptors. TxDOT may not be the ideal applicant agency as awards are most frequently distributed to local government entities.

- **Homeland Security Grant Program (FEMA):** Funding to build, sustain, and deliver the capabilities necessary to prevent, prepare for, protect against, and respond to acts of terrorism.
- **Regional Catastrophic Preparedness Grant Program (FEMA):** Funding to build core security capabilities by providing resources to close known gaps in Housing and Logistics and Supply Chain Management, encourage innovative regional solutions to issues related to catastrophic incidents and build on existing regional efforts.
- **State and Local Cybersecurity Grant Program (FEMA):** Funding for eligible entities to address cybersecurity risks and threats to information systems that are owned or operated by, or on behalf of, state, local, or Tribal governments.

Financing Opportunities

Access to funds through debt issuance can be important for funding projects and in securing grants, especially those that require a local match component. Bonds focused on extreme weather events offer a unique financial instrument to raise capital for resilient investments. Examples include Climate Resilience and Environmental Impact bonds.

- **Catastrophe Bonds:** An innovative, high-yield financing tool that allows issuers to receive funding in case of natural disasters, including extreme weather events.
- **Green Bonds:** Specifically finances capital-intensive projects to adapt to or mitigate extreme weather events.
- **Revenue or General Obligation Bonds:** Issued to pay for projects that do not have a revenue stream. Debt is repaid through local revenue sources, such as taxes.

Revenue-Generating Tools

TxDOT currently receives funding from Proposition 1,[58] which directs a portion of existing oil and natural gas production taxes to the State Highway Fund, and Proposition 7,[59] which authorizes a portion of sales and use taxes to construct, maintain, and acquire ROWs for public roadways other than toll roads. Both of these revenue sources will expire after Fiscal Year 2043. Additional revenue-generating tools may be needed to support implementation of the adaptation strategies, either by levying a new tax or by earmarking future, replacement Proposition 1 and Proposition 7 funds for adaptation-specific uses.

Monitoring and Key Performance Measures

TxDOT and other state departments of transportation use performance measures to monitor the transportation system's condition and performance. Performance measures cover a range of metrics, such as asset condition, travel time, maintenance costs, and system reliability. Metrics track and improve operations by establishing targets, evaluating progress, and reporting to agency departments, decisionmakers, and the public. Over time, performance measures provide a systematically tracked, standardized set of indicators that can inform project planning, prioritization, and investments.

Key Performance Measures

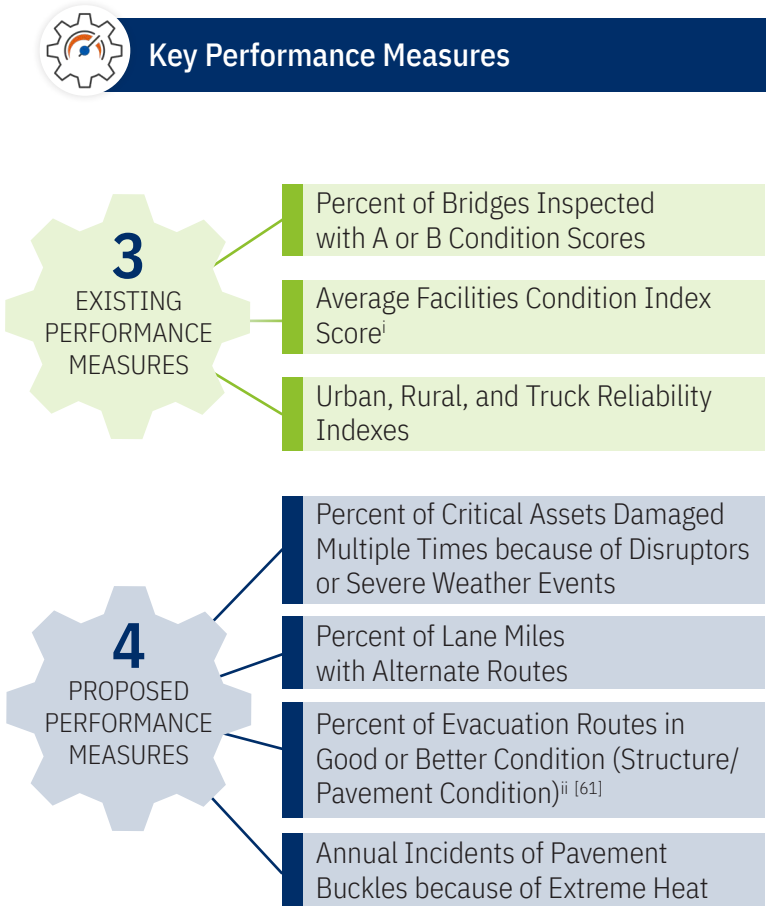
7 resilience performance measures

3 existing measures

4 proposed measures

TxDOT currently uses a set of performance measures that is aligned with the agency's strategic goals and is reported through TxDOT's public performance dashboard.[60] Although many of these measures relate to resilience, they do not specifically track resilience. A set of performance measures focused specifically on resilience can enable TxDOT to better monitor asset performance and the overall transportation system with respect to its ability to respond to and withstand disruptors. A set of resilience performance measures also can support evaluating resilience-related funding and strategy implementation and inform

decision-making. With input from TxDOT leadership, the RSC, and TxDOT divisions, the STRP team developed a set of seven key resilience-focused potential performance measures that apply to assets throughout the entire transportation system. Of these, three are existing and four are proposed performance measures.

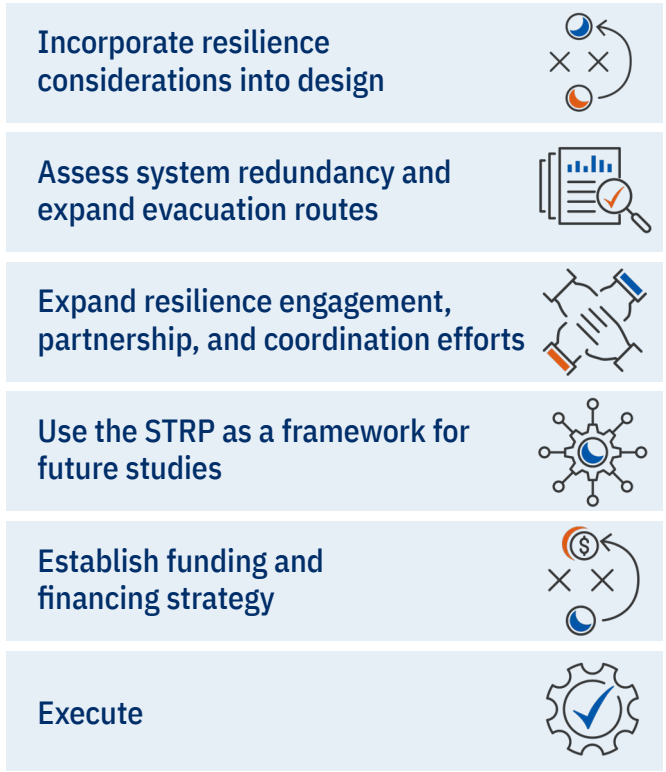


i The National Bridge Inventory (NBI) assigns bridges to a condition group with a letter score of A, B, C, D, or F based on the minimum of NBI items 58, 59, and 60--or 62 (if a culvert). Condition groups are assigned numeric values (95 for A, 85 for B, 75 for C, 65 for D, 50 for F). The Bridge Condition Score is the weighted average of these numeric values by deck area: the sum total of each bridge's numeric score multiplied by its deck width (or approach width) and length, divided by the sum total of statewide bridge deck area.

ii Pavement condition is determined by pavement distress (deterioration) and ride quality (smoothness).

Catalysts for Implementation

To achieve the STRP's goals of strengthening infrastructure resilience, ensuring operational continuity, and improving organizational adaptability, resilience strategies must progress from innovative ideas to implemented actions. Resilience strategies are intended to be incorporated into TxDOT's standard processes as part of the UTP and project selection and funding process. However, to catalyze implementation, external funding and financing could be considered. The STRP outlines 116 resilience strategies and identifies the expected timeline for implementation: short-term (0 to 4 years), medium-term (5 to 9 years), and long-term (10+ years). This implementation plan identifies five critical short-term resilience implementation topic areas that relate to several resilience strategies. These topic areas will serve as implementation catalysts to help TxDOT move the ideas presented in the STRP from concept to reality.



Incorporate Resilience Considerations into Design

A key short-term resilience topic area for TxDOT is to incorporate resilience considerations into project design and delivery. TxDOT can accomplish this by developing a Resilience Design and Construction Concepts Guide that can include many resilience strategies. TxDOT's Design and Maintenance divisions can use the guide to understand when and how to upgrade infrastructure to be more resilient to various extreme weather events. For instance, the guide may specify that resilience designs are to be implemented as the opportunity arises, either at the time of scheduled maintenance or during emergency repairs. The purpose of the guide is to safeguard TxDOT's investments in physical infrastructure by accounting for projected weather conditions in project design and construction. New or repaired infrastructure will not only be resilient to conditions today but would also be prepared to withstand future conditions, such as by using materials resilient to projected extreme temperatures. The guide can help catalyze strategy implementation by establishing a comprehensive internal references list for resilient design and construction projects. The following list highlights a selection of project resilience strategies that can be incorporated into the guide.

Related Resilience Strategies

- Prevent scour of roads and bridges in the floodplain or that are projected to be exposed to coastal flooding through armoring, bank stabilization, and river training.
- Elevate roadways, railways, transit, and bridge assets in the floodplain above projected flood heights, particularly on evacuation routes.
- Treat metal components of assets to resist corrosion because of increased salinity exposure.
- Use fire-resistant materials in the construction and maintenance of buildings and infrastructure in areas with high wildfire vulnerability or areas that have experienced increases in wildfire activity in the past decade.
- Adjust the structural design of pavements, bridges, and railways to sustain higher temperatures and more intense heat waves.
- Elevate all TxDOT electrical equipment above projected flood heights to prevent damage.
- Ensure proper insulation of ITS cabinets, particularly in areas where extreme heat, freezing temperatures, or flooding is expected.
- Upgrade medians to handle higher precipitation volumes.

Assess System Redundancy and Expand Evacuation Routes

Another implementation topic area for TxDOT is to assess transportation system redundancy and identify additional evacuation routes. Improving the redundancy of Texas' transportation system could enhance TxDOT and first responders' ability to respond effectively during emergencies and to provide safe evacuation for Texas' growing population. Sufficient and reliable evacuation routes are a critical component of the Texas transportation system and directly contribute to system and community resilience. The STRP outlines several resilience strategies related to increasing evacuation route capacity and effectiveness. A selection are highlighted below.

Related Resilience Strategies

- Conduct a study to evaluate the redundancy of the roadway network, including identifying alternative routes for vulnerable roadways to increase redundancy.
- Develop median breaks or crossovers on evacuation routes to support roadways and manage high traffic volumes temporarily.
- Widen roadways that serve as key evacuation routes, focusing on areas where bottlenecks have occurred historically or where projected traffic volumes during an evacuation will exceed the current carrying capacity of the roadway.
- Continue to develop resources and materials that effectively communicate with non-English speakers in emergency and evacuation situations.

- Develop ITS asset management, a communications network, and strategic, operations, and emergency plans. As part of the emergency plan, include periodic TMC emergency exercises to test the effectiveness of current emergency response capabilities.
- Adjust digital maps (e.g. Waze, Google Maps, and Apple Maps) to guide users to the best available evacuation route during an emergency.

Expand Resilience Engagement, Partnership, and Coordination Efforts

TxDOT has solicited internal feedback on the STRP through the RSC in addition to obtaining external feedback from MPOs and other agencies like FHWA. Internal and external engagement is crucial to implementing the STRP goals, objectives, and strategies because it allows groups to leverage each other's resources and expertise and coordinate to establish an efficient resilience, recovery, and response strategy. Continued engagement, partnership, and coordination efforts make up a key short-term implementation topic area that will support TxDOT and partners in successfully implementing resilience strategies. Specific ongoing engagement efforts will include TxDOT continuing to conduct regional resilience planning efforts and participate in multi-agency resilience working groups. The list below highlights a selection of related strategies.

Related Resilience Strategies

- Continue convening cross-departmental stakeholders through the RSC to coordinate and streamline resiliency efforts at TxDOT.
- Enhance coordination with emergency services, such as the Texas Department of Emergency Management, Texas Public Utility Commission, and local emergency service authorities.
- Develop an ITS Emergency Response Plan that includes training on how to strengthen ITS infrastructure to handle disruptors and leverage stakeholder partnerships.
- Form a Resilience Working Group with partner agencies and municipalities.
- Use the Texas Wildfire Risk Assessment Portal and coordinate with the Forest Service to improve communication of wildfire danger.
- Develop an interactive data depository and dashboard where local governments can upload and access emergency response and other resilience data.
- Coordinate with flood control districts to implement additional flood control measures (e.g. planting trees and vegetation) in TxDOT project areas prone to flooding.

Use the STRP as Framework for Future Studies

Another priority implementation topic area is to ensure that the STRP can be accessible as a framework for future resilience studies, including regional transportation plans. This may include developing a data hub to share data on assets and extreme weather events or developing tools to help inexperienced users complete a vulnerability assessment. These efforts will support expanded coordination efforts by creating a shared data resource that internal and external groups can leverage for informed planning. This implementation topic area specifically can support information and technology resilience strategies. The list below highlights a selection of related strategies.

Related Resilience Strategies

- Help MPOs and RPOs evaluate the performance of pavements and bridges outside TxDOT responsibilities.
- Expand the scope of future vulnerabilities assessments to include additional asset types and consideration, including fleet vehicle conditions.
- Create a data clearinghouse and resilience and adaptation project status tracker that allows local agencies and other TxDOT partners to access adaptation and resilience information.
- Encourage maritime port authorities to use resilience assessment tools.

Establish Funding and Financing Strategy

This short-term implementation topic area is to establish a resilience funding and financing strategy to support strategy implementation. Developing a funding and financing strategy will be critical to support implementation and requires thorough consideration of the existing funding landscape, political opportunities, administrative capacity, and relative project priority. Separate funding is not required to implement strategies, which should be considered as part of TxDOT's standard project development and funding process. However, separate funding mechanisms could be considered to catalyze implementation.

In the near-term, TxDOT may consider the following to develop its funding and financing strategy:

- Understand potential investments' scale and timing to determine funding needs.
- Assess current funding sources and capital plans for opportunities to include adaptation strategies within existing planned capital projects.

Match near-term strategies with current grant opportunities:

- Develop partnerships and conduct initial studies, as needed, to support applications.
- Identify local match funding, as needed.
- For larger grant opportunities (e.g., BRIC), establish partnerships and a strategy for developing projects that may be included in a future grant application.
- Identify adaptation strategies that may be supported by local partners and work with local partners to incorporate these strategies into their planning efforts and to source funding.

Ultimately, resilience strategies will need to be funded to be implemented. Establishing a funding and financing strategy can help catalyze the implementation by identifying funding sources and/or partners.

Execute

The STRP provides a framework for TxDOT to enhance the resilience of its multimodal transportation system. Executing short-term strategies will create momentum for resilience improvements and take advantage of available federal funding opportunities as they arise. Resilience is an iterative process requiring sustained focus on both near and long-term solutions. Tracking resilience performance measures and implementing medium- and long-term resilience strategies will improve safety and prevent damage-related costs far into the future.

Implementation Timelines

A strong understanding of and commitment to short-term implementation topic areas will help TxDOT effectively start the process of implementing STRP resilience strategies. Additional considerations are outlined as follows:

Short-term (0 to 4 years) strategies may be in place already or require minimal funding or coordination to complete. These strategies may require immediate action and can contribute more quickly to increased system resilience.

Medium-term (5 to 9 years) strategies may require additional planning, funding, or coordination to complete. TxDOT should begin working towards medium-term strategies as soon as possible, because they may take several years to implement successfully.

Long-term (10+ years) strategies are likely to require the most significant planning, funding, or coordination. TxDOT can work towards these strategies by establishing the necessary internal conditions, such as internal buy-in and funding sources.

While TxDOT should work to implement all resilience strategies across timelines, focusing on the implementation topic areas can be an effective way to jump start the implementation process and contribute to achieving the STRP goals.

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Texas Department of Transportation

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