Impacts of Extreme Weather on Transportation: National Symposium Summary

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Table of Contents

Introduction

Over the past several years, extreme weather has disrupted transportation systems in nearly every region of the United States. Derechos, snow storms, and intense hurricanes have plagued the east coast, while the Midwest has suffered massive and prolonged flooding. In the southwest, dust storms and wildfires have forced extended road closures and endangered drivers. Transportation agencies have decades of experience managing weather variability and are able to quickly and efficiently handle common weather disruptions. However, many state transportation officials are now managing disruptions from more frequent and intense events.

Extreme and high impact weather events disrupt service, damage expensive infrastructure, and necessitate more frequent maintenance. Transportation agencies must manage both the rising costs of extreme weather as well as the public's expectation of rapid transportation system recovery following these events. In several instances, recurring pressures on state transportation officials to prepare for, manage, and recover from extreme weather events have caused organizational change, including new management activities (e.g., staff assigned emergency management responsibilities), modified standard operating procedures, and expanded staff training in managing and administering recover efforts.

In recognition of the extreme weather event challenges facing state transportation officials, the American Association of State Highway and Transportation Officials (AASHTO) sponsored a two-day symposium in May of 2013 entitled, *National Symposium: Impacts of Extreme Weather Events on Transportation.* The first day of the symposium focused on the impacts and costs associated with extreme weather events; the second day examined different ways of managing the events and how transportation officials can incorporate weather concerns into agency decision making. The major findings of the symposium are presented in this document, organized by the six conference session topics.

State DOT Experiences with Recent Extreme Weather Events

The diversity of extreme weather events impacting transportation is immense and each event poses unique challenges. Hurricanes often cause power disruptions, road washouts, vehicle crashes, and sign damage due to a combination of precipitation, storm surge, and high wind. While the impacts of hurricanes can take months to repair, the event itself is relatively short-lived (several days) and repairs can begin quickly. On the other hand, riverine and stream flooding due to heavy rain can result in prolonged flooding (multiple weeks). The prolonged inundation of infrastructure prevents repairs, exacerbates scour, and damages paved roads. Transportation agencies are able to predict hurricanes and severe floods in advance to some extent, which informs sophisticated emergency response efforts. However, in the southwest, dust storms can develop suddenly with very little warning. Dust storms cause unsafe driving conditions and vehicle crashes due to reduced visibility, but are of short duration (up to 8 hours). Similar to dust storms, wildfires also endanger drivers by reducing visibility. However, wildfires often also necessitate prolonged road closures (weeks) at urban-rural interface areas where detours are often very long.

The following case study examples illustrate the specific challenges that can face state DOTs:

- **New Jersey DOT**: Super Storm Sandy caused 80 road wash outs and 581 vehicle crashes and incidents within three days. NJDOT had to replace or fix 1,250 signs, remove 4,400 truckloads of debris, and clear sand and debris from 12 miles of a major state highway. The agency also provided over 59,000 gallons of fuel to first responders.
- **Minnesota DOT**: A 2,000-year storm and resulting floods in Minnesota resulted in road closures on 26 state trunk highways.
- **Colorado DOT:** A massive forest fire closed a major interstate route so that adjacent communities could be evacuated. In addition, another major U.S. highway was closed due to fire threats. In the aftermath, DOT officials discovered that the stability of roadway embankments had been threatened in numerous locations due to fire damage.
- **Arizona DOT**: Blowing dust has been a contributing factor in more than 1,000 vehicle crashes in Arizona since 2000. For example, in October of 2011, a dust storm engulfed a heavily traveled freeway corridor causing three separate, multi-car collisions involving more than 25 vehicles. One fatality and multiple critical injuries resulted, and the freeway was closed for emergency response, cleanup and incident investigation.
- **District of Columbia DOT:** In winter 2011, the District of Columba faced "snowmageddon," with a total of 65 to 70 inches of snow falling during the season. This total accumulation represented the top five snowfalls ever recorded in Washington D.C. Back-to-back storms stretched the resources in removing the snow, requiring the DOT to hire specialized equipment from contractors throughout the mid-Atlantic and Northeast. The DOT also borrowed salt from depots in Baltimore to address salt shortages. The total amount of snowfall was so large that the DOT ran out of locations to put the snow removed from the road system.
- **Vermont Agency of Transportation:** The August 2011 floods caused by Tropical Storm Irene isolated 13 communities for days due to the loss of numerous roads and bridges. Nearly 2,000 road segments were damaged, with 118 sections of state roads and 175 local roads completely washed out, and nearly 300 bridges needing repairs. Several rail and major telecommunication lines were damaged or destroyed by fast-moving flood waters.

- **Iowa DOT**: One year's worth of rain fell in the Upper Missouri River Basin the last two weeks of May 2011. The Missouri River in Sioux City, Iowa was above flood stage from June 5 to August 26 (82 days), the longest duration flood event in U.S. history. Over 60 miles of Iowa's Primary Highway System, including 50 miles of interstate highways, were closed for nearly five months. Decreased mobility impacted the flow of goods and services and resulted in economic displacement in affected communities. Each of three closed river crossings was part major commuter route. The detour for the closure of I-29 in southwest Iowa resulted in an additional 150 miles for the trip from Kansas City to Sioux Falls, SD.

Despite the diversity in extreme weather events, symposium participants identified common best practices for preparing, responding, and recovering from weather impacts (see "Best Practices for Extreme Weather Management" box). In addition to specific practices, state DOTs emphasized the importance of strong leadership, teamwork, and coordination. For example,

Best Practices for Extreme Weather Management

- **It pays to be ready and pre-plan:** Anticipating the consequences and potential impacts of extreme weather events can pay off in more effective and successful response efforts. Participants suggested the following tactics: develop an emergency response plan that outlines roles and responsibilities; improve the plan based on lessons learned from the most recent weather event; pre-position materials (such as signs and culverts) to minimize response and recovery time.
- **Practice, practice, practice:** Many of the state DOT best practices included efforts to practice agency responses given different scenarios. Participants recommended undertaking practice sessions that simulate a real emergency to identify glitches in communications, command structure, resource allocation, and logistical support.
- **Know what is out there:** Monitoring likely "problem" areas that could create dangerous and unsafe conditions during and after the weather event is an important agency capability. For example, CO DOT actively monitors areas that may be susceptible to wildfire. Participants recommended using technology such as rain and flood gauges, dust monitoring devices, and smoke/fog warning sensors to provide early warnings.
- **Use all forms of communication media:** Prepare a communications strategy that recognizes the many different audiences that will be interested during an event. Utilize social media, radio, television, print news, overhead message boards, 5-1-1 system and travel alerts, text messages, highway advisory radio, and web notices. Each of these channels targets a different audience.

strong leadership and coordination enabled NJ DOT's successful response to Hurricane Sandy. As part of an emphasis on coordination, participants recommended building relationships with key partners ahead of time in order to improve emergency response. For example, DDOT relied on partners to provide salt supplies and snow equipment during the 2011 "snowmageddon" and MoDOT relies on relationships and clear communications with commercial motor vehicles in order to clear roads during storms.

Extreme Weather Events – Trends, Projections, and Integrating Information into Decisions

Key Messages

- **Extreme weather events will continue to present challenges:** We will continue to experience extreme events and changes in climate may exacerbate some of their impacts.
- **Trends in extreme weather events vary by weather type:** For heat, heavy rainfall, and coastal flooding, there is strong evidence that such events have become more pronounced and that they will grow in frequency and severity. Details about future circulation patterns that affect local storminess remain uncertain.
- **Sensitivity information about your assets/services is critical:** Uncertainty related to weather and climate can motivate building resilience to all sorts of shocks. Strategies include fortifying, monitoring, hedging, and establishing redundancy.
- **National resources exist to help transportation professionals understand climate and weather trends and forecasts:** The National Oceanic and Atmospheric Administration (NOAA) has a long-standing history of regional climate science and service, as well as extensive service delivery capacity. It acts as a repository for data and information on regional climate. NOAA is developing further information sources that will be useful to a range of audiences for a variety of data needs. The Federal Highway Administration also provides important capabilities in its Road Weather Management Program.

Defining Extreme Weather

Understanding the magnitude, extent, and timing of impending extreme weather can vastly improve emergency preparedness. Different definitions of "extreme weather" exist. For example, the climate modeling community often defines extremes based on a threshold (e.g., days exceeding 95^{o}F) and/or a distribution (a 1 in 100 event). As the Draft of the National Climate Assessment (Jan 2013) notes, "researchers use different definitions depending on which characteristics of extreme they are choosing to explore at any one time." On the other hand, the hydrology community often defines extreme events based on average annual exceedance probabilities or average recurrence intervals. Regardless of definition, it is clear from historical records that extreme weather events can be costly, causing an estimated $880 billion in damage nationally from 1980 to 2011 (see Table 1).

Table 1: Damage by Disaster Type, 1980-2011, (2011 Dollars) (Smith and Katz, 2013) , presented at the symposium by Dr. Joe Casola (C2ES)

Number of Disaster Events		Adjusted Damage ($ billions)	Percent Damage	Percent Frequency
Tropical cyclones	31	$417.9	47.4%	23.3%
Droughts/heatwaves	16	$210.1	23.8%	12.0%
Severe local storms	43	$94.6	10.7%	32.3%
Non-tropical floods	16	$85.1	9.7%	12.0%
Winter storms	10	$29.3	3.3%	7.5%
Wildfires	11	$22.2	2.5%	8.3%
Freezes	6	$20.5	2.3%	4.5%

Trends in Extreme Weather and Projections for the Future

Over the past several decades, trends in the severity and frequency of extreme weather events have emerged. For example:

- On average, the U.S. has experienced more frequent high temperatures, heat waves, and record-breaking hot summers. The strongest trend can be seen in the West, while less warming is evident in the Southeast. Climate models project that these trends will become more apparent across all regions in the future.

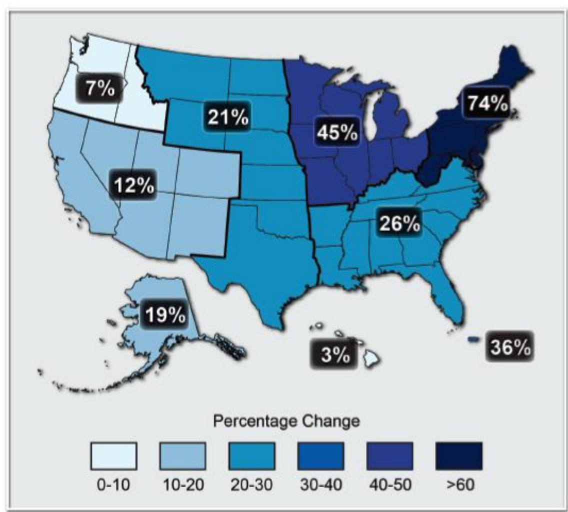

Figure 1: Percent change in very heavy precipitation (Source: Draft National Climate Assessment Chapter 2– Figure 2.16)

- Heavy rainfall events have increased, particularly in the East and Midwest (see Figure 1). However, riverine stream flow records show both increases and decreases in flooding. The U.S. as a whole has become slightly wetter, led by Northern areas, whereas the Southwest has become slightly drier. Climate models project further increases in heavy rainfall across all regions. However, it is important to note that flooding patterns may not increase in lockstep with increased precipitation due to local factors influencing flooding patterns.

- There have not been any strong drought trends; periods of intense drought have periodically occurred in different regions. Overall, more area has been burned in wildfires.
- Many coastal areas are experiencing frequent and severe flooding. Future sea level rise will exacerbate the intensity of these events.
- In the West, changes in snow accumulation and snowmelt are altering the timing of peak flows. Climate models project that changes in snow hydrology will continue to alter streamflow patterns.
- Tropical storms have become more intense in the Atlantic basin, but there is no clear trend in changes in thunderstorms and tornadoes. While there are no clear trends in overall storminess, there is evidence that storm tracks are shifting northward through the Northern Hemisphere.

Sources of Information on Weather and Climate Trends

Several sources of information on climate trends and data on weather events exist at the national level. For example, the National Oceanic and Atmospheric Administration (NOAA) has established six regional climate data centers that house historical data on climate trends for different regions of the country. NOAA's National Climate Services program is developing a website that will offer a well-integrated, on-line presentation of NOAA's climate data and services. It will feature ClimateWatch for the general public; data and services for scientists and data users; a section on understanding climate for policy leaders, and outreach materials for educators and students. It will also provide access to past weather data so that users can easily retrieve weather data for any given location and date.

Another example for the Northeast is ICNet, which is a collaborative research network of over 50 people across climate and engineering disciplines. The intent is to fast track research in infrastructure engineering (bridges, roads, and transportation networks) by identifying, prioritizing, and facilitating access to appropriate data, tools, partnership, and education. The Federal Highway Administration (FHWA) Road Weather Management Program and the Clarus Initiative—the Nationwide Surface Transportation Weather Observing and Forecasting System--provides other capabilities for monitoring weather conditions.

State DOT Weather and Climate Data Needs

Symposium participants recommended that efforts be made to better forecast weather (across all types of extreme weather events) at levels of detail that are needed for operational preparation and response decisions. Participants identified the following specific needs:

- Real-time data on actual weather conditions during an event.
- An ability to translate weather forecasts into metrics that matter to specific types of transportation decision-making.
- Information on the reliability of weather forecasts, or a measure of how confident users can feel about a given forecast.
- A centralized place to get information on extreme weather.
- Weather forecasts with sufficient forecast horizons that could be used to influence operations and maintenance budget cycles.
- Information on internal thresholds that state DOTs can use to inform extreme weather response. For example, if a state DOT knows that it cannot keep up with road maintenance once the storm reaches 3 inches per hour, it can use snowfall forecasts to trigger response decisions, like preemptively closing roads or requesting help.
- Frameworks for making decisions in the absence of complete data about projected extreme weather events could help state DOTs if other data needs cannot be met.

Costs of Extreme Weather

Key Messages

- **Extreme weather events can result in significant costs to transportation agencies and to the traveling public.**
- **Different analysis tools can be used to assess the desirability of pursuing actions today that would prevent damage during future extreme weather events, however, their use is based on assumptions associated with frequency of event occurrence and likelihood of damage.**

Roadway assets impacted by weather events require immediate corrective measures, resulting in costs that are usually above planned budget expenditures. The Bonner Bridge in North Carolina's Outer Banks, for example, has experienced extra costs due to extreme weather event damage. Since 1998, the NCDOT has had to spend $36.5 million repairing storm damage. The biggest costs occurred with Hurricanes Irene and Isabel, $16 and $8.8 million, respectively, but even a nor'easter caused over a million dollars in damage.

Not only do such costs represent direct costs to the agency restoring the facility, but if the disruption causes delays and necessitates detours, there are costs to users as well. For example, Michigan has estimated that the economic costs of disruption from a snow storm range from $66 to $700 million for just a one-day shutdown due to impassible roads.

Benefit-cost analysis, net present value, and life cycle cost analysis represent three common approaches to analyzing the relative value of implementing one alternative over another, where one alternative might include spending dollars today to avoid future damage. However, one of the basic inputs to such approaches is the timing of costs (e.g., replacement or reconstruction costs). Given that by their nature extreme weather events, and certainly those occurring at levels that might cause asset failure, are very difficult to predict, the use of such approaches needs to proceed with caution. In particular, some form of probabilistic input will likely be necessary to account for the uncertain nature of storm events and the varying likelihoods that damage will occur during any given event.

Managing Extreme Weather (Design Standards, Operations and Maintenance)

Key Messages

- **Extreme weather events are affecting the operations and maintenance functions of state DOTs today and will do more so in the future:** State DOTs have responded to extreme weather events for many years, but in many cases the frequency and intensity of the storms being faced today is presenting new challenges to state officials. For example, emergency management and response is becoming a more important staff function in many state DOTs.
- **Successful state response in the aftermath of extreme weather events involves coordinated efforts on the part of numerous governmental and emergency response agencies:** Numerous examples of effective state response to the extreme weather events illustrated the importance of having strong partnerships among state DOTs, emergency management agencies, emergency responders, enforcement agencies, public health officials, and humanitarian relief organizations.
- **The impacts of extreme weather events could change the way one designs infrastructure:** Design procedures and design standards are based in many cases on the ability of assets to cope with environmental stresses and conditions placed on an asset. The design of storm water drainage systems, roads, bridges, culverts, small dams, detention basins, and airport runways all reflect considerations for temperature, precipitation and wind. To the extent that these inputs will be different in the future, designs could change as well.
- **Given the important role that weather-related variables have in determining design parameters, more information is needed on how designers can take likely changes into account:** Engineering design is dependent on inputs relating to the stresses that will likely be placed on assets (e.g., intensity-frequency-duration curves for precipitation). More information and research is needed to inform designers on what approaches might be taken for considering changes in such inputs over time.

Operations and Maintenance

Many of the symposium participants noted that they are already experiencing the changing characteristics of extreme weather in their operations and maintenance functions. In Michigan, extreme lake effect snow storms have been changing the DOT’s operations and management strategies with respect to such things as the number of employees assigned to weather response, the numbers and start times of shifts, use of temporary winter employees, and the need for staff lodging when the weather is so bad staff members cannot return home after their shift. In addition, DOT officials are continually looking for ways to improve the types of materials being used to bring a road back to safe operation, e.g., types of salts for ice removal. Importantly, Michigan DOT is investing in ways to improve decision making during winter operations. For example, the DOT is piloting a maintenance decision support system along a major interstate corridor.

The Missouri DOT has focused attention on conveying information to road users, particularly commercial vehicle operators. The DOT has found that communication is key to a successful response and recovery from an extreme weather event. DOT experience was that a wide range of communication channels is necessary to "get the word out," including cell phones/texting, e-updates, Facebook updates, Twitter, Sirius Radio, as well as using the communications capabilities of other organizations such as trucking associations.

Alabama DOT (ALDOT) has also experienced an increasing number and severity of extreme events, ranging from severe wet and dry cycles to tornadoes and hurricanes. In response, ALDOT has created a full-time emergency management position, improved their relationship with the state emergency management agency, and increased recurring trainings for staff related to these issues. They have also found it useful to focus on specific solutions, such as using portable highway radios, increasing coordination across and divisions, and using less specialized equipment so that what equipment they do have can be used anywhere. The organization, like many other state DOTs, is continuing to monitor their disruptions from and responses to extreme events, and make adjustments accordingly to their operations and maintenance practices.

Design

Weather variables are one of the inputs into design standards. For example, design for storm water drainage systems, roads, bridges, culverts, small dams, detention basins, and airport runways reflect standards for coping with rainfall and runoff.

The Vermont Agency of Transportation (VTrans) presented an example of how the DOT's experiences during Hurricane Irene fundamentally changed how the agency operates and also how it thinks about design. For example, stream-related erosion and flooding were a major factor in many of the road failures that occurred in the aftermath of the hurricane. VTrans is now changing the way it considers hydraulic capacity, employing a "river science" approach and considering not only hydraulic capacity, but also sediment and debris. The new approach will likely allow for more risk-based design in terms of roadway safety and stream stability. In addition, the sections used on slope repairs adjacent to rivers have been re-designed. Whereas in the past VTrans had simply placed stone to stabilize the slope, now DOT engineers are first defining stable channel dimensions and building the slope to match that as best as possible.

VTrans has also adopted a process-based approach to identify and prioritize risk in river-roadway corridors: 1) use of hydrologic and hydraulic modeling to quantify river and floodplain erosion potential, 2) LiDAR slope mapping to identify slopes >100% in between roadway and river, and 3) identification of roadways that are susceptible to erosion during flood events. This VTrans example illustrated a context-sensitive design change in a critical and vulnerable area.

A design process that relies on formal analysis procedures for determining design parameters is sensitive to input variables and assumptions. Given the importance of environmental variables on design, symposium participants expressed the need for further information on the potential impact of changing weather conditions on design parameters. For example, intensity-frequency-duration (IDF) curves provide important input into the design of drainage systems, and it will be important for engineers to know to what extent such input will change as the result of changing extreme weather events.

Managing Extreme Weather (Emergency Management)

Key Messages

- **Because emergency management involves many different agencies and organizations, often from other states, there is a need for a strong coordination structure:** The management and response to large-scale disasters involves agencies from different levels of government; and from public, private and non-governmental sectors, each having their own mandates and responsibilities and often their own standard operating procedures for handling emergency responses.
- **Communication is key:** Effective communication strategies are particularly critical during emergency management. It is important to engage resource agencies, U.S. Army Corps of Engineers, and FHWA early and throughout the event. In addition, a state DOT should utilize as many media outlets as possible to keep the public informed, including social media.
- **Emergency response often requires atypical contracting procedures:** Given the magnitude of recovery from extreme weather events and the need to get the transportation system back operating as soon as possible, many state DOTs have utilized innovative contracting strategies. These strategies have allowed DOTs to redirect current contractors/consultants and to expedite the hiring of new contractors/consultants.
- **State DOTs are using a wide range of technologies to better manage emergency response:** DOT officials are discovering that new communications technologies, surveillance and monitoring capabilities, and electronic database management programs are allowing their agencies to respond quickly and efficiently to the impacts of extreme weather events.

Emergency management has always been a critical part of the state DOT role, but, as noted by one state DOT official at the symposium, unlike previous years, "emergency management has now become a full time job." Even though specific emergency response strategies differ according to the type of extreme weather event, there are strong similarities among many of the emerging best practices and data needs. The following paragraphs enumerate these best practices and data needs in more detail as articulated by the symposium participants.

Most importantly, disaster response almost always involves a myriad of organizations and agencies. The resources that these agencies bring to emergency management are critical to effective response and recovery. Given the sheer scale of agency involvement, a ***structured command and control framework*** may be beneficial for both how a state DOT operates under direction of a state's emergency management decision-making structure as well as how its own forces are managed. For example, the aftermath of Tropical Storm Irene in Vermont saw the participation of over 700 employees of the DOT itself, 225 people and 205 pieces of equipment from Maine and New Hampshire, National Guard soldiers from eight states, over 200 private contractors and consultants, 1,800 private organization volunteers, medical assistance from seven states and outreach to local government, funded by VTrans through regional planning commissions.

Best Practices for Emergency Response to Extreme Weather

- Improve and strengthen relationships with the state emergency management agency.
- Increase training for Division and District personnel.
- Use more accessible and interoperable response equipment (such as compatible communication systems).
- Develop expedited procurement practices.
- Adopt more effective internal communications platforms.
- Use enhanced communication strategies for disseminating road condition information.
- Conduct post-event audits to identify improvements for future emergencies.

Symposium participants recommended that the ***decision-making structure for emergency management*** be clearly defined and communicated from the onset, simple, and adhered to throughout the process. As noted by an Iowa DOT official, "understanding what you need, where to acquire it, and who is responsible for it is key to rapid response." For example, to coordinate the wide ranging participation of agencies and organizations after Tropical Storm Irene, VTrans used an incident command system (ICS) decision-making framework, which is a "systematic tool for command, control and coordination of an emergency response" (see Figure 2). This structure is part of the National Incident Management System (NIMS), and is flexible, scalable and ready to use (FEMA provides training on its use). Incident command centers (ICCs) were established in different regions affected by the storm, operated under the direction of a Unified Command (UC) in the state capital. The UC's role was to set priorities, provide overall management through directives, and take the lead on communication and public information.

Throughout the symposium, participants continually emphasized the importance of ***effective communications***. Nowhere was this more important than in emergency management. As noted by one state DOT official, "ensuring that the information is 100 percent accurate 100 percent of the time is key to helping the public, emergency responders, and businesses make key decisions." Partnerships with information providers to understand what data exists and associated uncertainties are important relationships to establish early in the process. Early coordination with emergency responders and keeping them updated on closures and openings throughout the event is extremely important. VTrans is developing and maintaining an active distribution list of cell phones, exploring the use of cloud technology, formulating a recommendation for data storage during emergency response, exploring and developing connectivity between traffic simulation and GIS, exploring the use of IT applications (5-1-1, Google, etc.) for emergency response, developing a process to track equipment and materials from contractors, and standardizing data collection and data integration.

In today's information age, using ***social media*** becomes an important part of an agency's communications strategy. If there is time before an extreme weather event occurs, DOTs recommended directing people to resources to keep in touch with on-going developments. Washington State DOT established a 24-hour emergency operating center with social media staffing, coordinated media relations across state regions, updated press releases and media briefings to coincide with media cycles, provided constant web and 5-1-1 updates, used Listserv, Twitter, Facebook and email alerts sent directly to public and industry (freight), all with an intent to enhance public safety. The key to success was understanding the information needs of the different audiences, e.g., motor carriers, media, governor's office, legislators, and the general public.

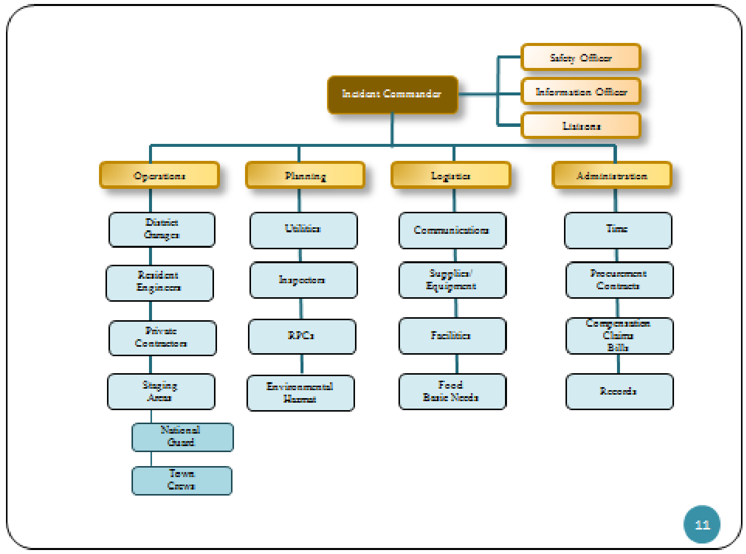

Figure 2: Diagram of Vermont's Command and Control structure

Innovative contracting and consulting practices were used by several state DOTs in emergency management and recovery. For example, in response to the Missouri River flooding, the longest duration flood event in U.S. history, the Iowa DOT hired a consultant to do the damage assessment on an accelerated schedule, 15 calendar days to complete the damage inspection reports (22 covering 59 miles). Contractors were used to dispose of hazardous material and for pavement cleaning and debris removal.

State DOTs are utilizing a ***wide range of technologies*** as part of their emergency management and recovery efforts. Technologies are rapidly emerging to collect real-time information on road weather conditions (e.g., using data collected by vehicles), improve the way information is stored and displayed geospatially and to monitor real-time conditions on the road network. For example, Iowa DOT developed electronic "as-builts" that utilized survey grade accuracy as part of its efforts to determine needed reconstruction designs, as well as LiDAR to expedite needed design development in the event of asset failure (all survey control points on a major interstate had been lost in an earlier flood, thus indicating the need for LiDAR data). The DOT also developed an electronic detailed damage inspection report (DDIR) that expedited both the assessment of damage on affected facilities, but which were also used in providing data to emergency response agencies.

Pre-planning for disaster response is an important first step in effective emergency management. For example, knowing how evacuation procedures will likely occur is a critical piece of information that will affect DOT operations. The establishment of evacuation routes and where possible have the signing already in place can save a lot of time and effort during an emergency management process.

Finally, as in other sessions, participants emphasized the need to ***learn from one's experiences***. In most cases, state DOTs reported on debriefings and critical assessments post-weather event to determine what was necessary to improve agency efforts for the next time. VTrans, for example, established an innovation task force whose charge was to coordinate different efforts to enhance its response to future extreme storms. Efforts included incident command training, river management training, emergency response task team, contracting/business task team and an information technology (IT) governance committee.

Risk Assessment and Asset Management

Key Messages

- **Understanding vulnerability and risk is an important step in anticipating and preparing for extreme weather event impacts:** The key consideration in decisions aimed at preparing for and responding to extreme weather events is determining the risk associated with potential facility disruptions and asset failures. Risk includes consideration of the likelihood that an extreme whether event will occur at such a level that the chances of damage to an asset are extremely high.
- **Asset management systems are logical platforms to consider extreme weather event impacts on infrastructure:** Given that most state DOTs have some form of an asset management program in place and that MAP-21 now requires each state to have a risk-based system, asset management systems provide an excellent starting point for vulnerability and risk assessment.
- **Vulnerability and risk assessments can inform a range of transportation decisions:** There is a range of agency decision making processes where extreme weather events could be considered, including emergency and risk management, long range transportation planning, project prioritization, data collection/operations/design, maintenance management and public outreach efforts.

The final sessions of the symposium focused on approaches for assessing extreme weather vulnerability and risk. The Federal Highway Administration defined vulnerability as a function of exposure, sensitivity, and adaptive capacity and risk as a combination of the magnitude of potential consequence(s) of climate change impacts(s) and the likelihood that the consequence(s) will occur. Asset management was defined as per recent federal legislation as "a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at minimum practicable cost."

The Federal Highway Administration (FHWA) presented FHWA's Climate Change and Extreme Weather Events Vulnerability Assessment Framework as a way of systematically considering asset vulnerability in agency decision making. The framework consists of three major steps: define project scope, assess vulnerability, and integrate vulnerability into decision making. Importantly, several types of agency decision making were identified as being likely areas where information on vulnerability of assets could be useful: asset management, emergency and risk management, long range transportation planning, project prioritization, data collection/operations/design, and public outreach.

Asset management systems and spatial data on asset locations enable effective vulnerability assessments. Assessing the risk to the system and to individual assets is a key element of what an asset management system should do. As noted by one participant, “major external events such as extreme weather events create havoc with transportation asset management plans, which are often based on predictable deterioration curves. . .Hurricanes Katrina, Irene and Sandy probably did more damage in a few days than normal condition deterioration on the nation’s road network over decades.” Successfully incorporating extreme weather event stresses into asset management systems will require: assessing risk to the system (network) and to individual critical facilities, understanding the effect of uncertainty on asset management objectives, determining the likelihood and consequence of stresses occurring, and relating these findings to project cost, scope and schedule.

Washington State DOT provided an example of how the consideration of changes in climate and extreme weather events could be applied in the context of asset management. The major concepts underlying the DOT’s approach was to be ready for severe weather events and long-term changes in site conditions, inform long-term decisions, and build resilience into the state transportation network where possible. These objectives were achieved by conducting a statewide vulnerability assessment. An examination of the flooding history in the state showed that flooding in western Washington had changed in magnitude and frequency due to the combined effects of warming, increasingly intense winter storms, and sedimentation. In other parts of the state, changes in flooding were mixed, and in eastern Washington projected reductions in spring flood risk were common due to loss of spring snow cover. The results of the assessment showed that additional stress was likely to be placed on key, vulnerable highways, which reinforced the DOT’s value of emphasizing maintenance and retrofit programs. Much of the information on vulnerability came from the DOT’s maintenance staff, and an overall assessment of the process concluded that drawing upon the institutional knowledge of maintenance staff and working with locals to understand vulnerability was key to the success of the effort.

Next Steps

Symposium participants agreed that the time spent exchanging information on how others are dealing with extreme weather events was very useful. Importantly, this exchange showed that there were common approaches and “best practices” that seem to exist in successful and effective responses. There was a sense from the participants that the field is rapidly evolving; it is critical for state DOTs to share best practices with each other and to learn from past experiences through post-event "debriefs" and events such as this symposium. They expressed a desire for continued facilitated information-sharing between state DOTs. This consensus was considered particularly important as technologies rapidly evolve to provide state DOT officials with more reliable and effective means of monitoring changing conditions, communicating to a range of audiences, and directing resources during an extreme weather event.

In addition, the symposium highlighted the need for information and guidance on how changing weather conditions should be incorporated into state DOT practices, including operations and maintenance strategies, flexible design approaches, and emergency response plans. During the symposium, participants identified the following specific needs:

- As state DOTs begin to take more proactive action to prepare for extreme weather events, additional information is needed regarding whether and how to track costs associated with extreme weather events. In addition, state DOTs need a transparent framework to help them weigh the costs and benefits of proactive strategies against the consequences of inaction.
- State DOTs requested information on how to begin considering extreme weather and climate projections in design. They were also interested in finding case studies of DOTs that have begun to make design updates in response to extreme weather.
- State DOTs expressed interest in sharing emergency response strategies to enable quick and efficient recovery from extreme weather events. In particular, participants wanted to exchange examples of how to write effective contracts during post-event recovery efforts and streamline reimbursement procedures.
- State DOTs are experimenting with a range of communications strategies before, during, and following extreme weather. They want case studies and information on how to improve the success of their communication and relationship-building efforts.

References

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