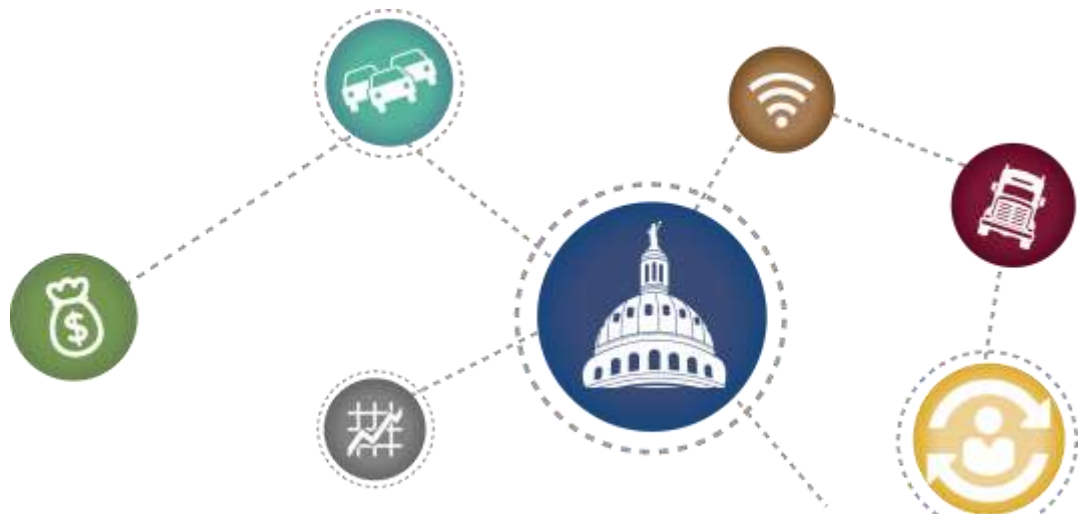


How Vulnerable Is Texas' Freight Infrastructure to Extreme Weather Events?

Final Report

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How Vulnerable Is Texas' Freight Infrastructure to Extreme Weather Events?

Texas A&M Transportation Institute

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Introduction

The Texas Freight Mobility Plan forecasts significant increases in freight volumes across all transportation modes over the next three decades. An increased frequency of extreme weather events such as prolonged droughts and flash flooding is also expected during this time frame. Repeated severe flash flooding across the state has demonstrated the vulnerability of Texas's freight and transportation assets to extreme weather events.

The freight community's ability to prepare for and respond to extreme weather events is in part dependent upon the resilience of the transportation infrastructure and whether the system maintains functionality during and following adverse conditions. However, freight infrastructure resilience analysis, design, and planning methods are relatively immature and may limit the freight community's ability to effectively plan and respond to extreme weather events.

Research Goal

The goal of this research was to better understand the basic issues, impacts, and current best practices to address the vulnerability of critical freight infrastructure to extreme weather events.

Critical Infrastructure

Infrastructure systems provide essential services to support the nation's economy. Federal law defines *critical infrastructure* as systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of these matters (1). Sixteen such critical infrastructure sectors are identified by Executive Order (2); one of them is transportation.

Considerations for critical infrastructure include geographic and information-related relationships between manufacturers, shippers, wholesalers, retailers, and consumers; cybersystems; physical, logical, and functional connections; and situations where these relationships have or create dependencies or interdependencies that could affect an asset's operation (3).

The U.S. Department of Homeland Security Office of Cyber and Infrastructure Analysis has determined that the most likely sectors to experience infrastructure impacts from severe winter storms are transportation and energy (4).

Extreme Weather

Transportation systems have traditionally been designed to withstand historical ranges of local weather and climate. However, due to documented increases in significant weather events, the historical record of climate and weather is no longer a reliable predictor of future risk.

The term *extreme weather* includes severe or unseasonable weather, heavy precipitation, storm surge, flooding, drought, windstorms (including hurricanes, tornadoes, and associated storm surges), extreme heat, and extreme cold. Extreme weather events are rarely occurring, weather-induced events that usually cause damage, destruction, or severe economic loss (e.g., a prolonged drought) (5).

The Federal Highway Administration (FHWA) makes a clear distinction between extreme weather events and extreme events such as earthquakes or tsunamis not related to weather or climate change.

Causes of Weather Events

It is less clear if recent extreme weather events are attributable to climate change, normal weather variability, or some combination of the two. The recently published National Academies of Sciences report *Attribution of Extreme Weather Events in the Context of Climate Change* examined the science of attribution of specific extreme weather events to human-caused climate change and natural variability. The report concludes that the ability to understand and explain extreme events in the context of climate change has developed very rapidly over the past decade and is still evolving (6). The report also notes that it is now possible to estimate the influence of climate change on *some types* of specific extreme events such as heat waves, cold events, droughts, and heavy precipitation (6).

Increasing Prevalence of Weather Events

A significant issue for the transportation industry is that climate change may make extreme weather events more common on a yearly basis. An Intergovernmental Panel on Climate Change study, released in March 2014, found that the increasing prevalence of severe weather will have negative effects on infrastructure, agriculture, and the overall well-being of humans (7).

Most Common Hazard: Flooding

Flooding is the most common environmental hazard because about 10 percent of U.S. land is considered in a flood plain (an area prone to flooding), and every state has at some time in the recent past experienced floods or flash floods. From 2005 to 2014, total flood insurance claims averaged more than \$3.5 billion. Death and fatalities from these floods are in the thousands. Ninety percent of Presidential Disaster Declarations involve some sort of flooding (8), and research has shown that the risk of floods is increasing because of rising sea levels (9).

Vulnerable Communities

An additional concern is that the population in the United States is moving to and becoming denser in vulnerable areas such as coastal communities and hurricane-prone areas (10).

Weather Information

An assessment of available weather information for surface transportation, conducted in 2002 (11) and updated in 2006 (12) and 2007 (13), found that a considerable amount of information

regarding current weather conditions and forecasts is available to the consumer, and that both safety and economic benefits can result from efforts to further improve weather information.

Extreme Weather Impacts on Transportation

Key Research

Extensive research exists on the impacts of extreme weather on transportation—infrastructure, personnel, and practices. Key reports include:

- *Literature Review: Climate Change Vulnerability Assessment, Risk Assessment, and Adaptation Approaches* reviews transportation vulnerability and risk assessments up to 2009. The author notes, “Incorporation of climate change impacts into transportation decisions is still a relatively new concept” (14).
- “The Potential Impacts of Climate Change on Transportation” describes the findings of a 2002 workshop held by the U.S. Department of Transportation (USDOT), U.S. Department of Energy, and Environmental Protection Agency (15). A number of governmental and nongovernmental entities attended the workshop. The workshop noted a significant need for research about the relationships between climate change and transportation.
- *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study* (16) examined the Gulf Coast from Houston/Galveston, Texas, to Mobile, Alabama. This area was selected “due to its dense population and complex network of transportation infrastructure, as well as its critical economic role in the import and export of oil, gas, and other goods” (17). Phase 1 was completed in 2008, and phase 2, focusing on the Mobile area, was completed in 2015. Key concerns are sea level rise and increase in temperatures, which will speed up deterioration of highways, bridges, and rail lines; exacerbate flash flooding; and affect the integrity of soils and foundations. The study resulted in development of tools for assessing vulnerability and a webinar series on building a climate-resilient transportation system. These tools are online at https://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/. The results of this study have informed later FHWA efforts to guide transportation entities, such as *Climate Change and Extreme Weather Vulnerability Assessment Framework* (2012) (18) and *Planning for Systems Management and Operations as Part of Climate Change Adaptation* (2013) (19).
- *Impacts of Extreme Weather on Transportation: National Symposium Summary* (20) provides the findings of a May 2013 symposium sponsored by the American Association of State Highway and Transportation Officials (AASHTO). The symposium addressed defining extreme weather, projecting the future, determining extreme weather costs, and developing mitigation strategies through infrastructure design, operation, and maintenance.

- *Response to Extreme Weather Impacts on Transportation Systems (21)* covers a variety of extreme weather events and lessons learned from those events, devoting an entire chapter to drought and wildfires in Texas. The report highlights issues of concern to transportation infrastructure providers, such as the off-system role of a state department of transportation (DOT) in disaster, communications, interagency coordination, and knowledge management. The report also discusses the need for strategies for detours and outreach to the freight community.
- *NCHRP Report 750: Strategic Issues Facing Transportation, Volume 2: Climate Change, Extreme Weather Events, and the Highway System: Practitioner's Guide and Research Report (22)* notes the evolving understanding of the relationship between climate change and transportation infrastructure, reiterates findings about climate change, and lays out an eight-step framework for planning extreme weather adaptation. Regarding Texas, the study cites the National Resources Defense Council's statistics that in 2012 Texas had "a total of 144 broken heat records, 8 broken snow records, 115 broken precipitation records, and 34 large wildfires" (22).
- *Surface Transportation System Resilience to Climate Change and Extreme Weather Events (23)* summarizes a 2015 international conference on the subject and notes urgency for action even in the absence of government requirements regarding preparation for or mitigation of extreme weather events. The summary discusses climate change in the contexts of inland waterways, airports, and ports, and case studies of the Massachusetts Port Authority and Alaska's Dalton Highway.
- Other studies suggest innovations such as including crowd-sourced information in post-event roadway assessment (24), using quantitative methods to enhance resilience in intermodal logistics networks (25), routing multi-commodity intermodal freight during disruptions using models (26), and using ground-based LiDAR and drone-based photography to assess infrastructure damage and inspect bridges (27).

Impacts to Traffic Volume

Transportation modes are sensitive to any weather—for example, a light mist can make highways slick and more conducive to vehicle crashes—but are more sensitive to weather extremes (28). Extreme weather can affect traffic volume during the event and have long-lasting impacts on infrastructure afterward. In one case study, unusually heavy rainfall reduced vehicle speeds by one-fourth, cut traffic volume in half, and flooded or damaged many bridges, underpasses, road surfaces, and vehicles (29).

Increases in delay and travel time created by weather events can have a direct financial impact on users in an area. For example, freight operators lose about \$3.4 billion (about 32 million hours) stuck in weather-related traffic delays in metropolitan areas. A one-day highway shutdown can cost a metropolitan area up to \$76 million in lost time, wages, and productivity (30).

Impacts to Infrastructure

Understanding and classifying the impacts of weather events on transportation resources have also been pursued. The New York Academy of Sciences developed three categories to identify potential impacts:

- “Temperature-related infrastructure and material stresses such as greater freeze-thaw cycles, buckling of road and rail beds due to intense heat etc.
- “Temperature-related user stresses such [as] requiring more use and employment of ventilation, air conditioning etc.
- “Water-related infrastructure stresses such as flooding, saltwater intrusion, moisture damage from humidity, bank erosion due to heavy rainfalls etc.” (31).

Extreme Weather Impacts on Freight

Freight Industry Recognition of Weather Patterns

The trucking industry has recognized increased difficulties from extreme weather and the need to address the resulting issues. In 2015, Phil Sneed of Tandem Logistics wrote (32):

Trucking and logistics companies, in addition to drivers, also have to account for more disruption, including the changing environment. Truckers have long been accustomed to driving through all types of weather, rain or shine. However, recent country-wide weather patterns have contributed to more transformational changes.

Sneed cites the polar vortex of 2013–2014, the resulting shutdown of multiple interstate highways, and their effects on up to 50,000 trucks and 200 trains as key indicators.

Go by Truck News wrote, “Increased flooding in the Midwest has caused so much sediment degrading around bridge abutments that the bridges are likely to give way under the force of an added stress, whether from overloading, wind or earthquake” (33).

A study of the Boston metropolitan area found that climate change may result in “a doubling of delays and lost trips” but that this outcome would “probably not” be sufficient to justify large expenditures to adapt infrastructure (34).

It is also possible that climate change results in milder winter conditions, which could decrease time lost to shipments due to severe winter weather and improve safety for some modes (28).

Plans to Address Extreme Weather

Identifying specific industry plans to address extreme weather is difficult. Those identified during this investigation include general and practical guidance. For example, XTL, a Canadian transportation and logistics company, advises shippers that best practices are to pre-plan, monitor weather conditions, and work with the carriers (35).

Public- and Private-Sector Cooperation

Programmatic efforts to address the critical infrastructure aspect of transportation are increasingly risk informed but vary widely from jurisdiction to jurisdiction (36). Efforts are enhanced through the use of public-private partnerships, which are particularly successful at acquiring and disseminating best practices (36). Once created, public-private partnerships are challenging to sustain because funding is reduced and personnel face other demands (36).

The freight network in particular can involve a combination of public- and private-sector ownership structures and thus can have a complex web of laws and regulations that apply (37). A number of useful public- and private-sector planning guides and resources exist, such as the National Oceanic and Atmospheric Administration Sea Level Rise and Coastal Flooding Viewer (<https://coast.noaa.gov/slr/>), but their use may require a certain level of expertise (37). A private

company's ability to invest in mitigation or resilience measures may depend on its business continuity planning process, level of vulnerability assessment (single asset to entire system), financial resources, and perception of risks and consequences (37).

Suggested Approaches

The following approaches offer ways to deal with extreme weather:

- One approach to resilience is to have redundancy in routes—multiple routes that can accommodate the same shipment (38). In terms of railroads, options have decreased over time because the miles of rail nationally have decreased from 254,000 in 1914 to 138,000 in 2014 (38). For hazardous materials, railroad shippers are required to follow a number of federal mandates, including the use of a 27-factor algorithm assessing relative risk and the avoidance of densely populated areas (38).
- To ensure minimum disruption and a quick return to normal operations, intermodal coordination and cooperation are required. A study of Hurricane Sandy cited lack of intermodal coordination. The study found that efforts put into restoring port operations were not met with sufficient road or rail efforts to provide adequate service (39).
- Based on lessons learned in Hurricane Irene, the Research Foundation of the National Association of Development Organizations recommends involving regional transportation planning entities to improve coordination among local and state agencies and formalizing these entities' roles in transportation disaster response (40).
- The New York City Panel on Climate Change identified several possible steps to take in the operations and management area: improve pumping, increase backup emergency equipment, and improve storm information and forecasting; for soft infrastructure, make areas around stations porous to promote drainage; and for hard infrastructure, raise seawalls and barriers, and elevate runways and low-lying tracks and roadways (41).
- Researchers have suggested that actions taken to increase resilience, such as storing extra vehicles to replace those disabled, system redundancies, and relocation of facilities to high ground, may increase economic efficiency as well (31).
- Current research has developed methods of identifying dollar value benefits of winter maintenance operations in terms of safety, mobility, and fuel savings (42). Future efforts may help provide a cost-benefit basis for expenditures on resilience.
- Current research holds hope for improving resilience. Research in areas such as soil temperature prediction (43), extreme weather risk indicators for transportation systems (44), urban traffic flow in inclement weather (45), anti-icing applications (46), a combination of historical and scenario-based data for weather projections (47), and railroad ballast erosion (48) continues to improve our ability to provide mobility in extreme weather conditions.

Freight Industry Response to Extreme Weather Impacts

The freight industry has pursued a variety of responses to extreme weather events. Table 1 provides a summary of extreme weather effects and the potential responses by the freight industry.

Table 1. Extreme Weather Effects and Potential Responses by Freight Transportation.

Extreme Weather Effect	Freight Transportation Response
Increased frequency, duration, and intensity of droughts; increased coastal and inland flooding	Restricted access to ports and shipping channels for inland waterways
Increased frequency, duration, and intensity of droughts; increased coastal and inland flooding	Mode shift to trucking due to reduced reliability of other modes
Intense single event severely damaging or destroying asset	Re-routing or delay in shipping freight
Longer duration and/or shifting of springtime freeze/thaw period	Mandatory freight diversion to more robust alternative routes
Increase in magnitude and duration of severe heat waves	Mandatory freight diversion to more robust alternative routes or modes
Increase in magnitude and duration of severe heat waves	Dynamic or seasonal restrictions for trucks or rail during times of high heat, reducing either acceptable speed or weight
Increase in magnitude and duration of severe heat waves	Policy and regulation changes to restrict truck size and weights for entire roadway network or specific highway classes
Increase in magnitude and duration of severe heat wave	Maintenance to address potholes and buckling issues

Freight in Texas

Texas's Freight Infrastructure

An efficient, reliable, and safe freight transportation system is critical to the economic prosperity of any region. It reduces transportation costs (and therefore supply chain transaction costs) and increases connectivity, reliability, and accessibility to local and global markets. Texas's freight transportation system has been a critical contributor to the state's economy, serving the state's business community, facilitating the expansion of international trade, and ensuring the quality of life of the state's citizens.

In 2015, Texas's gross domestic product exceeded \$1.6 trillion (current dollars), of which the transportation and warehousing sectors contributed almost \$62 billion (49). The Texas Freight Mobility Plan reported that in total, industries and businesses directly and indirectly impacted by freight transportation represent approximately 43 percent of the state's economy.

The public and private sectors have invested extensively in the state's freight transportation system to accommodate the movement of billions of tons of both domestic and international freight. Texas's transportation system that moves freight consists of:

- More than 312,000 centerline miles of public roadways, including more than 3,200 miles of interstate highways and 12,000 miles of U.S. highways.
- More than 10,000 track miles of freight rail.
Three Class 1 railroads and 46 short line railroads operate in the state.
- 11 deep-water ports and 15 shallow-draft channels that are connected to the Gulf of Mexico. Texas's Gulf Intracoastal Waterway facilitates the movement of interport freight.
- 23 commercial service airports, six of which are among the top 50 cargo airports in the United States (in terms of landed weight).
- More than 426,000 miles of pipelines (i.e., approximately 59 percent is intrastate, and the remainder is interstate).
- Four commercial traffic (truck) border crossings and six rail-only crossings between Texas and Mexico (50).

In 2014, Texas's:

- *Highways moved more than 1 billion tons of freight.*
- *Railroads moved an estimated 400 million tons of cargo, equivalent to 21 million truck trips.*
- *Waterways transported 560 million tons of freight.*
- *Commercial traffic and rail border crossings facilitated the movement of more than \$246 billion in goods from Mexico (i.e., 83 percent by truck and the remainder by rail) (50).*

Effects on Just-in-Time Supply Chain

Extreme weather events can present significant challenges for Texas freight transportation infrastructure. The freight industry relies on Texas's transportation infrastructure to move intermediate inputs and final products to production and consumption centers in Texas, the United States, and internationally—often in a just-in-time (JIT) supply chain. Given the lack of redundancy in the JIT supply chain, the potential impact of extreme weather events on freight transportation infrastructure can have a more severe disruptive impact on JIT production and distribution (with a potentially larger economic impact) than disruptions to traditional freight movements.

Since the 1950s, the JIT business model has been used to maximize businesses' return on investment. JIT started off as an operations management approach that aimed to reduce in-process inventories and their associated costs. Over the years, JIT has developed into a demand-responsive model with almost no inventory, requiring frequent deliveries of small shipments the same or next day. This has translated into partnerships with single-source suppliers, transportation systems functioning as mobile warehouses, and the removal of any redundancy in the supply chain.

Extreme Weather Events in Texas

Past Events

According to the National Centers for Environmental Information, the United States experienced 203 (Texas experienced 84) weather and climate disaster events that resulted in more than \$1 billion¹ (51) in losses between 1980 and 2016. These events included:

- 24 droughts.
- 26 floods.
- Seven freeze events.
- 83 severe storms.
- 35 tropical cyclones.
- 14 wildfires.
- 14 winter storms.

Of concern, however, is that more than one-third of these weather and climate disaster events happened in the last six years (i.e., between 2010 and 2016). Between 2010 and 2016, the United States experienced 74 (Texas experienced 35) weather and climate disaster events that resulted in more than \$1 billion in damage (51). These events included:

- Six droughts.
- 13 floods.

¹ Adjusted for inflation with the Consumer Price Index.

- 43 severe storms.
- Five tropical cyclones.
- Four wildfires.
- Three winter storms.

Furthermore, the Southern Plains Transportation Center noted that extreme summer temperatures, flash floods, and the large number of freeze-thaw cycles, coupled with poor soils in most Region 6 states (52), create challenges to transportation infrastructure health and to public safety. The result has been losses worth nearly \$9 billion annually to manage transportation systems in Oklahoma and Texas.

Future Events

It is expected that Texas will experience more—and more frequent—instances of severe weather, including heat-related deaths, wildfires, and coastal storm-related losses and rising sea levels (53, 54). The *Texas Tribune* cites a report from the Risky Business Project, which projects Texas seeing:

- More than twice as many days above 95 degrees by 2050 (going from 43 to 105 per year).
- A sea level rise of up to 2 feet, impacting Galveston.
- A \$650 million per year increase in coastal storm-related losses (54).

An Austin climate study finds:

- Great certainty in projected temperature increases, including frequency of temperature extremes.
- Moderate certainty in projected extreme precipitation in the general area.
- Less certainty in predicted rain changes specifically in Central Texas because increased rain generally would be offset by the area's arid nature (55).

However, the *Texas Tribune* also notes that many, including the Texas Association of Business, are skeptical about projected climate change and its speculated causes (54).

National Aeronautics and Space Administration (NASA) scientists analyzed data for 100 years in the Houston-Galveston area and discovered a long-term pattern of relative sea level and temperature rise, with projections continuing these increases. The data also led NASA to believe the number of extreme heat days per year will “rise dramatically in the coming century,” affecting energy use and the ability to work outside (56).

Texas Case Studies

Case Study Description

Events Studied

This section of the report explores specific extreme weather events that have impacted Texas transportation service providers and shippers in the past. Three case studies were conducted exploring the freight impacts of:

- The Memorial Day 2015 and spring 2016 flooding.
- Hurricane Ike.
- The ice event in the Dallas/Fort Worth/Texas Panhandle area in 2011.

The study team contacted 10 companies/businesses to understand:

- The impact of these three extreme weather events on their operations.
- The information they need before and during an extreme weather event.
- Whether the company/business has a formal coordination/communication strategy that takes effect in the event of an extreme weather event.
- The critical infrastructure in Texas that if failed would have a crippling impact on their operations/business.

Participants

The 10 companies that provided information to the study team are:

- Gulf Winds International.
- Port of Houston.
- Port of Brownsville.
- Port of Corpus Christi.
- DHL.
- Walmart.
- Lockheed Martin.
- FedEx.
- Union Pacific Railroad (UPRR).
- BNSF Railway.

In addition, three members of the Transportation Club of Dallas/Fort Worth provided anonymous feedback to the questions of the study team.

Extreme Weather Events of Concern to Participants

Table 2 lists the potential extreme weather events that the companies/businesses approached were most concerned about in Texas. Most of the companies/entities indicated that they consider

extreme weather events in their planning, investment decisions, project design/development, or maintenance strategies.

Table 2. Extreme Weather Events of Concern.

Extreme Weather Event	Number of Times Mentioned
Hurricanes	8
Intense rainfall events/flooding	5
Ice storms	5*
Tornados	1
Temperature extremes	1

* Lockheed Martin mentioned that the company would be concerned about a severe ice storm that would result in major road closures because it would prevent Lockheed Martin's employees getting to work, rather than because it would impact the company's receiving and delivery of shipments.

UPRR specifically stated that it is actively strengthening the railroad's ability to withstand future extreme weather events, as well as increasing the overall resiliency of the rail system to deal with extreme weather events. UPRR noted that temperature extremes can create harsh work environments for employees who work outside, increase rail maintenance costs, and impact service by decreasing train velocity. Severe weather events, such as hurricanes, impact UPRR's network by causing slower train speeds, service interruptions, and recovery costs.

Impact of Three Case Study Extreme Weather Events

Memorial Day 2015 and Spring 2016 Flooding

In May 2015, Texas experienced record levels of rainfall. The National Weather Service in Fort Worth reported that Texas received over 35 trillion gallons of rain in May 2015. Some areas experienced up to 19 inches of rain in 24 hours, resulting in floods that damaged homes, businesses, roads, bridges, and rail track.

In Houston, up to 11 inches of rain fell on Memorial Day in 2015 (57). Rainfall rates were often greater than 2 inches an hour, and the damage to critical infrastructure and utilities in Harris County was estimated at \$25 million (58). Several roadways were closed, and highways were damaged.

Trucking Companies

Damaged and flooded highways and bridges prevented trucking companies from leaving their pickup and delivery locations for days, causing late deliveries and lost revenue for logistics service providers, trucking companies, drivers, and customers. Corporate office staff, operations management personnel, auditors, sales personnel, and other staff were also delayed or could not make it into the office during flooding events, disrupting business operations.

Gulf Winds, for example, reported that the trucking company's operations were completely disrupted for a day as a result of the Memorial Day 2015 weekend flooding in Houston. Gulf Winds did not incur any damages as a result of the flooding but did lose revenue. The company did submit an insurance claim for the loss in income.

Shippers

Similarly, Walmart reported that several distribution centers needed to be closed during the Memorial Day 2015 flooding. Trucks could not get in or out of Houston for two days. Walmart reported that some third-party carrier trucks were flooded. Walmart also experienced some road damage (erosion) that the company paid to repair. Walmart is self-insured.

Parcel Deliveries

DHL and FedEx reported minor disruptions/impacts caused by the Memorial Day flooding. For DHL, the impacts only lasted a few days. DHL managed to continue to operate, and disruptions were limited to a few flooded areas that the company's delivery vehicles could not access. No major impacts on any specific customer were documented. The company did, however, emphasize safety and the safe operations of its drivers to avoid any unnecessary incidents in the areas affected.

FedEx reported that impacts were limited during the Memorial Day flooding because the company has the flexibility to divert shipments that would normally be shipped by air to truck or vice versa.

Marine Ports

The Port of Houston was affected by the Memorial Day weather event but not by the flooding per se. Rather, strong winds associated with the storm blew a ship shore crane down that collided with a ship. Although the direct supply chain impacts only lasted a day, the damaged crane resulted in the Port of Houston losing infrastructure capacity² that hampered the port's ability to provide service to its customers at the specific berth for six months. The costs to replace the crane were claimed from the insurance company (who paid for the crane after the port paid the deductible).

Similarly, the Port of Brownsville claimed windstorm damage from its insurer, while the Federal

The Port of Houston conducted a formal investigation to determine the need for any changes to the port's infrastructure/operations, but it was determined that everything that could have been done was done. The Port of Houston already considered extreme weather events in its planning, investment decisions, project design/development, and maintenance strategies.

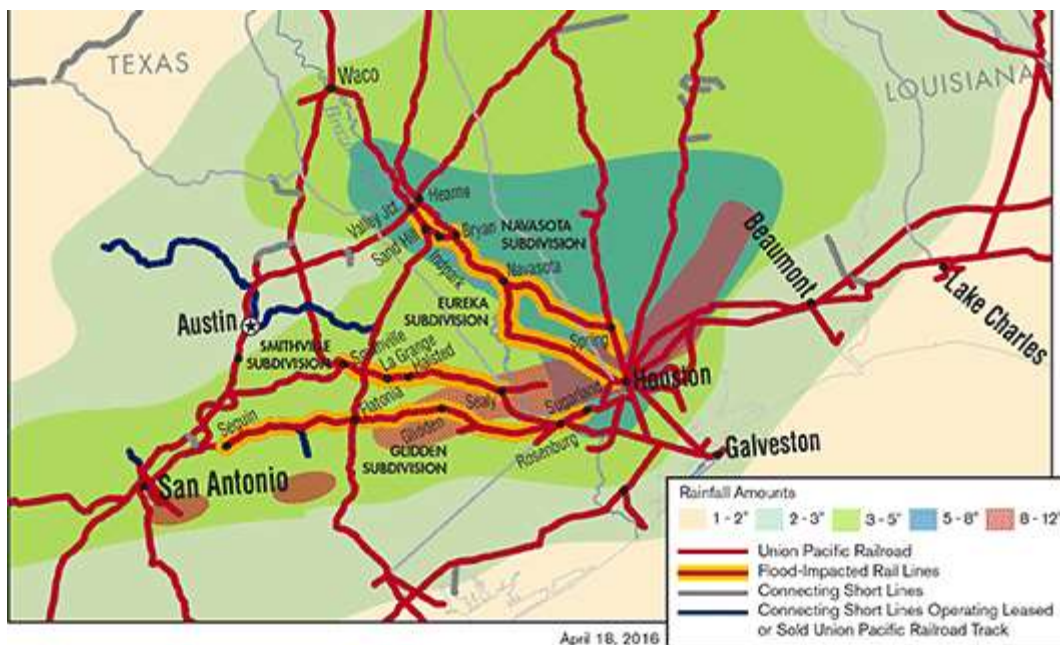
² The Port of Houston could not use the berth or the other crane serving the specific berth.

Emergency Management Agency paid for past insurance deductibles associated with windstorm damage from hurricanes.

Railroads

BNSF Railway reported that the Memorial Day flooding in Houston impacted the company's rail network, but the railroad did not provide the study team with specific information. UPRR also did not provide the study team with specific information about the 2015 Memorial Day flooding events in Houston but provided the study team with access to UPRR's public statements on the impacts to its infrastructure and customers associated with the flooding in Texas in spring 2016. The company reported that some segments of its rail system were closed (as a result of washouts or water over the track), while train operating speeds on other segments were slower than normal.

Figure 1 shows the rail lines in the Houston area that were impacted by flooding in spring 2016 (59). For example, a bridge over the Brazos River on the Glidden subdivision experienced extensive damage. This route, between Houston and San Antonio, was expected to be out of service for up to two weeks (60). UPRR communicated to customers that it could take several weeks before UPRR could resume normal operations. In the interim, UPRR rerouted traffic where feasible and warned customers to expect delays of up to 48 hours. All customers were encouraged to submit service issues and communicate critical needs through UPRR's National Customer Service Center (61).



Source: (59)

Figure 1. UPRR Rail Lines Impacted by Spring 2016 Flooding.

Hurricane Ike

Hurricanes bring wind, precipitation, flooding, storm surge, and tornadoes. The coastal United States along the Gulf of Mexico is heavily populated but has no topographic relief,³ and its low elevation means it is vulnerable to flooding and storm surges associated with hurricanes (62). Within the Gulf of Mexico area, 64 percent of interstates, 57 percent of arterials, 29 airports, 50 percent of rail miles, and most sea ports are below 23 feet (7 m) in elevation and thus could endure damage during hurricane storm surges (16).

*A **storm surge** is a wave of water that is pushed ashore by the wind accompanying a hurricane. The shallower the offshore water, the stronger the surge. The storm surge can combine with normal high tide and wind-driven waves to produce severe flooding (16).*

Storm surges and strong wave action can displace rail and highway bridge decks (16). It is anticipated that the intensity of hurricanes will increase in the future, which can increase damage and lengthen disruption periods (63). Shipping routes and intermodal freight facilities in coastal areas are therefore vulnerable (64).

Hurricane Ike reached the Texas Gulf Coast and Galveston in the early morning hours of September 13, 2008. The maximum sustained wind speeds reached 110 mph and extended 20 miles outward from the eye of the storm (65). The damage caused by Hurricane Ike left highways in Houston impassable (66), and the Port of Galveston, petrochemical plants, refineries, and offshore oil rigs were shut down.

In total, the Insurance Council of Texas estimated the insured property damage in Texas alone at approximately \$12 billion. This total is, however, a low estimate because many properties are not insured or without flood insurance (65).

Damage to the transportation system in the impacted area was estimated at \$131.8 million, which included a \$643,381 contract to repair the Rollover Pass Bridge in Gilchrist and the restoration of a segment of SH 87. Damages to the administrative offices, locomotives, and track of the Galveston Railway that serves the Port of Galveston were estimated at \$628,000. Finally, it was estimated that \$2.4 billion was needed “for erosion, waterway dredging and other infrastructure repairs to navigable waterways, ports, and coastlines” (67). Funding for recovery efforts came from the U.S. Economic Development Administration (\$40 million), the Federal Emergency Management Agency (\$1.5 billion), and the U.S. Department of Housing and Urban Development (\$3.4 billion). The Gulf Coast Economic Development District and the Houston-Galveston Area Council allocated \$2 billion of the funding to support a Revolving Loan Fund to help businesses and local governments in recovery and economic development, to repair critical infrastructure, and to replace housing (66).

³ In areas with mountainous terrain, hurricanes tend to weaken when they hit higher terrain.

Trucking Companies

Gulf Winds reported that Hurricane Ike resulted in a partial shutdown of its business for a week and a half. The company also incurred water damage that its insurance covered. Hurricane Ike prompted the development of a weather emergency plan for the company.

Marine Ports

Both the Port of Houston and the Port of Brownsville expressed concern about the damage that hurricanes can bring to port infrastructure. Specifically, the Port of Brownsville mentioned the possibility of shoaling⁴ as a result of a hurricane or extreme rainfall event. Also, the wind that hurricanes bring can damage facilities, such as sheds, cranes, and security cameras.

Ice Event in Dallas/Fort Worth/Panhandle Area in 2011

Ice events lead to reduced travel speeds, accidents, road closures, power outages, and flight⁵ cancellations. Railroad track switches may also freeze, but this is typically a rare event. Often, an ice event can delay or shut down businesses, such as trucking operations, for several days. The Dallas/Fort Worth/Panhandle area is prone to severe ice events in winter. Since 2011, the following ice events have impacted the region:

- In February 2011, during the Super Bowl in Arlington, 4 inches of sleet and ice accumulated, concurrently with over 100 consecutive hours of temperatures below freezing. At the Dallas/Fort Worth International Airport (DFW), pipes froze, and thick sheets of ice fell from overhangs onto the airport's monorail system (68).
- In February 2015, 600 flights were canceled at DFW (69). Freezing rain and sleet fell, while ice accumulated on roads and highways (70). Iced-over trees fell, resulting in power outages for thousands of people (71).
- In November 2015, about an inch of ice accumulated in the Dallas/Fort Worth/Panhandle area, resulting in 120 car crashes near Amarillo (72). Several tractor-trailers jackknifed on IH 40, resulting in the closure of eastbound IH 40, west of Bushland, for five hours (73).

Trucking Companies

Gulf Winds reported that ice events in the Dallas/Fort Worth area impacted the company's business.⁶ The direct impacts on the company's supply chain typically last two days, but the secondary effects resulting from high volumes of loads that have to be accommodated after the interruption in service can last up to six months. Ice events typically do not result in any damage

⁴ A shoal (also known as a sandbank or sandbar) is a sandy elevation at the bottom of a body of water that can present a danger to navigation.

⁵ Flight cancellations are primarily for commercial airlines, but other air traffic can be affected if weather hinders the functioning of the airport.

⁶ Gulf Winds also reported that every time an ice event occurs in Houston, the company's business (supply chain) is disrupted for a day. The impact is, however, less severe than an ice event in the Dallas/Fort Worth area.

but do result in loss of income. According to the representative, the company did file a lost income claim with the insurance company, but the representative was unsure if a payment was ever received.

Shippers

Walmart reported that several distribution centers needed to be closed for several days in the event of a major ice event. During the last major ice event, the distribution centers in Fort Worth were closed for two and a half days, while nearer to Lubbock some distribution centers were closed for a day. During this time, no shipments are received or deliveries made, which typically results in a subsequent surge in required capacity. Since Walmart operates in a JIT environment, the impacts are noticeable when the company experiences multiple days of not delivering. Walmart also reported that when power outages are experienced, the company usually realigns where its distribution network sources product. In other words, the company changes the origin of the delivery in an attempt to address the impacts quickly.

Lockheed Martin, based in Dallas/Fort Worth, noted that the Dallas/Fort Worth area provides a number of intermodal options. The company therefore has several options for highway deliveries and access to a runway to fly shipments in and out in the event of a major ice event.

Parcel Deliveries

DHL and FedEx reported a minimal impact on their operations and customers imposed by ice events in the Dallas/Fort Worth area. Typically, service restrictions are implemented in the heavier-hit areas in West Texas and the Panhandle that are more remote for DHL, but this tends to be minimal and only last a few days. DHL, however, emphasizes safety and safe operations to its drivers during ice events to avoid unnecessary incidents in the areas impacted. FedEx reported that the impacts associated with ice events tend to be minimal because the company has the flexibility to divert shipments that would normally be shipped by air to truck (and vice versa).

Marine Ports

The Port of Houston did not report any direct impact associated with ice events in the Dallas/Fort Worth area but mentioned that some delays of shipments to the port may result from such events.

Information Needs before and during Extreme Weather Events

In general, the companies/businesses approached were satisfied that they had access to all the information that they needed about pending extreme weather events—at the time of the weather event and in the aftermath of the weather event. Most companies/businesses stated that they require information about:

- The event (updated weather information).
- Any associated road closures.
- The estimated duration of the event.

Shippers

Walmart requires accurate information in advance about the event and the duration of the event. For example, the duration of a recent ice event in Dallas was forecasted to be a day and ended up being two days.

Lockheed Martin requires radar forecasts and information about any highway closures. The company needs this information to assist its 14,000 employees with travel information to get to and from work, rather than for the company's receiving and delivery of shipments. The company noted that it would take a prolonged extreme weather event to negatively impact the company's manufacturing schedule.

Trucking Companies

Gulf Winds uses the road closure map (provided by the Texas Department of Transportation [TxDOT]), media updates (television and radio), National Weather Service updates, and private-vendor weather alerts at the time of the disruptive event and in the aftermath of the disruptive event to prepare the company's response to the pending event.

Gulf Winds also reported that a range of mediums (social media, news radio, and websites) should be used to notify the freight community about pending events, the duration of the event, and any associated road closures. Gulf Winds commented that it would be beneficial to all parties (shippers, receivers, and carriers) if technology could be used to inform en-route truck drivers about a weather event so that drivers could reroute. Specifically, Gulf Winds would like an application that would allow truck drivers to register their cell phone number to receive a text (similar to an AMBER Alert) that certain routes could experience flooding and that all large trucks are encouraged to use a different route when and where possible. This would allow the carrier to reroute the driver and better accommodate shippers and receivers, ultimately avoiding unnecessary delays and added expenses.

Finally, in the aftermath of a disruptive event, it was regarded as important that trucking companies communicate information about shipment status so that the delivery status can be communicated with shippers, receivers, and logistics companies.

Parcel Deliveries

DHL monitors the normal weather station reporting prior to and during an extreme weather event. DHL also has a coordination center in Cincinnati that assists the Texas operations with any major situations that can potentially disrupt service. Coordination occurs both before and after any major issues.

Marine Ports

The communication mediums used by the Port of Brownsville are determined by the damage/disruption to communication services. The Port of Brownsville also stated the need for information about available emergency supplies and aid available from the state.

Hurricane preparedness is of critical importance to the Port of Houston. Information required, however, relates more to the assurance of employee safety. The Port of Houston requires information that can inform evacuation notices and when employees can return to work after the hurricane.

Formal Coordination/Communication Strategy

Most companies/businesses indicated that they have a formal coordination/communication strategy in case of an extreme weather event. Gulf Winds, the Port of Houston, the Port of Brownsville, the Port of Corpus Christi, Walmart, Lockheed Martin, and FedEx have a formal strategy that clearly identifies responsible parties and their responsibilities in case of an extreme weather event. Some companies also have access to an emergency-response-type center to communicate and coordinate the response to an extreme weather event. Most of the companies/entities also consider extreme weather events in their planning, investment decisions, project design/development, or maintenance strategies.

Trucking Companies

Gulf Winds has an emergency weather program in place to inform employees and customers about the expected disruptions imposed by the extreme weather event. Therefore, no long-term changes to its infrastructure/operations were required after the Memorial Day flooding in 2015 or the ice events in the Dallas/Fort Worth area in 2015.

Parcel Deliveries

DHL had developed a master operating plan to deal with hurricanes. The master plan, for example, required the purchase of backup power generators to ensure that the company could continue to be operational in the event of a power outage. Neither the Memorial Day flooding event nor the ice events in the Dallas/Fort Worth area in 2015 resulted in any changes to the master operating plan or required purchases.

DHL also has a coordination center in Cincinnati that assists the Texas operations with any major situations that can potentially disrupt service.

Shippers

Depending on the event, Walmart operates an emergency operation center that is responsible for coordination and communication.

Railroads

UPRR maintains quality relationships with local emergency responders in the 7,300 communities in Texas that the railroad travels through before extreme weather events occur and during emergency situations. UPRR has established a variety of emergency response and resiliency plans—which include strategically staging resources in affected regions prior to flooding, hurricanes, or other major weather events—to mitigate the impacts of extreme weather events.

The railroad has also developed a robust internal emergency management system that allows the company to implement rapid repair and reconstruction plans in an efficient manner, minimizing disruptions to customers. When those repair plans involve outside entities such as regulatory bodies, roadway authorities, or other organizations, UPRR works closely with them to communicate and coordinate efforts as necessary.

BNSF Railway has a hurricane response plan that includes a checklist that the company mobilizes in the event of a hurricane. For example, when resources are limited, some rail lines are a higher priority than others during and after an extreme weather event. BNSF Railway also has a command and control system for severe weather that is responsible for dispatching resources to assist the areas impacted.

Critical Infrastructure

Most of the companies/entities reported that they have identified the critical freight transportation and non-transportation infrastructure in Texas that if failed will have a crippling impact on their business.

Damage to Transportation Infrastructure

Trucking Companies

Gulf Winds reported that any damage to roads in the Houston and Dallas area has a crippling impact on its company/business. Gulf Winds used a risk matrix to assess business vulnerability to the failure of critical freight transportation infrastructure in Texas.

Marine Ports

The Port of Houston and the Port of Brownsville reported that they are very concerned about damage to their own infrastructure. For example, structures that are blown over into the ship channel or damage the channel could have a significant impact on the ports' operations.

Similarly, in terms of landside access, the Port of Houston expressed concern that the failure of the freeway system and rail infrastructure that serve the port could significantly impact port operations.

The Port of Corpus Christi expressed concern that the railroad lines may be impacted by an extreme weather event.

Although the Port of Houston has conducted a vulnerability and risk assessment of critical infrastructure, it determined that most of the vulnerable and at-risk infrastructure that could impact port operations belongs to others.

Damage to Electric Grid

Gulf Winds, the Port of Houston,⁷ Lockheed Martin, and BNSF Railway further reported that damage to the electric grid (i.e., a power failure) would have a crippling impact on their company/business.

Shippers

Lockheed Martin reported that access to safe, reliable, and affordable electricity is key to its manufacturing process.

Railroads

In the case of BNSF Railway, power outages can result in the signal systems shutting down, resulting in trains needing to be stopped and delayed or rerouted to avoid the outage. BNSF Railway has invested in a robust backup energy system, including temporary or mobile backup energy generation. Although BNSF Railway is self-sustaining, the company relies on public entities and utilities to operate.

Damage to Dams

Gulf Winds and BNSF Railway also reported concern about the impacts of extreme weather events (prolonged droughts, flooding, etc.) on the integrity of Texas dams. Gulf Winds, however, expressed concern about how the failure of dams would affect the families of employees rather than the direct impact of a dam failure on the company's ability to transport freight.

⁷ A reliable power supply is so important to the Port of Houston's business that the entity has invested in a backup power supply.

Government Efforts to Mitigate Extreme Weather Impacts on Transportation

Federal Programs

Federal-Aid and Federal Lands Programs

Activities to plan, design, and construct highways to adapt to current and future climate change and extreme weather events are eligible for reimbursement under the Federal-Aid program and for funding under the Federal Lands program (5). Adaptation activities such as stronger bridges and larger storm water infrastructure can be applied to existing and planned facilities to protect and extend the useful life of federal highway investments and conserve funding resources.

Although FHWA has not provided any new funding to address adaptation needs, FHWA has promoted that adaptation should be considered in the context of the overall goals of the Federal-Aid and Federal Lands programs as a cost-effective means to extend and preserve the useful life of Federal-Aid and Federal Lands highway facilities.

USDOT Policy Statement

Creating a more resilient transportation system has been identified as a priority for FHWA and is consistent with a USDOT policy statement in June 2011 on climate change adaptation

(https://www.fhwa.dot.gov/environment/sustainability/resilience/policy_and_guidance/usdot.cfm).

The policy statement notes USDOT's intention to integrate consideration of adaptation into its planning, operations, policies, and programs, and also describes some of the guiding principles. Title 23 identifies eligible activities and guidelines that could support adaptation goals, including planning, preventive maintenance, infrastructure preservation, and construction of highways to address present and future environmental conditions. Examples include the following:

- Preventive maintenance is eligible as a “cost-effective means of extending the useful life of a federal-aid highway” (23 U.S.C. 116[e]).
- Federally funded highway restoration, rehabilitation or resurfacing projects shall be performed to “preserve and extend the service life of highways and enhance highway safety” (23 U.S.C. 109).
- Designs for new or reconstructed facilities on the National Highway System may account for the “constructed and natural environment of the area” (23 U.S.C. 109).
- “It is in the national interest to...promote the safe and efficient management, operation, and development of surface transportation systems” (23 U.S.C. 134) (5).

Transportation Asset Management Plans

The recently expired Moving Ahead for Progress in the 21st Century legislation required DOTs to develop a risk-based process to incorporate climate change and extreme weather consideration into Transportation Asset Management Plans (TAMPs).

The recently passed Fixing America’s Surface Transportation Act (Pub. L. No. 114-94) also included TAMPs to address integration of climate change and extreme weather event resilience approaches into transportation asset management. Therefore, a variety of organizations are applying climate change and extreme weather event information into asset management and plan development.

Climate Resilience Pilot Program

FHWA published the final report on its Climate Resilience Pilot Program in July 2016. This multiyear effort sought to assist state DOTs, metropolitan planning organizations, and federal land management agencies in enhancing resilience of transportation systems to extreme weather and climate change. Nineteen pilot teams partnered with FHWA to assess transportation vulnerability and evaluate options for improving resilience. The report synthesizes lessons learned, identified needs, and recommended next steps for transportation organizations to pursue from the pilot program. Illustrative project findings, outcomes, and examples are distributed throughout the report (74). Two of the pilots were located in Texas—one by the Capital Area Metropolitan Planning Organization and the other by the North Central Texas Council of Governments. Table 3 provides a summary of the pilots and the illustrative project findings and key outcomes.

Table 3. Overview of FHWA 2013–2015 Climate Resilience Pilots in Texas.

FHWA Pilot	Project Description	Illustrative Project Findings and Key Outcomes
Capital Area Metropolitan Planning Organization (CAMPO)	The CAMPO team used a data- and stakeholder-driven approach to assess risks to nine critical assets from flooding, drought, extreme heat, wildfire, and ice. The project team conducted a criticality workshop, developed local climate projections, and performed risk assessments for each asset.	The project team conducted research and interviews to identify sensitivity thresholds for each stressor—that is, the levels of rain or temperature at which the region’s transportation infrastructure experiences disruptions or damage. These thresholds helped identify what climate data to develop and how to apply the climate data in a vulnerability assessment. CAMPO also used a regional climate model rather than a downscaled global climate model.
North Central Texas Council of Governments (NCTCOG)	The NCTCOG team assessed the vulnerability of existing and planned transportation infrastructure in the Dallas/Fort Worth region, where extreme weather events will add an additional stress on the transportation system in the rapidly growing region.	The vulnerability assessment found that 636 miles of roads in the region have the potential to be inundated by a 100-year flood. The pilot project also found that the increase in temperature, compounded by a projected decrease in annual rainfall in the region, may reduce soil moisture, which could cause pavement cracking and stresses on bridges and culverts.

Source: (74)

The pilots used and built on FHWA's Climate Change and Extreme Weather Vulnerability Assessment Framework developed in 2012 (18). The framework was developed as a guide for transportation agencies to assess vulnerability to climate change and extreme weather events. The framework provides an overview of key steps in conducting vulnerability assessments and methods used by transportation organizations to gather and process information. The framework is comprised of three key steps:

1. Define study objectives and scope.
2. Assess vulnerability.
3. Incorporate results into decision making.

Figure 2 provides an overview of the three key steps of the framework.



Source: (18)

Figure 2. Diagram of FHWA's Climate Change and Extreme Weather Vulnerability Assessment Framework.

Programs and Practices of State DOTs

State-Run Programs

State-wide programs exist to plan for and address the impacts of extreme weather on transportation infrastructure. The Michigan Department of Transportation (MDOT), for example, created a statewide risk analysis of extreme weather events where risk is a combination of assessment of:

- **Criticality:** Criticality is based on an existing MDOT method to identify the importance of the asset in the network.

- **Vulnerability:** Vulnerability is defined as the intersection of asset data and climate analysis results. The Michigan assessment includes multiple scenarios to account for uncertainty (e.g., assumptions about medium and high emissions), and evaluated five different climate models.

NCHRP 20-83 Framework for Adaption Strategies

AASHTO established the National Cooperative Highway Research Program (NCHRP) Project 20-83 research series to examine long-range strategic issues and their implications for DOTs. *NCHRP Report 750: Strategic Issues Facing Transportation, Volume 2: Climate Change, Extreme Weather Events, and the Highway System: Practitioner's Guide and Research Report* provides guidance on adaptation strategies to likely impacts of climate change and extreme weather in the planning, design, construction, operation, and maintenance of infrastructure assets (22). The project examined adaptation to climate change on three scales of application—road segment, corridor, and network—including the types of impacts likely to be faced in coming years and the different design, operations, and maintenance strategies that can be considered.

The report lays out the following diagnostic framework for developing adaption strategies (22):

1. Identify key goals and performance measures for the adaptation planning effort.
2. Define policies on assets, asset types, or locations that will receive adaptation consideration.
3. Identify climate change and effects on local environmental conditions.
4. Identify the vulnerabilities of asset(s) to changing environmental conditions.
5. Conduct risk appraisal of asset(s) given vulnerabilities.
6. Identify adaptation options for high-risk assets and assess feasibility, cost-effectiveness, and defensibility of options.
7. Coordinate agency functions for adaptation program implementation (and optionally identify agency/public risk tolerance and set trigger thresholds).
8. Conduct site analysis or modify design standards (using engineering judgment), operating strategies, maintenance strategies, and construction practices.

2015 Conference on 21st Century Mobility for Freight and Passenger Transportation

As an outcome of the 2015 Conference on 21st Century Mobility for Freight and Passenger Transportation, AASHTO published the following top-10 list of ways transportation agencies could better prepare for extreme weather events (75):

1. **Vulnerability assessment:** Based on past extreme weather events, experiences in neighboring states, available data, and expert judgment; identify what components of

your system—including specific facilities or operational activities—may be most vulnerable to extreme weather events.

2. **Operations planning:** Monitor trends in extreme weather events over time, and adjust operations and maintenance plans to accommodate shifting trends as needed.
3. **Traveler information:** Develop effective public and traveler information systems/services to inform travelers of travel options (including social media tools, mobile apps, and real-time condition data collected through vehicle technology).
4. **Coordination:** Coordinate across departments within your agency and with federal, local, and private-sector partners to share information about real-time conditions, closures, plans, initiatives, risks, and resources.
5. **Infrastructure design:** Incorporate extreme weather event trends into design processes. For example, prepare for higher-than-normal weather events by hardening infrastructure, or incorporate flexible or adaptive design concepts into project design.
6. **Emergency management:** Have contingency plans for vehicle and capital preservation, power outages, floods, detours, debris clearance, and routing for overweight or disabled trucks—to include preapproved contractors and funds. Operate effective evacuation routes in high-risk areas.
7. **Siting:** Consider trends in extreme weather events and risk (e.g., floodplains) in project siting.
8. **Project planning and prioritization:** Include resilience to extreme weather events in project evaluation criteria.
9. **Asset management:** Use risk-based asset management systems to track relevant information on extreme weather vulnerabilities to inform decision making over time.
10. **Data collection:** Develop and track performance metrics related to extreme weather (e.g., number/duration of weather-related road closures).

Disaster Relief Acts

Stafford Act

The Robert T. Stafford Disaster Relief and Emergency Assistance Act, 42 U.S.C. 5121–5207 (the Stafford Act) Section 401, states in part that “All requests for a declaration by the President that a major disaster exists shall be made by the Governor of the affected State.” In the United States, all emergency and major disaster declarations are made solely at the discretion of the president of the United States.

Texas Disaster Act of 1975

In Texas, the disaster grants program provides for implementation of the Texas Disaster Act of 1975, as amended, Texas Government Code, Chapter 418. If the governor finds regularly appropriated funds to state and local agencies are insufficient to respond to a natural disaster, the governor may make additional funds available. The Texas Government Code, Section 403.075, also authorizes the governor to fund and solve fiscal problems of state agencies without having to call a special legislative session or to use budget execution authority by the issuance of Emergency and Deficiency Grants. These funds are provided to state agencies with insufficient funds to operate or to meet special needs in cases of emergency or unforeseen circumstances.

Budgeting for Disaster Relief

For presidentially declared disasters, the federal government generally pays 75 percent of disaster costs, and states cover the rest. As a result of this trend, governments at all levels have incurred increased costs for disaster response and recovery related to extreme weather events. In response, the U.S. Office of Management and Budget fiscal year 2014 budget included a discussion of the need for federal spending to take into consideration the fiscal impact of extreme weather events.

Extreme weather events can result in significant costs to transportation agencies, freight organizations as facility users, and local communities. Follow-on corrective measures to transportation assets following extreme weather are usually above planned budget expenditures. DOTs are increasingly challenged with difficult decisions about the criteria and to what extent to incorporate adaptation measures into existing and future facilities to provide more resiliencies in the event of extreme weather or in response to the evolving effects of climate change.

U.S. Government Accountability Office Report

In a 2105 report (76) to Congress, the U.S. Government Accountability Office found that no states are aggressively proactive when budgeting for disasters by maintaining reserves dedicated solely to future disasters outside the current fiscal year. The report also notes that if states are denied federal disaster assistance, they may choose to cover some of these costs out of the state's annual operating budget. Therefore, disaster costs typically compete with other state spending priorities.

TxDOT Maintenance Management Manual

The *TxDOT Maintenance Management Manual* discusses how the agency is refunded for disaster repairs (the paperwork to get FHWA or state reimbursement) if a disaster is declared. Current TxDOT practice is that districts use maintenance funds to pay for extreme weather impacts and get reimbursed if a disaster is declared. Allocating funds to correct extreme weather issues can be problematic when an official federal disaster is not declared. In such cases, TxDOT uses funds designated for unanticipated expenses.

FHWA Executive Order 5520

As noted previously, FHWA allows states to use federal money to be proactive about extreme weather and climate change via FHWA Executive Order 5520

(<http://www.fhwa.dot.gov/legregs/directives/orders/5520.cfm>). The trend at the federal level appears to be programs to assist states with planning for extreme weather events.

Upcoming NCHRP Guidelines

The costs and benefits involved in enhancing the resilience of transportation systems involve many variables and the development of adaptation measures. An NCHRP study is currently underway to develop guidelines to incorporate the costs and benefits of adaptation measures in preparation for extreme weather events and climate change, with results expected in early 2017.

Conclusion

The frequency and economic impact of extreme weather events are increasing in the United States. Extreme weather has a direct impact on existing infrastructure assets because it can cause these assets to deteriorate more quickly. In certain scenarios, the transportation infrastructure can fail. By extension, extreme weather and severe weather events have direct impacts on freight transportation.

An important consequence of companies/businesses adopting JIT production and distribution business models has been the elimination of inventory and the associated requirement for smaller and more frequent deliveries. This has resulted in the removal of any redundancy in supply chains in an effort to reduce costs and increase productivity. A survey of freight-industry-related organizations found that the JIT business model requires redundancy in the transportation system to allow freight to be diverted to other modes or routes in the event of extreme weather. Specifically, DHL and FedEx noted that their operations could continue in the case of the extreme weather events explored because these businesses could capitalize on the flexibility offered by Texas's multimodal transportation system.

A few companies/businesses also indicated concern about the impact of extreme weather events on their business operations in terms of their employees' ability to get to and from work rather than the impact that it would have on the company's receiving and delivery of shipments. Extreme weather events also disrupt business operations because corporate office staff, operations management personnel, auditors, sales personnel, and other staff are delayed or cannot make it into the office.

A variety of industries, including the transportation sector, are investigating the impacts of extreme weather events and are seeking proactive rather than reactive efforts. Given the threats of extreme weather events to business operations, the freight industry has undertaken various strategies (such as advanced logistics software programs) to mitigate the impact of individual extreme weather events that affect ground transportation.

Government and private-sector efforts are underway to better understand the relationship of extreme weather impacts to economic and infrastructure vulnerability. FHWA's Climate Change and Extreme Weather Vulnerability Assessment Framework is a guide for transportation agencies interested in assessing their vulnerability to extreme weather events.

Extreme weather events have had significant impact on infrastructure in Texas. Current practice is reactive to specific events. TxDOT districts use maintenance funds to pay for extreme weather impacts and get reimbursed if the incident is declared a disaster. If a disaster is not declared, then funds are typically drawn from the maintenance budget.

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