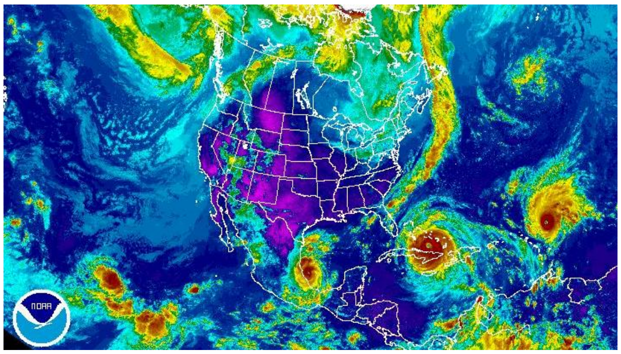
Planning for Rapid Response to Disasters Near Roadway Work Zones



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16. Abstract

When a closure due to road or bridge construction coincides with an adverse event such as a severe storm, earthquake, or forest fire, difficulties in minimizing traffic delays, reducing the risk of traffic crashes, and protecting the health and safety of workers and the public can arise. One way agencies can help reduce these difficulties is to add a disaster resilience planning component to the planning and design phase of their roadway projects.

This document outlines actions that state, county, and local transportation agencies can take during program coordination, project scheduling, design, and construction staging to reduce the potential for fatalities, injuries, and property damage. Key topics include techniques for assessing work zone disaster vulnerabilities, suggestions for mitigating vulnerabilities through the contracting process, and strategies to help reopen work zones quickly.

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Chapter 1. Why Include Disasters in Work Zone Planning?

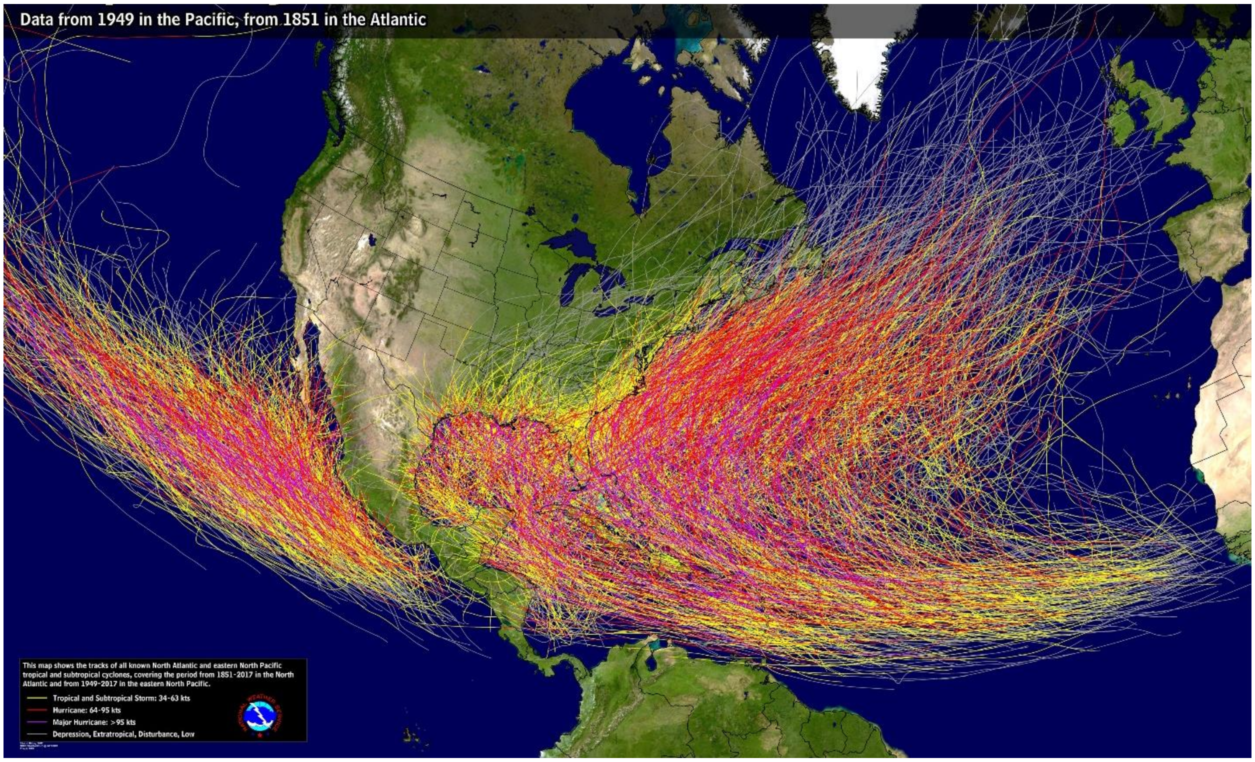
Introduction

Roadway contractors and construction engineers are often tasked with three overlapping objectives: minimizing traffic delays related to construction, reducing the risk of traffic crashes in work zones, and protecting the health and safety of workers and the public. By themselves, construction activities often reduce the amount of traffic a roadway can carry and pose some level of risk to workers and the traveling public. These impacts can be exacerbated when construction coincides with fog, severe weather, or other adverse events. For example, bottlenecks can become severe if a road that is under construction is needed for an evacuation or for use by personnel responding to a hurricane, wildfire, earthquake, or similar incident.

Another guide in this series, *Rapid Response Techniques for Disasters Near Roadway Work Zones*, addresses disasters near work zones from the construction perspective, offering a menu of rapid response techniques for building expedient roads and trails that can allow access for first responders, facilitate evacuation, or allow traffic to be rerouted. The present guide addresses adverse events from the preconstruction perspective, with emphasis on actions that state, county, and local transportation agencies can take during program coordination, project scheduling, design, and construction staging to reduce the potential for fatalities, injuries, property damage, and other undesirable outcomes when road work and adverse events occur at the same time. This guide provides techniques for assessing work zone disaster vulnerabilities, suggestions for mitigating vulnerabilities through the contracting process, and strategies to help reopen work zones quickly, such as pre-positioning rapid response supplies near the work zone to support response and recovery.

Design engineers, roadway designers, and work zone planners have a lot on their plates: developing preliminary and final project plans, shepherding projects through the environmental review process, monitoring the acquisition of right-of-way and rights of entry, developing construction schedules and cost estimates, identifying appropriate specifications and special provisions, preparing transportation management plans (TMPs), and more. It is natural to wonder when it makes sense to add a disaster resilience planning component to this process. Without doubt, there are some projects where it is unlikely for an interaction to occur between construction-related road or bridge closures and an adverse event such as a forest fire, flood, or hurricane. Conversely, there are projects where the combination of an adverse event and roadway closures could have a devastating effect on human lives or on the social and economic wellbeing of communities in the project area.

Galveston, Texas, is an example of a community that is vulnerable to the effects of climate and weather. Located about 50 miles southeast of Houston, Galveston sits on an island on the western side of the Gulf of Mexico. Between 1900 and 2017, Galveston was struck by hurricanes 22 times, and these strikes were usually head-on (Figure 1).



NOAA

Figure 1. Tracks taken by tropical storms (yellow lines), hurricanes (red lines), and major hurricanes (magenta lines) in the Americas, 1851–2017 (Atlantic) and 1949–2017 (Pacific).

The Galveston Hurricane of September 8, 1900 is still remembered as the deadliest weather-related disaster in US history, with the bustling boom town and beach resort sustaining a direct hit with 135 mph winds and a 15 ft storm surge (NOAA 2021). The exact number of casualties is unknown, but reliable estimates suggest 6,000 to 12,000 deaths out of a population of about 40,000. Over 3,600 buildings were destroyed. Transportation played a major role in the severity of the disaster; overland evacuation attempts were hampered by bridge failures, and wreckage clogged the city's harbors. Today, just two bridges connect Galveston to the Texas mainland, so the Texas Department of Transportation (TxDOT) and other transportation agencies are careful to avoid lane closures during hurricane season (Urbina and Wolshon 2003).

In another example illustrating the importance of disaster planning, public agencies in Puerto Rico were insufficiently prepared for Hurricane Maria in 2017, resulting in much reputational damage to those agencies in addition to the human casualties and property damage caused by the storm. Thousands of road washouts and bridge failures cut off access to communities, hampered the restoration of electricity and telecommunications, and made it extraordinarily difficult for residents to obtain food, medicine, and fuel. Management of the disaster was also affected by difficulties with coordination across various levels of government.

Scenario Planning and Risk Assessment

The effects of an adverse event that occurs at the same time as a construction closure are site-specific. Factors influencing the impacts of a combined event include the location and extent of the construction closure(s), the amount of traffic to be diverted to other routes, the capacity and traffic volumes on alternative routes, and the nature and timing of the disaster.

A scenario planning and risk assessment process allows agencies to evaluate risks and prioritize mitigation efforts. The activities involved in this process can be quantitative, qualitative, or semiqualitative (NIST 2013). The process provides agencies with a consistent way of determining which mitigation measures are likely to be relevant for any particular construction project. It can be integrated into the development of the project's TMP alongside plans for other types of work zone disruptions, such as traffic crashes or planned events like festivals, concerts, or sporting events.

Although the effects of a combined event can vary from project to project (or even from one stage/phase of a project to another), it may be possible to develop a package of mitigation measures that can be reused for similar projects. For example, semi-trailers preloaded with Bailey bridge components, bags of sand-gravel mix, and temporary traffic control devices could easily be moved from jobsite to jobsite to provide resilience for an ongoing series of rural bridge replacement projects. Similarly, a van preloaded with materials for setting up temporary roundabouts could be moved from one urban project to another.

Scenario Planning

Almost every region in the United States is subject to at least one weather or environmental hazard. Examples include hurricanes along the Gulf of Mexico and Atlantic coast; tornadoes in the central and southeastern US; floods in the Mississippi Valley, Great Lakes, and Great Plains; extreme heat and dust storms in the Southwest; tsunamis along the Pacific Rim, Hawaii, and Puerto Rico; and wildfires in Alaska, California, and numerous other forested, prairie, and scrubland areas. Less dramatic but more frequent disruptive events include fog and heavy rainstorms. In many parts of the United States, heavy snowfall can occur—sometimes unexpectedly—from the early fall through the late spring. Many areas are also susceptible to localized fires, rockslides, industrial incidents, train derailments, or similar situations. Adverse events deliberately caused by humans include arson, vandalism, terrorism, and acts of war.

Chapter 4 discusses data sources that can help designers and planners identify disaster scenarios relevant to the project site. Factors such as climate, seismic risk, and geography will affect the scenarios relevant to each area. Consider the following examples:

- A typical planning scenario for the US East Coast or Gulf Coast is a community evacuation in anticipation of a hurricane. This risk is seasonal. Key challenges include uncertainty in the locations that will be most heavily impacted by the hurricane and variability in the extent to which residents shelter in place. The scale of potential impacts can be broad, creating challenges for coordination between states and between federal, state, county/parish, and municipal agencies.
- A number of areas in the Midwest and South-Central states are prone to flooding along major river basins. These events usually occur just after the spring snow melt or as a result of summer storms. One of the more challenging aspects of this situation is that it affects long, linear corridors with the potential for flooding at multiple river crossings. Like hurricanes, the impacts often cross jurisdictional boundaries because rivers often *are* the boundaries.
- An increasingly salient planning scenario for the Western states is the rapid evacuation of a community suddenly threatened by a wildfire that has changed direction. Challenges inherent in

this scenario include the speed with which such an event can occur and the high degree of randomness in the potentially affected locations.
- Although every schoolchild has learned to associate earthquakes with Southern California, several other parts of the country have significant seismic risks, including Alaska and Hawaii. Human activities such as mining and hydraulic fracturing can amplify natural risks, as is the case in portions of Oklahoma and Texas.

Risk Management Concepts

To determine whether it is worth developing a disaster mitigation plan for a work zone, it is useful to consider some concepts used in formal risk assessments. In everyday speech, people often use the words "hazard" and "risk" interchangeably, but from a technical perspective these terms are distinct:

- A *hazard* is a potentially dangerous situation (also called a *threat*).
- *Risk* is the likelihood and extent of deaths, injuries, and property damage that could result from a hazard.

In some industries, "risk" is formally defined as the *likelihood* of an incident multiplied by a measure of its *consequences*, such as the number of people injured or the amount of money that will be required to repair damage:

$$\text{Risk} = \text{Likelihood} \times \text{Consequences}$$

For example, consider two buildings (Building A and Building B) that sit side by side near a river that is prone to flash flooding. Both are valued at $1 million (structure and contents combined), and both are in the 100-year flood plain, i.e., the annual probability of flood damage is 1%. In terms of property damage, the annual risk for each individual building is as follows:

$$\frac{1\text{ flood}}{100\text{ years}} \times \$1{,}000{,}000 = \$10{,}000$$

In terms of property damage alone, it is worth spending $10,000 on a floodwall that can protect one of the buildings or $20,000 on a floodwall that can protect both. Nevertheless, there are other risks that require consideration. Suppose Building A is a grain bin filled with corn, while Building B houses a preschool. If a flash food inundates the preschool, there is a risk of human casualties (death or injury), coupled with reputational damage to the organization that operates the school. Conversely, the consequences of a flood at the grain bin are likely to be limited to property damage. From this perspective, the *criticality* of the preschool is greater than the criticality of the grain storage facility.

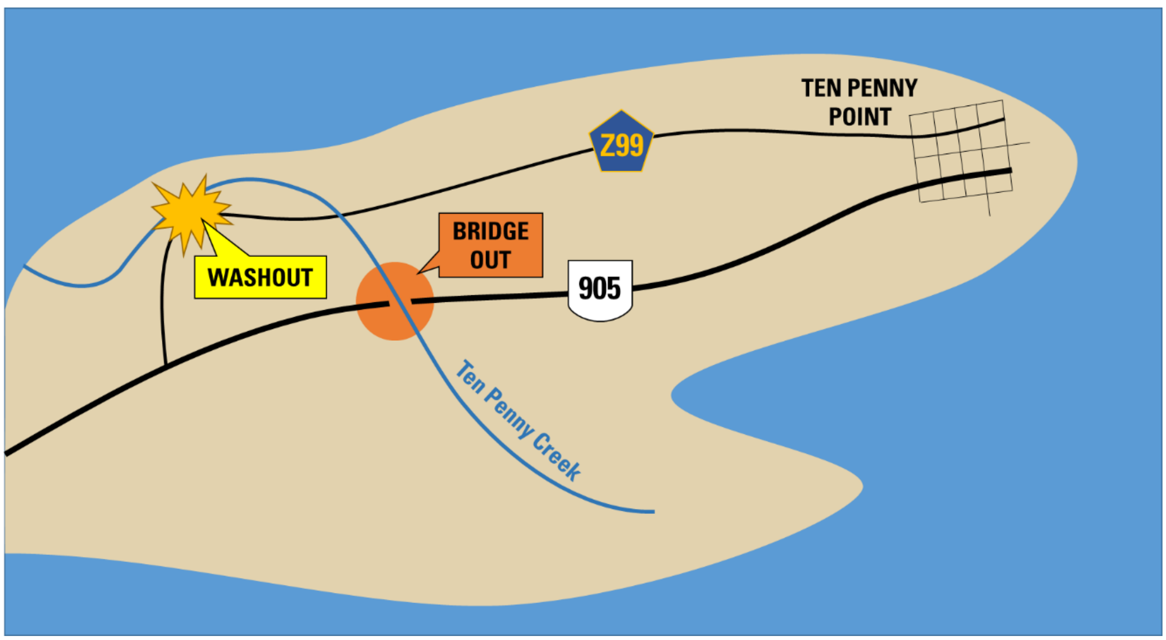
The following are some examples of the potential consequences of a combined event:

- Casualties (death or injury) to the public, workers, or first responders
- The need to evacuate people living or working near the stricken area or the difficulty in completing an evacuation
- Environmental damage
- Direct and indirect financial losses to the agency and its contractors
- Economic losses to households and businesses at a local, statewide, or regional scale
- Reputational damage to the agency

- Media exposure and public anxiety affecting people that may be distant from the event location

In a quantitative risk assessment, an estimated monetary value is assigned to each of these potential losses. After multiplying by the relevant probabilities, the results are summed to estimate the total risk. Returning to the example above, Hazard A is operating a grain bin within a floodplain, and Hazard B is operating a preschool within a floodplain. The annual risk for Hazard A was determined to be $10,000. Even without a formal assessment, it is clear that the annual risk for Hazard B will be considerably higher, and as a result it is rational to spend well over $10,000 to mitigate that risk.

For example, Figure 2 illustrates a fictitious coastal community that is vulnerable to weather-related incidents due to its geography and the layout of the road system. In this case, the village of Ten Penny Point sits at the tip of a peninsula. The State Highway 905 bridge over Ten Penny Creek is being removed and rebuilt, and the traffic management plan relies on County Highway Z99 to provide access to the village. But this plan leaves an important vulnerability: if an adverse event such as a severe storm damages County Highway Z99, the community will be cut off. This guide explores several ways for determining the seriousness of such a vulnerability and making the area more resilient in the event of a problem. Some of the potential solutions will be inexpensive, while others could require major changes in the traffic management plan, contractual requirements, or even the design of the project. Of course, the local conditions at a real site will also affect the designer’s approach.



Source: FHWA

Figure 2. Hypothetical example of a community that is vulnerable to weather-related incidents during road construction.

Why Is It Becoming More Important to Plan for Adverse Events during Project Design?

As discussed in more detail in Chapter 1 of another guide in this series, *Rapid Response Techniques for Disasters Near Roadway Work Zones,* several trends are combining to increase the risk and consequences of adverse events that happen at the same time as roadway construction projects:

- **More projects**. Many transportation agencies are working to resolve a backlog of deteriorated roads. As a result, the exposure (number of sites affected by construction) is increasing.
- **Increasing traffic volumes**. In many areas, traffic volumes have roughly doubled in the past 20 years.
- **Population growth and changes in land use**. As urban areas continue to expand, developed areas cover an increasingly large amount of land. In an emergency, more people need to evacuate, and they will need to travel farther to find accommodations.
- **Higher expectations**. To control costs, many American businesses rely on just-in-time inventory management systems. Similarly, business and personal travelers have come to expect a very reliable transportation system that supports a highly mobile lifestyle.

Severe flooding has been a major factor in many of the recent adverse events in the United States, often resulting in bridge damage, roadway washouts, or rockslides. Flood risks are increasing for two main reasons:

- **More runoff from developed areas**. As more natural terrain is replaced by hard surfaces like roofs and pavements, less stormwater is absorbed by the soil. Hard surfaces also allow stormwater to flow quickly downstream; if the stormwater retention capacity is not sufficient, flash flooding can occur.
- **More precipitation**. Although there is considerable year-to-year fluctuation, Figure 3 shows that much of the US has experienced a long-term increase in precipitation. Gradual increases in ocean and land surface temperatures are causing more water to evaporate into the atmosphere. As a result, the southwestern states are becoming drier while the central and northeastern states are receiving more rain and snow. The slow increase in average daily temperatures also seems to contribute to faster spring snowmelt in the mountains. More intense cycles of wet weather and drought have increased the potential for forest fires and brush fires, such as that depicted in Figure 4.

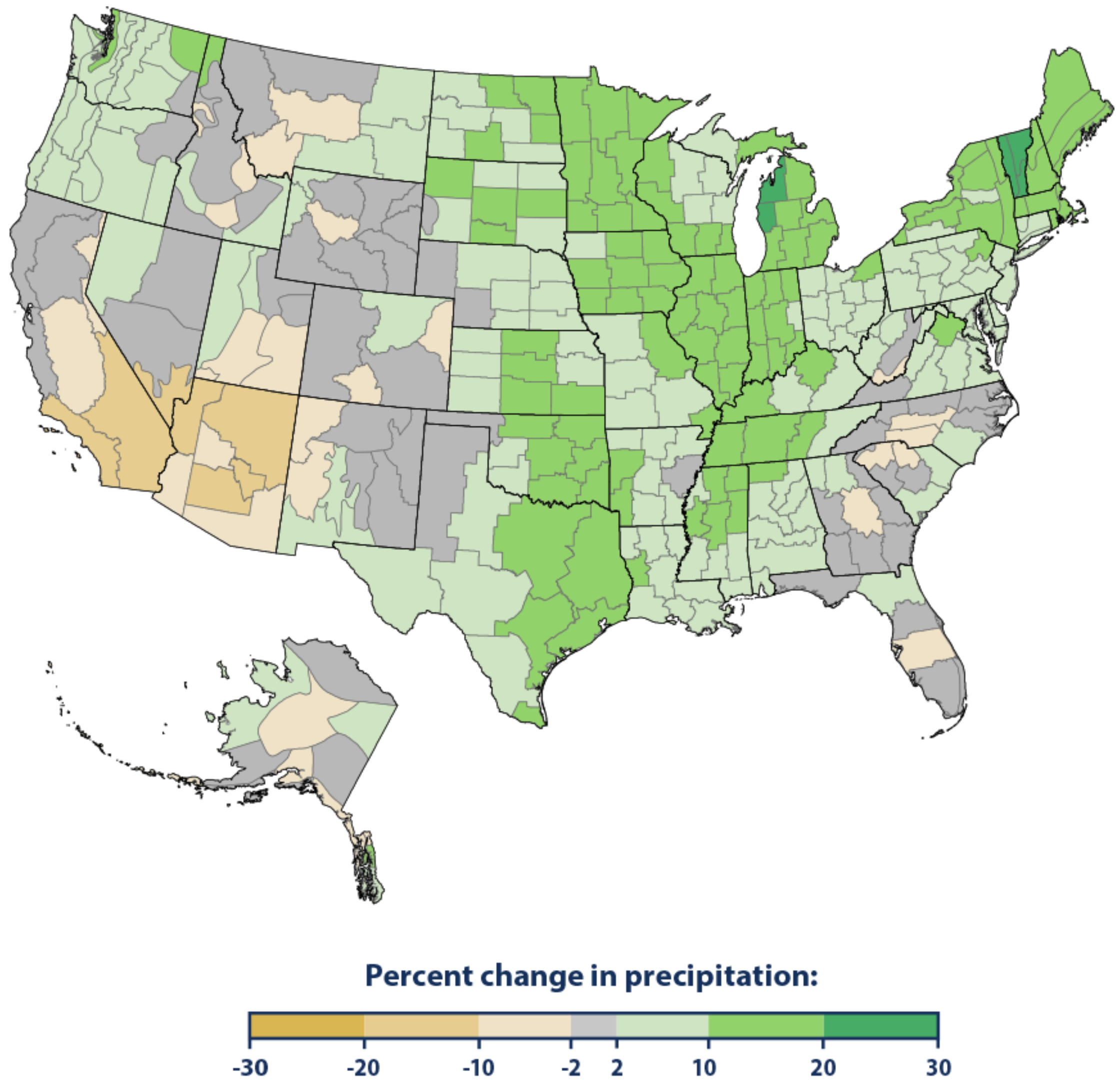


Figure 3. Change in precipitation in the United States, 1901–2020 (with Alaska data starting in 1925).

Figure 4. A car fire sparked a brush fire at a work zone on US 93 near Wikieup, Arizona, in 2012.

The convergence of these trends points toward an increasing need to plan for adverse events during the project design process.

Which Types of Projects Are Vulnerable to Adverse Events?

The need for adverse event plans can arise in a variety of urban, suburban, and rural settings. The location and function of a roadway are important factors in deciding whether an adverse event plan is appropriate. In mountainous areas, for example, there may be only one road that provides access to a community, and any construction project with a major impact on that road's capacity could create a vulnerability. For example, in the event of a forest fire, it could be critical to reopen the roadway quickly so that residents can evacuate and firefighters can reach the affected area. A coastal area prone to hurricanes is another example where an adverse event plan is appropriate: although a coastal community might have multiple access points, a closure affecting even one route may not leave enough capacity for a prompt pre-hurricane evacuation. Additionally, some roads are candidates for an adverse event plan because they provide access to an important facility, such as a hospital.

There are also site-specific risks for designers to consider when deciding whether an adverse event plan should be developed. For example, some sites have geotechnical risks like unstable slopes. Others may face a vulnerability because of nearby land use, such as a facility that processes hazardous materials. Seismic (earthquake) risks should also be considered, not only in California but also in locations where hydraulic fracturing is being used to extract petroleum or natural gas.

Site conditions and the nature of the project will influence how easily an adverse event plan can be developed. For example, options for addressing risks associated with a bridge replacement project might include changing the way the construction is staged (so that two lanes can be maintained at all times), upgrading an alternate route to accommodate heavier traffic, or building a low-water crossing that allows vehicles to ford a stream bed if emergency access is required, as shown in Figure 5. Later sections of this guide discuss additional mitigation techniques.

Figure 5. Low-water crossings and pedestrian bridges can be an inexpensive way to provide secondary access to an area that has the potential to be cut off by an adverse event.

How Do Adverse Events Affect the Jobsite?

Severe weather and other adverse events can affect highway construction in many ways:

- Increasing the risk of injuries to workers, drivers and passengers, and other road users
- Damaging partially completed work
- Degrading productivity or disrupting construction operations

On short notice, highway agencies and contractors often need to respond in the following ways to several interrelated issues that can arise from an adverse event:

- Protecting road users and the highway construction workforce from injury
- Minimizing damage to partially completed work, the construction area, and adjacent roadways
- Preventing or halting environmental damage from erosion and fuel spills
- Reopening the roadway as an evacuation route
- Making the roadway passable for first responders and emergency management services attempting to reach the affected area
- Evacuating affected construction personnel

The complexity of these responses depends on the scope of the construction project and the severity of the incident. Some situations simply require getting workers and equipment out of harm's way. Other situations require more intensive actions, such as placing gravel to create a temporary driving surface, deploying a temporary modular bridge, or building a temporary road to bypass a road closure. There are also situations that require making the best possible use of already completed work, for example, modifying temporary traffic control or reversing the traffic flow direction.

What Is Resilience?

The concept of "resilience" refers to the transportation system's ability to withstand the impacts of adverse events. A resilient system can recover from problems quickly; although operations might not be entirely normal in the immediate aftermath of an event, the basic needs of road users and first responders are accommodated reasonably well.

A resilient construction project should also incorporate the Safe System approach, a set of road safety principles developed by the International Transport Forum (ITF) at the Organization for Economic Co-Operation and Development (OECD). All roadways involve continuous interactions between the roadway infrastructure, vehicles, traffic speeds, and the behavior of road users such as drivers, motorcyclists, bicyclists, and pedestrians. In a Safe System, if a problem arises in one of these elements, the other three elements are sufficient to prevent fatalities and serious injuries from occurring (ITF 2008, ITF 2016). Transportation agencies play a key role in managing these interactions. For example, when the roadway infrastructure is degraded by a combination of construction and bad weather, agencies may need to intervene to ensure that traffic speeds are reduced to a level that protects the safety of workers and the public.

Chapter 2: What Are Some Problems that Happened in the Past?

Many situations involving the combined impacts of construction and adverse events have occurred in the past. Historically, the effects of highway work zones have often been overlooked during hurricane evacuation planning (Urbina and Wolshon 2003). For example, during the evacuation for Hurricane Georges in 1998, the states of Alabama, Mississippi, and Louisiana all had construction zones on evacuation routes, and in Louisiana evacuation traffic on westbound I-10 out of New Orleans was limited to a single lane. Fortunately, the 1998 storm followed a track that gave the Louisiana Department of Transportation and Development (LaDOTD) and the contractor enough time to clear construction equipment and reopen both of the partially constructed lanes to outbound traffic. The lessons learned from this close-call were considered in subsequent evacuation planning efforts.

When Hurricane Katrina struck New Orleans in 2005, residents with motor vehicles were able to evacuate efficiently. Unfortunately, Hurricane Katrina revealed another transportation issue: residents without access to private cars were stranded in the storm-stricken areas. About 30,000 people (including many elderly and disabled residents) took shelter in an understaffed, storm-damaged stadium. The resulting refugee problem proved difficult for city, state, and federal officials to resolve.

An important lesson from these events is that even when a situation only impacts a limited area, it usually affects highway traffic in all travel directions. Quite often, a surge of people attempting to *leave* the affected area coincides with the arrival of response/recovery vehicles and emergency services personnel attempting to *enter* the area. With these unusual traffic demands, construction-related closures that are normally only a nuisance can become choke points. These problems are amplified if other nearby routes are also impacted by the incident.

The integrity of construction equipment at work sites was a serious concern when Hurricane Irma struck Florida in 2017. At the time, about 30 tower-type construction cranes were in use at building construction sites in the southern part of the state. Three of the cranes collapsed: two in downtown Miami and one in Fort Lauderdale (Phillips 2017). Although the storm's progress across the Caribbean was tracked for several days before it made landfall in Florida, press reports suggest that some contractors failed to secure or remove their cranes prior to its arrival. Although there were no injuries, the resulting property damage was substantial.

Sometimes there is a mismatch between perceptions of risk and actual risk. Big Sur is a small California community just off Highway 1, the Pacific Coast Highway. Once known as a haven for surfers, the resort also attracts upscale clientele. In 2017, when press reports indicated that access to Big Sur had been cut off by a bridge failure, many Californians immediately assumed the problem was at the Baker Bridge, a major arch truss that is designated as a national landmark. In fact, the problem occurred at a rather small and unremarkable bridge; a landslide triggered by winter storms undermined the center pier. The failure severed Highway 1 for months and put a severe economic strain on Big Sur and its residents.

An event does not need to generate headline news to have an effect on work zone safety. For example, among the 6,581 police-reported work zone crashes that occurred in Iowa from 2007 through 2016, weather conditions were indicated as a contributing factor in 221 crashes (Iowa DOT 2017).

In some of these situations, it can be difficult to tell how much the presence of a work zone influenced the crash outcomes. For example, in February 2018 a 70-car pileup occurred on I-35 in central Iowa, resulting in one fatality and numerous injuries. Although the primary cause of the incident was a winter storm that suddenly reduced visibility and traction, it occurred in the immediate proximity of a major interchange reconstruction project. It remains unclear whether the work zone contributed to the incident. What is evident is that by crossing the shoulder onto a temporary haul road, some drivers were able to avoid hitting vehicles that had already crashed.

Insufficient preparation for adverse events sometimes has long-term political and economic consequences. For example, when Hurricane Maria struck Puerto Rico in 2017, difficulties with the response resulted in months of criticism of public agencies and elected officials. The island's businesses—especially those involved in manufacturing—were impacted by difficult transportation for inbound materials and outbound finished products. Five months after the storm, an official estimate predicted a permanent population loss of 200,000 by the end of 2018, and this 5% population drop was expected to delay economic recovery (Hernández 2018).

Case Example: Scheduling Major Construction Projects in Galveston, Texas

The deadliest weather-related disaster in American history occurred on September 8, 1900 in Galveston, Texas. Located on an island off the Gulf Coast, Galveston was a bustling boom town and beach resort. The Galveston Hurricane struck the city directly with 135 mph winds and a 15 ft storm surge (NOAA 2021). The exact number of casualties is unknown, but reliable estimates suggest 6,000 to 12,000 deaths out of a population of about 40,000. Over 3,600 buildings were destroyed. Transportation played a major role in the severity of the disaster; overland evacuation attempts were hampered by bridge failures, and wreckage clogged the city's harbors (Figure 6).

Underwood & Underwood / Public Domain

Figure 6. Bridge collapses made it difficult to evacuate Galveston in 1900, contributing to the high number of casualties.

Weather records indicate that the Galveston area has been struck by hurricanes many times: 1766, 1818, 1839, twice in 1842, twice in 1871, 1877, 1900, 1915, 1942, 1943, 1947,1959, 1983, 1989, 2008, and 2017 (Roth 2010, Valle-Levinson et al. 2020). Today, only two roadways connect Galveston to the Texas mainland. A project on either route would severely limit evacuation when the next hurricane occurs and would make it difficult for first responders to reach people who are unable to leave on their own. Therefore, TxDOT and other transportation agencies in the Galveston area are careful to avoid lane closures during the hurricane season (Urbina and Wolshon 2003).

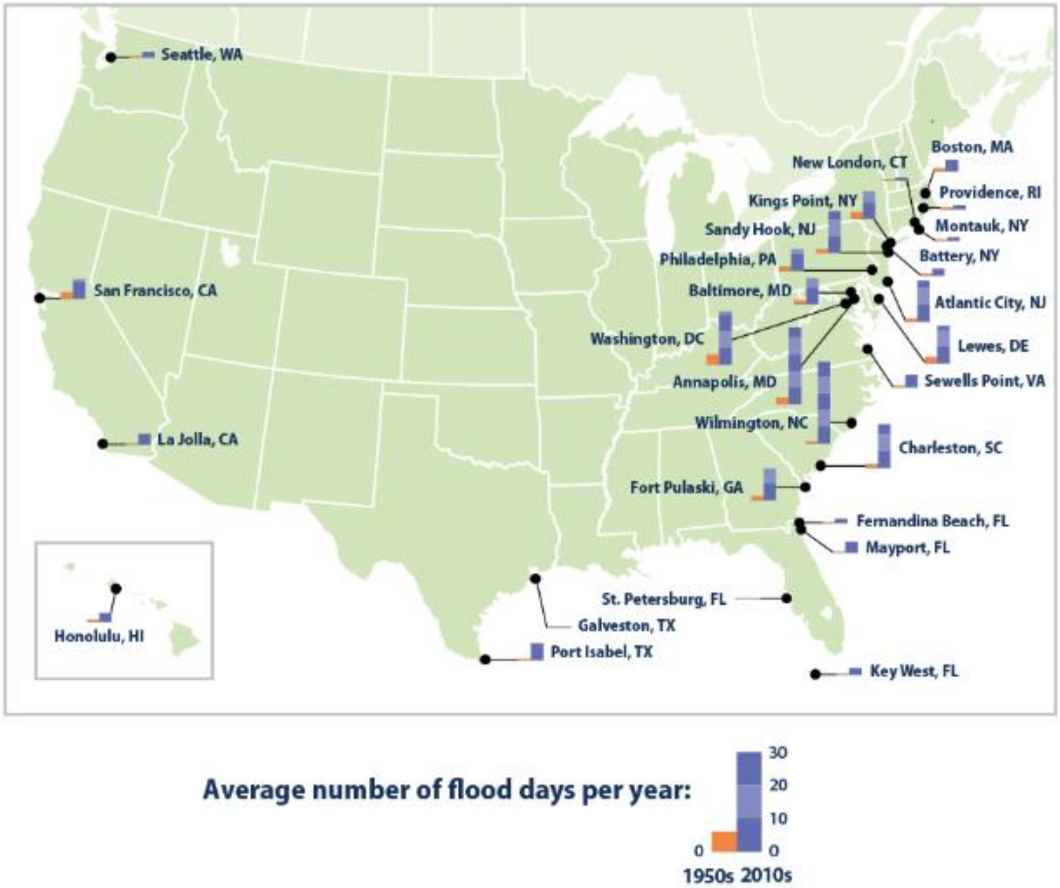
Chapter 3: Is Severe Weather Becoming More Common?

Comprehensive daily weather records have been collected throughout the United States since 1895, and records in some cities go back much further. Severe storms have been reported in newspapers since the 1700s and recorded in ship captains' logbooks since the 1500s. These sources clearly indicate that severe weather is occurring more frequently than in the past.

Notable increases in severe weather have occurred over the past few decades but do not affect all areas of the country equally. The following are a few examples:

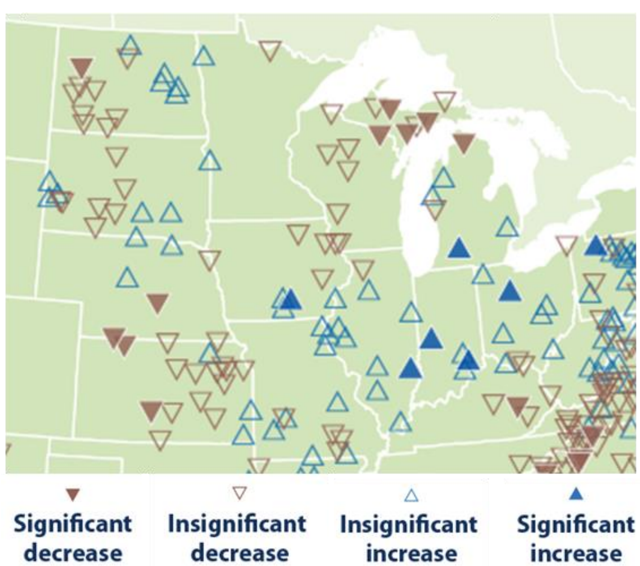
- The National Oceanic and Atmospheric Administration (NOAA) examined the frequency of flooding at 27 coastal weather stations and found that since the 1950s the number of flood days per year has increased at nearly all sites, with especially large increases in the mid-Atlantic region from Georgia to New Jersey (Figure 7) (EPA 2021a, Sweet et al. 2014).
- Researchers who examined more than 50 years of records from almost 800 stream gauge stations on rivers in the central United States found long-term increases in the frequency and severity of flooding along most of the waterways (Figure 8) (EPA 2021b, Mallakpour and Villarini 2015).
- The frequency of extreme snowstorms in the eastern two-thirds of the contiguous United States has increased over the past century (NOAA 2016). Approximately twice as many extreme snowstorms in the US occurred in the second half of the 20th century compared to the first half.
- Analysis of satellite images collected since the 1960s indicates that the spring snow melt in the Northern Hemisphere is occurring earlier in the year (Lindsey and Dahlman 2020). This has allowed some transportation agencies to extend their construction season, which in turn increases the potential for late-spring snowstorms that coincide with roadwork.
- From 1984 to 2015, the extent of area burned by wildfires increased in Georgia and nearly all western states, including Alaska and Hawaii (EPA 2021c). Especially large increases were recorded in Idaho and Oregon. Due to a combination of natural events, changes in forest management procedures, and other human interventions, forests in the western US are becoming drier, and the acreage affected by forest fires more than doubled from 1984 to 2015 (Abatzoglou and Williams 2016).

With these and other examples in mind, agencies and contractors need to prepare for the "new normal." Good preparation is essential to ensure that the public remains safe and secure when construction and adverse events coincide.



EPA 2021a

Figure 7. Average number of flood days per year for 27 coastal weather stations, 1950s versus 2010s.



EPA 2021b

Figure 8. Changes in the magnitude and frequency of flooding on waterways in the central US, 1965–2015.

Chapter 4. How Can We Improve Resilience?

Spurred by the 2007 Federal Work Zone Safety and Mobility Rule, transportation agencies in the United States have become increasingly accustomed to evaluating work zone traffic impacts using low-cost analysis tools such as CA4PRS, Freeval, Q-Dat, Quadro, and QuickZone or using various commercial traffic modeling/simulation software packages. The resulting information helps agencies establish the phasing and sequencing of construction projects, determine the timing of lane closures, and select appropriate traffic mitigation strategies such as improvements to alternative routes.

The process for determining the combined effects of construction and adverse events is similar to the general work zone analysis process but requires taking a broader look at the project, the hazards that are common in its area, the likely impacts of those hazards, and ways to make the network more resilient to combined disruptions. This process is called risk analysis.

In recent years, a number of resources have been developed to help agencies and businesses plan for adverse events. A basic framework is provided on the Climate.gov website. It recommends the following steps:

1. Explore hazards
2. Assess vulnerability and risks
3. Investigate options
4. Prioritize and plan
5. Take action

Each of these steps is discussed in more detail below.

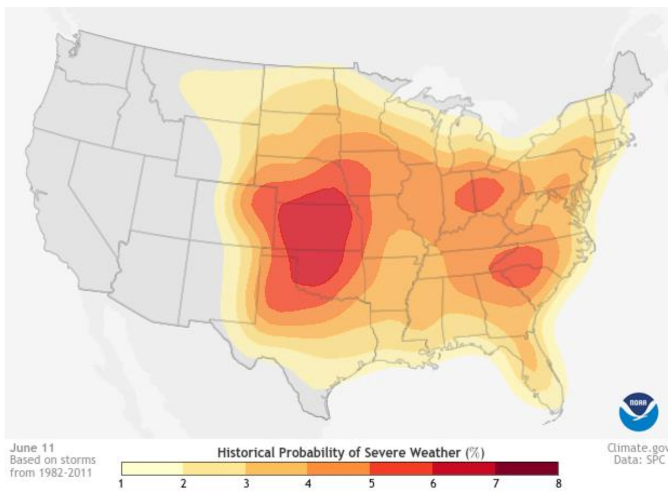
Exploring Hazards with Objective Data

Although most people have general knowledge of the hazards prevalent in their area, quantitative data can help agencies and contractors avoid misperceptions and achieve consistent results. For example, the risk of tornados is well known in the Midwest, but personnel may not be certain how this risk varies during the construction season. Historical weather records show that tornado risk varies by location. For example, in Iowa the peak months for tornado activity are April, May, and June, while in neighboring Minnesota they are June, July, and August (Livingston 2016).

Several sources offer objective data on weather and related hazards:

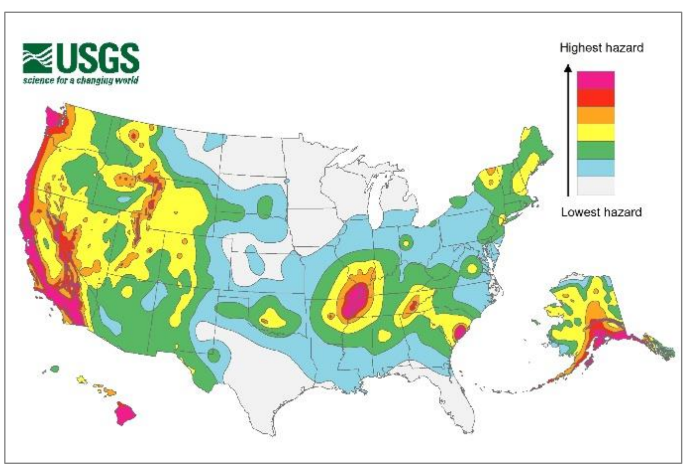
- Climate.gov provides localized projections of future climate trends such as maximum daily temperature and the probability of precipitation. The website also provides predictions of the probability of severe storms (tornadoes, thunderstorms with high winds, or large hail) for the lower 48 states for each day of the year (Figure 9).
- Detailed climatological records are available from the National Weather Service (NWS) website, both at the aggregated level (for example, an entire state) and the local level (individual weather monitoring stations).

- In many states, university extension offices provide climatological summaries as part of their work to support agriculture. These sources often provide information about the microclimates within a state, which can help support project-level decision making.
- The National Interagency Fire Center and the Monitoring Trends in Burn Severity (MTBS) Program provide information about the extent and severity of wildfires.
- The National Centers for Environmental Information provides online climate data summaries for extreme events such as tornadoes, hurricanes, drought, and wildfires.
- The United States Geological Survey (USGS) provides information about how earthquake hazards vary by location (Figure 10). In addition to long-term forecasts based on natural seismic activity, USGS prepares annual near-term forecasts that consider seismic hazards associated with human activities. For example, in 2017 USGS forecasted a 12% chance of damaging ground shaking in central Oklahoma due to the combined effects of natural tectonic activity and intensive petroleum extraction (USGS 2017). For that year, the probability of a seismic event was about equal in Oklahoma City and Los Angeles.



NOAA

Figure 9. Probability of severe storms for the contiguous United States on June 11 of each year.



United States Geological Survey

Figure 10. Simplified national seismic hazard map (2014).

Assessing Vulnerability and Risks

A vulnerability and risk assessment seeks to answer three main questions:

- What kinds of adverse events could occur?
- How likely is an adverse event?
- What are the likely consequences of an adverse event?

Risk assessments can be carried out at the program level or the project level and can be qualitative or quantitative. The choice of approach should reflect agency and contractor needs, the scope of the proposed work, and the extent of the anticipated hazards.

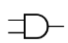
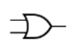
In addition to information about natural and manmade hazards, a project-level assessment will require site-specific information such as the following:

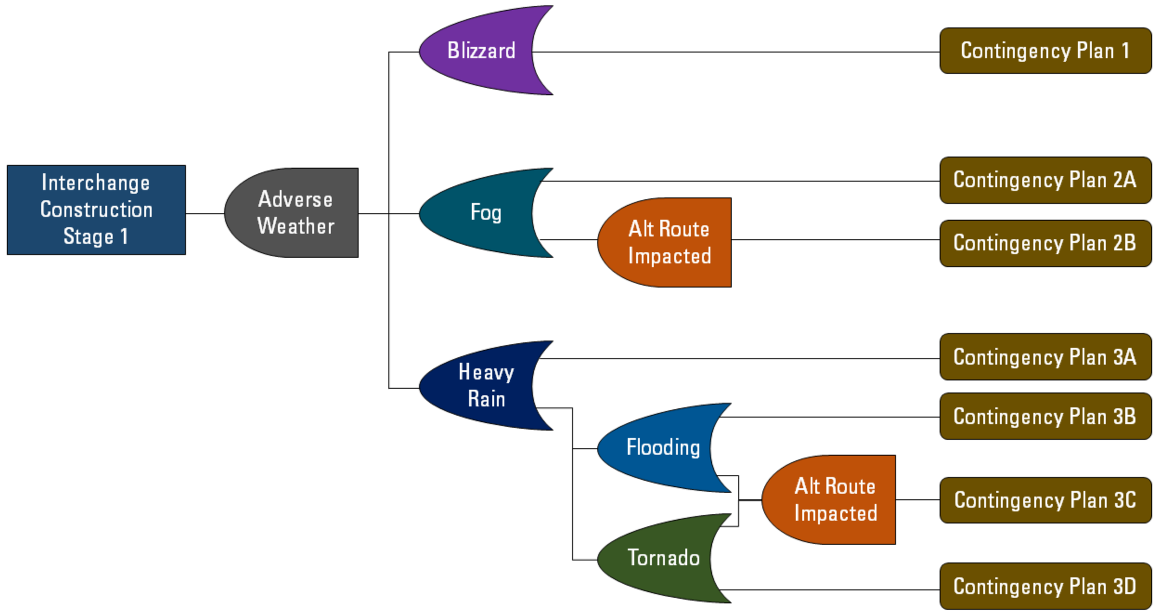
- The location of the work zone
- Any nearby projects that are expected to be under construction at the same time
- The anticipated types, durations, and timings of lane closures
- The characteristics and traffic-handling capacity of the work zone and alternative routes

Program-level risk assessments are usually performed on an areawide basis. Typically, this requires combining information about natural and manmade hazards with data about all projects that will be under construction concurrently during a specific time period. The analysis is usually repeated for each relevant time period. For example, an agency on the Atlantic coast might wish to perform separate analyses for the early and late parts of the June–November hurricane season, along with the spring and winter.

Fault Tree Development

Typically, the first step in a risk assessment is to develop a fault tree. This diagram outlines potential hazards and allows related situations to be grouped for analysis and contingency planning.

The engineering logic symbols for AND  and OR  are typically used to indicate which situations occur by themselves and which are likely to occur in combination. For example, Figure 11 illustrates several weather-related hazards that could affect year-round reconstruction of a major freeway interchange in a Midwestern city.



Source: FHWA

Figure 11. Fault tree for weather-related hazards affecting year-round construction of a major freeway interchange in the Midwestern United States.

Qualitative Risk Assessment

A risk matrix is a qualitative method for comparing the risks associated with various scenarios. An example risk matrix is shown in Table 1. Typically, the vertical axis of the matrix indicates the likelihood of an event occurring, while the horizontal axis identifies the severity of the expected consequences. Various situations are then listed inside the matrix according to their combined probability and severity. If the criteria are listed in the order described above, higher-risk combinations will fall toward the upper right corner. Higher-risk combinations are usually higher priorities for further analysis and risk mitigation planning.

Table 1. Example risk matrix for year-round construction of a major freeway interchange in the Midwestern United States.

Likelihood	Minor Consequences	Moderate Consequences	Serious Consequences	Severe Consequences	Extreme Consequences
Certain	Heavy Rain (Risk Level 3)	— (Risk Level 4)	— (Risk Level 5)	— (Risk Level 6)	— (Risk Level 6)
Likely	— (Risk Level 3)	Light Fog (Risk Level 4)	Blizzard (Risk Level 5)	— (Risk Level 5)	— (Risk Level 6)
Possible	— (Risk Level 2)	— (Risk Level 3)	Flooding (Risk Level 4)	Heavy Fog (Risk Level 5)	— (Risk Level 5)
Unlikely	— (Risk Level 1)	— (Risk Level 2)	— (Risk Level 3)	Flood + Alt Route Blockage; Tornado (Risk Level 4)	Heavy Fog + Alt Route Blockage (Risk Level 5)
Rare	— (Risk Level 1)	— (Risk Level 1)	— (Risk Level 2)	— (Risk Level 3)	Heavy Fog + Chain Reaction Crash; Tornado + Alt Route Blockage (Risk Level 4)

Risk matrices are sometimes developed through group discussions. This process has advantages and disadvantages. If used correctly, risk matrices developed in this way can help decision makers focus on the highest priority risks and identify scenarios that require further analysis. Reliable information from subject matter experts should be incorporated into the discussion to minimize speculation, and discussion leaders need to be frank about the limits of their knowledge (Brown 2014). Group discussions need to be approached cautiously if there is a history of mistrust resulting from problems with previous incidents. Since disagreements can arise regarding the interpretation of qualitative terms such as "likely," "rare," "minor," or "severe," it is important to ensure that the discussion ends with a clear understanding of the situations requiring follow-up and how the analysis will be incorporated into contingency plans.

Quantitative Risk Assessment

Probabilistic risk assessment (PRA) is the most rigorous type of risk analysis. In this method, each hazard scenario is evaluated mathematically based on its probability and the severity of its adverse consequences. Results are scored using quantitative performance measures such as the number of hours of traffic delays and the expected numbers of injuries or fatalities. PRA is particularly useful for large projects with complex risk profiles, such as projects where the risk level changes as construction proceeds.

Traffic-related risks are often an important component of PRA. Areawide traffic models can be useful in gauging the traffic impacts that would result from a storm, evacuation, or similar incident. Modeling is particularly useful if a project involves several different closure configurations or an incident is expected to affect two or more routes at the same time.

The use of a microscopic, mesoscopic, or macroscopic network-based model allows the analyst to quantify the amount of traffic affected by the incident and its effects on other streets and highways:

- In macroscopic and mesoscopic models, weather impacts such as severe rain or heavy snow can be modeled by reducing the capacity and maximum speed of the affected links.
- In microscopic models, these effects can be simulated by adjusting speeds and headways for the affected links.
- In macroscopic and mesoscopic models, emergency services vehicles seeking access to a stricken area can be included in the model as special generators. In microsimulation, they can be modeled as special vehicle types that get priority over other traffic.

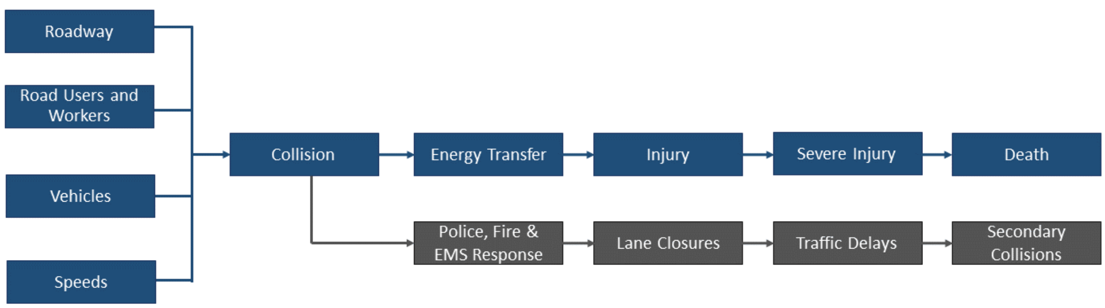
If an areawide model is not available, traffic analysis for the probabilistic risk assessment could be conducted using a sketch planning tool. For example, Quadro is a freeware work zone analysis package from Highways England. It allows analysts to quantify the road user delays and traffic safety impacts of a roadway closure for a project that includes a main route (where the construction is occurring) and an alternate route. Weather impacts can be modeled in Quadro by adjusting the capacities and speed limits on the affected routes or by using the Incident feature. Other sketch planning tools, such as QuickZone (developed for the Federal Highway Administration and distributed by McTrans), can also be applied for this purpose, though the results are very sensitive to the analyst's assumptions about the amount of traffic diverted from the construction zone to alternate routes. (Network models and Quadro make this calculation internally.)

After results are obtained from suitable traffic analysis tools, they can be combined with estimates of the probability of each event to create a weighted estimate of likely impacts.

The risk of worker casualties (death or injury) resulting from an adverse event can also be included in a probabilistic risk assessment. For example, a construction staging option for a project in an earthquake-prone area might expose workers to the risk of falling debris in the event of a quake. An alternate staging option for the project might better protect workers but introduce a higher risk of traffic crashes. By including both the earthquake and traffic risks in the PRA, the trade-offs between the risk to workers and the risk to the public can be compared objectively.

Causal Chains

A causal chain is a tool for understanding a sequence of events that results in death, injury, or property damage. An example causal chain for a fatal work zone collision is shown in Figure 12. Mapping out the sequence helps agencies identify opportunities to prevent casualties and limit risk. The idea is to break the chain upstream before a problem escalates into a serious incident. Alternatively, the consequences of an adverse event can be reduced by starting at end of the chain and working backwards to identify opportunities to reduce its severity.



Source: FHWA

Figure 12. Causal chain for a fatal work zone collision.

Investigating Response Options

Once the adverse events that are likely to affect a project (or program) are reasonably well understood, options for minimizing and mitigating risks can be explored. This part of the risk management process provides many opportunities for innovation and ingenuity.

Broadly speaking, interventions can be grouped into three time periods: pre-event, event, and post-event. Interventions during these time periods have the following general aims:

- Pre-event interventions are intended to prevent a hazardous situation from occurring.
- Interventions during the event are intended to minimize casualties and damage.
- Post-event interventions are intended to locate, evacuate, and treat victims quickly; prevent secondary incidents; and identify ways to reduce the impact of future events.

The following are some examples of the preconstruction actions that an agency can take to increase the resilience of highway construction projects:

- Make sure that emergency response equipment, construction materials, and construction equipment are available on both sides of a significant highway closure so that response and recovery can occur quickly if one side gets cut off from the other. For example, referring back to the scenario of Ten Penny Point in Figure 2, it will be much easier to restore access to Ten Penny

Point if suitable materials and equipment are available on the peninsula and crews do not have to wait for help to arrive from the mainland.

- Sequence individual projects and the annual construction program as a whole to ensure that suitable detour, evacuation, and incident access routes will be available at all times.
- Establish a plan for reopening travel lanes if they are needed for emergency evacuation or to minimize the risk of traffic backups (queues) when fog, heavy snow, or other adverse conditions occur.
- Specify warning signage to reduce the risk of back-of-queue crashes during low-visibility conditions such as fog, dust storms, and heavy smoke from wildfires.
- Specify flashing beacons and other lighting that will maximize the visibility of construction equipment and workers during fog.

Efficient construction staging can contribute considerably to reducing the risks associated with adverse events. By reducing the amount of roadway that is under construction at any one time, temporary restoration of the affected facilities can be completed more quickly when an adverse event occurs. Agency specifications and contractor procedures may need to be adjusted to accommodate these practices. The following are examples of such adjustments:

- Instead of treating pavement removal, repaving, and striping as separate work operations to be carried out on different days, these steps could be transformed into a continuous train that leaves only a short section of the roadway unserviceable at any given time.
- Instead of removing large roadway sections for underground utility repairs, a core-and-vacuum excavation system could be utilized, as shown in Figure 13. This technique has been shown to expedite construction, minimize the amount of material that needs to be hauled to and from the site, and reduce pavement damage (DfT 2014). The process begins by using a core drill to remove a large, circular piece of pavement. A truck-mounted vacuum and an air pick are then used to excavate the soil, exposing the defective pipes or cables. After the pipes or cables are repaired, the original soil is replaced and compacted. Finally, the pavement circle is reinstalled in its original position using quick-setting grout.

Department for Transport, © Crown 2014

Figure 13. The core-and-vacuum technique reduces the traffic impact of underground utility repairs and makes it easier to reopen the road to traffic in an emergency.

Another set of strategies focuses on rapidly putting a road back into service if it is needed for an evacuation or if first responders need to access an incident site. Some examples of these rapid restoration techniques include the following:

- Construct temporary gravel surfaces that can be used to evacuate the public from a disaster area or to allow first responders to reach the site
- Install steel plates to cover trenches or similar excavations
- Place precast concrete segments over large excavations or rough surfaces
- Utilize military-style temporary bridges such as that shown in Figure 14 to provide temporary access across waterways, ravines, and similar features
- Construct a temporary bypass around the construction area, perhaps using gravel or similar materials
- Upgrade detours or alternate routes, for example, by building temporary turn lanes using materials that can be installed rapidly

Pfc. William Dickinson / Defense Visual Information Distribution Service

Figure 14. In 2017, members of the Puerto Rico National Guard installed a modular temporary bridge to restore access to the Guajataca Lake area impacted by Hurricane Maria.

To implement these strategies, agencies may find it necessary to maintain an inventory of suitable components, such as temporary bridge panels. Other items, such as street plates, can potentially be supplied by the contractor. To ensure that these devices and materials can be installed rapidly, appropriate pay items could be included in the contract as contingency items.

Some techniques for increasing resilience require adjustments to agency procedures. For example, it might be difficult to evacuate a hurricane-prone area if traffic that ordinarily uses a critical bridge is being detoured to a congested route. This risk might be reduced by keeping the old bridge in service while a replacement bridge is built on a new alignment or by constructing a temporary bridge. Although such measures could affect the cost and timing of the project, they might also offer opportunities to improve an area's long-term resilience. For example, reconstructing a bridge on new alignment potentially allows its hydraulic capacity to be increased, diminishing the risk of structural failure in the event of flooding or a hurricane storm surge.

Case Example: Flooding in Workington, England

Transportation agencies often show remarkable ingenuity when faced with adverse circumstances. In 2009, flooding damaged or destroyed all roadway bridges across the River Derwent, which runs through Workington, England, a city of 25,000 people. The resulting closings necessitated an 18-mile detour for residents to get from one side of the city to the other. Residents—especially those living on the north side of the river—faced many personal hardships, including loss of employment income, lack of access to health care services, difficulty visiting family and friends, and stress caused by extra travel time and heavy traffic on the detour (Guiver 2011).

Public agencies and local businesses implemented several creative strategies in response to the incident:

- Passenger rail service connecting the two sides of the city was temporarily implemented using an undamaged track located at a higher elevation.
- Portable pedestrian bridges were installed to allow residents to cross the river on foot.
- Telephone lines were relocated to the undamaged railroad bridge.
- A temporary supermarket and temporary medical offices were set up to provide northside residents with access to essential goods and services.
- The police department and library redeployed staff to allow employees to work on the side of the river where they lived.
- A temporary highway bridge with limited traffic capacity was completed about six months after the flood. This required modifying the city's road layout to prevent bottlenecks on the new bridge.

Although agencies and businesses in the Workington area made considerable efforts to implement these responses quickly, more pre-storm planning would probably have facilitated their responses. This is an important consideration, because full recovery from an adverse event can take years.

Prioritizing and Planning a Response

With a clear understanding of the risks posed by adverse events and possible interventions, agencies are positioned to make informed decisions about potential response actions and to prepare contingency plans. Typically, each contingency plan includes a short description of the situations it is meant to address, a discussion of who can authorize implementation of the plan, and an outline of the actions field engineering staff and contractor personnel are expected to take when the plan is put into effect. The level of detail should be sufficient to describe the basic tactics clearly while giving on-scene personnel discretion and flexibility to adjust to actual conditions as they unfold.

The format of the contingency plan should match the complexity of the scenario. In many cases, the recommended actions are a series of sequential steps, and it is sufficient to provide a numbered list of these steps (or a checklist). If the situation involves making complex decisions that result in different actions, a flowchart is often the most concise way to explain the plan. If there are only a few steps, a flowchart is unlikely to add value and might confuse non-engineers.

To facilitate the contingency planning process, an agency could develop generalized contingency plan templates. Appropriate templates can then be selected and modified based on the characteristics of specific projects, programs, or high-hazard conditions. For example, a general template might be developed for handling a tornado at a rural bridge replacement site. Conversely, highly customized contingency plans are likely to be necessary for major urban projects.

During an actual emergency, it is unlikely that personnel will have time to read a detailed plan. Therefore, it is good practice to highlight a few key words and phrases so that personnel can quickly verify that they have completed the most important actions. Alternatively, a quick reference card could be developed to serve as a reminder of the key steps in a complex plan.

Typically, contingency plans should distinguish between situations where work operations must be halted abruptly and those where the contractor has enough time to protect equipment, minimize damage to partially completed work, and safely relocate affected personnel. For example, the arrival of a tornado would typically require an immediate work shutdown, with field personnel taking shelter urgently. Conversely, the arrival of a hurricane can usually be predicted several days in advance, allowing quite a bit of time to "button up" the work, stow materials and equipment securely, and allow construction personnel to travel away from the storm path.

Another important consideration when developing contingency plans is to distinguish between situations that require a "hard" shutdown of work operations and those where a "soft" shutdown is acceptable. In a hard shutdown, all agency and contractor personnel and equipment would typically be expected to vacate the roadway as completely as possible; the entire roadway is cleared so that it can be used by first responders, evacuees, or the public. This can be contrasted with a soft shutdown, where personnel and equipment move away from travel lanes or other areas that are needed for emergency response, but are allowed to remain close to the work site so that construction operations can resume promptly when the situation is resolved.

Taking Action

Contractors and agency personnel should be briefed on adverse event contingency plans as part of the project kick-off process, and plans should be reviewed in advance if an adverse event is forecasted. During project kick-off, specific personnel should be designated to monitor weather forecasts and similar information. For example, storm and fire risks can be monitored using the free online eight-day advance forecasts offered by the National Weather Service Storm Prediction Center. This information will be of greatest benefit to the agency and contractor if someone reviews it at least once a day, or more often if a storm is imminent.

Tabletop and/or field exercises can help ensure that personnel have a clear understanding of the contingency plans. These exercises are often conducted during the early days of a project or prior to the start of a time with heightened risk (e.g., before the hurricane season begins). They provide a valuable opportunity for transportation agency and contractor personnel to develop working relationships, understand their roles and responsibilities, and gain confidence in working with first responders such as police and fire services. These exercises are also valuable for spotting and correcting flaws in contingency plans.

If an adverse event occurs, a post-event evaluation (sometimes called an after-action review) can be helpful in determining which aspects of the situation were handled well and which can be improved in the future. These reviews should be conducted carefully to ensure that they are not perceived as blame-finding events; the point of a review is always to determine ways to improve contingency plans and make future responses more efficient and effective. In this way, a continuous improvement loop can be established.

Chapter 5. Are There Common Situations that Require Special Attention?

Although events such as hurricanes, tornadoes, and earthquakes create obvious risks for workers and the travelling public, some less severe but more frequently occurring situations can also have significant safety impacts. As discussed in more detail in this chapter, these situations include various conditions that hamper visibility (fog, smog, dust storms, etc.). In addition, resilience can be improved in many parts of the United States through preparation for freezing rain, heavy snow, or ice if the project schedule calls for construction during times when such conditions are possible.

Fog, Smoke, and Dust Storms

Atmospheric conditions such as fog, smog (fog mixed with air pollution), dust storms, and heavy smoke from wildfires can result in traffic crashes. In these low-visibility conditions, crash severity tends to increase. Multiple-vehicle chain-reaction pileups can occur, sometimes resulting in a level of casualties that is very difficult for first responders to manage. The risk of these crashes increases when a roadway is also affected by construction-related lane closures, traffic backups, lateral lane shifts, or abrupt speed changes.

Fog and smoke have been found to be a factor in about 10 fatal work zone crashes per year in the United States, as well as numerous incidents of lesser severity (Hamilton et al. 2014). Because of differences in weather conditions and the extent of the roadway system that is affected by construction, the number crashes can vary considerably from year to year. For example, Oklahoma's annual crash reports indicate that from 2001 to 2015 the average number of work zone crashes that occurred during conditions of fog, smog, or smoke was 9.8, but this ranged from a low of 2 in 2005 to a high of 20 in 2001 (Oklahoma Highway Safety Office 2003–2016).

Crashes that result from combinations of low visibility and road work are often severe. For example, in March 2017 a police sergeant responding to a call in rural Nebraska struck a construction crane while driving through a two-lane rural highway work zone in heavy fog (Nelson 2017). In September 2014, a five-vehicle crash in a work zone on I-5 near Rogue River, Oregon, resulted in one death and two injuries.

Among non-work zone incidents related to low visibility, notable examples include a June 2017 dust storm on I-10 near the Arizona–New Mexico state line that resulted in a 25-vehicle pileup with 6 fatalities (Associated Press 2017); a September 1999 fog-related crash on a freeway in southwestern Ontario, Canada, that resulted in an 87-vehicle pileup with 8 fatalities and 45 injuries (Pearson 2014); and a December 1990 fog-related crash on I-75 in Tennessee that resulted in a 50-vehicle pileup with 15 fatalities and more than 50 injuries (Associated Press 1990).

What Causes Fog?

Fog occurs when the air is moist and the temperature is near the dew point. Under these conditions, clouds of water droplets or suspended ice crystals can form near the ground surface. Meteorologists refer to this condition as "fog" if it results in visibility of less than 1 kilometer (0.6 miles) or "mist" if the visibility is more than 1 kilometer (AMS 2012). The informal term "superfog" is sometimes used when visibility is less than 10 ft.

Airborne particles such as dust and salt act as "seeds" that hasten the condensation of water vapor into fog droplets. Thus, it is possible that dust or smoke generated by construction could accelerate fog formation near a work site.

Although fog and mist are often associated with mountains, lakes, and coastal areas, they can occur almost anywhere in the United States. The formation of fog can be very rapid when the conditions are favorable. Its location and intensity are often highly localized due to the combined effects of elevation, wind, and proximity to open water.

Identifying Fog-Related Risks

Station-level weather records from the National Weather Service provide objective historical information about visibility conditions. These stations are generally located at airports, government buildings, and educational institutions. When local data are not available, it can be helpful to consult someone who is very familiar with the site in question. If the potential for fog at a site is unknown, optical sensors can be deployed to determine the frequency and severity of fog.

Managing Fog-Related Risks

Remote sensors can be used to determine when fog is starting to form so that appropriate personnel can be notified and construction activities can be adjusted. For example, work activities that result in traffic queues (backups) could be suspended during the fog event to help prevent back-of-queue crashes.

Work zones in fog-prone areas present special hazards to drivers, even when workers are not present. A number of mitigation strategies can be contractually specified during the project design process. For example, internally illuminated signage tends to have much better visibility in fog than retroreflective signage. Thus, the use of LED-based portable changeable message signs (PCMS) could be considered to provide driver alerts such as speed reduction messages for foggy conditions. Similarly, LED-based changeable speed limit signs could be specified to increase the visibility of speed limits posted during fog.

At fog-prone construction sites, the specifications for construction vehicle warning lights should be carefully considered. Some strobe lights and flashing beacons direct a considerable amount of their optical energy upward. Under clear weather conditions, this light is simply wasted. Under foggy conditions, the extra light is scattered by the atmosphere, reducing the contrast between the construction equipment and its surroundings. This can make it very difficult for road users to see workers, work equipment, and temporary traffic control devices, as demonstrated in Figure 15. Most of the amber beacons currently marketed to contractors are much brighter than the 400-candela limit optics experts recommend for nighttime operations (FAA 2010). To address this issue, project specifications can require work vehicles to be equipped with lower intensity beacons for use when fog or smoke occurs at night.

Figure 15. Work zone in Britain obscured by fog.

It was previously believed that yellow lights were less affected by fog than other colors. One result of this mistaken belief was that for several years France required all motor vehicles to be equipped with amber headlamps. More recent research indicates that all colors in the optical spectrum are affected similarly by fog. Thus, while the use of fog lights on work vehicles possibly has safety benefits, the performance of white fog lights and amber fog lights is essentially the same.

Snow, Freezing Rain, and Ice

In recent years, "freak" snowstorms have become more common in the southern United States, where year-round construction is the norm. During the same time period, transportation agencies in cold climates have increasingly turned to year-round construction to expedite important projects; a few mild winters can also make it tempting for these agencies to begin construction earlier in the spring or extend construction later into the autumn. All of these factors increase the likelihood that construction-related traffic impacts will coincide with periods of snowfall, blowing snow, freezing rain, glaze ice (or "black ice"), frost, or similar conditions.

Snow and other types of freezing/frozen precipitation pose special challenges at construction sites. Like fog, falling or blowing snow can limit visibility, potentially leading to chain-reaction crashes. For example, in February 2018 a 70-vehicle pileup occurred near a major construction site on I-35 in Iowa, resulting in several casualties. While it is unclear whether the work zone was a factor in the event, it is generally believed that the rapid onset of the storm during a period of high traffic volumes and driver misperceptions of the safe speed were contributing factors.

Construction-related closures can have substantial impacts on snow removal and deicing operations. Sometimes these impacts occur even if construction activities are halted during the storm. For example, detours for a bridge closure could require areawide rerouting of snowplow trucks. In general, this will increase travel distances and "deadheading" for each truck. As a result, more trucks (and more equipment operators) might be required to maintain a safe and satisfactory level of snow and ice control. Some closures might also affect multiple jurisdictions or levels of government. For example, a bridge closure on a state highway could impact snow removal on nearby county highways and municipal streets, especially if the closure is close to the maintenance garages for the affected jurisdictions.

The presence of construction can also result in the need for increased levels of winter maintenance. For example, intensive snow removal and deicing might be required if a lane restriction results in stop-and-go traffic on a steep hill.

Another group of winter weather impacts relates to the surface conditions in the construction area. For example, even a small amount of snow can make steel trench plates quite slippery. Since truck-mounted snowplows are likely to dislocate these plates, it may be necessary to remove the snow by hand (using brooms, snow shovels, or portable snow blowers), and to apply sand, salt, or other deicing chemicals frequently. If snowy or icy conditions are expected to occur repeatedly during the construction period, it may be helpful to arrange for a tractor with a rotary snow broom, shown in Figure 16, to be kept on site.

All Seasons Equipment (Fiedler GmbH) / https://www.youtube.com/watch?v=USCMo-djXM8

Figure 16. Rotary snow brooms efficiently remove snow from uneven surfaces.

Snow accumulation may also reduce the visibility of some work zone temporary traffic control devices, most notably drums. In some cases, it may be necessary to remove the snow from these devices manually (typically with a broom). Temporary traffic control devices can also become buried by snowfall or snow plowing, requiring manual labor to remove and reset the devices. Occasionally, drum bases can also freeze to the pavement; keeping spare bases on hand is generally more cost-effective than trying to pry the base out of the ice. In all of these cases, the organization responsible for keeping the temporary traffic control devices serviceable should be determined in advance, with pay items as appropriate.

When construction continues through the winter, pedestrian facilities also are likely to be affected. While most US cities require abutting property owners to remove the snow from sidewalks and pedestrian pathways, there are some situations where this is not the case. For example, snow removal for the walkways within a freeway interchange is often the responsibility of public agencies, and it may be necessary to clarify whether the contractor is expected to complete this activity while construction is underway.

Appropriate procedures should be established to ensure that the field engineer, contractor, or another responsible party can arrange for snow and ice control to begin promptly. Pretreatment with salt or brine is often effective in preventing ice accumulation during periods of freezing rain. Otherwise, snow/ice removal can become quite difficult after snow is compacted by traffic or if an accumulation of wet snow is followed by a rapid drop in temperatures.

Various arrangements can be considered to provide reserve capacity for snow removal if it is required during construction:

- If the expected impacts are limited to the project area, appropriate services such as snowplowing and salting could be incorporated into the construction contract as an "if-authorized" bid item.
- For projects with areawide impacts, there are several potential staffing strategies. These include arranging for additional reserve snowplow drivers to be kept on call, contracting for snow removal services with another level of government, or contracting for private snow removal services. A strategy used in some northern cities is to reassign employees normally assigned to other duties, for example using sanitation workers to drive snowplows.

If the agency overseeing the project has a team of winter maintenance experts, the potential impacts of the project should be discussed with them in advance. Possible discussion topics include the following:

- The equipment and personnel currently available to support snow and ice control maintenance in the project area
- The types of precipitation that are the most likely to occur during construction. For example, at temperatures close to 32°F (0°C) precipitation tends to fall as freezing rain, sleet, or heavy wet snow. At colder temperatures, dry powdery snow is more likely (this type of snow tends to be quite slippery). The type of precipitation affects the extent of the required snow/ice control efforts and the most effective techniques.
- Adjustments to snowplow routes required as a result of the project
- Coordination of snow and ice control with neighboring jurisdictions and impacts on snow removal by other levels of government

References

Abatzoglou, J. T., and A. P. Williams. 2016. Impact of Anthropogenic Climate Change on Wildfire Across Western US Forests. *Proceedings of the National Academy of Sciences*. Vol. 113, No. 42, pp. 11771–11775. https://www.pnas.org/doi/10.1073/pnas.1607171113.

AMS. 2012. *Glossary of Meteorology: Fog*. American Meteorological Society, http://glossary.ametsoc.org/wiki/Fog.

Associated Press. 1990. 15 Killed and over 50 Hurt in Fog as 75 Vehicles Crash in Tennessee. *New York Times*, December 12. http://www.nytimes.com/1990/12/12/us/15-killed-and-over-50-hurt-in-fog-as-75-vehicles-crash-in-tennessee.html.

Associated Press. 2017. 6 Killed in 25-Vehicle Pileup at New Mexico–Arizona Line. *CBS News*. June 20. https://www.cbsnews.com/news/new-mexico-dust-storm-pile-up-i-10-near-arizona-border/.

Brown, V. J. 2014. Risk Perception: It's Personal. *Environmental Health Perspectives*. Vol. 122, No. 10, pp. A276–A279.

DfT. 2014. *Using the Core and Vac Technique at Road Works*. Traffic Advisory Leaflet 2/14. Department for Transport, London, UK.

EPA. 2021a. *Climate Change Indicators: Coastal Flooding*. U. S. Environmental Protection Agency. https://www.epa.gov/climate-indicators/climate-change-indicators-coastal-flooding#ref3.

EPA. 2021b. *Climate Change Indicators: River Flooding*. U. S. Environmental Protection Agency. https://www.epa.gov/climate-indicators/climate-change-indicators-river-flooding.

EPA. 2021c. *Climate Change Indicators: Wildfires*. U. S. Environmental Protection Agency. https://www.epa.gov/climate-indicators/climate-change-indicators-wildfires.

FAA. 2010. *Painting, Marking, and Lighting of Vehicles Used on an Airport*. Advisory Circular AC 150/5210-5D. Federal Aviation Administration, Washington, DC.

Guiver, J. 2011. *Travel Adjustments after Road Closure: Workington*. University of Central Lancashire, Preston, Lancashire, UK

Hamilton, B., B. Tefft, L. Arnold, and J. Grabowski. 2014. *Hidden Highways: Fog and Traffic Crashes on America's Roads*. AAA Foundation for Traffic Safety, Washington, DC.

Hernández, A. R. 2018. Exodus from Puerto Rico Grows as Island Struggles to Rebound from Hurricane Maria. *Washington Post*. https://www.washingtonpost.com/national/exodus-from-puerto-rico-grows-as-island-struggles-to-rebound-from-hurricane-maria/2018/03/06/b2fcb996-16c3-11e8-92c9-376b4fe57ff7_story.html?utm_term=.fe94786c19ca.

Iowa DOT. 2022. *Iowa Crash Analysis Tool (ICAT)*. Iowa Department of Transportation. https://icat.iowadot.gov/.

ITF. 2008. *Towards Zero: Ambitious Road Safety Targets and the Safe System Approach*. Organization for Economic Co-Operation and Development & International Transport Forum, Paris, France. https://www.oecd-ilibrary.org/transport/towards-zero_9789282101964-en.

ITF. 2016. Zero *Road Deaths and Serious Injuries: Leading a Paradigm Shift to a Safe System*. OECD Publishing, Paris, France.

Lindsey, R., and L. Dahlman. 2020. *Climate Change: Spring Snow Cover*. National Oceanic and Atmospheric Administration (NOAA). https://www.climate.gov/news-features/understanding-climate/climate-change-spring-snow-cover.

Livingston, I. 2016. Annual and Monthly Tornado Averages for Each State (Maps). *ustornadoes.com*. http://www.ustornadoes.com/2016/04/06/annual-and-monthly-tornado-averages-across-the-united-states/.

Mallakpour, I., and G. Villarini. 2015. The Changing Nature of Flooding Across the Central United States. *Nature Climate Change*. Vol. 5, pp. 250–254.

Nelson, A. J. 2017. Northeast Nebraska Police Officer Killed in Crash While Responding to Call. *Omaha World-Herald*. March 27. http://www.omaha.com/news/nebraska/northeast-nebraska-police-officer-killed-in-crash-while-responding-to/article_2daca492-132a-11e7-a047-cfbbc70a22b6.html.

NIST. 2013. *Guide for Conducting Risk Assessments*. NIST Special Publications 800-30 Revision 1. National Institute of Standards and Technology, U.S. Department of Commerce. https://nvlpubs.nist.gov/nistpubs/legacy/sp/nistspecialpublication800-30r1.pdf.

NOAA. 2016. *Climate Change and Extreme Snow in the U.S.* National Centers for Environmental Information, National Oceanic and Atmospheric Administration. https://www.ncei.noaa.gov/news/climate-change-and-extreme-snow-us.

NOAA. 2021. *The Great Galveston Hurricane of 1900*. National Oceanic and Atmospheric Administration, National Ocean Service. https://celebrating200years.noaa.gov/magazine/galv_hurricane/welcome.html.

Oklahoma Highway Safety Office. 2003–2016. *Oklahoma Crash Facts 2001–2015*. Oklahoma Highway Safety Office, Oklahoma City, OK.

Pearson, C. 2014. 15 Years after 401 Crash, Trauma Remains. *Windsor Star*. September 3. http://windsorstar.com/news/15-years-after-401-crash-trauma-remains.

Phillips, K. 2017. Florida's Construction Cranes Were Designed to Withstand Irma. Some Did Not. *Washington Post*. September 12. https://www.washingtonpost.com/news/post-nation/wp/2017/09/12/floridas-construction-cranes-were-designed-to-withstand-irma-some-did-not/?utm_term=.ad0893636fe0.

Roth, D. 2010. *Texas Hurricane History*. National Weather Service, National Oceanic and Atmospheric Administration, Camp Springs, MD. https://www.weather.gov/media/lch/events/txhurricanehistory.pdf.

Sweet, W., J. Park, J. Marra, C. Zervas, and S. Gill. 2014. *Sea Level Rise and Nuisance Flood Frequency Changes around the United States*. National Weather Service, National Oceanic and Atmospheric Administration, Silver Spring, MD. https://tidesandcurrents.noaa.gov/publications/NOAA_Technical_Report_NOS_COOPS_073.pdf.

Urbina, E., and B. Wolshon. 2003. National Review of Hurricane Evacuation Plans and Policies: A Comparison and Contrast of State Practices. *Transportation Research Part A: Policy and Practice*. Vol. 37, pp. 257–275.

USGS. 2017. *Short-Term Induced Seismicity Models: 2017 One-Year Model*. U.S. Geological Survey. https://www.usgs.gov/programs/earthquake-hazards/science/short-term-induced-seismicity-models.

Valle-Levinson, A., M. Olabarrieta, and L. Heilman. 2020. Compound Flooding in Houston-Galveston Bay during Hurricane Harvey. *Science of The Total Environment*, Vol. 747 (December). https://doi.org/10.1016/j.scitotenv.2020.141272.