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Transportation Resilience 2019

*2nd International Conference on
Resilience to Natural Hazards and
Extreme Weather Events*

November 13–15, 2019
Washington, D.C.



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November 13–15, 2019
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Hosted by
Transportation Research Board

With support from
Federal Highway Administration
American Association of State Highway Transportation Officials

Organized by
Special Task Force on Climate Change

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Preface

The Transportation Research Board (TRB) hosted the Transportation Resilience 2019: 2nd International Conference on Transportation Resilience to Natural Hazards and Extreme Weather Events (TR2019) at the National Academy of Sciences Building in Washington, D.C., November 13–15, 2019. This conference builds on the successes of the first Transportation Resilience conference held in 2015 and the 2018 Transportation Resilience Innovations Summit and Exchange (Transportation RISE). The conference was organized by TRB, a division of the National Academies of Sciences, Engineering, and Medicine (NASEM), with support from the Federal Highway Administration (FHWA) of the United States Department of Transportation (DOT) and the American Association of State Highway and Transportation Officials (AASHTO).

The primary purpose of TR2019 program was to present advancements made in transportation systems resilience to natural hazards, climate change, and impacts from extreme weather events. The program should highlight current state-of-the practice and through gaps needing further study, research, and development to achieve resilience to all hazards. The organizers set the following learning objectives for attendees when planning the conference agenda:

- **Greater Awareness and Understanding** of state-of-the practice information on incorporating resilience strategies into systems performance activities;
- **Vetted Resources and Data** for measureable progress and performance of transportation resilience strategies and approaches;
- **Identified Solutions** in planning and design to advance sustainable and resilient transportation systems;
- **Latest Policies and Standards** to advance transportation resilience to natural hazards impacts; and
- **Exchanged Ideas** with peers from the private sector and every level of government.

The content of this report is to inform researchers, practitioners, consultants and policy makers on the general resilience practices and areas of research and development to continue to enhance the resilience and sustainability of transportation systems and assets.

TR2019 included plenary sessions, technical sessions and posters, and an educational flood mitigation demonstration. The sessions were webcasted for remote access. Between the remote and in-person attendees, 288 people participated in the conference and represented 46 states, the District of Columbia (D.C.), and 10 nations. Participants gathered to learn more about emerging best practices and state-of-the-art research results to adapt surface transportation networks to natural disasters, extreme weather events, and climate change. The conference benefited from international and federal agency participation including Ministry of Infrastructure and Water Management, Rijkswaterstaat of the Netherlands; Norwegian Public Roads Administration; Transport Canada; U.S. Geological Survey (USGS); U.S. Naval Academy; U.S. Department of Agriculture (USDA); U.S. Army Corps of Engineers (USACE); National Oceanic and Atmospheric Administration (NOAA); numerous state and local transportation agencies; multiple universities; and many consulting firms.

In addition to keynote speakers, the conference included plenary sessions focused on framing the issues related to resilience in transportation including proactive adaptation,

investment and policy decisions, managed retreat, lessons learned from post-disaster response, and an update on science and emerging data sources. The conference PowerPoint presentations used by speakers can be accessed online through the links embedded in the final program at <http://www.cvent.com/events/transportation-resilience-2019-an-international-conference-on-natural-hazards-and-extreme-weather-ev/custom-35-e011e931bd2a46de8e2742a9ba14d3be.aspx>.

The planning committee for this conference was responsible solely for organizing the conference agenda and program to include administering a Call for Abstracts process, identifying speakers, and developing topics for the plenary and breakout groups. Aimee Flannery of Applied Engineering Management Corporation (AEM Corporation) along with her staff served as the conference rapporteur and prepared this document as a factual summary of what occurred at the conference. Responsibility for the published conference proceedings rests with the rapporteur. This report generally follows the conference agenda. It summarizes and paraphrases the presentations of each speaker and follows the speaking and audience discussion order of each session. Suggested research and research questions are included in the summary of the Closing Plenary session near the end of this report.

The views contained in this report are those of individual conference participants and do not necessarily represent the views of all participants, the planning committee, TRB, or NASEM. TRB thanks the following individuals for their review of the summary: Michael Culp, FHWA; Steve Godwin, NASEM; Heather Holsinger, FHWA; Carol Lee Roalkvam, Washington State DOT; and Kees van Muiswinkel, Rijkswaterstaat, the Netherlands.

Opening and Welcome Remarks

The 2nd International Conference on Transportation System Resilience to Natural Hazards and Extreme Weather was held November 13–15, 2019, in Washington, D.C. The conference was designed to provide transportation agencies with information, research results, and sample practices to assist in their ability to anticipate and adapt to the potential impacts of climate change and extreme weather events. The conference also included international dialogue on research, implementation, and lessons learned.

OPENING REMARKS

The conference opened with comments from the Conference Planning Committee co-chairs, including Michael Culp from FHWA; Carol Lee Roalkvam from Washington State DOT; and Kees van Muiswinkel of Rijkswaterstaat in the Netherlands. Michael Culp recognized the Conference Planning Committee and TRB staff for their efforts and gave special recognition to Bill Anderson and Gary Jenkins of TRB for their leadership in planning the conference. Kees van Muiswinkel noted that the first resilience conference held in 2015 had 250 participants, while the 2019 conference had 310 participants registered (288 attending) from more than 70 international entities.

Carol Lee Roalkvam facilitated the opening plenary session and thanked TRB for arranging the facility and hosting the conference. Remarks from the planning committee were followed by remarks from the three convening organizations: TRB, FHWA, and AASHTO.

Neil Pedersen thanked FHWA and AASHTO for supporting the conference. Pedersen also thanked the planning committee and TRB staff and provided an update on the latest products by TRB and what TRB is working on in the area of resilience. TRB's Executive Committee identified resilience and security as one of 12 critical topic areas for transportation for the next 10 to 20 years. Within the topic of resilience and security, Pedersen identified three major areas. The first area was risk assessment and management for assets vulnerable to extreme events. TRB recognized a need for decision-making tools to help transportation agencies make decisions about climate change, terrorism, and risk management. These tools will allow risk and resilience to be incorporated into transportation planning and decision-making, as well as translating results from climate models into changes in design standards for severe weather events. The second major area was adaptation. Pedersen noted there is a need for policies, programs, research topics and investments to adapt existing transportation facilities to sea-level rise, stronger storm surge, frequent flooding and extreme weather events. In addition, there is a need to evaluate and share the experience of communities already beginning to adapt to climate change. The third major area identified includes the need for policies, designs, standards and funding for resilience, including how to develop policies to fund adaptation, and timing of future impacts from climate change. Pedersen noted that solid evidence is needed to convince policy makers and the public to begin funding adaptation now.

Pedersen went on to outline several Cooperative Research Program products released since 2018. Publications of note from the National Cooperative Highway Research Program (NCHRP) and the Transit Cooperative Research Program (TCRP) included the following:

- *NCHRP Synthesis 527: Resilience in Transportation Planning, Engineering, Management, Policy, and Administration;*
- *NCHFRP Research Report 39: Freight Transportation Resilience in Response to Supply Chain Disruptions;*
- *NCHRP Research Report 930: Update of Security 101: A Physical Security and Cybersecurity Primer for Transportation Agencies (2020);*
- *NCHRP Research Report 931: A Guide to Emergency Management at State Transportation Agencies (2020);* and
- *TCRP Web-Only Document 70: Improving the Resilience of Transit Systems Threatened by Natural Disasters, Volume 1, A Guide.*

Also, ongoing research projects includes:

- NCHRP Project 20-59(53), "FloodCast: A Framework for Enhanced Flood Event Decision Making for Transportation Resilience"
- NCHRP Project 20-59(54), "Transportation System Resilience Research Roadmap Research and White Papers;"
- NCHRP Project 20-59(55). Transportation System Resilience: Chief Executive Officer (CEO) Primer & Engagement; and
- NCHRP Project 59(56), "Support for State DOT Transportation Systems Resilience and All-Hazards Programs."

Other projects in the procurement process (as of November 2019) include:

- NCHRP Project 20-44(23), "Pilot Test of Climate Change Design Practices for Hydrology and Hydraulics;"
- NCHRP Project 20-116, "An Emergency Management Playbook for State Transportation Agencies;" and
- TCRP J-05, Topic 19-05, "Legal Aspects of Transit and Intermodal Transportation Programs."

Pedersen explained that the three standard technical committees on resilience are being reorganized into a Sustainability and Resilience Group with three sections: Transportation and Sustainability, Transportation Systems Resilience, and Transportation and Society. Finally, Pederson closed with an overview of upcoming TRB activities including the 99th Annual Meeting in 2020 that is scheduled to include a workshop on humanitarian logistics during natural disasters and a Freight System Resilience Workshop scheduled for the fall of 2020.

Tom Everett thanked Pedersen and TRB, as well as Jim Tymon of AASHTO, the organizing committee, and FHWA staff who helped to organize the conference. Everett began his remarks by noting that every year the transportation system is stressed by blizzards, searing heat, ice storms, flooding, wildfire and other severe weather events. Hurricanes Katrina, Sandy, Irma, Maria, and Harvey raised awareness of the vulnerability of coastal communities. And recent hurricanes along the coast have cost the American taxpayer \$4 billion in federal and emergency relief funding. He noted that it is not only coastal states that are affected, but interior states as well including serious flooding in Texas, Oklahoma, Arkansas, Missouri, and all along the Mississippi River in recent years. It was noted that in the weeks prior to the conference,

Americans watched as severe wildfires in California forced people to evacuate their communities. Everett stressed that it is necessary to learn from these events, to anticipate future risk to maximize service while ensuring the safety of the traveling public, and work to minimize disruption. This need will require work together on resilience issues, and across all disciplines—from planning, to design, to operations. As an example, during the 2013 Colorado flood, a stretch of U.S. Highway 36 (US-36) was washed out and FHWA partnered with the Colorado DOT to reconstruct US-36 and make it more resilient to future flooding by realigning the highway on more stable bedrock. Everett announced that U.S. DOT recognized the importance of resilience in its 2018–2022 strategic plan by working to ensure that infrastructure is resilient enough to withstand extreme weather. One of the fundamental roles of FHWA is to work with partners to extend the service level of U.S. highways while enhancing public safety. Together with state DOTs, metropolitan planning organizations (MPOs), federal, and international partners, FHWA has been developing training and technical assistance and other resources on resiliency for more than 15 years. FHWA has also put together numerous collaborative research projects to advance the state-of-the-practice on how to integrate resilience into planning and asset management, design, and operations. Most recently FHWA released an *Implementation Guide* on incorporating nature-based solutions for coastal highway resilience.

Jim Tymon thanked the planning committee, FHWA, TRB staff, and AASHTO for organizing the conference and noted that many transportation organizations are grappling with multiple challenges including a potentially insolvent highway trust fund. With only a matter of months before the expiration of the Fixing America's Surface Transportation (FAST) Act, the prospects for a new surface transportation authorization seem slim based on the current political climate. Despite that, AASHTO's Board of Directors in October approved a set of reauthorization principles that inform and support the development of future legislation.

Tymon noted that the United States continues to set records for annual vehicle miles traveled, however, DOTs now recognize the need to focus on mobility, moving people and goods, not just vehicles. While technology advances, from connected vehicles, to drones, to innovations in retail and manufacturing, state DOTs are re-doubling their focus on Toward Zero Deaths, the national strategy for eliminating serious and fatal crashes, a major priority for the current AASHTO President, Patrick McKenna, the director of the Missouri DOT, and the AASHTO Board of Directors.

Tymon described extreme weather as one of the most important and critical problems facing transportation today including fires in California, flooding in the Midwest, and massive storms pummeling the southeast and Gulf States. However, no matter the stresses to the system, the traveling public expects the transportation system to keep running. AASHTO's Board of Directors recognized this and approved a resilience resolution during its annual meeting in St. Louis in the fall of 2019. That resolution called for increasing the flexibility of the Transportation Performance Management and the Emergency Relief (ER) programs to improve resilience that will help state DOTs develop climate-resilient infrastructure following extreme weather events and use ER program funds to incorporate betterments to reduce the risk of future reoccurring damages.

AASHTO's commitment to helping states prepare for extreme weather and natural disasters extends to all its activities including the Resilient and Sustainable Transportation Systems (RSTS) Technical Services Program. This program provides state DOT practitioners with technical assistance through newsletters, webinars, and case studies to provide information sharing opportunities and other resilience-related resources and tools. In addition, the AASHTO

Committee on Transportation System Security and Resiliency (TSSR), and the Committee on Transportation System Operations (TSO), provide forums for the exploration of best practices and research in these areas. The cross-discipline approach of these groups is an example for how the industry must work outside traditional DOT silos to think creatively about solutions to climate change challenges.

Prioritizing Resilience at State Departments of Transportation

Progress and Challenges

PAULA J. HAMMOND
WSP, Inc., Moderator

State DOTs face threats to their statewide systems daily. Whether nature- or man-made, disasters can close critical facilities on a moment's notice, disrupting the economic vitality and quality of life of communities. In this session, state DOT leaders discuss their progress and challenges in becoming more resilient agencies; in their organizational approach and through all phases of infrastructure development and operations.

Hammond framed the partnership that TRB, AASHTO, and FHWA have had around this conference and on many of the topics of resilience as being an important way for identifying resources, policies, and research needs to address the challenge. She noted that research has been ongoing for several years on the topic of resilience and recent research includes a Chief Executive Officer (CEO) Primer on the topic and a guidebook anticipated in 2020 through NCHRP 20-117, "Deploying Transportation Resilience Practices in State DOTs." The documents are intended to support agencies as they determine what resilience means to various agencies as agencies face increasing threats. From the aspect of maintenance, planning, operations, budgeting, engineering, and financing, every agency has to think differently in the face of the threats that are realized and try to insulate and create programs that will deliver systems in a way that are resilient and can recover from disasters.

Recognizing the cycle of activities needed to support resilience within an agency, the AASHTO Committee TSSR created a graphic (Figure 1) that reflects incorporating resilience into every aspect of a transportation project life from development, design operations, and maintenance.



FIGURE 1 AASHTO TSSR event circle of life. (Source: AASHTO Committee on Transportation System Security and Resilience)

EDWARD SNIFFEN*Hawaii DOT*

Sniffen stated that the Hawaii DOT is a relatively small state DOT agency with 2,500 lane miles spanning six islands serving upwards of 1 million residents and approximately 300,000 visitors daily. The Hawaiian highway system consists of a belt on each island servicing communities that developed around the ocean; the highway belts ensure connectivity and beautiful views of the ocean; but also pose significant dangers daily. Sniffen noted that 20% of the system is impacted by shoreline erosion, an annual ongoing challenge. Hawaii DOT's initial thoughts were to harden everything at risk. The agency soon learned that wrap-around erosion, in different areas of the system, as a result of hardening can occur.

Initial reports predicted that within 50 years, 15% of the system would be inundated, not only by sea-level rise, but also by rising ground water. In fact, two 500-year floods have occurred in the last 3 years.

Hawaii DOT began to prioritize areas and look for proactive approaches to improving resilience including a predictive erosion analysis of the shoreline which was developed to allow for resilience planning. In areas with 20% roadway inundation anticipated in the next 100 years, elevation or relocation plans were considered, with estimated costs of \$15 billion, or \$7.5 million per lane mile, \$40 million per bridge, plus acquisition costs.

During the floods that occurred on Kaua'i in 2018, there were 29 landslides along the highway that cut off two portions of the island resulting in \$100 million of recovery costs from that event and to improve future resilience. However, it is recognized that the efforts taken are incremental given the existing slopes above the roadway and ocean below. Hawaii DOT also has considered the rockfall threat to their system and recent analysis found that the top 10 at-risk sites are anticipated to cost more than \$100 million to mitigate.

Hawaii DOT has attempted to build resilience into their operations in the past through rockfall reports in 2000 and a shoreline erosion and protection study completed in 2003. Currently, the agency is pulling their staff together to make sure a report format and process can be developed that all can agree to, including planners and emergency management staff from the state. The agency recognizes they do not only build roads but build roads to connect people and to build communities.

The agency is working to consider resilient solutions that address concerns, such as inundation that may relocate a community in the next 50 years and trying to localize solutions when possible. The land use considerations are tremendous when considering the anticipated \$15 billion to address resilience needs. In those areas where the road is inundated, where houses remain, the agency is working to build roadways that keep a connection in the area of homes. Hawaii DOT is also considering emerging technologies that may allow for service in new ways.

Hawaii has established a climate change commission to ensure the right stakeholders are engaged including land use, permitting agencies, and local community leaders to help determine connections for the future. The state is also working with large landowners to ensure their plans and the agency's policies align better. Hawaii DOT is also considering resilience in their day-to-day operations with emergency management agencies to prepare so agencies can act immediately to respond to events.

When considering the overwhelming \$15 billion problem, it is difficult to act. If the focus is put on priority issues (such as roadways that will be inundated tomorrow), it becomes easier to start a process that will address resilience. A prioritized list can assist with improving resilience

in a more deliberate manner. In doing so, it is very easy to come up with a plan to address future needs. The agency has initiated a stepwise process to first establish emergency management protocols, first to respond no matter what occurs, and then next address issues in the near term and far term as needed.

GREG SLATER

Maryland State Highway Administration

Slater spoke about a series of revelations at Maryland State Highway Administration (SHA) related to resilience and climate. The first revelation was over 10 years ago when the industry was focused on mitigation and air quality. At that time, adaption was not discussed, although it was of concern and a bigger issue for the organization. The second revelation was that adaptation is not just about water and weather, it's about how these factors impact the function of the system day-to-day. The third revelation is that dedicated staff to address resilience and climate change are needed. The last revelation—it's about everything—resilience should be considered in planning, engineering, asset management, land use, assessing risk, and operations every single day.

Due to the amount of coastline in low-lying proximity to the Chesapeake Bay and Atlantic Ocean, Maryland is one of the three most-vulnerable states to climate change in the nation along with Louisiana and Florida. Each day on average, two sections of the agency's system are inundated and cut off communities because of tidal shifts. As an example, roadways outside of Annapolis were built on a streambed and when it rains, the community is cut off for days at a time.

Land use and how agencies deal with land use and climate change are also under consideration by the agency. Maryland SHA received a FHWA Resilience Pilot Grant that resulted in a culmination of the 2014 Climate Change Adaptation Plan and the development of a detailed vulnerability assessment. The agency sought to understand the evaluation framework and the engineering approaches for risk resulting in an agency Hazard Vulnerability Index (HVI). Working with Salisbury University, Maryland SHA sought to understand what the data was revealing about impacts on the system and travel, and not just the state system but also the local system. The agency sought to integrate this information into the project development process.

In 2019, the agency sought to integrate extreme weather and climate risk into their asset management program and worked to bring those aspects into day-to-day operations and project delivery. The agency reviewed the goals of their vulnerability assessment and worked to understand and mitigate identified risks. Questions considered include, how does risk to an Interstate or an evacuation route differ from risk to other types of roadways? What is the redundancy of the system? How many detours exist? Will a community be cut off? Is the agency addressing redundancy that is needed in the system? The agency sought to study linear assets and bridge assets while addressing asset management federal regulations and legislation resulting in long debates in the state capital.

Slater provided an overview of several vulnerable locations in the state including Annapolis, the state capital, built on the coastline in an historic town. It is constantly inundated by large rainfall and the projected sea-level rise anticipated by 2050 is of concern. Kent Island, another coastal area, was affected by a 50-year storm in 2015 resulting in many coastline homes, state and local highways inundated. Downtown Crisfield, located in the lowest part of Maryland, experiences sunny day flooding from water levels rising on a windy day that pushes the tide

inland. This type of flooding adds wear and tear of assets and may degrade the local transportation system and effect the community.

Maryland SHA has been considering land use, mobility, and safety when considering resilience and climate change and consider day-to-day management of these challenges. The agency's HVI is a data-driven approach to assess risk that considers functional class of the system: how the system is used, how much freight it carries, and the level of commuter traffic. Maryland is looking at the vulnerability of every part of their system including local roads and using this as a tool to reach out to communities to help them understand what their vulnerabilities are on the system. The vulnerability assessment tool can provide a scale of risks and vulnerabilities to help the agency prioritize investments.

Maryland has also integrated the Vulnerability Assessment Scoring Tool (VAST) model from FHWA, a tool for assessing vulnerability of asset points. Through this work the agency identified over 8,500 structures—bridges, culverts, and drainage—and classified three out of four of those structures as highly vulnerable. The agency uses such tools to reach out to local government and stakeholders to help explain the issues present in the system. The agency also uses this information to prioritize assets that have the greatest vulnerability and integrates this information into the planning process, engineering design, systems operations, and asset management. By allowing this information to be incorporated into the planning process, issues can be identified early, at the beginning of a project. Guidance and tool development have been a priority to provide planners and engineers what they need to address resilience. By integrating resilience into the planning stage when operational, safety, and asset needs are considered, vulnerabilities can be addressed systematically. Maryland SHA is looking to expand vulnerability assessment tools to other modes of travel and engaging a wider group of stakeholders into the conversation, including communities, land use professionals, local governments, and municipalities.

The greatest challenges used to be addressing safety, the agency's first and foremost concern, growing congestion and maintaining a state of good repair of the highway assets. Recruiting and maintaining the workforce of tomorrow is also a challenge. Flooding has emerged as one of those top challenges of the agency as it also impacts mobility, resources, safety, and connectivity of the system. It can be argued that flooding, weather, and resilience have become critical issues, along with congestion, safety, and asset management.

ELLEN GREENBERG

California Department of Transportation

This presentation addressed the efforts California has made to incorporate resilience into their planning. Governor Arnold Schwarzenegger started addressing climate change between 2003–2011. Current Governor Gavin Newsom has prioritized resilience and made the statement, “Together, let us build a house stronger than the coming storms, yet open to the world.”

What is the difference between adaptation and resilience? Adaptation is the steps taken to enable greater resilience. In California, “Resilience is the capacity of any entity—an individual, a community, an organization, or a natural system—to prepare for disruptions, to recover from shocks and stresses, and to adapt and grow from a disruptive experience.” California is a place already experiencing extreme weather events and the impacts of climate change; however, intensity has been exacerbated and the frequency is increasing.

The state's framework for action broadly consists of three components. The first component is to reduce emissions. The 2017 Climate Change Scoping Plan addresses California's plan for reducing greenhouse gas emissions. The second component is preparing for impacts, addressed in the *Safeguarding California Plan: 2018 Update*. The third component is research, an example is *California's Changing Climate 2018 Report*. All three reports are available online (https://ww3.arb.ca.gov/cc/scopingplan/scoping_plan_2017_es.pdf; <https://www.slc.ca.gov/sea-level-rise/safeguarding-california-plan-2018-update/>; and https://www.energy.ca.gov/sites/default/files/2019-08/20180827_Summary_Brochure.pdf).

California's adaptation vision includes all people and communities responding to changing conditions in a manner that minimizes risks to public health, safety, economic disruption, and maximizes equity and protection of the most vulnerable. Natural systems adjust and maintain functioning ecosystems and infrastructure and built systems withstand changing conditions, while continuing to provide essential services.

Several case studies have been developed and hosted on the Adaptation Clearinghouse, along with a sister site referred to as Cal-Adapt. Cal-Adapt also hosts climate projections for snowpack, wildfire, sea-level rise, drought, and annual averages. As part of an outreach effort, California DOT (Caltrans) staff spoke about the Safeguarding California program at a public forum and found that participants were baffled that Caltrans' vulnerability assessments are focused on state-owned roads. Many people are not aware that different roads are owned by different agencies which highlights the need to look at the whole system in a more integrated way.

Caltrans has several vulnerability assessments underway, addressing such climate stressors as sea-level rise, storm surge, precipitation, high temperatures, and wildfire. The assessments are being prepared for all 12 Caltrans Districts and include summary reports, technical reports, and an online tool viewer. Caltrans has reached out to its 12 Districts to see how each is using this information. Right now, as a department, there seems to be no clear path as to how to integrate the outputs of these studies into statewide activities. When looking at risk and prioritization, the agency is working to integrate each district's prioritization and assessment of risk into a statewide program. The agency is also working through methods to consider climate risk alongside all the other risks, such as seismic.

It is not just the matter of triage, that is, the prioritization within the climate or extreme weather risk, but the other risks to the system as well. For example, how will the workforce be affected? What are the consequences for people working in construction and maintenance? What about the hardships the workforce manages when responding to extreme events? In addition, there are equipment shops that are not air conditioned that are already reaching temperatures over 80 degrees inside the facility, creating unacceptable working conditions.

Highlighting operational strategies, District 10, which includes the city of Stockton and some of the Sierra Nevada Mountain Range, including Yosemite National Park, has partnered with the National Weather Service so that when storms are anticipated, roads leading into Yosemite National Park can be closed in advance of rain events. These road closures were activated during the last storm season, minimizing risk to the roadway and allowing the focus to be on reopening the roadway rather than rescuing stranded people and clearing stranded vehicles.

Caltrans is also responding with more traditional infrastructure solutions for example, Highway 1 in Central California is scenic and historic that has been realigned because of accelerated rates of coastal erosion. This has been a very complicated process involving obtaining an easement from the property owner, working with the California Coastal Commission and a wide range of other stakeholders.

In addition, there are many communities outside of urban areas that are dependent on state highways and the issue of stranded communities and the necessary investment to maintain connectivity is a key issue Caltrans is considering. In addition to rural area connectivity challenges, these areas often have substantial tourism which is an important part of the economy.

MARK RUSSO

New Jersey Department of Transportation

New Jersey has 38,000 mi of roadway with approximately 55% of the system on the local system. As a whole, New Jersey highways carry 2.6 million vehicles per lane, compared to the national average of 1.5 million vehicles per lane. New Jersey is also the third smallest state, geographically, but the 11th most populated, making it the most densely populated state in the nation. New Jersey has 6,752 bridges that are more than 23 years over their anticipated 75-year life expectancy. Regarding climate stressors, the northeast of the United States has experienced a 2°F increase in mean temperature in the past century and a 71% increase in the amount of precipitation falling as heavy events, defined as the heaviest 1% of all daily events from 1958 to 2012. In addition, annual precipitation has increased at a rate of 2.4 in. per century. As a result, since 2009, there have been 16 federal disaster declarations and 28 state emergency declarations and a total of 44 severe events in New Jersey. Hurricane Irene alone cost the state \$15.8 billion in damages in 2011 and Hurricane Sandy cost \$50 billion in 2012. The impacts of extreme weather can also be cumulative, for example after Hurricane Sandy, New Jersey suffered a “nor’easter” winter storm.

Hurricane Sandy rendered 12.5 mi of Route 35 useless which runs the length of the peninsula, with 12.5 mi of the divided highway destroyed during the storm. In this event concrete slab sections of the roadway were tossed like dominos resulting in scores of sinkholes where the drainage system collapsed and raging storm surf cut three channels across the island from the ocean to the bay; taking the highway with it. Extended stretches of the highway were buried under sand dunes strewn with vehicles, boats, and houses. Emergency responders could only watch from the distance while fires fueled by broken natural gas lines consumed an entire neighborhood. To permanently restore the project in kind required complete reconstruction of 43 lane miles of highway, construction of a new drainage system, complete reconstruction of the Route 35–Route 37 interchange, and extensive relocation of underground facilities. The total project cost reached \$348.51 million.

As part of FHWA reporting guidelines under 23 Code of Federal Regulations (CFR) 515,¹ New Jersey DOT embarked upon reporting its assets, their status and a long-term management plan with input from subject matter experts throughout the New Jersey DOT. Staff from the Division on Environmental Resources made note in the Transportation Asset Management Plan (TAMP) regarding the risks to assets under future climate change and past extreme events. Furthermore, FHWA guidance regarding resiliency was issued under the Moving Ahead for Progress in the 21st Century Act (MAP-21) and the FAST Act.

As a natural outgrowth of the TAMP work activities, FHWA sponsored a resilience pilot study that New Jersey DOT participated in that investigated asset management, extreme weather, and proxy indicators within the agency’s network. Using the department’s drainage management system, sections of the New Jersey DOT were selected for study and reviewed to identify potential problem areas from future events. The pilot study investigated culverts in an area prone to flooding partially due to topography, but it was determined that flooding was not due to

undersized culverts but due to a lack of maintenance. The lesson learned was to understand the nature of the problem before attempting solutions. This report was included in the final New Jersey DOT TAMP report and as part of a FHWA guidance manual.

In 2018, New Jersey formed the New Jersey Department of Environmental Protection (NJDEP) Coastal Resilience Working Group. Through professional connections with sister state agencies, New Jersey DOT Division on Environmental Resources staff attended meetings and forums that discussed coastal resiliency. In October 2018, key staff from New Jersey DOT Division of Environmental Resources attended the Transportation RISE conference. Here NJDEP staff presented draft findings of their FHWA Pilot and learned about other states and their efforts in resiliency, specifically Colorado DOT. These lessons helped drive the current approach to addressing resiliency at New Jersey DOT. Later in 2019, Governor Murphy signed Executive Order 89, establishing a statewide climate change resilience strategy and established the office of New Jersey Chief Resilience Office.

New Jersey DOT's approach to resilience is to integrate resilience into all aspects of New Jersey DOT's organization and create policies and procedures to reduce impacts from climate stressors. New Jersey will accomplish this with the Resilience Working Group. Senior New Jersey DOT directors and managers, climate scientists, and third-party stakeholders are working on policies, design standards, asset management, project delivery, maintenance and operations strategies for resilience. In addition, New Jersey has created an enterprise-wide systemic approach to resilience, developed a New Jersey transit resilience program, written and implemented preparedness plans and is building a coastal storm surge emergency warning system.

Remaining challenges include how to define resilience, asset failure and system failure; how to identify new risks that need to be addressed; and how to determine what year event to design for and how to set design standards. Climate stressors and what they mean to infrastructure in terms of impacts and consequences needs to be determined along with climate data projections across the state. Coordinating statewide is also a challenge along with encouraging local efforts to address the resilience of the transportation network. Finally, there are both fiscal and regulatory challenges including a constrained capital program of \$2.3 billion. Incorporating resilience likely increases upfront costs and FHWA (ER) funding currently does incentivize resilience measures. In addition, regulatory challenges include replace-in-kind requirements for funding, and NJDEP regulations that prohibit use of future projections in design.

Note

1. Code of Federal Regulations, Title 23-Highways, Part 515 Asset Management Plans.

Integrating Transportation Resilience into Asset Management

NASTARAN SAADATMAND
Federal Highway Administration, Moderator

This session explores approaches to address the impact of current and future environmental conditions on transportation assets or highway networks. These approaches, whether focused on an entire network, a corridor, or a specific group of assets, provide a better understanding as to how to appropriately plan, design, manage, and make infrastructure investments to increase system resilience.

INTEGRATING EXTREME WEATHER RISKS INTO TRANSPORTATION ASSET MANAGEMENT PLANS AND PRACTICES

ROBERT KAFALenos
Federal Highway Administration

Background

Resilient practices are important to protect the public and save financial resources. Environmental conditions are changing faster than at any point in the history of modern civilization, including global sea-level rise, expected to rise between 1 to 4 ft in the 21st century, and average temperatures in the United States, expected to rise between 3°–11°F this century.

An overview of methods outlined in a forthcoming FHWA guide provides methods for incorporating resilience into asset management practices and plans and includes examples of new areas to consider like life-cycle planning, asset deterioration models, and financial planning.

Innovations

FHWA has sponsored several climate change and extreme weather pilots in the past several years that address several topics. As shown in Figure 2, the geographic distribution of the pilots seeks to address challenges not only in coastal locations but also to inland areas dealing with extreme weather risks.

A few examples of the work completed in these studies to incorporate resilience into asset management plans include:

- Kentucky Transportation Cabinet:
 - Use of vulnerability assessment in development of risk register and
 - Consideration of the effect of extreme weather events on asset deterioration rates and life-cycle planning.
- Maryland SHA:
 - Development of methods to pull coastal vulnerabilities and hazards into bridge and pavement management systems and
 - Update of life-cycle management plans to reflect future environmental risk.



FIGURE 2 Resilience and durability pilots to date. (Source: FHWA)

Contribution

FHWA is developing a handbook on the topic of resilience in asset management; related resources can be found at <https://www.fhwa.dot.gov/asset/resources.cfm>.

PRIORITIZING INFRASTRUCTURE RESILIENCE THROUGHOUT THE TRANSPORTATION CAPITAL PLANNING PROCESS

JON CARNEGIE

Rutgers University, Voorhees Transportation Center

Background

The Voorhees Transportation Center is conducting an ongoing study on the topic of documenting methods and approaches being used by transportation agencies to incorporate resilience into capital planning processes. Project authors are seeking to document

- Vulnerability assessment methods,
- Asset management methodologies,
- Benefit–cost (B/C) and return on investment (ROI) methodologies,
- Project identification and prioritization methods,
- Project design and construction methods,

- Regional coordination and interdependencies, and
- Personnel and organizational structure.

The study seeks to generate several case studies, hold a peer exchange, and develop a final report in the next several months.

Innovations

The study is documenting practices in the following locations:

- Maryland DOT,
- Massachusetts Bay Transportation Authority (MBTA),
- Massport,
- Metropolitan Atlanta Rapid Transit Authority (MARTA),
- Metropolitan Transportation Authority New York City Transit (MTA-NYCT),
- Port of Long Beach,
- Port Authority of New York & New Jersey (PANYNJ), and
- Southeastern Pennsylvania Transportation Authority.

One of the locations being studied is the MTA-NYCT. Figure 3 shows an overview of the various activities undertaken at the agency to address resilience in their capital planning process.

MTA-NYCT is working to incorporate resilience into multiple areas of their capital planning program including asset management, project identification and prioritization, and project design and construction.

Metropolitan Transportation Authority New York City Transit (MTA-NYCT) – New York City, NY

Vulnerability Assessment

- System-wide assessment for storm surge and SLR, SLOSH Cat 2 + 3 feet
- Limited assessments for heat, rain event flooding, winter weather
- Currently modeling sub-surface water movement

B-C / ROI Methodologies

- Utilize FTA Hazard Mitigation Cost Effectiveness Tool

Project Design and Construction

- Recommended mitigation measures
- Performance-based design criteria

Asset Management

- Legacy system “flags”
- More comprehensive treatment in emerging enterprise-wide TAM system

Project Identification/Prioritization

- Separate capital program funded by Sandy Disaster Relief
- Transitioning to resilience in standard capital program

Other

- Modified SOPs to address new resilience features
- Training, drills and new tools

FIGURE 3 Resilience activities at MTA-NYCT.
(Source: Voorhees Transportation Center)

Contribution

The project seeks to add to the state-of-the-knowledge by documenting processes and methods to incorporate resilience into capital planning programs at transportation agencies with an emphasis on transit and port authorities. The project is expected to be completed in 2020.

SOUTHEAST MICHIGAN FLOODING STUDY: ASSESSING RISK AND BUILDING RESILIENCE

KELLY KARIL

Southeast Michigan Council of Governments

Background

The Southeast Michigan Council of Governments (SEMCOG) is a regional planning partnership that provides technical assistance to over 170 units of local government in seven counties serving 4.7 million residents. SEMCOG has 8,322 centerline miles of federal aid-eligible roadways with over 25,000 mi of overall roadway generating 100 million mi of travel daily.

Michigan DOT was included in a climate vulnerability pilot project funded by FHWA in 2015 that resulted in a statewide flooding analysis of roads, bridges, culverts, and pump stations, and included a robust criticality assessment capturing the consequences of removing an asset from service.

Innovations

Building on the climate vulnerability pilot, a new project was initiated to provide a risk score for flooding risk assessment for major roads, bridges, culverts, and pump stations in the SEMCOG region. The project focused on all assets on the three major Michigan DOT functional classification roadways including: Interstates, other freeways, and other principal arterials. Example indicators as to potential risk from flooding include:

- Past flooding experience;
- Federal Emergency Management Administration (FEMA) flood zone location (in or near 100-year or 500-year flood zone);
- Flow accumulation and ponding: characterizes asset exposure based on the area surrounding the asset;
- Impervious surface: the percent of the watershed sub-basin that is impervious surface, based on SEMCOG land cover data; and
- Change in days with precipitation greater than 3 in.

An example of risk scores across SEMCOG is included in Figure 4.

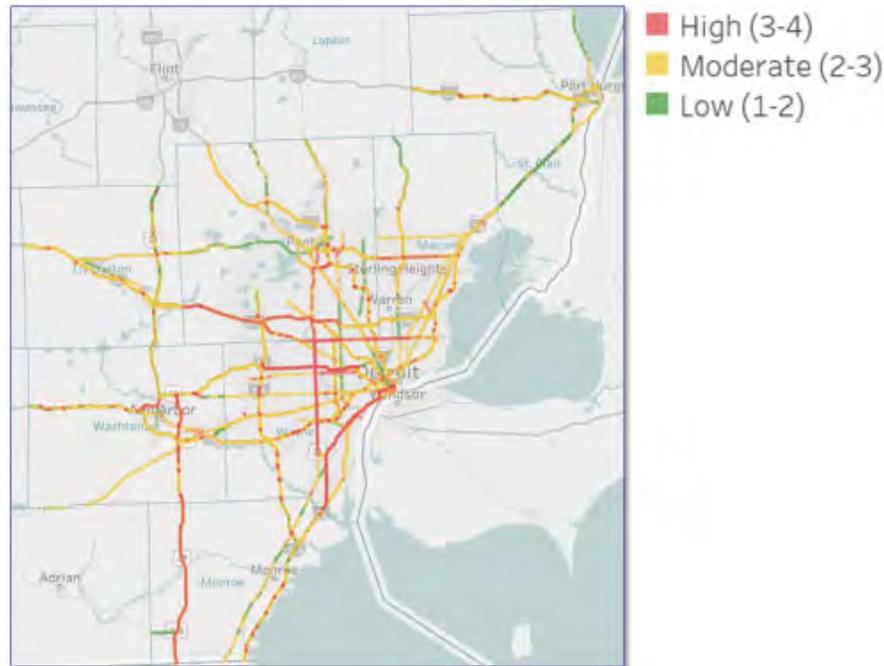


FIGURE 4 Road flooding risk results. (Source: SEMCOG)

Contribution

Through this project SEMCOG sought to improve the ability to integrate risk assessment data from flooding into its decision-making process by creating a numeric score to rate risk across their highway system based on several factors they feel are indicators of risk from flooding. This contribution to the state-of-the practice is through the move from qualitative and visual inspection of flood risk toward a more quantifiable rating of risk to ease the inclusion of such information into capital planning activities.

MAXIMIZING THE RESILIENCY FROM YOUR CAPITAL SPEND: ANALYSIS TOOLS TO ADDRESS RESILIENCY GOALS MANAGEMENT

ISTER MORALES
Gannet Fleming, Inc.

Background

Methods for increasing resilience by incorporating the management of extreme weather and climate change into the life-cycle planning and management of transportation projects—assets were developed in projects for two state DOTs that were reviewed. This study focused on the identifying root causes of impacts and vulnerabilities from extreme weather events when seeking alternatives to reduce future risk. The study included two case studies from New Jersey DOT and Arizona DOT that sought to better understand how the agencies could reduce vulnerabilities from extreme weather events by using a three phased approach as shown in Figure 5.

Innovations

An approach illustrated in this study was to address the entire life cycle of an asset when seeking reductions in vulnerability. For example, the authors studied information provided by safety and maintenance records to identify high-crash locations that coincidentally also saw a reduction in maintenance activity to clear inlets and manholes of debris during the same study periods. The authors concluded that extreme rain events during the month of July resulted in a peak in flood incidents during a period with reduced maintenance activity. In addition, the authors noted the potential relationship between the reduced maintenance activity and the increase in vehicle incidents.

Contribution

The study included the demonstration of a geographical information system (GIS) -based dashboard that included information on extreme weather event maps, asset information such as culvert condition information, and local information such as river level gauge status. By providing this type of information to Arizona DOT staff in one central location, the authors surmise that resilient solutions will be better incorporated into the decision-making process throughout the life cycle of the asset.

Methodology

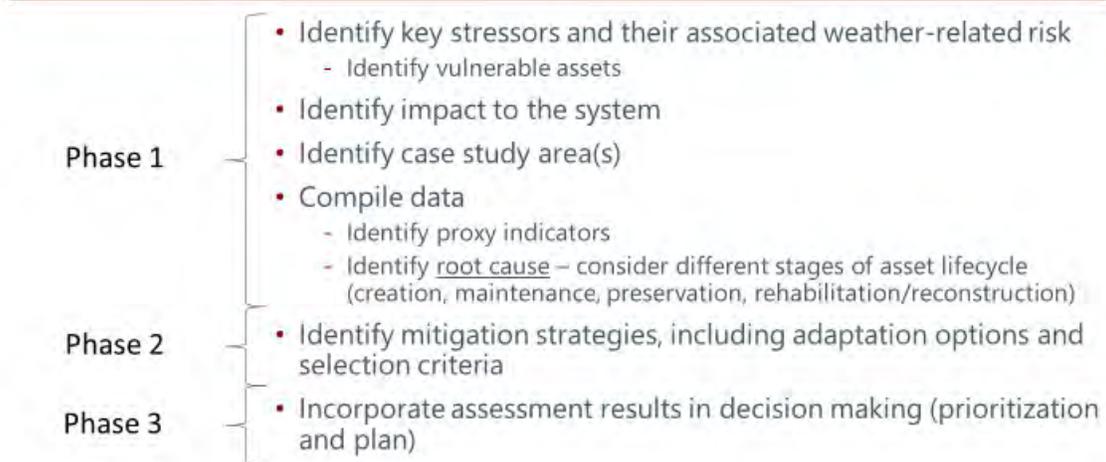


FIGURE 5 Three-phase methodology utilized. (Source: Gannett Fleming)

DEVELOPMENT AND INCORPORATION OF QUANTITATIVE RISK AND RESILIENCE ANALYSIS STANDARDS INTO AGENCY DECISION-MAKING

Aimee Flannery

AEM Corporation

Background

This presentation provided information on methods developed for Colorado and Utah DOTs on methods to quantify annual risk to both the owner (agency) and the public (traveler) from a range of physical threats including flooding, rockfall, debris flow, and landslides. The studies sought to engage DOT staff to consider anticipated losses to highway assets, such as culverts, roadway prisms, and bridge approaches that reflect the age, design standard, and condition of the asset as well as information on the magnitude of the event feasible to affect the asset. Agency staff from a range of backgrounds have been engaged in both Utah and Colorado DOTs to consider empirical, theoretical, and expert opinion information on anticipated asset performance from physical threats and provide their input. From here, models were developed to estimate anticipated consequences to the agency and the traveling public (from closures and detours) should events occur that have the potential to damage the highway network. The result was agency-specific models that reflect threats that are important to each agency, asset condition and performance information specific to each agency's data availability and maturity, and expert opinion as to the expected performance under stress from relevant threats to each agency.

Innovations

This study highlights the innovations associated with moving toward a quantitative method to assess the annual risk from a range of physical threats to assets and also highlights the establishment of measures and metrics to better align risk assessment with more traditional measures used in decision-making such as those used in operational and safety assessments. The authors note the introduction of risk and system resilience metrics by the Utah DOT into story maps used in the corridor planning process as shown in Figure 6.

Contribution

As the use of risk and resilience assessment methods continue to mature within the transportation industry, methods by which to streamline the use of such assessments within traditional engineering and planning decision-making processes is critical to normalize the use and consideration of such concepts. This study highlights the use of these methods by Colorado and Utah DOTs to begin to establish methods, measures, and metrics to assess risk from a range of physical threats to highway assets and impacts to the traveling public.

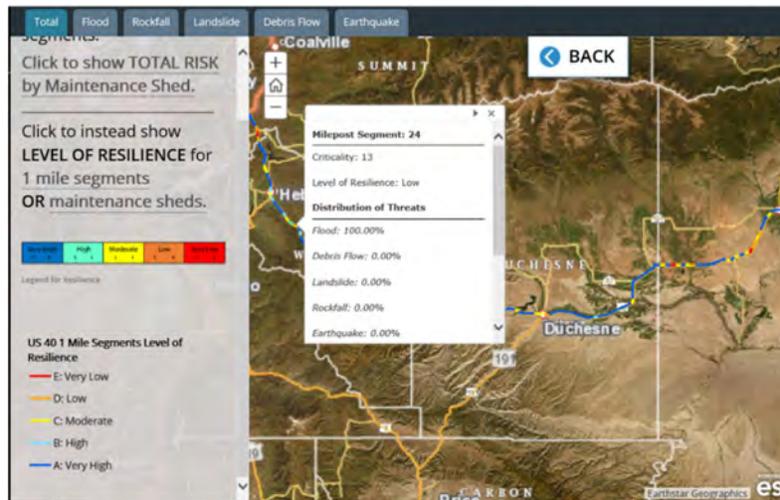


FIGURE 6 Quantitative risk and resilience metrics used in Utah DOT's corridor planning. (Source: AEM Corporation)

SESSION QUESTIONS AND DISCUSSION

Q. Has FHWA considered high-performance concrete as a solution for flood vulnerability of pavement?

A. FHWA: Not currently.

Q. The Port of Long Beach, California, has made the business case to clients and tenants for resilience to support investments, has this been considered in the locations studied by Rutgers University?

A. Not specifically, but it is easier to make the case post-Hurricane Sandy.

Q. Did Rutgers University note any construction practices change due to resilient practice implementation?

A. Not specifically, findings are more post construction focused (existing infrastructure).

Q. How did Arizona and New Jersey use the data generated for planning?

A. Resiliency Working Group formed in New Jersey and Arizona DOT has started a second phase of the project.

Q. Are agencies beginning to look into climate data?

A. Yes, both New Jersey and Arizona DOT are working to incorporate such data.

Regional and Multisectoral Scale Approaches to Resilience

SUSAN ASAM
ICF, Moderator

The transportation network is not an isolated system. Cities and regions depend on it for safety and economic vitality while other sectors rely on it for access to their infrastructure and transportation assets can sometimes serve as the first line of defense for protecting a community. This session explored how transportation agencies are partnering with others to more holistically plan for the resilience of a region.

OPPORTUNITIES FOR DYNAMIC ADAPTATION

Niek Veraart
Michael Baker International

Background

For nonemergency funding, regions incur debt that typically means issuance of bonds and risk disclosure for insurance and loans. On the Standards & Poor's bond index, regions with climate change impacts account for more than 15% of the debt. Organizations across sectors should have tools and scenario planning methodologies and be working toward standardized master plans with different levels of risk for investment/debt ratios. A high-risk plan, for example, would be one that calls for asset replacement after destruction. A lower-risk plan would be one that renews assets periodically with preventative and predictive investments—one that controls the amount of excess planning, yet still manages to enhance resilience.

Innovations

In New York, predictive modeling of the 2050 shoreline and storm surge has been completed to better understand vulnerable assets. At-risk assets were then ranked to a B/C index and the top 10 market valued sites prioritized.

Contribution

New Jersey has begun to integrate coastal resilience plans in response to changing climates and rising sea levels. Multiple plans are underway on the state and county level to improve coastal resilience, rebuild infrastructure, improve community and regional resilience, and to improve the level of education of relevant stakeholders. Fifteen municipalities were involved in the development of resilience plans in which local communities could identify important community assets via an online GIS system.

Questions that arose during the development of the resilience plans included whether permanent change will accompany climate change and what impacts of these changes are anticipated. To address these questions, the municipalities developed action scenarios to suggest

areas that could be adapted, protected, or extracted. A similar approach was taken in Norfolk, Virginia, where areas more prone to incurring risk were identified and action taken to determine how to integrate resilience into the National Environmental Policy Act (NEPA) planning process to address these risks.

SAFEGUARDING ASSETS WHEN YOU CAN'T GET THERE FROM HERE: SHARED CHALLENGES IN THE NEXUS OF MULTIMODAL SURFACE TRANSPORT, BUILDINGS, AND MISSION

A.R. ANN KOSMAL

FAIA, U.S. General Services Administration

In summary, the presentation discussed safeguarding assets that are not easily accessible to mitigate risks efficiently. Places such as ports of entry cannot be closed for maintenance, so owner–operators need to both protect the asset and foresee what’s possible while practicing adaptive resilience. An overview of potential approaches to resilience management was discussed including the use of probabilistic analysis.

Background

Per the Government Accountability Office’s (GAO’s) 2019 “high-risk” report update, management of the risks from a changing climate continues to be a fiscal risk and the GAO rating has regressed since 2017. This high risk compels agencies to safeguard assets for the observed and expected changes in climate and extreme weather for the asset service life. At General Services Administration’s (GSA’s) Land Port of Entries (LPOE)—the nexus of both multimodal surface transport and buildings—these activities are undertaken to ensure reliable performance of mission and operations in changing conditions for its LPOE tenants: the U.S. Customs and Border Protection (CBP), USDA, U.S. Food and Drug Administration, and U.S. Fish and Wildlife Service.

The session provided a methodical overview of the prioritization, use of actionable science including detection and attribution science, engineering options analysis and adaptive management integrated into capital planning and risk-based asset management regarding proactive adaptation and transformative resilience. The session also addressed how these tactical and technical efforts are building capacity to manage the intertwined risks which closely connect buildings and multimodal transportation particularly regarding urban heat island and pluvial, fluvial, and urban flooding to ensure not only mission but life safety, public safety, and public health.

Innovations

Remote mission critical sites like LPOEs are difficult to access in response to near-term acute incidents. Interruption, relocation, or replication of mission is not acceptable which requires both robust design and planning with adaptive resilience in mind. Both observed and expected changes in extreme weather and climate have implications to the intended asset life. Over design for an initial time frame may be under designed and not able to cope in expected future

conditions. Methods to monitor for change, design for flexibility, and adaptation both manage risk and are fiscally prudent.

Contribution

The GSA is grateful for the technical and agency leadership of the both USACE and U.S. DOT and their interagency collaboration in resilient and adaptive design. GSA has integrated these methods to promote resilience into the GSA's P-100 Facilities Standard; GSA applies these methods to LPOEs for its customer agencies which are an important part of the nation's multimodal transportation.

STATE HAZARD MITIGATION AND CLIMATE ADAPTATION PLANNING

STEVE MILLER

Massachusetts Department of Transportation

Background

Massachusetts Executive Order 569 required a reduction in greenhouse gases to protect life and property from the effects of climate change. The state issued a \$1.4 billion bond to tackle the issue of climate change resiliency, of this, \$300 million was utilized for hazard mitigation and climate change adaptations.

A series of four planning and stakeholder workshops were held to identify high-risk areas that reflected downscaled climate adaptation center projections in order to create a risk assessment topography to help assist with the state's capabilities and capacity.

Innovations

Combining the FEMA Flood Insurance Rate Maps (FIRMs) with hazard mitigation plans was the main accomplishment of the study. The speaker hypothesized that in the future State Hazard Mitigation Climate Adaptation Plans that incorporate a broader stake of partners, including the Boston Harbor Authority, need to be developed.

Contribution

Using sea-level rise scenarios and comparing FIRMs for adjusted 2050 and 2100 case studies, the authors processed 4,800 mi of coastline with four super computers. This information was used to generate a resilient plan for the state which can be accessed at www.resilientma.org. The plan can assist in determining wave overtopping and water propagation and is available for all coastal communities.

ENHANCING LOCAL CLIMATE RESILIENCE WITH STATE-LEVEL TRANSPORTATION RISK

JUDY GATES

Maine Department of Transportation

Background

The speaker noted that understanding the ability of assets to withstand extreme events and climate change is important to be addressed early in the NEPA process.

Innovations

Following a federal mandate to establish risk-based transportation asset management plans, Maine DOT has created a matrix that informs funding and scheduling on an asset-specific or program-wide basis (Merrill et al. 2015). Building on this work, Maine DOT has established the Transportation Risk Assessment for Project Planning and Delivery (TRAPPD) initiative. Maine DOT opted to consider risk in terms of project delivery (i.e., on schedule, on budget). This mirrors strategic goals of the department and does not lessen the ability to maximize safety, condition, and level of service when determining priority of work on one asset over another. Generally, it has been a project's environmental context (i.e., landscape setting) in combination with specific scopes and practices that have constrained projects' schedules and threatened budgets. Contextual elements that pose inordinate risk include the presence of an endangered species; hydrologic and hydraulic limitations; natural resource impacts; and/or traffic management. Incorporating these concerns for Maine DOT roads, bridges, culverts, multimodal facilities, and other assets, TRAPPD provides a numeric comparison using only existing data, or "proxy indicators," to reduce or eliminate costs of gathering new asset information. Proxy indicators are those that provide parallel information or context for questions that would otherwise require a data gathering effort.

Contribution

Using TRAPPD online, asset managers can now view combined risk scores and individual proxy scores and adjust expectations for asset condition and project delivery in real time, prior to inclusion of a project into a work plan. This capability represents a transition from proof-of-concept status to an automated, implemented, and transferable framework for risk-based decision-making by state DOTs or municipalities.

SESSION QUESTIONS AND DISCUSSION

- Q. How might strategic retreat options play a role within some of the proposed perspectives offered in the first presentation related to "Opportunities for Dynamic Adaptation"?
- A. The graphic in the presentation was more of a life-cycle example at the system level. One potential effect could be that climate risk may reduce an asset's life expectancy.

Q. Did Maine DOT adopt the FAST Act to control the NEPA process?

A. Yes, Maine had before validation and it's helping very well. Massachusetts also answered that they have a local act too.

Additional Discussion

- The public might not understand new prices for trying to mitigate near future issues. Transparency is critical with the public; withholding information from the public is a bad practice. Be clear and explain that unknown risks and threats exist. Some information might not be known by the DOT, but the community might know.

- There is a need for a community and regional resilience notion of infrastructure life cycles; a transportation agency can build a 500-year bridge but it will be not worthwhile if the rest of the area remains at a lesser design standard. Flooding is not an asset–threat pair, it's a community–threat combination.

Bridges and Culverts

Assessment of Resilience for Planning

DEREK CONSTABLE

Federal Highway Administration, Moderator

High water is a predominant climatic hazard that impacts bridges and culverts. High water can damage foundation material, structural members, and approach embankment and roadway. High water can also exceed hydraulic capacity causing overtopping and traffic interruption, as well as potentially causing problems upstream of the bridge or culvert. Resilience planning requires techniques for assessing or analyzing many locations within a jurisdiction to estimate the effects of current and future waterway flows for prioritizing mitigation. This session provides some assessment techniques that are in use or under study.

RESILIENT BRIDGE PLANNING IN MOZAMBIQUE: BRIDGE FAILURE RISK FROM FLOODING AND CLIMATE CHANGE

SEBASTIAN YOUNG

KYLE KWIATKOWSKI

University of New Hampshire

Background

Mozambique has a tropical Savannah climate with a dry season (April to October) and a wet season (November through March). It is one of the 10 poorest nations on Earth. In the year 2000, flooding killed 700 people and estimated damages reached 20% of Mozambique's gross domestic product (GDP). In 2013, flooding killed 113 people, displaced more than 200,000, and ruined 89,000 hectares of cultivated land. In 2015, flooding killed 140 people, affected 326,000 people, and caused damages estimated at \$371 million and in 2019, flooding killed 602 people and ruined 716,000 hectares of crops.

The World Bank funded a risk assessment of bridges in Mozambique to enhance rural access in selected districts in Nampula and Zambezia by adopting climate-resilient interventions across the road network in an integrated manner. Researchers conducted site surveys of impacted bridges and found that the three most common reasons for bridge failure during a flood was impacts from debris, deck uplift, and scour. The research team provided technical assistance, advising stakeholders to routinely remove debris from channels, add scour protection, and anchor decks to piers. Stakeholders provided researchers with flood maps for flood depth for 10- to 1,000-year storms.

Innovations

Researchers conducted a risk assessment by estimating the probability of flood events, bridge failure and repair–reconstructions costs utilizing the following equation:

$$Risk_i = P_{event,i} \times P(failure|event_i) \times C(cost|failure)$$

The probability of an event was derived from hazard curves and their associated flood return periods. To estimate the probability of failure, the research team used flood depth data and HAZUS software's scour damage fragility curves. The unit cost to replace bridges was estimated to be \$54,000 per meter. In addition, the researchers correlated future flood estimates to return periods to estimate future risk from climate change. Under a Representative Concentration Pathway (RCP) 8.5 scenario, flooding is estimated to increase 88% by 2050. The estimated risk to Mozambique's bridges, in 2050, ranges from \$187 million (1.4% GDP) annually, under the most optimistic scenario, to \$403 million (3.1% GDP), under the worst-case scenario.

Contribution

The researchers provided valuable technical expertise to Mozambique on how to make bridges more resilient to flood damage. They demonstrated that it is possible to batch process a risk assessment with limited data. In addition, they were able to estimate the return period of future flood events with climate change projections. This made it possible to predict the annual risk of flood damage for future events.

Presentation Questions and Discussion

Q. Did you try to get data on what magnitude of flood causes bridges to fail?

A. Yes, but the data was not available.

Q. Were the dollar figures shown estimated costs?

A. No. The dollar figures represented aggregated risk only.

Q. Did you incorporate the uncertainty of the general circulation models (GCMs) into your tool?

A. No and it's not clear how that would have changed the results. However, it would be good to factor in the uncertainty of the GCMs in the future to show a range of projected values.

Q. Were your estimates accurate for the bridges you assessed?

A. Ideally, we would have had local data for elevation, flows, soil, etc., however, we didn't have that. We used National Bridge Inventory (NBI) data to do a high-level analysis. The tool wasn't used to predict failure but to calculate aggregated risk.

EVALUATING THE PERFORMANCE AND RESILIENCE OF MAJOR STORMWATER INFRASTRUCTURE SYSTEMS UNDER CLIMATE CHANGE AND LAND USE CERTAINTY

TANIA LOPEZ-CANTU

Carnegie Mellon University

Background

Extreme rainfall has intensified everywhere across the United States in recent decades. For example, storm intensity has increased by 55% in the northeast United States from 1958 to 2016, according to the National Climate Assessment (2017). Under high emissions scenarios, it is expected that even more extreme precipitation events will occur in the future. However, there is a high degree of uncertainty associated with climate models and projections of future extremes, thus deciding on adaptation measures is not straightforward. In addition, increasing urbanization will result in increased runoff and erosion. Land cover changes must also be factored into any analysis of climate change impacts.

Innovations

This study used a three-step process to analyze culvert resilience under climate change: 1) estimate the culvert's current capacity; 2) generate future climate and land use scenarios; and 3) estimate the culvert's resilience to future rainfall. To estimate flow at given culvert's location for a series of return periods, open-source data, including elevation, slope, longest flow path, time of concentration, land cover, hydrological soil group, precipitation depth, and Normalized Difference Vegetation Index from Landsat 8 imagery, were supplied to a rainfall–runoff model. U.S. Department of Agriculture's Technical Release-55 (TR) rainfall–runoff model was used for this study. Hydraulic equations estimate the culvert's design flow:

$$\frac{HW_{i_{max}}}{D} = c \left[\frac{Q_{max}}{AD^{0.5}g^{0.5}} \right]^2 + Y + k_s S$$

where

- D = diameter
- g = gravitational constant
- S = culvert slope
- AD = culvert area
- c, Y, k_s = constants depending on culvert inlet shape

Once the maximum capacity of the culvert is calculated, the maximum capacity can be compared to the discharges outputted from the runoff model to estimate the culvert's design return period. Next, future climate and land use scenarios were generated using downscaled climate projections and maps of projected land use change.

Intensity–duration–frequency (IDF) curves can reflect future conditions if updated with global climate model (GCM) outputs. Different climate data downscaling methods can produce different results as shown in Figure 7.

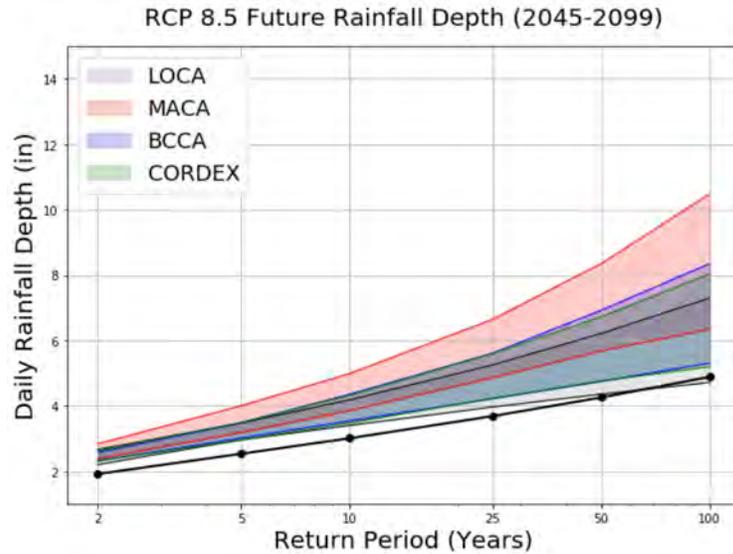


FIGURE 7 Datasets disagree in change magnitude and uncertainty bounds. (Source: Carnegie Mellon University)

This study used four downscaling methods and two emissions scenarios. The downscaling methods included Bias-Correction Constructed Analogues, Multivariate Adaptive Constructed Analogues (MACA), Localized Constructed Analogues (LOCA), and Coordinated Regional Climate Downscaling (CORDEX). The two emissions scenarios were RCP 4.5 and RCP 8.5. Different combinations of downscaled data and emissions scenarios were run to quantify the uncertainty. The graphic in Figure 8 demonstrates the spread between different GCMs run with MACA downscaled data under an RCP 8.5 scenario. Stakeholders might ask if the design for the median increase in rainfall depth or the 75th quantile. Because of the large uncertainty, it would be prudent to look at alternatives to upsizing.

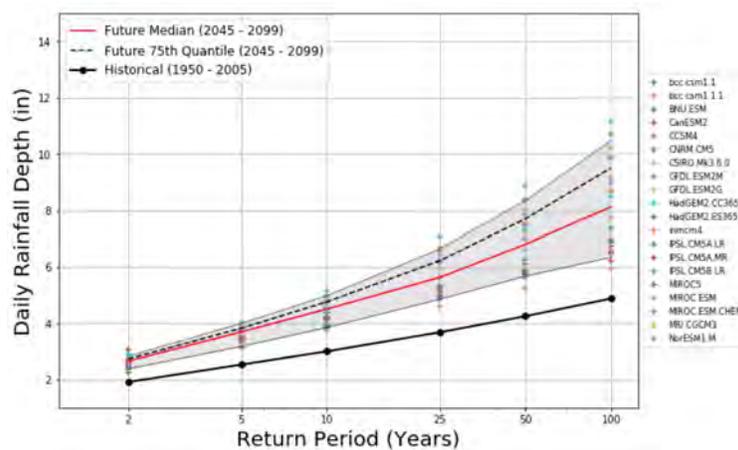


FIGURE 8 High uncertainty in future exceedance using GCM downscaled projections of a single data source. (Source: Carnegie Mellon University)

A change factor derived from the projected climate data-generated IDF curves were input into the rainfall–runoff model to calculate flow from future precipitation events. Comparing the projected flows to the calculated culvert design flow can determine whether the culvert was adequate or undersized for future precipitation events.

Contribution

Open-source data can be used to calculate current design flow for a given culvert, as well as project future precipitation depths and flow. By assigning return periods to projected flows, a culvert’s design flow can be compared to projected flow to determine whether the culvert is adequately sized for future precipitation events. However, due to the high uncertainty of GCMs, stakeholders should consider the full range of possible adaptation measures and not solely rely on upsizing.

Presentation Questions and Discussion

Q. Did you consider other options for adaptation besides upsizing, such as permeable surfaces?

A. This tool was just a prioritization tool that shows which culverts will not be able to handle projected future flows and thus should be prioritized for adaptation. The tool does not assume that upsizing is the solution.

Q. Did you calibrate the tool with existing events?

A. Many culverts are not in a perennial stream and, therefore, not gauged. We used the National Water Model instead.

Q. What about climate data?

A. We are working with National Center for Atmospheric Research to incorporate climate models in the future.

CULVERT RESILIENCE ASSESSMENT: FROM PILOT TO PRACTICE

CHARLES HEBSON

Maine Department of Transportation

Background

The FHWA Order 5520 defines resilience as “the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.” This order encourages state DOTs to minimize climate and extreme weather risks and protect critical infrastructure. The Maine DOT is responsible for 1,832 large culverts, culverts between 5- and 10-ft in diameter, and 35,791 cross culverts, culverts less than 5-ft in diameter. The goal of this project was to assist regional engineers manage their culvert programs reflecting risks and supporting system resilience.

Innovations

The outcome of this project was the development of a GIS tool for assessing the resilience and sizing of the entire statewide culvert database. Step one of the process involves using StreamStats, a web-based tool hosted by the USGS. Users can submit up to 200 points as a zipped shapefile for batch processing and receive a report for each point consisting of basin characteristics and flow values for return periods, ranging from 2- to 500-years. Users must ensure that the submitted points snap to a stream reach within the National Hydrology Database.

The highlighted equation can be used to estimate the required culvert barrel height for a given flow. This equation can be run in GIS to evaluate all state culverts in a single run:

$$Q^* = Q / \{A \times (2Dg)^{0.5}\}$$

$$D = \{(Q/Q^*) / ((\pi/4) \times (2g)^{0.5})\}^{0.4}$$

where

Q = design flow from USGS regression equation in ft³/s (m³/s);

Q^* = from FHWA hydrology model (HY-8, for a dimensionless, specified ratio between the headwater depth and diameter; I^* equals 0.50 for cross culverts and 0.32 for large culverts);

A = full cross-sectional area of culvert, ft² (m²);

D = interior height of culvert in ft (m); and

g = gravitational constant, 32 ft/s² (9.8 m/s²).

Whether a culvert is potentially undersized can be determined by comparing the estimated required design size with the culvert's actual size.

One potential issue with the process was noted that the StreamStats batch processing tool did not return results for all points and in some cases, points were snapped to the wrong watershed or were not snapped to any watershed. Other suggestions for enhancements included adding calculations for overtopping as well as sensitivity for climate change.

Contribution

The results of this project produced a tool that is simple to understand and requires minimal inputs. It can be used to assess an agency's culverts in a single run and assist engineers in determining the proper sizing for their culverts and potential vulnerabilities. One requirement to conduct this work, however, is the agency needs a comprehensive culvert database.

State of Play of Proactive Adaptation

Focus-Point Session

The following is an edited transcript of a speech given by Alice Hill during the first Focus-Point Session of the conference. Additions have been made to the transcript to help the reader follow the train of thought of the speaker when needed (in parentheses).

ALICE C. HILL

Council on Foreign Relations, Speaker

When I think about climate change, or any condition that exacerbates natural disasters, to many societies living with those events there is a pattern that occurs. I call it the “No More Moment.” In the Netherlands, the No More Moment was in 1953. There was terrible flooding and the country determined that people would not die as a result of flooding if they could avoid it. They devoted themselves to changing that story.

In 2003, extreme heat hit Europe. France had its No More Moment and it became a leader in combating extreme heat events with cooling stations, checking on the elderly, and making sure water was widely available.

The United States has had several No More Moments and perhaps there is one right now with wildfires in California in the fall of 2019. These No More Moments are influencing civilians in the way people do business or make life choices. The wildfires may affect where people choose to live, perhaps away from areas that are close to wild lands. Certainly, during my time in government the No More Moment was Superstorm Sandy, which happened about 7 years ago. When it approached the United States, it was a very large storm. Its strike zone was over a 1,000 mi that eventually hit almost half of the states, but it particularly hit the northeastern section of the United States. As the storm approached people were worried. There were many warnings issued by the state of New York and by Mayor Bloomberg, the mayor of New York City at the time. Manhattan evacuated 375,000 people. The New York Stock Exchange, worried about flooding, decided they needed some flood protection. Sandbags were placed in front of their headquarters in lower Manhattan. Similarly, Goldman Sachs placed 25,000 sandbags in front of their building. Superstorm Sandy brought these big storms, a big storm surge, and a wall of water over the eastern shore.

New York’s planning had assumed a maximum storm surge of about 12 ft. What they had failed to include was that the city had already experienced about a foot of sea-level rise since the turn of the century. Superstorm Sandy happened during a full moon with high tide and it brought in close to a 14-ft storm surge. That storm surge immediately overcame New York City’s barriers and a substation in Manhattan blew up. Goldman Sachs had taken extra precautions. The Goldman Sachs CEO at the time said, “You know, the building came through pretty well. The only challenge is nobody can get to work.” That is the No More Moment lesson.

Once a key piece of critical infrastructure fails it can have dire consequences on the transportation system. Seven substations on the East River flooded because the storm barriers were too low. The South Ferry Station had opened only 3 years earlier at the price of half a billion dollars. It was filled with 15 million gallons of foul water, including saltwater, and the head of the Metropolitan Transportation Authority termed it a “fish tank.” It took another half billion dollars to rebuild. Private transportation stalled because without electricity, it was not

possible to pump fuel. It was difficult transporting the fuel to those stations that still had electricity.

There were dire consequences to the healthcare system. Patients were evacuated down darkened stairwells with a flashlight, some of them intensive care unit (ICU) cases. In total, roughly 6,500 patients were evacuated. There was water treatment disruption because there was no electricity, so nowhere to pump it out. In total, 11 billion gallons, a third of it untreated, went into the riverways.

Now the Earth is heating up. This is well documented. Scientists have been keeping temperature records since the 1880s. As the result of greater heat in the atmosphere, consequences occur: sea-level rise, drought, wildfire, more intense precipitation. The past 5 worst years have been the hottest on record. October 2019 was the hottest October ever in recorded history. It's heating up and it's bringing these worsening natural hazards. What can be done? What can be done before another No More Moment?

There are lessons learned. Of course, lessons motivate people that are caught in the moment but need to figure out how to prepare better in advance of an event and save money and trauma. One thing to recognize is that stationarity is dead. These beautiful systems have been built with a fundamental assumption that the climate really doesn't change much within certain boundaries. This is a lousy assumption when talking about climate change.

One example from the U.S. military and climate change involves an island in the West Pacific called Kwajalein Island. There are anti-ballistic missile detecting capabilities on this island. The Air Force also decided it is a good place to be able to track space junk the size of a baseball that could collide with a satellite and cause damage. In 2013 a contractor in Milwaukee decided to invest a billion dollars in building a new radar system. They did it with the vulnerability assessment at the time. The assessment concluded there was no risk from tidal flooding and no risk from wave action. Halfway through the project they conducted another vulnerability assessment considering sea-level rise, and it turns out that the fresh water supply would be damaged in about a dozen years. There is a lease on this island to 2055, but it will probably be underwater before that lease expires.

Those are the types of investments that are too expensive. As these major investments are made, be they in road infrastructure or other infrastructure, it must be acknowledge that stationarity is dead. It is also necessary to look at railways. Rails buckle in extreme heat, known as sun kinks. The same kind of effect happen with cold. With climate change there is going to be extreme cold and extreme heat. A danger is that freight lines carry a lot of hazardous materials and extreme temperatures could result in a derailment.

The San Francisco Bay Bridge to Oakland (eastern span expansion project between 2002 and 2013) opened about five years ago. Because sea-level rise was not considered, the bridge will need remediation of at least \$17 million dollars. A long-term view is needed. It is necessary to accept that climate change is going to be here a while, so it is necessary to think through the kinds of extremes infrastructure will experience so that expensive retrofits will not be needed.

Looking at New Orleans, when Hurricane Katrina hit in 2005, the levees failed even though they were built for the 100-year storm. The one in 100-year storm means that there is only a 1% chance of flooding in any given year, but during the life of a 30-year mortgage it will flood. It was decided it was too expensive to build to a higher level. Now it is known that a city already built below sea-level is protected by levees that probably will not protect it going forward. It is necessary to think about how long infrastructure should last because mitigation saves money.

The most important study about climate change was done by the National Institute of Building Sciences and looked at savings resulting from mitigation grants over a certain period of time. Overall, for \$1 spent for resilience—building a bigger culvert, building a road higher, or using more durable materials—results in \$6 in disaster reconstruction savings. In the culvert example, it is well over 200-to-1. People should consider those kinds of cost savings when making choices about spending additional money now to save in recovery costs from more extreme events moving forward.

In the Netherlands, the Dutch are planning for a once in 10,000-year storm for long-term protection of themselves. Flooding is an existential threat for them. Incorporating considerations of future risk requires a lot of modeling and data.

There is some progress. Because of Hurricane Sandy, that No More Moment in Manhattan, there are resilience guidelines. But building codes do not yet reflect the effects of climate change. Structures today are built to withstand historic risk; they are not built to withstand future risk during the life of a structure. Building standards are needed as is flexibility in design. Along the coastline from San Diego to Los Angeles, the trains run along the coast. Obviously, there is a concern about sea-level rise and resilient materials. Homes were built with a particular type of concrete are very fire-resistant. It is necessary for people to be more creative about how they are living.

Bangladesh is one of the most flood-prone parts of the world. It has a population of 160 million crammed into the space of the size of Iowa interlaced with all kinds of rivers. The country has floating schools so that during monsoon season, school can continue. The Getty Museum in Los Angeles was built to very (high) fire-resistant standards. It has been threatened several times, but it has never had to evacuate its collection. The Texas Medical Center in Houston had their No More Moment, which was Hurricane Allison. Staff there said they would remain open during a hurricane in order to remain accessible. During Hurricane Harvey 4 ft of rain fell and most of Houston was flooded. Texas Medical Center remained open. It was a challenge to get transportation there, but they had plans for their personnel to stay in the hospital.

There are good examples of planning for future risk around the world, but fewer in the United States. One example of planning for future risk is the Thames barrier in London that will likely protect the city from storm surge coming up the Thames until at least until 2080. Kuala Lumpur has a smart tunnel underneath their city which can act both as a commuter route and during flooding it can act as a giant drain to get the water out and keep it from flooding the city. China has required cities to make sure they can absorb extreme precipitation events. They use permeable materials and terraces to capture water, creating “sponge cities” that capture as much as 70% of the runoff. Rotterdam has plans for floating neighborhoods so as to live with the water instead of constantly trying to figure out how to keep it out. The United Nations has plans for the world’s first floating community, called Oceanix City.

Failure to engage in making the decisions now to address resilience has already cost significantly in consequences. With investments now for further preparedness, further resiliency measures, a lot of money can be saved.

Session Questions and Discussion

Q. Your focus on enlarging infrastructure, for example with the Dutch learning to live with the water, also recognizes increasingly moving people away from hazardous areas even as they

change their infrastructure. What do you see here in the future in the United States if we have the option to move people?

- A. We will have to restrict certain areas as the land erodes beneath us. I don't think we can be building in wildfire areas; we need to get people away from those areas. It is going to be too expensive to keep people safe in those areas. Decisions about where people can live fall to states and local governments, but the risk ends up in the hands of the federal government. The GAO has said the risk should not fall to the federal government. We are going to have to look at reducing risk. If communities want to develop that way, that's fine, but they shouldn't expect, for example, the homeowner in Maine, to support those decisions. Right now, we are putting the cost back on the federal government.

- Q. I am wondering what role the private sector, particularly the financial sector, has in addressing risk and whether you consider that role to be helpful.
- A. The private sector could play a very important role and are already doing so in the modeling and data, for a fee. The markets have not responded. I don't think the real estate market is yet reflecting what is occurring. By 2100, 1.7 million homes will be chronically inundated. That real estate happens to be among the most valuable real estate. I also think our securities and bond markets are not accurately reflecting this risk. One solution is mandated disclosure, that is, disclosure of flood risk. There is a task force for climate-related disclosures, a voluntary assemblage with leaders in the business world that would require companies to disclose their own risk to their supply chains, to their operations, and to their core business. Of 1,100 companies surveyed, only 4% accurately disclose their risk.

Frameworks and Methods to Address Coastal Resilience, Part A

DAVID KRIEBEL

U.S. Naval Academy, Moderator

The built environment in high-risk coastal areas is confronted by natural hazards such as severe storms, flooding, sea levels rising, and erosion. In this session, panelists will present methods and frameworks to support decisions to reduce the ecological, structural, and economic risks of coastal hazards.

HIGHWAYS IN THE COASTAL ENVIRONMENT: A U.S. ENGINEERING MANUAL

SCOTT DOUGLASS

South Coast Engineers

Background

FHWA has sponsored the development of a manual to aid in the planning and design of coastal highways and bridges to make them more resilient to extreme events. For the purpose of this guide, the term, extreme events, refers to catastrophic storms that cause substantial damage, especially hurricanes. Considering climate change, the possibility that extreme storms will change must be considered; but the most important change is relative sea-level rise (RSLR). Relative sea-level is the mean sea-level related to a local reference land level. RSLR has affected every coastal state and is responsible for what is commonly called “nuisance flooding.”

In the past several decades, millions of Americans have migrated to the coast. At the same time, FHWA has the responsibility of ensuring that America’s roads and highways continue to be the safest and most technologically sound in the world. FHWA *Hydraulic Engineering Circular (HEC 25): Highways in the Coastal Environment*, is now being updated. Volume 1 was published in 2008. Volume 2 was published in 2014 and addressed methods of assessing vulnerability to climate change and extreme events, specifically how to quantify SLR, storm surge and waves.

Innovations

The two volumes comprising HEC-25 are being combined into a new, single edition. The new HEC-25 is organized into four parts.

- Part 1: Background and Context:
 - Coastal roads,
 - Policy, and
 - Coastal engineering as a specialty.
- Part 2: Principles of Coastal Science for Highway Engineering:

- Water levels,
- Waves, and
- Coastal sediment processes.
- Part 3: Issues and Applications in Coastal Highway Design:
 - Coastal revetments,
 - Roads in areas of receding shoreline,
 - Highway overwashing,
 - Coastal bridges, and
 - Coastal scour.
- Part 4: Coastal Highway Vulnerability Assessment:
 - Engineering risk at the coast,
 - Analysis methods for assessing vulnerability to extreme coastal storms, and
 - Adaptation strategies for coastal highways.

Three important recommendations came out of the research for HEC-25.

- Projections of future RSLR should be considered in the design of coastal highways;
- Coastal infrastructure should be designed with the RSLR corresponding to Global Mean Sea-Level Rise (GMSLR) of about 2-ft by year 2100; and
- Practitioners should be aware of, and account for appropriately, the magnitude of the overall uncertainty in SLR projections.

Douglass explained why SLR is important. First, SLR causes increased flooding and flooding is becoming more frequent and deeper. Second, it has been shown that RSLR can exacerbate storm damage to a bridge. The Interstate bridge in Pensacola, Florida, would not have been as badly damaged during Hurricane Ivan if it were not for RSLR.

Adapting to RSLR does not automatically mean upsizing or building bigger. Nature-based solutions should also be considered. Nature-based solutions use natural materials to reduce erosion, wave damage, and flood risk. They often serve as alternatives to, or enhancements of, traditional engineered solutions.

Contribution

The new HEC-25 includes a 28-page glossary and gives the coastal engineer a solid primer on the terminology, concepts and quantitative methods used for coastal highway planning and design. In addition, the manual covers assessing vulnerability to extreme storms and climate change as well as adaptation strategies. Also, of interest, FHWA sponsors a companion, traveling short course, National Highway Institute Course No. 135082: Highways in the Coastal Environment.

Presentation Questions and Discussion

- Q. How many state DOTs have coastal engineers on staff?
 A. None (as per the panel response).

STRATEGIES TO INCREASE RESILIENCE OF FLORIDA DOT’S FACILITIES

JENNIFER CARVER

Florida Department of Transportation

CARL SPIRIO, JR.

GHD

Background

The list of natural hazards impacting Florida include hurricanes, precipitation events, SLR, wildfires, drought, and sinkholes. Of special concern is SLR. In Hollywood, Florida, for example, nuisance flooding is a normal occurrence; but there is an upward trend in the height of “king tides” that cause nuisance flooding. King tides are exceptionally high tides that result when the Earth, moon, and sun are aligned at perigee and perihelion.

Innovations

Figure 9 outlines the transportation system project development process. Florida DOT recognizes that resilience is not a linear process but should be factored in all phases of the planning process.

Florida DOT has launched a series of resilience initiatives, including the Florida Transportation Plan (FTP), the Freight Mobility and Trade Plan (FMTP), the Sea-Level Scenario Sketch Planning Tool, the Strategic Intermodal Systems (SIS) Risk Assessment, interagency coordination, guidance for MPOs and Drainage Manual update.

The top priorities of the FTP/SIS Resilience Subcommittee include:

- Policies, tools, guidance, and design standards;
- Consistent statewide transportation planning;
- Ensure vulnerable populations are considered fully;
- Integrate resilience data; and
- Both coastal and inland resilience considered.



FIGURE 9 Planning for transportation system and transportation project development phases. (Source: Florida DOT)

The FMTP outlines possible consequences for the following 2045 scenario: Greater than 4°F temperature increase, a SLR of 12 in., and an increase in the frequency and strength of extreme events.

- Coastal communities and downtown Jacksonville, Miami, and Tampa have had to reinforce and expand seawalls and bulkheads.
- For communities that cannot afford desalination plants, pipelines have been built for the transmission of potable water.
- Significant Florida DOT investments in pervious pavement, ultra-high strength concrete, roadway elevation projects, bio swales (channels designed to concentrate and convey stormwater runoff while removing debris and pollution), pumping/lift stations, and other washout prevention strategies are utilized.
- Resources have been allocated to “push-button (on-call) contracts” to rapidly deploy supplies to storm-affected areas, in addition to regulation waivers regarding hours-of-service, vehicle weight, and other factors for emergency management operations.
- Regular, daily freight operations rely more heavily on parallel corridors and freight bypass routes, which has created a desire to expand the SIS and National Highway Freight Network.
- Aviation for freight movement is now common for mid-value commodity movement within and out of Florida (not just high value).
- Perishable goods are more commonly seen on rail as a result of refrigerated containers.
- Importing supplies such as fuel, potable water, and food are coordinated so they are in strategic locations for rapid delivery.
- Seaports and airports have identified facility vulnerabilities to threats including SLR, and are addressing potential effects to cargo handling capabilities.
- With increased adoption of electric passenger and commercial vehicles, roadside photovoltaic cells and inductive charging loops embedded in the roadway have been deployed to ensure vehicles stay charged during emergency evacuations.

This is what Florida DOT is doing to plan for resilient freight infrastructure:

- Defining critical supply chains that must be maintained during and immediately after emergencies, then identifying locations throughout the state to pre-position critical commodities and primary and secondary routes for movements.
- Assessing the risks. The SIS facilities move most people and freight in the state, so the SIS study to identify critical infrastructure, network risks, and vulnerabilities due to impacts of flooding is a starting point to know where to retrofit, adapt, or diversify.
- Looking to expand on this effort to identify critical freight facilities of all modes that are the most critical to freight handling capacity for Florida’s freight shippers, receivers and communities. These could be constructed or retrofitted to higher resiliency standards.
- Prioritizing policies and investments that promote and enhance the interconnectivity and interoperability of different freight transportation modes, routes, and corridors, maximizing the chances that transportation services and complex supply chains can be maintained under conditions of stress.

The Sea-Level Scenario Sketch Planning Tool is a planning tool for screening and comparing SLR scenarios and potential transportation impacts. Local SLR projections were mapped for 36 counties, for decades 2040–2100. An updated version will include NOAA’s 2017 projections, updated data, local roadways, and current flood risk.

The SIS Risk Assessment assessed three types of high-priority transportation facilities: (1) hubs (not including stations); (2) corridors (highways, rail lines, waterways, urban fixed guideway transit); and (3) connectors (highways, rail lines, waterways) linking hub-to-corridor, hub-to-hub. The assessment was conducted in two phases:

Phase I: SIS Risk Assessment:

- Identify and assess potential risk and vulnerabilities to SIS highway corridors and military access facilities due to:
 - Storm surge;
 - Flooding (100-year); and
 - Sea-level rise.
- Assess impacts to SIS highway corridors due to evacuating and return traffic impacts from Hurricane Irma.

Phase II: SIS Risk Assessment:

- Expand facilities to be assessed to include:
 - Rail;
 - SIS hubs (airports, seaports, etc.); and
 - SIS highway connectors.
- Expand risks and vulnerabilities to be considered, such as:
 - Wildfire;
 - Extreme heat; and
 - Sinkholes.
- Expand assessment of hurricane impact case study.
- Development of a Resiliency Action Plan.

Florida has several initiatives promoting interagency coordination. The Florida Resilient Coastlines Program provides resources, funding, and coordination for vulnerability assessments, adaptation–resilience plans and implementation. The Period of Flood law, passed in 2015, requires consideration of current and future flooding from storm surge and SLR in the coastal management element of comprehensive plans. A total of 211 Florida communities, 35 counties and 174 cities have a coastal management element and are required to complete the Peril of Flood Analysis. The Department of Environmental Planning has funded 29 of these communities.

Regional collaborations are multicounty and are not limited to transportation. An example is “Resilient Tampa Bay Transportation.” Resilient Tampa Bay Transportation is a FHWA-sponsored pilot regional vulnerability assessment for surface transportation assets. The assessment is incorporated into the regional long-range transportation plan (LRTPs), hazard mitigation plans, emergency management plans, and post-disaster redevelopment plans.

Florida DOT has also updated its *Drainage Manual*, effective January 2020, to account for SLR projections, coastal FEMA floodplain map updates, and criteria for pressurized storm sewer systems.

Contribution

Florida DOT has incorporated resilience into all phases of transportation planning. Florida's FTP and FMTO have been modified to emphasize resilience and adaptation to climate change. Florida DOT's Sea-Level Scenario Sketch Planning Tool enables the public to visualize the impact of SLR to their community with an interactive web mapping tool. Initiatives promoting interagency coordination and regional collaboration encourage communities to develop strategies to reduce their flood risk from storm surge, high-tide events and SLR.

A STEPWISE AND FLEXIBLE ADAPTATION FRAMEWORK FOR COASTAL ROAD INFRASTRUCTURE RESILIENCE TO A CHANGING CLIMATE

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Background

Global temperatures are rising and are projected to continue to rise. Similarly, precipitation patterns are changing and sea levels and groundwater levels near the coast are rising. These changes will affect pavement performance and service life all over the world. The increase in the cost of maintaining roads due to climate change is estimated to be billions of dollars in the United States. The Earth's mean surface temperature is projected to increase between 1°C and 4°C, depending on the emissions scenario. While sea levels are projected to rise to nearly 0.5 m (1.6 ft) by the year 2030 and 2.5 m (8.2 ft) by the end of the century in the northeast if emissions maintain the same trajectory. Along the coast of Maine, tidal surface-water flooding is expected to reach 1.5 km inland, and groundwater rise is expected occur up to 4 to 5 km inland.

Innovations

Common questions from stakeholders include the following.

- How will climate change affect pavement life?
- Which scenario or scenarios should be used?
- Does the choice of scenario matter?
- What if scenario choice is wrong or the projections change?
- How to justify the added cost now for resilience later?

This study attempted to address these questions. Climate change can degrade pavement when increased temperature and soil saturation weaken the asphalt concrete and the underlying layers. There are two basic approaches for accounting for climate change in pavement design, the top-down approach and bottom-up approach. The top-down approach is used to initially determine the range of projected temperature rise and finally to determine the timing of impacts to support staged-adaptation planning and budgeting.

The bottom-up approach accounts for the effects of incremental temperature rise on season length, seasonal average temperatures, pavement material properties, and pavement life. It reveals trends in pavement damage and projected pavement response to rehabilitation actions. A more complete understanding of the pavement’s climate–stress response supports more-effective adaptation strategies. A hybrid approach was utilized for this study to take advantage of the benefits of each approach.

The case study for a section of Route 286 along the coast in New Hampshire shows that pavement design must consider groundwater rise caused by SLR, temperature increases, and other parameters. A cross-section of Route 286 shows that with 2.7 ft of SLR the groundwater level will permeate through the entire subgrade and base layer as shown in Figure 10.

The pavement evaluation was conducted using layered elastic analysis with MNPave software from Minnesota DOT. Fatigue cracking failure was determined by calculating the horizontal tensile strain at the base of the hot-mix asphalt (HMA) layer and rutting failure was determined by calculating the vertical compressive strain at the top of the subgrade. Pavement layer thickness was determined as the thickness required to avoid premature pavement failure at the 85% reliability level.

Finally, the HMA thickness required for 85% reliability can be estimated by RCP and year. Figure 11 shows projected required HMA thickness versus year and base layer thickness for four RCPs and four base layer thicknesses.

Each graph of projected HMA thickness over time for each scenario is called an Adaptation Pathway.

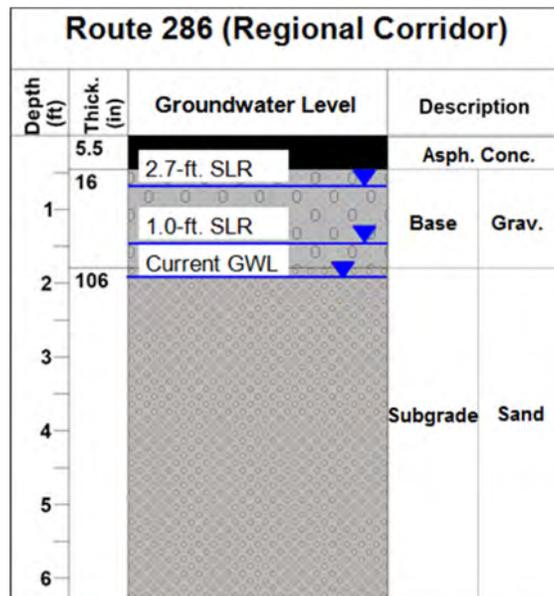


FIGURE 10 Pavement evaluation site. (Source: JFK Environmental Services, LLC)

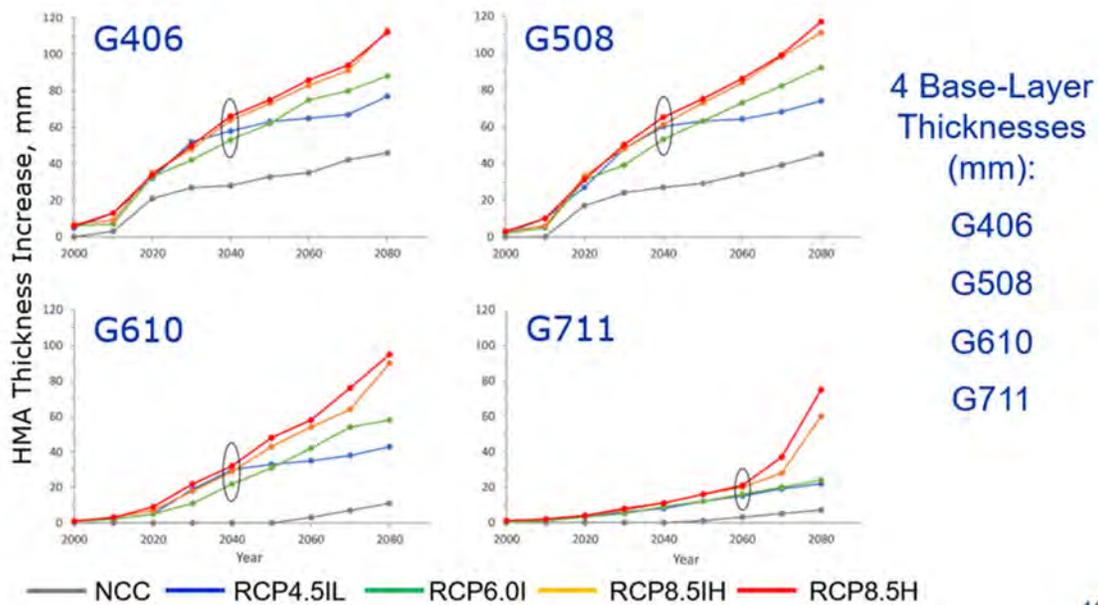


FIGURE 11 Projected O-HMA thickness increase.
(Source: University of New Hampshire, ICNet)

Factors to consider when creating or changing the adaptation plan include:

- What is the current condition of the pavement?
- Have the climate/traffic projections changed?
- Are there new materials to consider?
- What is the projected condition of the service area?
- Re-evaluate the adaptation plan every 10 to 20 years.

Contribution

Material properties are affected by temperature and ground water level. The HMA thickness needed to maintain 85% reliability can be estimated given changes in temperature and groundwater level. Temperature and ground water level change over time for different RCPs.

This project demonstrates that the required HMA needed to maintain 85% reliability can be estimated, given changes in temperature or groundwater level and emissions scenario. The different adaptation pathways representing a graph of HMA thickness versus changes in climate stressors for different emissions scenarios can be compared to determine which is the most economical.

A FRAMEWORK FOR SELECTING SEA-LEVEL RISE FOR THE DESIGN OF RESILIENT INFRASTRUCTURE

ROGER KILGORE

Kilgore Consulting and Management

Background

While there is broad consensus that sea-level is rising, transportation planners and engineers ask what level of SLR should be selected when designing for resilience. In determining what level of SLR should be selected, agencies must determine their risk tolerance, system sensitivity, and network redundancy. In addition, there are policy choices to consider: protect or retreat for short-term or long-term planning horizons.

Innovations

Figure 12 provides a suggested decision framework for selecting a level of GMSLR. For general use roads and bridges, culverts, and stormwater management it is suggested agencies consider the minimum scenario of 2-ft SLR by 2100. For major roads and bridges and freight infrastructure it is recommended agencies consider higher thresholds of anticipated SLR of between 2 and 4 ft by 2100. Finally, for evacuation routes, tunnels and major interstates, agencies should consider using higher scenarios of 4- to 8-ft SLR by 2100.

Traditional top-down analysis often involves picking several criteria and designing for those criteria which may omit valuable information. When the future is uncertain, it is useful to identify critical thresholds as is proposed in the decision framework which may also allow for design plans to be adaptive and responsive to changing observations. For example, an analysis of GMSLR for the Central Artery/Tunnel System in Boston yielded three thresholds: 0.5, 1, and 4 ft GMSLR. When these thresholds are reached depend on real-world GMSLR. As observations are made, plans and adaptation measures can be adjusted.

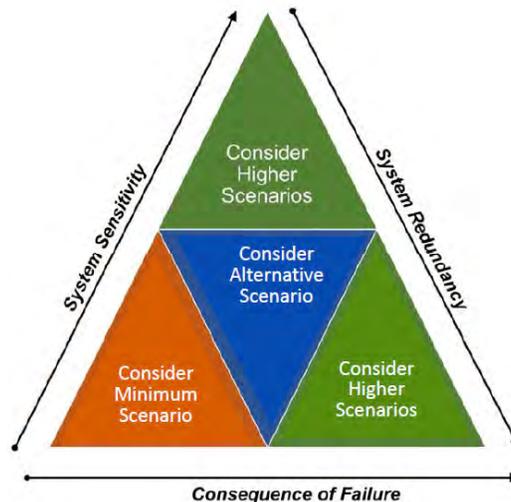


FIGURE 12 Decision framework. (Source: Kilgore Consulting and Management)

Contribution

This presentation demonstrated a simple tool for determining what level of GMSLR to use when planning for SLR. Apply minimum (2 ft), alternative (2 to 4 ft), or higher (4 to 8 ft) projections of sea-level depending on the situation (sensitivity, redundancy, consequences, etc.). Also suggested was considering adaptive thresholds as a design approach and adjust plans in response to observations and advances in SLR science.

Presentation Questions and Discussion

- Q. How do you justify using the RCP 4.5 scenario when emissions have been mostly equal to or above the RCP 8.5 scenario?
- A. Considering the uncertainty, as a rule of thumb in Hydrology and Hydraulics (H&H) engineering, there is a tendency to pick the mean value and not the extremes.

Transforming Design for Resilience, Part A

SUSANNE DESROCHES

New York City Mayor's Offices of Resilience and Sustainability, Moderator

This session examined the practical world of design through the exploration of lessons learned from various organizations who have updated their design approaches to include nature-based solutions, as well as translate climate science into design-level guidance.

FLOOD RESILIENCY: THE ADDED BENEFIT OF AQUATIC ORGANISM PASSAGE USING THE STREAM SIMULATION DESIGN METHODOLOGY

NATHANIEL GARDNER GILLESPIE

U.S. Forest Service, U.S. Department of Agriculture

Background

The USDA Forest Service (USDAFS) manages 380,000 mi of roadway, 220,000 mi of streams, and 65,000 crossings. Roadway crossings are the largest disturbance source for streams and an important aspect of the USDAFS mission. The agency has more than 40,000 inventoried culverts and estimates between 60% to 90% of these road–stream crossings impede the movement of fish at some point in their life cycle. Often culverts are undersized for the natural stream width, and they block upstream passage of fish when they are perched too high, are too shallow or water velocities are too high. In many locations, fish listed under the federal Endangered Species List and recreationally valuable fish have been the focus of efforts to improve these crossings. Many other types of aquatic animals are also impeded by poor crossings. Reconnecting aquatic habitat was the number one strategy to ensure these animals can survive climate change.

The relationship between bankfull width and culvert size should be addressed at road–stream crossings as well as the velocity of water passage through designed crossings and the potential outfall depth which can also impede aquatic life migration and spawning.

A case study of post-Tropical Storm Irene demonstrates the relationship between stream crossings and bankfull to culvert ratio. Prior to Irene, 43 stream-road crossings in the Upper White River Watershed had been flagged as barriers to fish movement and of those, the average bankfull to culvert ratio was 0.54. Of these 43 stream–roadway crossings, 15 failed during Tropical Storm Irene.

Innovations

Stream simulation design principles show one approach to try to improve the connectivity of aquatic life habitat while also reducing the failure probability of stream–roadway crossings. These design principles require engineers to “design a stream and put a lid on it.” Figure 13 demonstrates some of the principles and includes an example channel.

Stream Simulation Design Principles

- Combines engineering, geomorphic and ecological analyses
- 100+ Recurrence Interval with freeboard or room for debris
- Mimics natural channel structure, sediment characteristics, water velocity & depths, and resting areas for aquatic organisms



FIGURE 13 Example stream simulation design principles. (Source: USDAFS)

Contributions

Recognizing the number of stream–roadway failure points that often severely damage highway systems during large rainfall or flood events, the concepts presented provide one potential approach to alleviate the challenges presented not only to maintaining connectivity of aquatic life habitats but also improving roadway network resiliency.

IMPROVING RESILIENCY AND SUSTAINABILITY OF VULNERABLE INFRASTRUCTURE BY USING NATURAL STREAM CHANNEL DESIGN AND RESTORATION: THREE CASE STUDIES

THOMAS A. GRAUPENSPERGER

Dewberry

Background

This presentation focuses on a review of resilient solutions including Natural Channel Design (NCD) for multiple case studies in Pennsylvania and New Jersey. The increase in billion-dollar weather and climate disasters in the United States results in increased vulnerability and risk to infrastructure and streams. New guidance is available to engineers and planners who seek to increase preparedness and resilience including several documents published by FHWA.

Innovations

NCD restoration can improve water quality and system resiliency. Three case studies were reviewed that ranged from large to smaller investments to improve resiliency including floodplain restoration post-Hurricane Sandy at Oakwood Beach in New Jersey; highway bridge replacement over Muddy Creek at SR-2075 in York County, Pennsylvania; and a bridge replacement at SR-1003 at Wallis Run in Lycoming County, Pennsylvania. Figure 14 demonstrates some of the benefits seen from NCD.

Presentation Questions and Discussion

Q. With natural bottom culverts, is additional maintenance required?

A. Expect materials to move so size materials accordingly. USDAFS does not normally reset rocks or boulders after events.

Q. Can you speak to the cost of natural bottom culverts?

A. Three streams were reviewed in Vermont, estimated the cost was between 5% to 25% higher than traditional methods. These were also built for 75-year life span. Multiple funding sources were used to fund the natural stream bottom culverts.

Natural Stream Stabilization/Restoration at Structure Crossings

- NCD creates a win-win by providing:
 - Reduced sediment discharge
 - Stable channels and streams
 - Scour protected bridges, structures & streambanks
 - Stream habitat and fisheries improvements
 - **Improved Resiliency (Redundant Measures)**



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FIGURE 14 Example benefits of NCD. (Source: Dewberry)

Approaches to Addressing Multiple Hazards Within a Larger Multimodal Program

PAULA J. HAMMOND
WSP Inc., Moderator

Public agencies are working to develop more-resilient infrastructure systems to ensure access and limit disruptions to the traveling public. This session will explore various state, regional and national organizational approaches to address hazards within a program-wide context.

ARIZONA DOT: DESIGNING, FUNDING, AND BUILDING RESILIENCE INTO A \$1-BILLION CONSTRUCTION PROGRAM

STEVEN OLMSTEAD
Arizona Department of Transportation

Background

Arizona DOT is seeking to blend science, technology, and engineering into one co-dependent discipline, especially when considering evidence-based engineering solutions. Arizona DOT has invested \$1.123 billion derived from aid and other sources into its asset management program including resilience planning for at-risk assets for over 25 different extreme weather cases identified by the agency.

Innovations

Arizona DOT has expanded its modeling to include life-cycle planning for bridges with probabilistic models, including deterioration and resilience curves. This information is tied together in a GIS dashboard, using live data from USGS and NOAA to help monitor threats and serves as a screening tool.

The project began as an ad-hoc response to their organization's needs, but has developed into the Arizona DOT Resilience Screening Tool, a checklist and risk register that drops data into a GIS database. The system allows agency personnel to drop data into the total systems view, including anecdotal information which can be key in the screening process. This information, plus a financial toolbox, loops back to decision makers.

Contribution

Aging assets require remedial procedures to improve resilience. To that end, Arizona DOT has partnered with USGS to model water and 3D erosion change, mapping both to further help understand changes in floodplains and their effects on highway assets. The driver for the development of this tool was torrential floods that have occurred in the past and this new tool will allow the agency to monitor rapidly changing conditions near assets to potentially reduce losses. Probability based risk modeling combined with deterioration models have helped Arizona

DOT successfully monitor multiple sites. The agency believes its partnership with USGS was a worthwhile investment and should be considered by other agencies to improve their monitoring of highway assets under threat from flooding or debris flow.

ASSESSMENT OF INCORPORATING CLIMATE ADAPTATION INTO A STATE DOT: CALTRANS EXPERIENCE

TRACEY FROST

Caltrans

Background

California is a big state and has been scourged by extreme wildfires and climate conditions that have brought forward a multitude of other extreme weather-related risks such as landslides, debris flows, large precipitation events, and even concerns from SLR. Along with having three of the 10 largest cities in the United States, an estimated 40 million residents, three of the top 10 ports in the United States, and two of the top 10 cities by GDP in the United States, it also has 51,000 lane miles of state highways.

Three pieces of legislation have required California to consider climate change, resilience, and sustainability in their planning practices. As a result, the agency has transformed district-level Vulnerability Assessment Reports into overarching climate adaptation strategies reports.

Innovations

The inventory of climate impacts on state highways and transportation assets are generated from district-level vulnerability assessments. These provide tangible GIS products to assist with the next step: climate adaptation strategy reports, which prioritize next steps for asset assessments and help to identify the adaptation strategies to address potential threats. The scope of these climate change assessments is limited to three scenarios (2025, 2055, and 2085), which leads to the quantification and mapping of climate change stressor impacts and the identification of at-risk assets. This allows for strategy development and guidance along the lines of protecting the most-vulnerable assets. Each district is responsible for the development of a summary report, a technical report, and an online viewer tool.

Contribution

Currently the agency is gathering district feedback on what is working and what is not working from the process and working to establish a steering committee. Next, the climate change adaptation recommendations and strategy report will serve as an in-depth look at Caltrans policies and procedures to identify changes to help Caltrans adapt the agency to climate stressors. Finally, the district-level adaptation assessment and strategy reports will use a weighted scoring system to prioritize projects within each district in terms of the climate-related threats and the consequences of inaction.

DEVELOPMENT OF A CONCEPT FOR RESILIENCE MANAGEMENT FOR FEDERAL HIGHWAYS IN GERMANY

MARTIN KLOSE

Federal Highway Research Institute

Background

In Germany, climate change remains a challenge to road infrastructure. From extreme weather events and natural hazards to the structural damage they may cause, resulting in a loss of infrastructure availability, along with the disruptions to the economy they bring, climate change presents consequences for owners, operators, and users of the roadway alike. This brings forward the need for resilience management, done so through a holistic perspective to plan and manage roadway infrastructure in the times of climate change and disruptive events as described in Figure 15.

Innovations

Federal Ministry of Transport and Digital Infrastructure is a network of subject matter experts brought together to help write a roadmap for future research strategies. Climate change is identified as a challenge to road infrastructure, whether it be from extreme weather events—natural hazards, structural damage and nonavailability of road infrastructure, or the disruption of transport and the economic activities that rely upon it. Resilience management from a holistic perspective contains planning measures to prepare for infrastructure management in the times of climate change and disruption. Resilience must also be put in context of sustainability for social-cultural mechanisms, alongside economic and ecological sustainability.

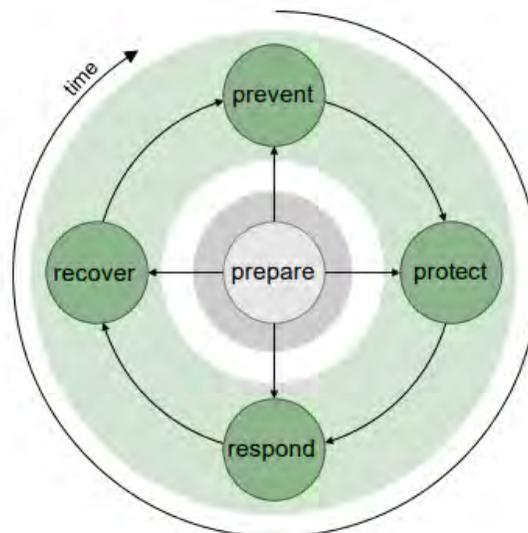


FIGURE 15 Resilience management. (Source: Federal Highway Research Institute)

Contribution

The project started with a review of basic resilience principles and existing management systems, and then moved on to determining the objectives of integrating resilient design into management systems. The process helped reinforce the idea that resilience should not be too overarching or standalone and needs integration into existing processes and management systems to achieve the desired outcomes. The resulting process should also be iterative over the course of an asset's life cycle, to constantly re-evaluate potential threats and consequences. For example, a bow-tie model that starts from identifying sources of hazards, to prevention and protection in preparation of an event, while post-event includes response, recovery, and finally assessing the effects of the event on functionality to complete the loop-back process. The project is expected to be completed sometime in 2020.

COLORADO'S ROAD TO RESILIENCY

JOHNNY OLSON

Horrocks Engineering, on behalf of Colorado Department of Transportation

ELIZABETH KEMP HERRERA

Colorado Department of Transportation

Background

In 2013, record floods hit northern Colorado hard, causing damage and problems for roadway infrastructure and communities. This was Colorado's "never again" moment and the mindset afterward was to reduce risk, protect assets, and improve safety.

Innovations

The state of Colorado established an Office of Resilience within the Department of Local Affairs to establish a resiliency framework for the state. In 2018, the Colorado DOT Policy Directive 1905.0: "Building Resilience into Transportation Infrastructure and Operations" was established to foster and support resiliency initiatives in the agency.

Recently completed initiatives included a pilot study of the I-70 corridor to analyze risk to highway assets from a range of threats including flooding, rockfall, and landslides completed by AEM Corporation. This resulted in information on owner and user risk for a variety of assets and threats, including roadway-rockfall and bridge flood.

Next, Colorado DOT is attempting to identify locations where poor condition culverts on critical highway facilities may be a threat to operations. The agency has a large GIS database of over 60,000 culverts and recently completed an in-field inspection of these culverts. The agency hopes to cross reference poor condition assets with critical highway facilities to develop potential maintenance strategies to address these locations.

Contribution

Colorado DOT is working towards an online operational dashboard of its assets and is working on integrating a real-time avalanche tracker. It acknowledges that there seems to be a disconnect between emergency resilience and planning resilience and is working to plug the data in to the planning process in the next year.

FLOOD-RESILIENT CRITICAL INFRASTRUCTURE: DUTCH POLICY AND THE ROLE OF THE NATIONAL HIGHWAY NETWORK

KEES VAN MUISWINKEL

*Rijkswaterstaat Water, Traffic and Environment–
Ministry of Infrastructure and Water Management, The Netherlands*

Background

The policy in the Netherlands is to adapt to the changing climate while still supplying fresh water to its citizens. The goal of the country is to climate proof its infrastructure with a three-layered safety approach: emergency management to reduce loss of life, sustainable spatial planning to limit the effects of flood damage, and prevention activities to limit the probability of flooding using dikes and natural barriers.

Innovations

Emergency management to reduce loss of life includes tools such as a model for flood evacuation planning, which includes a public app to see “Will I be flooded?” to raise awareness. It also includes evacuation routes, along with regional plans by safety regions and different dike rings. On the national level, a national response plan including a mass evacuation framework, and traffic management of evacuation routes through Rijkswaterstaat has been developed. This includes a module for major flood evacuations. The next phase includes the development of a climate–spatial–adaptation policy, which is intended to make the Netherlands as climate proof and waterproof as possible by 2050. The goal is to have incorporated climate proof and water-resilient planning into policies and actions by 2020 with special attention placed on critical and vulnerable infrastructure.

Contribution

To summarize, efforts are regionally focused, including pilot studies in the Province of Limburg that focused on stress testing the roadway network in order to determine hotspots of low travel reliability. This project brought together interdisciplinary stakeholders to address the issues facing transportation infrastructure (road and rail). A second pilot executed in the city of Maastricht focused on pluvial flooding and found that there should be different strategies to plan for major floods versus pluvial flooding and that stress tests need to be further validated to support this identified difference. More engagement leads to better solution identification among

stakeholders and, in the future, a multimodal analysis for transport corridors might be appropriate.

SESSION QUESTIONS AND DISCUSSION

Q. What did Colorado find surprising during analysis?

A. That it wasn't so much the flooding as it was the condition of the minor culverts that was a major culprit of risk.

Q. What best practices need to be learned before getting started?

A. Getting buy-in on change management (is important) to get climate change prioritization. An existing resilience plan will help. Outreach helps to reach a consensus around environmentally sensitive areas.

Integrating Resilience in Transportation Planning, Part A

HEATHER HOLSINGER

Federal Highway Administration, Moderator

Resilience touches all aspects of transportation policy, planning, design, finance, operations, and management. In these Part A and B sessions, panelists identified natural and climate mitigation and adaptation strategies that can be mainstreamed into transportation planning programs and projects.

TRANSPORTATION PLANNING, CULTURAL RESOURCES MANAGEMENT, AND CLIMATE RESILIENCE

JANUARY TAVEL

TAID ELDER

ICF

Background

The intersection of climate change and cultural resources can help to better understand how the decisions made to address climate change may impact vulnerable cultural resources. Cultural resources can include buildings, objects, structures, districts, archeological sites, landscapes, etc. Climate change events such as SLR, increases in flood frequency and intensity, ocean acidification, drought, wildfires, permafrost melt, and changes in ozone all can impact cultural resources. Also, given the scale of many transportation infrastructure projects, efforts to improve resilience of these projects from climate change can peripherally affect cultural resources. Figure 16 provides additional detail on the types of transportation projects that may affect cultural resources.

Contribution

Often a transportation project must be underway before a cultural resource is considered for protection from climate change and extreme events. At this point in the industry, there is often not a plan for cultural resource resilience.

Presentation Questions and Discussion

Q. Resilience is a multidimensional problem. Have you run into conflicting objectives?

A. Identifying significant impacts to cultural resources can become the basis of resilience conversation which may help to drive conversations about what strategies can protect high-risk resources.

What Types of Climate Resilience and Adaption Strategies Are Most Likely to Impact Cultural Resources?

- Projects where transportation infrastructure is itself a historic resource
- Projects where transportation infrastructure is located in historic districts or archeologically sensitive areas
- Projects where changes to transportation infrastructure reduces access to historic communities
- Projects where the presence of historic resources are unknown.



<http://sdblog.seattle.gov/2015/02/11/a-seawall-update-jet-grouting-is-providing-a-strong-foundation/>

FIGURE 16 Example transportation projects that may impact cultural resources.
(Source: ICF)

- Q. Do you see a need for the industry to revisit NEPA to consider resilience and cultural resources?
- A. I think that is a good suggestion as NEPA standards are not difficult to achieve.
- Q. Can you elaborate on how cultural resources are not currently a priority?
- A. We observed that a project must be underway before a historical-cultural resource is considered a priority to be protected from threats. Presently it does not appear that we are compelled to plan for cultural resource resilience.

Transforming Design for Resilience, Part B

JOSH DEFLORIO

Port Authority of New York & New Jersey, Moderator

As Part B, this session will continue to explore the practical world of design, exploring lessons learned from various organizations who have updated their design approaches to include nature-based solutions, as well as translate climate science into design-level guidance.

PORT DECISION MAKERS' BARRIERS TO CLIMATE AND EXTREME WEATHER ADAPTATION

ELIZABETH MCLEAN

University of Rhode Island

Background

The goal of “Measuring Vulnerability to Inform Resilience: Pilot Study for North Atlantic Medium and High Use Maritime Freight Nodes 2016–2018” was “to measure port–expert perceptions of the suitability of available data to serve as indicators of seaport vulnerabilities to climate and extreme weather impacts.” The goal of a second study discussed, “Port Decision Makers Barriers to Climate and Extreme Weather Adaptation,” was “to understand port decision makers’ perceptions on the barriers to climate and extreme weather adaptations.” The study area included medium and high use ports of the USACE North Atlantic Division.

Innovations

Researchers set out to find (a) barriers that prevent decision makers from making resilient investments at their ports as well as (b) the resources or strategies that can help overcome these barriers. They turned to port decision makers, i.e., stakeholders who have expertise and decision-making roles within the studied ports. The researchers conducted 30 interviews at 15 out of 22 potential ports, 17 interviewees were directors and managers, eight were safety planners, and five were environmental specialists. According to the interviewees, there were seven key barriers to adaptation identified:

- Lack of understanding of risks,
- Lack of funding,
- Perceived risks do not exceed action threshold,
- Physical constraints limit options,
- Lack of governance,
- Lack of communication, and
- Overwhelming nature of problem.

When asked what resources or strategies could help them overcome these barriers, interviewees responded with strategies such as:

- Fostering collaborations,
- Making regulatory changes,
- Conducting risk assessments,
- Developing financial incentives, and
- Using new technology to enhance communication network.

Contribution

Key recommendations for port decision makers included:

- For directors and managers:
 - Establish collaborations,
 - Assess regulatory changes needed to encourage climate change resilience,
 - Lead working groups to develop strategies needed,
 - Direct working groups to include SLR projections in port master plans and/or development of risk management plans–vulnerability assessments, and
 - Promote learning opportunities.
- For safety planners:
 - Integrate climate risk assessment into port master plans–management plans,
 - Organize working groups to address climate change risks, and
 - Organize drill exercises to enhance ability of port personnel to respond to disasters.
- For environmental specialists:
 - Integrate climate risk assessment into port management plans and
 - Organize working groups to address climate risks.

SUPPORTING STORMWATER INFRASTRUCTURE DECISIONS UNDER UNCERTAINTY THROUGH A SPATIAL AND TEMPORAL ANALYSIS OF ENGINEERING STANDARDS

TANIA LOPEZ-CANTU

Carnegie Mellon University

Background

Engineers, planners, and architects are responsible for multigenerational decisions that can be impacted by factors such as the increase in extreme rainfall events across the United States. This presentation reviews stormwater infrastructure design standards in the United States, precipitation documents used to retrieve rainfall information for design standards, and a risk index to inform where standards should be revised based on factors that have the potential of increased infrastructure failure.

Innovations

Infrastructure is sized based on storm characteristics with national and state agencies guiding engineering to select infrastructure minimum return periods. Across states, engineers design for different standards for the same types of infrastructure, i.e., design return periods of 10, 25, 50, and 100 years. The researchers found that some states were more stringent than others within the same climate region. Undersized infrastructure can be one factor leading to high economic damages during extreme weather events.

Contribution

Researchers concluded that numerous states should prioritize updating standards and work to install adaptive measures now. By running two separate climate scenarios, both lower and higher emissions scenarios, researchers found that the priority level increased for all states under future climate change. Overall, existing standards are not likely to be adequately sized to address climate change and resilient infrastructure design standards will need to be updated and tested as information resources evolve.

ADDRESSING INFRASTRUCTURE RESILIENCE AT ROAD–RIVER INTERSECTIONS USING THE GEOMORPHIC APPROACH

SALAM MURTADA

*Floodplain Program, Ecological and Water Resources Division,
Minnesota Department of Natural Resources*

KEVIN ZYTKOVICZ

*River Ecology Unit, Ecological and Water Resources Division,
Minnesota Department of Natural Resources*

Background

Improving waterway infrastructure design through roads requires a transformative ecological system-based approach. The approach to designing bridges and culverts at road–river intersections demonstrated geomorphic principles. Specifically, both channel and floodplain connectivity establish a “least impactful” design allowing for improved safety and resilience, reduced maintenance; and improved river function and stability.

By focusing only on conveyance and ignoring sediment transport, traditional design methods impact natural waterways in many ways. For example, confining all the flows to on-channel and overlooking floodplain conveyance created Flood Flow Confinement (FFC). FFC adversely impacts waterways and road infrastructure through scour, head-cuts, discontinuity of flow, sediment transport, increased maintenance, and channel erosion. These impacts may be further exacerbated by climate and land use changes. Thus, applying a natural-based approach on a national level is essential to transportation and waterway resilience over time.

Innovations

The geomorphic approach to infrastructure design at road–river intersections requires an assessment to document local landform condition and basis of design. The assessment involves treating the channel and the floodplain as independent design entities. The design is further optimized through two-dimensional (2D) hydraulic modeling to quantify benefits in water surface elevation, velocity, shear stress, and connectivity. Through support from Minnesota DOT, outreach and partnerships, 29 sites were assessed and modeled, seven of which were proposed for construction, not including sites done by others.

Contribution

The research team demonstrated how shear stress can be reduced at cross-sections adjacent to roadway embankments when utilizing a “least impactful” design as shown in Figure 17.

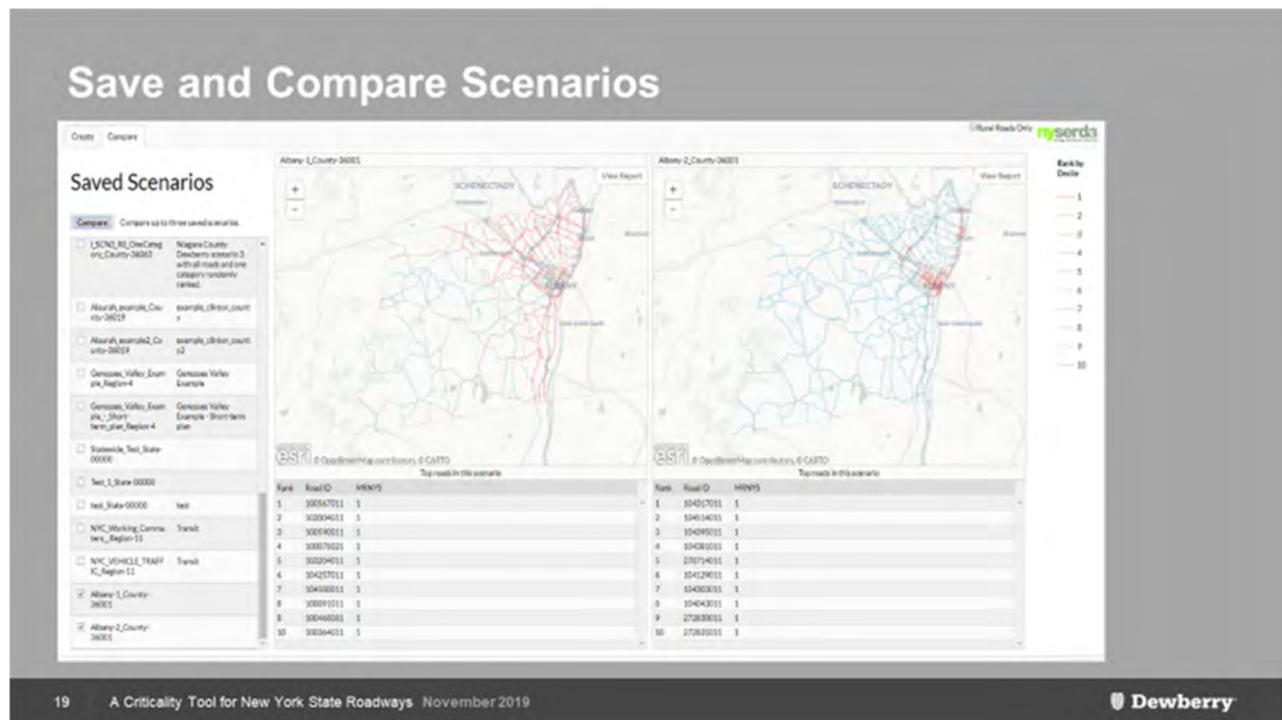


FIGURE 17 Shear reduction at cross-section adjacent to road embankment, modeled using 2D-SRH. (Source: Murtada and Zytковicz)

Projections and Downscaling

Developing and Applying Precipitation and Temperature Projections, Part 1

JEFFREY ARNOLD

U.S. Army Corps of Engineers, Moderator

This session consisted of panel and group discussion involving those who generate the projections and the people who use them. In addition, provides information on how to deal with uncertainty, including where to get the projections; how to apply them; and provide examples of building considering climate projections. The presentations highlight tools and techniques to predict storms, precipitation and flows utilizing climate projections for transportation planning, and risk-based asset management.

RISK ASSESSMENT AND RESILIENCY FOR DESIGN RAINFALL

ROBERT ARMSTRONG

ALLISON WOOD

Huitt-Zollars

Background

Consequences of flood events over a 30-year period reveals an average of 85 fatalities per year in the United States and an annual average financial loss of \$10 billion. Precipitation probability exceedance estimates are needed to calculate annual risk. The National Weather Service's Hydrometeorological Design Studies Center publishes *NOAA Atlas 14*, an atlas of point precipitation probability exceedance estimates for recurrence intervals ranging from one to 1,000 years. The Hydrometeorological Design Studies Center bases its estimates on rain gauge data, but many places in the United States have 50-years or less of rainfall data. Naturally, there is a lot of uncertainty associated with estimates for recurrence intervals greater than the period of available rainfall data. In addition, there is uncertainty associated with climate change projections for precipitation due to the disagreement between the models.

Innovations

How do people build for resilience in view of the uncertainty? An approach is to use the upper confidence interval of the 90% confidence interval. For example, Figure 18 shows the 90% confidence interval for precipitation depth at the Houston International Airport (IAH). The yellow line intersects with the curves at the 1% Annual Exceedance Probability (AEP) 90% confidence limit of 21.7 in. and the lower 1% AEP 90% confidence limit of 12.2 in. Engineers should consider the upper confidence limit when designing for extreme events.

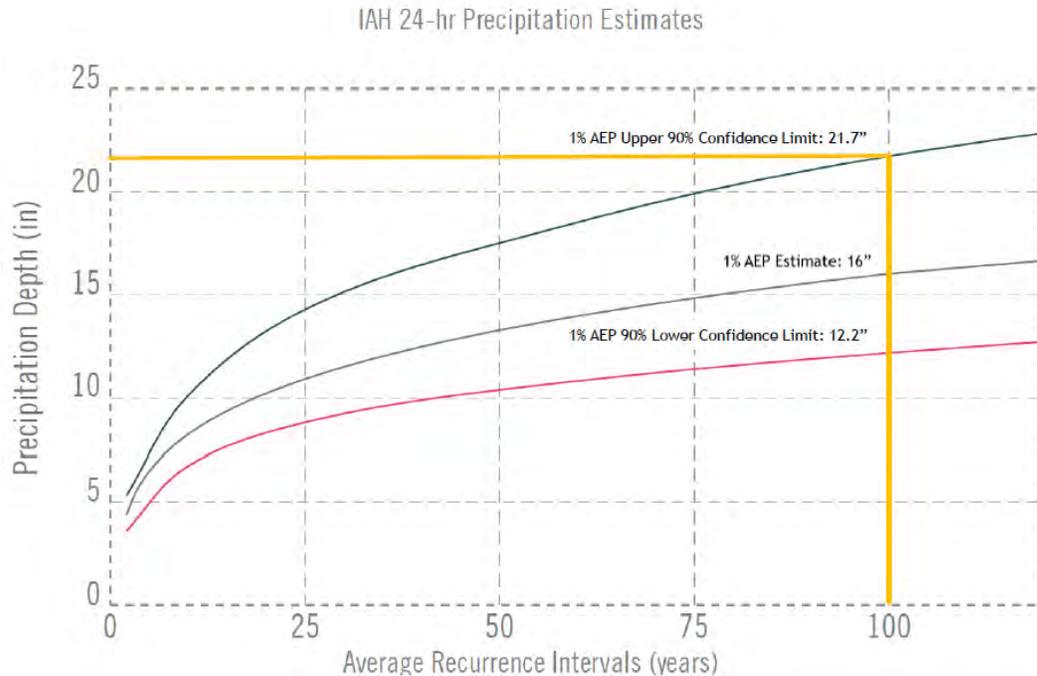


FIGURE 18 IAH 24-h precipitation estimates. (Source: Huitt-Zollars)

In addition, several free government tools that can assist in designing for climate change including:

- Environmental Protection Agency’s (EPA) Stormwater Management Climate Adjustment Tool (SWMM-CAT) allows future climate change projections to be processed with the Stormwater Management Model (SWMM). This tool accepts Coupled Model Intercomparison Project (CMIP) Type 3 data.
- Climate Resilience Evaluation and Awareness Tool. This tool, also sponsored by the EPA, assists utilities in assessing their risk from the impacts of climate change.
- FHWA CMIP5 Climate Processing Tool is an Excel spreadsheet that processes downscaled climate data to produce projections for several climate variables relevant to transportation infrastructure.
- USACE Hydrologic Engineering Center’s Meteorological Visualization Utility Engine (HEC-METVUE <https://www.hec.usace.army.mil/software/hec-metvue/>) website enables users to view and do a variety of computations and analysis of meteorological datasets.

Also, a Regional Storm Analysis Approach can be used to analyze risk that a region might face from extreme events rather than just one specific location.

Contribution

This presentation addressed the uncertainty in estimating precipitation depths and introduced four free, government-sponsored tools as well as additional methods that can assist planners in planning for climate change and uncertainty related to extreme storm events.

BREAKING THE MOLD: CHANGING THE PRACTICE OF PROCESSING CLIMATE PROJECTIONS FOR TRANSPORTATION PLANNING

ANNIKA RAGSDALE
WSP

Background

In general, when selecting GCMs for climate change modeling, the state-of-the practice is to use as many models as possible and to use the ensemble mean. However, in truth, there is no one GCM that can support this multimodel combination. Relying on the ensemble mean could result in values that are physically implausible.

Innovations

Options for validating projections from GCMs includes using proxies as indicators, such as rail bucking and an increase in landslides. Rather than isolate climate variables, climate models should recognize how they may affect each other; for example, as sea-level rises, ground water levels may rise too. Researchers may want to use the Student's *t*-distribution to see if a projected climate change is statistically significant from present conditions. For complex phenomena, such as landslides, researchers could run physical models for each climate simulation and then average the results. Another approach to climate change analysis is the narrative-based analysis. With the narrative-based approach, it is possible to estimate the severity of climate change variables and their impacts in their community.

Contribution

This presentation provided several alternatives for assessing climate change projections considering the uncertainty associated with GCMs.

INFORMING NEIGHBORHOOD-SCALE DECISIONS: ADVANCES IN CLIMATE IMPACT DOWNSCALING

THOMAS WALL
Argonne National Laboratory

Background

Climate models are mathematical representations of the climate system based on physical laws and understanding of processes. The Earth is divided into grid squares and for each grid square thousands of calculations are performed. The size of these grid squares has shrunk over time, from 200 to 300 km in the mid-1990s to 50 to 100 km in the present. In the future, the resolution will be reduced to 25 km or less. Dynamic downscaling runs regional climate models over a spatial domain using input from GCMs. The Weather Research Forecast (WRF) mode, V3.3.1, has a spatial resolution of 12 km in North America. The temporal resolution is 3-h with 8.8

gigabyte (GB) of data produced daily. The dataset currently has over 330 years of model simulation output and over 700 terabytes (TB) of data. Simulations include RCP 4.5 and RCP 8.5 scenarios.

Innovations

The WRF-Hydro model can model water depth and stream flow at a resolution of 200 m². In addition, outputs from the WRF model can be input into the Advanced Circulation Model (ADCIRC) and Simulating Waves Nearshore model to project future hurricane-related flooding. The resolution for projected coastal flooding ranges from 50 to 90 m². As a test case, Argonne National Laboratories projected coastal and inland flooding along the coast of Charleston, South Carolina, at 200 m² resolution. The objective was to assist AT&T with a risk assessment for their telecommunications assets. In addition, statistical modeling was used to project changes in wind intensities at 10, 50, and 100 m above ground across the southeast.

A second study assessed Maine's flood risk to urban and highway stormwater systems. Intensity–duration–frequency curves were updated for future precipitation. The study projected coastal flood risks due to sea-level rise and a “Sandy-like” hurricane storm surge using ADCIRC. Inundation was assessed at the asset level for energy and fuel infrastructure. Stakeholders were provided with tools to visualize the impact of inundation on their assets.

Contribution

Dynamic downscaling with regional climate models and substantial computing power can generate climate change projections down to very small scales. It is now possible to project high winds at a resolution of less than 90 m² and flood depth down to 200 m² which makes it possible to conduct risk assessments for climate change at the asset level.

NCHRP PROJECT 15-61, “APPLYING CLIMATE CHANGE INFORMATION TO HYDROLOGIC AND HYDRAULIC DESIGN OF TRANSPORTATION INFRASTRUCTURE”

ANNE STONER

Texas Tech University Climate Science Center

Background

Transportation hydraulic engineers are being asked to account for global climate change within hydrologic and hydraulic design practice. Current H&H design procedures stipulate use of historical data that are assumed to represent a stationary process. Climate change introduces nonstationary risks such as sea-level and temperature rise, and changes in timing and distribution of precipitation, snowpack, and snowmelt. Failure to account for such nonstationary risks may compromise the operational characteristics of existing and future transportation infrastructure. Climate change scientists employ outputs from a cascade of models to develop regional scenarios representing these nonstationary phenomena that are not associated with specific probabilities. Existing guidance for H&H design does not provide methods to incorporate such

information. Collaborative efforts and a common set of terms and definitions between climate change scientists, hydrologists, hydraulic engineers, and coastal engineers are essential to harmonize climate change inputs and H&H design practice.

Incorporating the results of climate models may have large cost implications for future infrastructure. For example, overestimation of the magnitude of peak flows can result in costly oversizing of drainage infrastructure, while underestimation might leave infrastructure vulnerable and the resultant flooding impacts on surrounding lands and structures inadequately addressed.

It is often questioned if the magnitude of change in hydrologic and hydraulic inputs due to climate change are within the range of uncertainties accounted for in the current state of practice and how the uncertainties vary for the design of various hydraulic features ranging from stormwater management facilities to bridges, given that they are typically evaluated for varying extreme events. Furthermore, accounting for climate change in hydraulic design is complicated by additional nonstationary processes arising from urbanization and other land cover changes. Research is needed to provide hydraulic engineers with practical tools to (1) account for the effects of climate change in hydraulic design where appropriate and (2) justify when such changes are not warranted for a project of a type or scale.

Innovations

This presentation addressed selecting GCMs and RCP scenarios. Unless there is a specific reason not to consider one end of the scenario range or the other, at minimum one higher and one lower scenario should be considered. Also, it was suggested that when designing for multiple scenarios for more than 30 years into the future it is recommended to not average across the scenarios.

For analyses with design lifetimes <30 years, scenario selection is not as critical as there is no significant difference in changes from a higher versus a lower scenario over shorter time horizons. It was recommended to use as many individual GCMs as possible to capture the range of natural variability and in some cases, it might be possible to use extrapolated trends based on historical observations. It was also suggested that simulations from newer models in the most recent CMIP should be prioritized over older GCMs in previous CMIPs. CMIP5 is currently the latest; however, CMIP6 will be available starting in 2020.

When electing climate models, the NCHRP Project 15-61 design guide specifically highlights and recommends prioritizing the use of Group 1 GCMs. Group 1 GCMs are defined as multigenerational versions (typically third to fifth) of long-established global climate models from modeling groups with decades of experience, whose performance is well documented in the literature. Attempts to identify a “best” subset of models or even a single model are strongly discouraged as they are more likely to generate false confidence in future performance. It is best to use as many GCMs as possible to encompass the range of scientific uncertainty. The minimum number of GCMs depends on the analysis objectives, meaning, more GCMs should be used for higher level analysis applications.

Two main types of downscaling methods are as follows:

- Empirical–statistical downscaling models (ESDMs) that combine observations with GCM output to bias-correct and spatially (and sometimes temporally) disaggregate GCM output to the scale of the observations.

- Dynamical models or regional climate models that use GCM output as boundary conditions to model climate over a smaller region at higher resolution (typically 10 to 50 km).

For most applications, specific downscaling methods are not as important as selecting the dataset of available projections generated by a given method. As with scenarios and global climate models, there is no one-size-fits-all “best” choice of projections or downscaling methods or models for all applications. The scope of the hydrologic assessment defines the most appropriate dataset (and corresponding downscaling method).

Contribution

NCHRP Project 15-61 provides guidance on GCM, downscaling method, and scenario selection. Several findings were reviewed:

- The level of effort and climate information to include and analyze depends on the level of analysis of each project.
 - Choice of future scenario(s) depends on the service life and criticality of the asset (there is no one more likely scenario).
 - Prioritization of climate models from newer CMIP collections and Group 1 models that span the range of climate sensitivity (use as many models as possible).
 - The choice of downscaled projections depends on the scope of the project, variables needed, spatial and temporal resolution.

Innovative Collaboration for Resilience to Extreme Weather Events

ANNIE BENNETT

Georgetown Climate Center, Moderator

This session focused on the theme of innovative collaborations for climate action and enhanced resilience to climate change and extreme weather events in the transportation sector. Presentations feature examples of how different agencies, local governments, and other stakeholders are working together across jurisdictional boundaries and multiple sectors and silos to improve collaborative decision-making in ways that better address climate change causes and impacts in transportation.

COLLABORATING FOR TRANSPORTATION RESILIENCE AND RECOVERY IN THE PORTLAND–VANCOUVER REGION

KIM ELLIS

Oregon Metro

Background

The reduction of greenhouse gas emissions has been a priority in Oregon since the 1970s, leading to one of the first statewide ban of chlorofluorocarbons. The state recently has set greenhouse gas emission targets in step with the Kyoto Protocol. Current plans revolve around reducing greenhouse gas emissions in order to increase regional resilience to the impacts of climate change through leadership, collaboration, and strategic planning measures. Centered around a 2040 growth concept started in 1995, the policy of regional climate action planning includes leaders from all levels of government. Commitments made in 2011 to conform to the Kyoto Protocol are achievable; however, they will require more effort and action to achieve. This presentation provides an overview of the three phases of efforts taken in Oregon–Vancouver region to address the regional climate change action plan.

Innovations

Phase 1 of the plan analyzed current plans and policies to determine what is achievable to reduce greenhouse gases and developed a toolbox of strategies gathered from international and domestic case studies. Three levels of climate strategies and a mix of policy and investment strategies show high, moderate, and low carbon reductions.

In Phase 2, three investment scenarios were developed that reflected political and fiscal feasibility. These scenarios were tested and determined that the region will fall short of its goals with current funding levels.

Finally, in 2014, Phase 3 was launched to shape the preferred approach focused on specific outcomes and sought strategies in order to advance social equity, diversify partners, and engage partners and the community throughout the process to achieve identified goals with multiple benefits.

Contribution

The 2018 Regional Transportation Plan renewed the region’s commitment to the 2040 Growth Concept and Climate Smart Strategy. Additionally, transit service investment has increased, and the Metro Council is preparing a major transportation funding package to accelerate investment. The region is also working on improving the region’s resilience and disaster preparedness.

WORKING TOWARD RESILIENT TRANSPORTATION IN THE TAMPA BAY REGION

ALLISON YEH
Hillsborough MPO

Background

Tampa Bay, which has over 3 million people and over 1,000 mi of shoreline, presents a challenge as it deals with SLR, increasing summer temperatures, and extreme weather events (hurricanes). This study was done in conjunction with the FHWA Resilience and Durability to Extreme Weather Pilot projects across multiple partner agencies. The study engaged heavily with the local communities to increase stakeholder participation and to determine what the best approach would be when trying to garner stakeholder support.

Innovations

Highly critical roads vulnerable to flooding were prioritized based on a qualitative stakeholder analysis and quantitative GIS-based assessment. Multiple adaptation strategies were considered, such as soil mats, road profile raising, seawalls, biofiltration swales, wave attenuation, and road surface enhancement. More robust adaptation strategies were considered for highly vulnerable roads with adaptation strategies aligning with the criticality of various roadway types. An example set of potential resilient investments are included in Figure 19.



FIGURE 19 Example resilient strategies. (Source: Hillsborough MPO)

Contribution

Regional resilience approaches were more efficient and impactful due to increased unity among stakeholders rather than an asset or single jurisdiction initiative, with many benefits derived from the study's approach. For example, a coordinated approach to address flooding in the LRTPs to focus on inland flooding, storm, surge, and SLR and complying with the FAST Act. Charts in some cases were difficult to interpret and three-dimensional (3D) depictions were found to resonate better with participants.

A multijurisdiction Resiliency Coalition, first in the nation, has also been established to continue to learn best practices from one another and to leverage regional efforts. The coalition holds monthly steering committee meetings to help communicate with elected officials to provide insight to policy direction. Efforts are currently underway to simulate the impacts of a category 5 hurricane with completion anticipated in 2020. The successes of this collaboration compact influenced other jurisdictions to follow their lead, such as a multicounty climate change compact in Colorado (www.compactofcoloradocommunities.org).

COLLABORATIVE EFFORTS TOWARD INCREASED AGENCY RESILIENCY

MELISSA SAVAGE
AASHTO

Background

AASHTO is a nonprofit, nonpartisan association representing all transportation modes and highway and transportation departments in all 50 states, the District of Columbia, and Puerto Rico. AASHTO supports state DOTs and community partners towards the goal of more-resilient transportation systems.

Innovations

AASHTO has had the same committees for 110 years, up until the introduction of Transportation System Security and Resilience Committee. AASHTO defines resilience as “the ability to prepare and plan for, absorb, recover from, or more successfully adapt to adverse events.” The inclusion of “Adapt” is unique for AASHTO in comparison to many resilience definition offered by other groups thus far.

Contribution

The formation of this committee signals AASHTO's commitment to helping agencies improve their overall resilience with the goal being to see resilience baked into every aspect of the transportation life-cycle and decision-making process. Additional assistance can be found at the RSTS Technical Assistance Program: <https://environment.transportation.org/center/rsts/>.

INNOVATIONS FROM PARTNERSHIPS IN RESEARCH AND PRACTICE

JENNIFER JACOBS

University of New Hampshire

Background

Infrastructure and Climate Network (ICNet) was established in 2012 by the National Science Foundation (NSF). It is a network of over 60 academics, students, and practitioners who are dedicated to accelerating climate science and engineering research in the northeastern United States. The ICNet focuses on climate change and SLR impacts and adaptation for sustainable bridges, roads, and transportation networks. In a field where resilience knowledge is blooming, it has been important to bring together research and practitioners so that the industry is not isolated.

Innovations

ICNet's work has utilized the help of sociologists in order to figure out how best to interface with different groups and organizations; including connecting climate scientists and transportation experts, both seeking solutions to impending challenges, to work together on those challenges.

Contribution

Both transportation agencies and climate scientists have observed that groundwater rise occurs three to four times further inland than SLR. As groundwater begins to rise, so too does the saline content within the groundwater, which can lead to infrastructure corrosion and farmland impacts.

Presentation Questions and Discussion

- Q. What is the most lasting thing from the ICNet collaboration?
- A. Trust, taking resilience into everything concurrently, improving communication across disciplines.
- Q. The current political culture is not good for discussions on carbon reduction, how did Tampa succeed so well?
- A. It became a state requirement and it was added to legislation; the state forced it, but, thanks to collaboration, many stakeholders eventually climbed on board.
- Q. How do you communicate optimism to stakeholders? How did a social scientist help?
- A. It helped to find common ground, using language and working with teams to listen for a common voice, not just the loudest voice.

Economic Analysis to Support Resilience, Part A

Rebecca Lupes

Federal Highway Administration, Moderator

This session explores approaches for evaluating and capitalizing on the economic value of adaptation improvements. Presenters will discuss cost–benefit analysis of resilience measures from varying perspectives. A framework for cost–benefit analysis helps DOTs compare projects and programs impacted by extreme weather from the perspective of the agencies’ own bottom lines. A case study of a highway in California considers the often-undervalued economic impact of roadway disruptions on businesses and communities. And an asset owner seeks to capture the value of risk reduction benefits in their insurance underwriters.

REAPING THE BENEFITS OF RESILIENT DESIGN TO REDUCE PROPERTY INSURANCE PREMIUMS

JOSHUA DEFLORIO

Port Authority of New York & New Jersey

Background

The New York/New Jersey Port Authority (PANYNJ) maintains a range of infrastructure including aviation, bridges, bus terminals, ports, tunnels, rail, and the World Trade Center. The PANYNJ recognized the need to develop strategies to reduce risk posed by climate change. To address this, the agency amended its 2008 Environmental Sustainability policy statement.

Risks recognized to threaten functionality of the Port District include sea-level rise, increased storm surge, extreme heat, and extreme precipitation. While some engineering solutions may be able to reduce risk from climate change and extreme weather, there remains residual risk that may be reduced through partnerships such as insurance companies. In order to attract such partners, it is important to convey to investors efforts to reduce financial losses from asset damage, or business interruptions.

Innovations

The newly published *Climate Resilience Design Guidelines* accounts for the expected life of assets under consideration and the likelihood of flooding based on existing or projected FEMA floodplains. The process also considers the criticality of an asset to the overall functionality of the Port District. An example application of the guidelines is outlined in Figure 20.



FIGURE 20 Example from *Application of Climate Resilience Design Guidelines*.
 (Source: PANYNJ)

Contribution

The presentation concluded with a review of the anticipated annual losses from relevant threats over the life of an example asset. The graphics provided allow potential investors to understand the measures taken by the Port Authority to reduce the anticipated losses through proactive risk management methods. Industry appears to be open to accepting such information to make better investment decisions and notes that similar approaches can be taken within an agency to make intelligent investment decisions.

RESILIENCE ECONOMICS AT THE FACILITY AND PROGRAM SCALES

SCOTT MIDDLETON
EDR Group

Background

Two examples of resilience planning in this presentation focus on the facility level to assess the cost of disruption of California Highway 101 (CA-101) and at the program level to help New Mexico DOT prioritize investments to improve system resilience.

Analysis of the impacts of a 1-year closure of CA-101 near the Redwood National and State Parks showed that the result would be a detour of approximately 311 mi in length to access the towns of Brookings and Acata north and south of the parks. In addition, the analysis revealed

the 1-year closure is estimated to result in the loss of 3,800 jobs, \$456 million in business output, and \$145 million in labor income. Some of the industries impacted included recreation, lodging, fishing, forestry, and animal and crop production.

New Mexico DOT incorporated and enhanced efforts published by the Colorado DOT that sought to classify the state's network using a multiple factor model known as a criticality model. A similar qualitative scoring approach was taken to consider the potential threats on the system for example wildfires, flooding, and rockfall in addition to characteristics such as pavement rating and bridge condition. The approach is to meld together asset criticality on system operations as well as potential physical and deterioration threats on the corridor.

Contribution

CalTrans is seeking input from the public and keeping the public abreast of progress made towards identifying solutions to address the vulnerable section of CA-101 and have launched a website to continue to share progress made (<https://lastchancegrade.com/>).

NCHRP PROJECT 20-101 “GUIDELINES TO INCORPORATE THE COSTS AND BENEFITS OF ADAPTATION MEASURES IN PREPARATION FOR EXTREME WEATHER EVENTS, AND CLIMATE CHANGE”

LAUREL MCGINLEY

Dewberry

Background

As agencies begin to plan for or respond to climate events, they need to understand how to identify cost-effective adaptation investments and could benefit from cost-benefit models. NCHRP 20-101 included a survey of nearly all state DOTs and revealed that benefit-cost (B/C) analyses are often not completed by agencies due to the perceived amount of data needed to complete analyses and the lack of sophisticated tools to address multiple threats, assets, and to consider operational impacts.

Innovations

NCHRP 20-101 included the development of what is referred to as Level 1 and Level 2 in which Level 1 “Provides the net present value of an incremental cost below which adaptation is likely to be cost-effective” and Level 2 “Calculates the benefit-cost ratio for an adaptation project under climate change conditions.” The approach allows agencies to begin to consider climate data in their analyses without overwhelming the agency analyst with required data inputs to run full B/C analyses when not economically viable. The types of data and information needed to complete the proposed analyses are summarized in the slide presented in Figure 21.

Analysis Data Needs and Sources

- Flood flows (or tide elevations for sea level rise analyses) associated with each return period
 - H&H studies
 - Flood Insurance Studies
 - Past event data
- Damages associated with each return period and corresponding flow
 - Historic events
 - Engineering estimates
 - FEMA project worksheets
 - Bid documents for construction
- Discount rate
 - OMB-recommended values of 3% and/or 7%
 - Other values will be used consistent with financing mechanisms, policies, etc.
 - Present value interest factor for selected discount rate(s) and project useful life
 - Optional: sensitivity analysis comparing discount rates
- Project Useful Life
 - Anticipated length of time the project will be in place and used

FIGURE 21 Data required to complete analyses. (Source: Dewberry)

Contribution

With the increases in climate change and extreme weather events, agencies are seeking tools to help in the decision-making process to better understand what adaptation measures are cost-effective and fiscally responsible. The products of NCHRP Project 20-101 (the prepublication draft became available as of April 2020) may provide agencies with methods to help fill that gap and increase the use of cost–benefit assessments in the future.

Session Questions/Discussion

Q. Does the tool generated in NCHRP Project 20-101 compare to FEMA’s Benefit–Cost Analysis Tool?

A. Not really as it was developed for transportation assets.

Q. As we are seeing urban area population growth increase and rural area population decrease, do the studies take this into account?

A. Somewhat with traveler delay estimations.

Q. Did the Caltrans study consider durations of closure less than 1 year?

A. No Caltrans wanted to consider the worst-case scenario, but shorter periods could be modeled.

Q. Does the PANYNJ Design Guidelines consider chronic tidal flooding?

A. Yes, but very few facilities are expected to experience this before 2050. At this point more focused on storm surge.

Q. Did insurance underwriters explain what your program is comparable to (meaning PANYNJ)?

A. One insurance company provided an estimated cost with and without mitigations in place.

Nature-Based Solutions for Coastal Highway Resilience

TINA HODGES

Federal Highway Administration, Moderator

Natural and nature-based features such as wetlands, reefs, beaches, and dunes, can protect roadways from erosion and flooding while offering environmental benefits. Building on work from the USACE and the NOAA, FHWA organized a research program to develop actionable information for transportation agencies to implement nature-based solutions to protect roadways. This work included a white paper, series of peer exchanges, pilot projects, and an implementation guide.

NATURE-BASED SOLUTIONS FOR COASTAL HIGHWAY RESILIENCE: ENGINEERING, ECOLOGY, AND PRACTITIONER PERSPECTIVES

TINA HODGES

Federal Highway Administration

BRET WEBB

University of South Alabama

Background

U.S. DOT's strategic plan states that the department "will increase its effectiveness in ensuring that infrastructure is resilient enough to withstand extreme weather." Additionally, various regulations and guidance either encourage or require resilience to be included in transportation plans, asset management plans, ER, and FHWA programs. As part of a portfolio of efforts to act on these commitments, FHWA undertook studies and developed multiple pilot programs for state DOTs and MPOs across the country to advance the state of practice on resilience. Most of FHWA's work on resilience up until a couple of years ago was focused primarily on structural solutions, armoring highways with rock revetments or changing materials, widening culverts, or raising roads. FHWA recognized there was a research gap in that not much information was available on how transportation agencies can use nature-based solutions, such as restoration of wetlands, dunes, and reefs to protect roadways from flooding. USACE and NOAA recommend an integrated approach to coastal resilience that considers both structural, nature-based, and policy-based solutions separately or in conjunction with one another.

Innovations

The Nature-Based Solutions for Coastal Highway Resilience project began in 2016 to produce research and provide technical assistance to enable transportation agencies to use nature-based solutions. This project builds off the nature-based solutions work by NOAA and the USACE.

FHWA sponsored five pilot projects with state DOTs and others to assess the potential for nature-based solutions to protect specific locations along coastal roads and bridges. The

program produced a white paper that describes the potential use of nature-based solutions for coastal highway resilience. FHWA also conducted four regional peer exchanges to solicit input from experts, end users, and key stakeholders on nature-based solutions. The project culminated in FHWA's publication of *Nature-Based Solutions for Coastal Highway Resilience: An Implementation Guide*.

Upfront, the guide summarizes the current scientific literature on the benefits of nature-based solutions, including flood reduction, habitat, water quality, and recreation. It then draws from a wide range of literature to provide low, median, and high ranges of costs per linear foot for nature-based solutions in comparison with structural measures. From there, it follows the steps in the transportation project delivery process, providing information on how to consider nature-based solutions in the planning process, how to conduct a site assessment to determine whether nature-based solutions are appropriate, key engineering and ecological design considerations, permitting approaches, construction considerations, and monitoring, maintenance, and adaptive management strategies. The guide also includes technical fact sheets with summary information on major types of nature-based solutions and appendices with site characterization tools, decision support for selecting nature-based solutions, suggested performance metrics, and links to additional tools and resources.

Contribution

One major contribution was the *Implementation Guide* produced through this program. The *Implementation Guide* provides information to transportation professionals to implement nature-based solutions to enhance the resilience of coastal highways to coastal hazards. The document aims to support transportation professionals with relevant, timely, and science-based guidance regarding the complete project implementation process for nature-based solutions. A technical review panel with representation from FHWA, state DOTs, USACE, NOAA, U.S. Fish and Wildlife Service (USFWS), and academia oversaw the development of the *Implementation Guide* and provided key input. The scope includes roads, bridges, and other infrastructure that make up transportation systems exposed to tides, storm surge, waves, and SLR. While nature-based techniques can also be used in inland areas, the scope of this document is coastal areas. The *Implementation Guide*, along with the pilot reports, white paper, and peer exchange report are available at https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/green_infrastructure/.

RESEARCH AND PILOT PROJECTS UNDER THE USACE ENGINEERING WITH NATURE INITIATIVE

JEFF KING

U.S. Army Corps of Engineers

Background

Engineering with Nature (EWN) is the intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental and social benefits through collaboration. The key elements of science and engineering produce operational

efficiencies using natural processes to maximum benefit, broaden, and extend the benefits provided by-projects, and to use science-based collaborative processes to organize and focus interests, stakeholders, and partners. The program, EWN, began in 2010, by engaging USACE, other agencies, NGOs, academia, the private sector, and international collaborators. The program is guided by a strategic plan and was established through the EWN proving grounds. Information through strategic communications and education was advanced through partnering and collaboration, and informed by focused research and development, and demonstrated through extensive field projects.

Innovations

International guidelines on the use of natural and nature-based features (NNBF) for sustainable coastal and fluvial systems are created with the purpose to develop guidance for using domestic NNBF to provide engineering functions relevant to flood risk management while producing additional economic, environmental, and social benefits. The guidance document is anticipated to be published in 2020. In addition, the USACE also developed a tool called the Natural Infrastructure and Opportunities Tool using a public-facing web viewer.

Contribution

In a case study, Orange County looked at a corridor from Sabine Pass to Galveston Bay. They proposed horizontal levees, considered designs, and characterized the environmental and social benefits. They looked at sediment sources and site proximity and established multiple lines of defense to protect communities and transportation corridors. As the speaker noted, in order to fully apply the EWN strategies, one must understand the system, approach it knowing not “one-size-fits-all” projects, use a multidimensional approach, and understand that it is not a “build-one-and-done” approach.

THE ECOLOGICAL EFFECTS OF THE SEA-LEVEL RISE PROGRAM

TREVOR MECKLEY

CSS, Inc.

Background

The Effect of Sea-Level Rise (ESLR) Program from NOAA focuses on three principles: advancement of predictive models and tools; evaluation of coastal community and ecosystem vulnerability; and a solutions-focused approach that quantifies ecosystem services and flood protection of possible flood mitigation options. These options include policy actions or natural habitat or built structures integrating natural features.

ESLR requires a collaborative approach among an advisory group of future users brought in at the beginning of the project. Stakeholders include anyone making policy, coastal land management, or project decisions.

Innovations

One innovative project involves the analysis of how sand dunes recover from storms and how they should be managed in North Carolina. Modeling dune evolution over 1 year and the effects of a storm event on the dune, the project helped determine that pre-storm sand nourishment of the beach led to natural nourishment of the dunes rather than reactive post storm-nourishment, driving policy decisions.

Additionally, modeling storm surge and sea-level rise in order to predict the inundation issues in different landscapes through Coastal Dynamics of Sea-Level Rise Model (CDSL/NGOM3) provided estimated impacts on infrastructure under different storm and SLR scenarios.

Contribution

The major contributions of this project, include highlighting the possibilities when connecting scientists, coastal decision- makers, and project planners, as well as proof-of-concept studies using the described process of inundation modeling to determine dynamic flood exposures that extend beyond still water flood plain, based on different SLR scenarios, along with that exposure's cost along the coast. NOAA is actively assisting in community planning and infrastructure analysis. Their work was noted as being integral to the future of coastal defense from climate change.

Geotechnical Aspects in Transportation Resilience

KALID MOHAMED

Federal Highway Administration, Moderator

This session will include a discussion of geotechnical considerations in transportation resilience; evaluation and management of weather elements effects on transportation geotechnical hazards (geohazards) to maintain a resilient transportation system; and the benefit of using GIS and databases for the analysis of geohazards risk and development of transportation resilience approaches

GIS MODEL FOR LANDSLIDE SUSCEPTIBILITY DUE TO HIGH-PRECIPITATION RAINSTORM

HANY HASSABALLA

GeoDecisions

Background

This project was sponsored by the Southwestern Pennsylvania Commission (SPC) Regional Planning Agency. The SPC is responsible for 10 counties encompassing over 7,000 mi², 2.6 million residents, 548 municipalities, three DOT Districts, and 10 transit agencies. The purpose of the project was to assess the landslide susceptibility in the planning region due to high-precipitation levels. The methodology was adapted from methods developed by the Minnesota DOT.

Innovations

Factor of safety (Okimura and Ichikawa, 1985):

$$FS = \frac{\hat{C} + [(\gamma_{sat} - \gamma_w)h/\cos^2\theta + \gamma(Z - h/\cos^2\theta)]\cos^2\theta \cdot \tan\hat{\phi}}{\left[\frac{\gamma_{sat}h}{\cos^2\theta} + \gamma \left(Z - \frac{h}{\cos^2\theta} \right) \right] \sin\theta \cdot \cos\theta}$$

where

- FS = factor of safety;
- h = ground water level;
- \hat{C} = soil cohesion;
- γ = unit weight of soil under normal conditions;
- γ_{sat} = is the specific weight of saturated soil;
- γ_w = the specific weight of water;
- $\hat{\phi}$ = effective internal angle of friction; and
- θ = slope angle.

The factor of safety equation can be re-arranged to calculate the critical seepage depth (H_{cr}) as presented in Figure 22.

$$H_{cr} = \frac{\frac{\hat{C}}{\gamma_w} - SG \cdot Z \cdot \cos^2 \theta (\tan \theta - \tan \hat{\phi})}{\cos^2 \theta [(SG_{sat} - SG)(\tan \theta - \tan \hat{\phi}) + \tan \hat{\phi}]}$$

where

- θ = the slope angle;
- $\hat{\phi}$ = effective internal angle of friction;
- \hat{C} = soil cohesion;
- SG = specific gravity of soil. The SSURGO dataset provides information on the bulk density of soil in grams per cubic centimeter (g/cm^3). SG of the soil layer can be said to be equal to its bulk density;
- SG_{sat} = saturated specific gravity; and
- Z = soil layer depth.

FIGURE 22 Calculating critical head of water. (Source: GeoDecisions)

The critical seepage depth formula can be calculated in GIS with open-source data.

1. The slope angle is derived from a digital elevation model.
2. The effective internal angle of friction is one of two factors determining the shear strength of soil. It can be determined if the soil type is known. The soil type is obtained from the USDA's soil survey database (SSURGO).
3. The second factor determining shear strength is soil cohesion. Soil cohesion can also be determined by knowing the soil type.
4. Specific gravity is the ratio of the density of soil over the density of water. The specific gravity of soil ranges from 2.65 to 2.85. In general, the specific gravity of soil equals its bulk density in g/cm^3 .
5. The specific gravity of saturated soil is calculated as follows:

$$SG_{sat} = SG + (\eta - \vartheta FC)$$

where

$$\eta = \text{soil porosity}, \eta = 1 - \frac{SG}{2.65}$$

ϑFC = soil field capacity

6. Z is the depth to water. This study used 6-ft as a default value.

The formula for the minimum amount of rain infiltration that will cause failure is calculated as follows:

$$F = H_{cr} \cos^2 \theta (\eta - \vartheta FC)$$

Storm precipitation estimates come from *NOAA Atlas 14*. The atlas includes 25-, 50-, 100-, 200- and 1,000-year storm precipitation rasters. The analyst can subtract the storm precipitation rasters from the H_{cr} raster to generate final susceptibility rasters.

Contribution

This project demonstrates that it is possible to map areas susceptible to slope failure using open data sources and information available through USDA regarding soil characteristics. This methodology can help highway officials visualize where slope failure is likely to occur, and which assets are most vulnerable.

GEOHAZARDS, EXTREME WEATHER EVENTS, AND CLIMATE RESILIENCE: THE DEVELOPMENT OF FHWA GUIDANCE

BRIAN ZELENKO
WSP

Background

Geohazards, including landslides, rockfall, liquefaction subsidence, debris flows, expansive soils and wildfire, pose a serious threat to transportation systems. Extreme weather events can trigger or exacerbate the intensity and frequency of extreme weather events. There has already been an observed increase in the frequency of extreme weather events and geohazards; for example, in 2017, rockfalls and debris flows followed wildfires in California while mudflows and flooding followed hurricanes in Texas, Florida, and Puerto Rico.

While many state agencies have taken a proactive approach and developed geohazard programs, other state agencies take a passive approach and do not act until an event has happened. Regardless, guidance is needed to aid agencies to improve their geohazard plans to address the consequences of climate change.

Innovations

FHWA completed a draft guide on April 30, 2019, *Geohazards, Climate Change, and Extreme Weather Events, and Resilience Guidance Manual*. Development of the guidance began with a literature review that included national and international sources from the previous 10 years. Research focused on the type and severity of geohazards, current management practices for geohazards affecting transportation systems, the link between geohazard, extreme weather events and climate change, and gap analysis. In addition, a peer exchange held in Atlanta in 2016 included experts from federal and state agencies as well as private industry consultants. Technical areas discussed included the various types of geohazards, climate conditions, extreme weather events, environment, hydraulics, socioeconomics, and geotechnical asset management.

Key elements of the guide include systemwide vulnerability analysis, adaptation analysis for individual assets, asset management system, and performance measurement and public communication.

- Systemwide vulnerability analysis:
 - Identify and characterize those geohazards that pose the greatest threat, and
 - Understand and characterize the impact that climate conditions and extreme weather events may have on geohazards.
- Adaptation analysis will use the FHWA Adaptation Decision-Making Process.
- Asset management system—transportation asset management is expanded to include geotechnical asset management. Examples of geotechnical assets includes slopes, embankments, retaining walls, and subgrade.
 - Performance measurement and public communication:
 - Determine the effectiveness of adaptation measures;
 - Develop risk maps; and
 - Communicate by social media, mainstream press, pamphlets, and hazard warning systems.

Contribution

FHWA has produced a guide to assist state agencies in developing, implementing, and maintaining a geohazards program. The guide identifies and characterizes geohazards, discusses evaluating the severity and frequency of geohazards, evaluating the influence of extreme weather events, risk analysis, geohazard mitigation strategies and climate change adaptation.

CASE STUDY: MARYLAND ROCKFALL INVESTIGATION AND BACK ANALYSIS

LIJUN ZHANG

Maryland State Highway Administration

Background

This project investigated a rockfall event on Maryland State Route 135 (MD-135), in Luke, Maryland, and included a study of the factors that affect rock stability including discontinuities, such as joints, bedding, foliation and faults, moisture, freeze–thaw, human activity and earthquakes. The investigation at the site found that the slope along MD-135 revealed unfavorable discontinuities with respect to the slope geometry as well as differential weathering of sedimentary rock, consisting of sandstone interbedded with shale and coal. In addition, water seepage was causing continuous erosion of the sandstone, resulting in unstable overhanging ledges.

Innovations

This study used the software package known as RockPack III (<https://www.rockware.com/product/rockpack-iii/>) to examine the discontinuities in the rocks at the site. RockPack III capabilities include kinematic stereonet analysis for rock slope stability, plane failure analysis, toppling failure analysis, and considers water pressure and seismicity.

A second software package, the Colorado Rockfall Simulation Program (3-D CRSP), was used to model rockfall trajectory. With 3-D CRSP it is possible to estimate runout distance,

bounce height, velocity, and kinetic energy. Outputs from the software models were also used to perform back analysis.

Back analysis involved collecting data on a slope failure and then using software to run simulations to closely approximate the actual event. In this manner it is possible to learn such conditions as the material shear strength, pore pressure or other conditions at the time of failure. The results of running simulations of the rockfall event on MD-135 include:

- Fallout distance from the toe of the slope ranged between 27 to 34 ft;
- Bounce height: up to 12 ft;
- Maximum kinetic energy: 284 ft-kips; and
- Velocity: 36 ft/s.

In addition, the researchers did back calculations using basic physical equations to calculate runout distance, dispersion and time for the falling rock to reach the ground. Results from the back calculations produced two equations that can be readily used by engineers to help design rockfall barriers. The horizontal range (D) of rock running out perpendicular to the slope face from the falling point is

$$D \approx 1. H \sin(2\theta)$$

where

D = runout distance in m (ft);

H = height of source rock from the from the point of impact in m (ft); and

θ = slope angle in degrees.

The estimated dimension of lateral dispersion is:

$$L \approx 3D$$

where

D = runout distance in m (ft); and

L = lateral dispersion in m (ft).

Contribution

Engineers can use rockfall simulation software to approximate conditions of actual rockfall events. Through back analysis it is possible to learn about the original conditions that led to the rockfall event. Back calculations support the ability to derive equations that can simplify the process of designing rockfall barriers.

RESILIENCE SYSTEM TO NATURAL HAZARDS IN NORWEGIAN PUBLIC ROADS ADMINISTRATION

MARTINE HOLM FREKHAUG

Norwegian Public Roads Administration

Background

Natural hazards and extreme weather events constitute a major threat to infrastructure in Norway. Each year 1,500 to 3,000 events are registered on the road network, where rockfalls, snow avalanches and landslides are the primary events registered. Norwegian Public Roads Administration (NPRA) has developed a resilience system which prevents and protects the road network and helps NPRA respond to and recover from unwanted events.

Beginning on January 1, 2020, 19 counties will form 11 regional agencies that will assume responsibility for maintaining county roads.

Innovations

To protect Norway's roads from avalanche and other hazards, Norway has installed many protection structures. However, it is not possible to install such structures everywhere. Instead, Norway is looking at alternatives, such as proactive avalanche control, detection systems, and warning systems.

The NPRA's goal is to close roads in advance of events happening as well as provide early warning. The NPRA launched the Norwegian Avalanche Warning Service (NAWS), 6 years ago, in 2013. The service is called "VAR SOM," which is Norwegian for caution. REGOBS is part of VAR SOM and is the information exchange system for the daily exchange of snow, weather and geohazard information. The data published on REGOBS is publicly available. Figure 23 represents the NPRA resilience, or preparedness system.

Norway at a Glance	
Public roads, total	93,214 km
National roads (state-owned):	10,500 km
County roads	44,000 km
Municipal roads	38,515 km
Bicycle paths	3,500 km



FIGURE 23 NPRA's resilience systems. (Source: NPRA)

The ways in which the NPRA contributes to the preparedness system include:

- Mapping avalanche paths, landslide areas and flood zones, digitally, so they may be reused in other systems.
- Conducting field observations from both contractors, back country observers as well as from weather stations and instruments monitoring snow conditions and geohazard incidents.
- Improving the automatic data analysis and use machine learning to improve sensor networks and image recognition from the network of web cameras.
- Presenting the data in user-friendly way, with filters and the possibility to combine relevant data sets.

The modified diagram presented in Figure 24 shows the interconnectedness and collaboration that is characteristic of the preparedness system.



FIGURE 24 NPRA's resilience system. (Source: NPRA)

An example of presenting data in a user-friendly way is Varson Xgeo, a GIS web map application for sharing snow, flood, and landslide data with the public. Users can click on a

camera icon to see real-time imagery from a web cam as well as access reports of avalanche danger, bad weather, flood, landslide, or rockfall events.

Contribution

The NPRA has demonstrated that a coordinated system involving regional agencies, early warning systems, weather stations, field observers, avalanche control and the Internet can enhance resilience through early warning, information sharing, and planned road closures. NPRA's preparedness system not only reduces the need for installing costly protection systems but also enhances public safety.

Causality and Surrogates *Bridge Vulnerability and Resilience*

BRIAN BEUCLER

Federal Highway Administration, Moderator

This session focuses on the relationship between changes in precipitation and the vulnerability of bridges to these changes. When examined comprehensively and in detail, this relationship can be simultaneously “compounding” and “confounding.” The scour processes and statistical relations between precipitation, flow, velocity, flow depth, and ultimately scour include uncertainties and other concerns such as watershed characteristics, bridge site geometry, and vehicle loading configurations, and how they complicate the picture. People will examine the ways floods are changing in the United States and the significance of those changes and will then review a project that strives to account for these changes so that bridges due for replacement can be built back in a resilient manner based on sound science.

IMPACTS OF FLOOD CHANGE ON BRIDGE SCOUR RELIABILITY

CHAO HUANG

GENEX Systems

Background

The goal of this project was five-fold:

1. Analyze changes of annual peak discharges for the 100-year period, from 1916 to 2015;
2. Determine the annual peak discharge distributions before and after a change point;
3. Conduct multiple hydrologic engineering center–river analysis system (HEC-RAS) flow simulations for a river crossing;
4. Compute changes for annual flow depth and velocity distributions; and
5. Determine the impacts of changes on annual scour exceedance probabilities.

The case study site was on the Piscataquis River near Dover–Foxcroft, Maine.

Innovations

The methodology included modeling rainfall intensity with multiple simulations, resulting in a probability distribution curve. Historical annual peak discharge data collected for the years between 1916 and 2015 identify significant change points using stream gauges selected from the Geospatial Attributes of Gauges for Evaluating Streamflow II (GAGES II) database. Annual peak-stream flow data came from the USGS National Water Information System Peak-Flow File and the Pettitt Test and identify change points within the annual peak streamflow data. The period before and including the change point year were labeled “pre” and the period after the change point was labeled “post.” Next, annual max discharge data was input into HEC-RAS or

SRH-2D hydraulic models to model flow depth and velocity. In turn, modeled flow depth and velocity were input into HEC-18 equations to calculate scour depth.

Modeling pre- and post-peak discharges showed a change of +17% and when comparing pre- Q_{100} events to post- Q_{100} events it was shown that discharge, flow depth, velocity and scour depth all increased. The 1% exceedance probability flow depth increased from 8.9 to 9 ft, or +1%. The 1% exceedance probability flow velocity increased from 8.3 to 9.9 ft/s, or +19%. The 1% exceedance probability scour depth increased from 14.9 to 16.0 ft, or +7%. The Poisson process was used to estimate the probability of scour exceedance for various bridge design lives.

Contribution

This case study showed a potential approach to determine scour exceedance probabilities before and after change points. The 1% exceedance probabilities of flow depth, velocity and scour depth may or may not be equal to flow depth, velocity and scour depth computed from a Q_{100} event. Finally, the exceedance probabilities of discharges, flow depths, velocities and scour depths are not enough to determine bridge failure probabilities because no structural (loads) and geotechnical (resistance) uncertainties are included.

SCOUR AND RESILIENCE: FOCUSING ON THE ISSUES

JOE KROLAK

Federal Highway Administration

Background

The speaker provided an overview of bridge scour that occurs when soil beds experience erosion as a result of hydraulic events upon a structure. Also provided was an overview of guidance and regulations related to scour due to flowing water around piers and abutments of bridges including National Highway Institute and EPA guidance.

Innovations

The speaker hypothesized that rainfall and discharge are scour surrogates as demonstrated in Figure 25.

The industry should consider integrating scour into resilience frameworks and presented three hypothetical approaches to doing so.

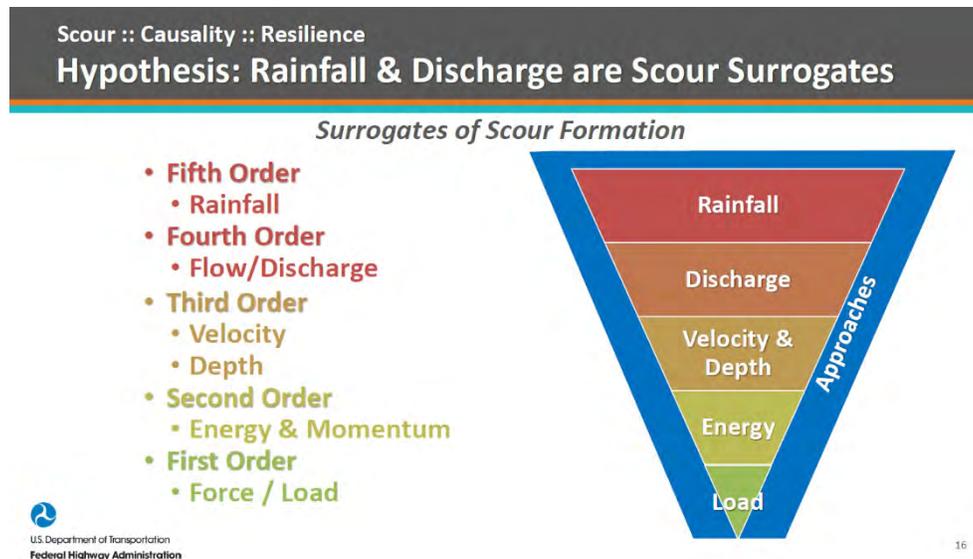


FIGURE 25 Hypothetical surrogates of scour formation. (Source: FHWA)

Contribution

Finally, there are research opportunities to consider the various contributors of scour including geotechnical stability, loads and stability of structures, and the relationship between scour and resilience.

DETECTION, ATTRIBUTION, AND ADJUSTMENT FOR FLOOD CHANGE ACROSS THE UNITED STATES

STACEY ARCHFIELD

U.S. Department of Interior, U.S. Geological Society

Background

There is an assumption that the past is a reasonable representation of the future, but what if that assumption is no longer valid? There is now increased attention to the potential violation of this assumption and its implications for decision-making. From USGS Bulletin 17C, *Guidelines for Determining Flood Flow Frequency*, in a statement regarding climate variability and change:

“There is much concern about changes in flood risk associated with climate variability and long-term climate change. In those situations where there is sufficient scientific evidence to facilitate quantification of the impact of climate variability or change in flood risk, this knowledge should be incorporated in flood frequency analysis. All such methods employed need to be thoroughly documented and justified.”

The speaker noted several other journal articles and research pointing towards the need to adjust flood frequency occurrence under climate variability and change.

Innovations

FHWA and USGS looked at detection, attribution, and adjustment factors to address what is happening with floods, what is causing the change and how should flood frequencies be adjusted for these changes. The study is seeking to capitalize on information that can be gathered from 1,464 stream gauges that have data for a 75-year period (1941–2015). Much of the United States has not experienced significant change in any flood properties, except for New England, the northern Great Plains and upper Mississippi Valley. Also for most stream gauges (71%), the largest floods were equally likely to have occurred in either the first or last half of the 50-year period.

Contribution

Floods are changing but the spatial pattern is fragmented and changes are not uniform. The intersection between science and engineering is at a particularly critical point for this topic. The research underway between USGS and FHWA will seek to identify engineering solutions to account for change. Finally, the simplest and easiest methods are always most attractive; but in their simplicity, the ability to account for complexity may be lost.

DEVELOPMENT OF SITE-SPECIFIC HYDROLOGIC AND HYDRAULIC ANALYSES FOR ASSESSING TRANSPORTATION INFRASTRUCTURE VULNERABILITY AND RISKS TO CLIMATE CHANGE

DANIEL SZEKERES

Michael Baker International

Background

The goals of the Pennsylvania DOT Pilot Study were to

- Address climate change in hydrologic and hydraulic studies and evaluate the use of ratios (e.g. adjustment factors, factors of safety) to increase existing precipitation.
- Determine what range of “ratios” are reasonable?
 - Determine if ratios vary by region?
 - Determine how ratios impact hydrologic and hydraulic outputs
- Determine if higher precipitation events result in changes to design. If so, what additional adaptive design strategies may be needed to improve resiliency? How much could they cost?

The study looked at available GCMs and eight unrelated models. Daily precipitation for all days and years from 1950 and 2099 were analyzed and grouped by the following time periods: 1950–2005 (historical), 2006–2050, and 2051–2099 (projections). The factor increase ratio was calculated for each AEP, time period, RCP, and GCM.

Detailed conclusions from the analysis of the GCMs included the following:

- Large variation in precipitation ratios across the eight GCMs for the three study areas.
- Some GCMs project decreases in extreme precipitation for both RCPs for 2050 and 2100.
- Ratios are unrealistically high for some GCMs for extreme precipitation (0.01 to 0.002 AEP).
- Ratios almost always greater than 1.0 for less extreme precipitation (0.5 to 0.10 AEP).
- Use the ratio for 0.10 AEP for the more extreme events (0.04 to 0.002 AEP).
- Average ratios for RCP4.5 for 2050 are greater than RCP8.5 for 2100 for York and Delaware.
- Average ratios for RCP8.5 for 2050 are greater than RCP8.5 for 2100 for Allegheny (0.02-0.002 AEP).
- Ratios for 2050 exhibit a lot of variability. The recommendation is to not to make discharge projections for 2050.
- On average, ratios for RCP4.5 for 2050 are similar to RCP8.5 for 2100. The recommendation is to only make projections for RCP8.5.
- Occasionally unrealistically high daily precipitation was projected for a grid by a GCM.
- Averaged daily precipitation over larger areas than the watershed (4 to 6 grids) to investigate impact.
- In general, the ratios did not change much from the watershed ratios.

Based on the conclusions generated from the study of the GCMs hydrologic conditions for Baker Road, estimates as are shown in Figure 26.

York Site Future Flows - With Carbonate Adjustment for 2100 (RCP 8.5)							
Site Location	GCMs	Return Period (yr)					
		2	10	25	50	100	500
Baker Road, York County, Pennsylvania	Existing Flows	1,700	2,870	3,963	5,019	6,576	10,962
	BCC-CSM 1.1-m	2,644	6,733	10,510	15,374	22,833	52,297
	CSIRO-Mk3.6.0	2,101	5,321	9,406	14,718	23,976	65,953
	GISS-E2-R	2,353	3,710	5,322	6,850	8,671	15,819
	MRI-CGCM3	2,019	3,675	5,940	8,036	10,904	25,040

FIGURE 26 Projected hydrologic conditions on Baker Road, 100-year predicted flow ranges from 8,700 to 24,000 cfs compared to existing 6,600 cfs. (Projected flow increase for 100-year event between 32% to 264%.) (Source: Michael Baker)

Contribution

Future steps for this project include:

- Finalize ratios (evaluate if extreme ratios or range of ratios should be used);
- Evaluate impacts on bridge design at three sites;
- Assess adaptation strategies (if needed) by site;
- Conduct economic analysis of strategies; and
- Continue evaluation of Pennsylvania DOT design manual.

Leading the Way to Great Resilience *Policymakers Talk About the Future*

VICKI ARROYO

Georgetown Climate Center, Moderator

Moderator Vicki Arroyo opened the session with a short overview of the resources available from the Georgetown Climate Center including a Green Infrastructure Toolkit, example adaptation plans, and transportation sector case studies.

Jennifer Jacobs, University of New Hampshire, noted that climate change must be incorporated into transportation policy. She said that academic researchers need to become more involved in the transportation industry and make themselves heard by policy makers. Jacobs also recommended that researchers make better choices about what research is conducted and how to communicate the results of the research so that engineers understand how it is used in decision-making and setting policy.

Secretary **Ben Grumbles** of the Department of Environment for the State of Maryland said that Maryland's Governor Hogan is focused on sustainability and resilience for state infrastructure and communities. He noted several pieces of legislation focused on climate change and SLR. These include the Coast Smart Design Bill focused on adopting specific Coast Smart siting and design criteria that address impacts associated with sea-level rise and coastal flooding on future capital projects. Grumbles also noted that the National Governors Association is focused on transportation resilience efforts under the leadership of Governor Hogan, who announced a year-long initiative to advance the repair, enhancement, and modernization of U.S. infrastructure. This will be done through innovative fixes to bottlenecks, creative partnerships with private investors, streamlined project review, smarter technologies, and improved cyber-defenses.

Andrew Wishnia, Senior Policy Advisor at the U.S. Senate Committee on Environment and Public Works (EPW), discussed the first resiliency grant program, which is currently in legislation passed by the EPW Senate Committee. The program currently includes the following: \$10 billion in resilience investments; \$5 billion in mitigation investments; \$1 billion in electric vehicle charging stations; \$5 billion in adaptation grants and formula programs stove piped to respond to natural weather and extreme weather events; and \$786 million formula program for state DOTs under the Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) Grant Program. Additional legislation is still under development.

Julie Rozenberg of the World Bank observed that there is \$15 billion in damages a year to roadways and railways from natural disasters globally. Network redundancy can greatly improve regional and community vulnerabilities. In addition, criticality analysis of highway assets is important to demonstrate where resilient investments can be more beneficial. There is a 4-to-1 net benefit for each \$1 invested in resilient projects and a \$100 billion cost of delaying action by 1 year.

SESSION QUESTIONS AND DISCUSSION

Conversation centered on the need for economic assessment of resilient investments to support potential grant programs included in pending transportation legislation. It was noted that silos can be barriers to implementing resilient strategies in the transportation sector.

Economic Analysis to Support Resilience, Part B

THOMAS BLES
Deltares, Moderator

This second session on economic analysis includes presentations and discussion underpinning the importance of economic analyses. The session started with view from the Office of the Secretary on U.S. DOT's current efforts to understand and incorporate the costs and benefits of resilience into long-range planning and disaster recovery, followed with presentations on regionally assessing economic resiliency and making the business case for road and stormwater investments to combat sea-level rise. The session ended with a review of economic tools for analyzing transportation projects incorporating resilience.

U.S. DOT'S TOOLS TO AUGMENT TRANSPORTATION RESILIENCE AND DISASTER RECOVERY

ALASDAIR CAIN
U.S. Department of Transportation

Background

U.S. DOT previewed a forthcoming tool to support transportation agencies seeking to prioritize projects to improve system resilience. This hazard agnostic tool is being developed with technical support from the U.S. DOT Volpe Center. The tool builds on existing travel demand modeling and exposure/vulnerability analyses tools to enable the comparison of resilience investment options across various disruption scenarios. The components for the tool and guidance-are outlined in the graphic in Figure 27.

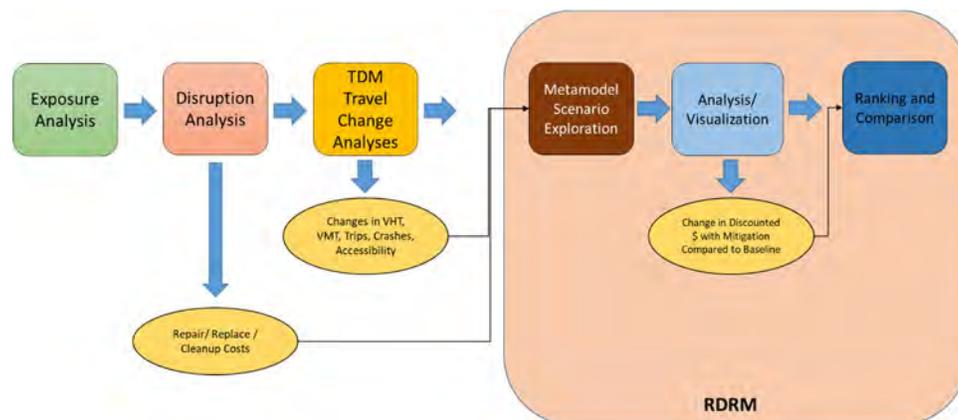


FIGURE 27 Components of resilience ROI analysis and planned resilience/disaster recovery metamodel tool development. (Source: U.S. DOT)

Innovations

The project seeks to develop a nationally replicable tool that provides the information needed by local, state, and federal agencies to incorporate the costs and anticipated benefits of resilient investments into their project-prioritization processes. It could also potentially assist industry with investment decisions.

Contribution

The lack of tools for agencies to assess the anticipated damage to highway assets from specific hazards, including the costs of disruption to the supply chain, hinders their ability to incorporate the ROI from resilient investments into project development processes. The proposed tool should serve to close one of the gaps that currently exists in the transportation sector to address recovery and resilience from extreme weather events, and eventually other hazards.

BUSINESS CASE FOR ROAD AND STORMWATER INVESTMENTS TO COMBAT SEA-LEVEL RISE

CASSANDRA BHAT
ICF

Background

The presentation focuses on helping build the business case for stormwater investments to address sea-level rise. The presenters will focus on two case studies from Florida that sought to quantify the ROI of stormwater investments to not only protect highway assets but also quantify the averted losses to surrounding private property from such investments.

Innovations

The project identified several investments that were made in south Florida to improve system resilience from sea-level rise including: elevating roadways, increasing drainage capacity, installing pump stations, and installing green infrastructure including stormwater ponds and swales. Next, an outline for making the business case for stormwater investments to address SLR is shown in Figure 28.

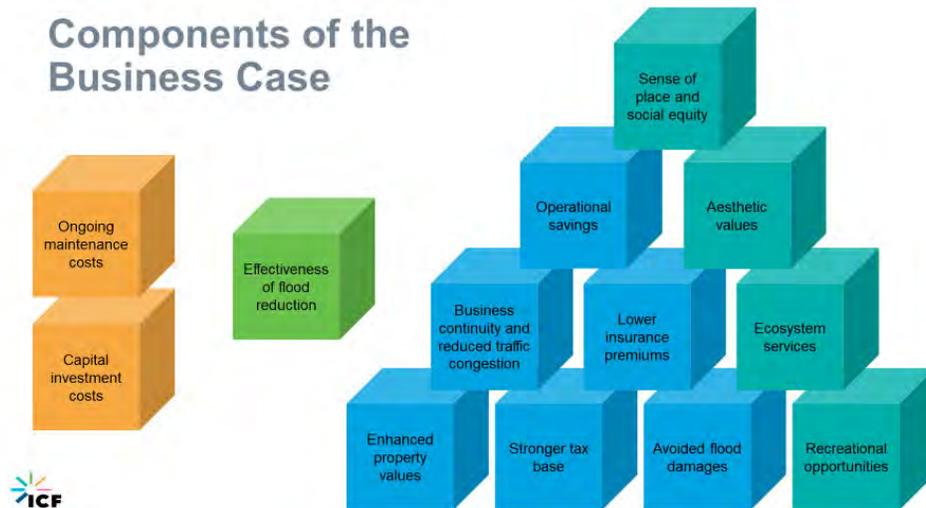


FIGURE 28 Components of a business case for stormwater investments. (Source: ICF)

Contribution

The presentation highlighted findings of the ROI of stormwater management systems to protect and improve the property values of a nearby condominium development holding all other variables constant by between 4.9% to 14.1% in value. South Pointe neighborhood would have flooded 44 times since 2017 without the investments made to stormwater management systems.

A REVIEW OF ECONOMIC TOOLS FOR ANALYZING TRANSPORTATION PROJECTS INCORPORATING RESILIENCE

PRERNA SINGH

Georgia Institute of Technology

Background

The presentation focuses on providing an overview of the need for tools to model the economic viability of resilience investments and the challenges faced by the transportation industry given the lack of available tools.

Contribution

Challenges to quantifying resilience benefits were noted. The speaker noted that agencies are more comfortable quantifying the benefits of reduced recovery or reconstruction costs and potential impacts to travelers, however, ancillary or indirect benefits are still considered undervalued.

With the uncertainty of future climate impacts, resilience benefits in the future are significantly uncertain. This type of modeling to understand the ROI under uncertainty of future climate impacts is a gap in the industry's current tool chest that should be addressed.

SESSION QUESTIONS AND DISCUSSION

- Q. Has the analysis conducted in south Florida analyzed how the flood mitigation utilized may have just moved the problems to another location?
- A. Water is mostly pumped into the bay. The model used isn't yet able to address the entirety of Miami Beach.
- Q. This is a curious idea about integrating stormwater management and transportation modeling of resilience, are you aware of other types of studies using this approach?
- A. The SEMCOG may have done this.
- Q. Has any study linked opportunity costs against more difficult decisions on land use in the future?
- A. Tampa Bay and Houston are considering different land use changes.
- Q. Have any of your tools been valuable at helping to make decisions about when to abandon due to areas being inhabitable?
- A. More economic models are needed.

Pavement Resilience

MILENA RANGELOV

Federal Highway Administration, Moderator

Design and analysis of pavement infrastructure typically include the consideration of environmental conditions. However, conventional design methods rely on the assumption of the stationary climate mainly inferred from the historical data. Nevertheless, the design of resilient and robust pavement infrastructure necessitates additional guidance on how to incorporate the effects of future climate trends and extreme weather events into the design. This session focuses on pavement design methodologies that take into consideration future environmental considerations and potential pavement adaptations targeted toward improved resilience.

DEVELOPING TIME–DEPTH–DAMAGE FUNCTIONS FOR FLOODED PAVEMENTS

JO E. SIAS

University of New Hampshire

YANING QIAO

China University of Mining and Technology

Background

The motivation behind this study was the increased severity and frequency of flooding; the lack of understanding of the level of damage to pavements; the vulnerability of local roads; and the insurance industry using depth–damage functions for buildings to quantify flood-related damages. The objective was to develop a methodological framework to quantify the long-term damage on flooded flexible pavements during recovery by establishing time–depth–damage functions.

Innovations

A section of Route 108 between Durham and Newmarket was selected to determine the damage effects on pavements with three different subgrade materials (sand, silt, and clay). Nine flood scenarios were studied with varying flood depths and time of inundation. Time of inundation ranged from 1 to 6 h and depth of flood ranged from 0.1 to 0.3 m. The goal was to study post-flooding accumulation of damage. Figure 29 demonstrates the effect of time of inundation on cumulative flood damage for clay subgrades.

Contribution

The framework for developing the time–depth–damage functions for flooded pavements was presented and a case study was illustrated using a case study pavement with sand, silt, and clay subgrades. Researchers found that post-flooding accumulation of damage was more affected by

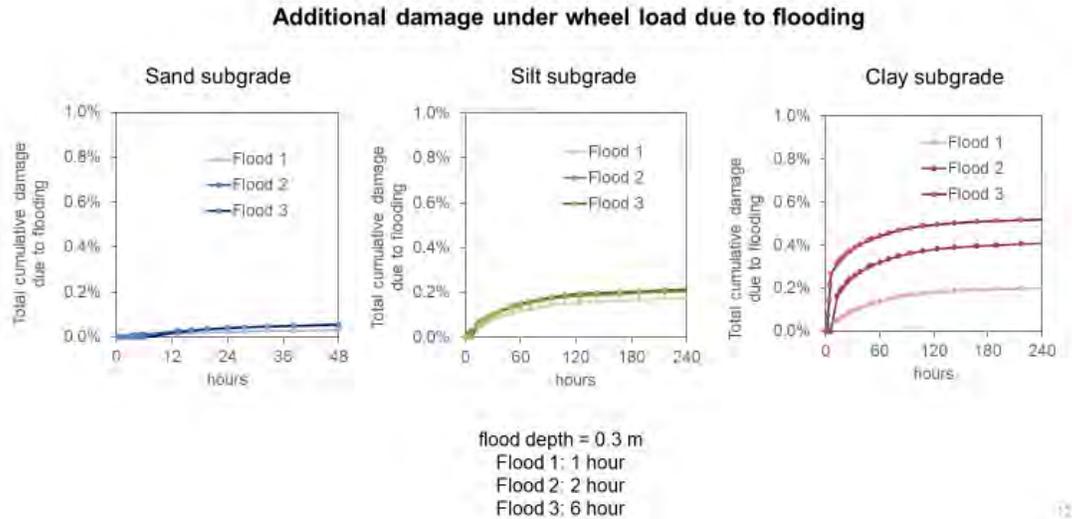


FIGURE 29 Additional damage under wheel load due to flooding.
(Source: University of New Hampshire)

inundation time than by flood depth for all subgrades with clay subgrades experiencing the greatest cumulative damage.

Ongoing research seeks to address

- Analysis of various pavement structures, materials and traffic levels;
- Consideration of existing pavement damage that would influence permeability;
- Develop generalized time–depth–damage functions for pavements;
- Laboratory evaluation of granular material permeability; and
- Validation of seepage modeling using smart sensors.

RESILIENCE ENHANCEMENT OF PAVEMENT INFRASTRUCTURE TO MITIGATE INFLUENCE OF CLIMATE CHANGE

VIVEK TANDON
University of Texas at El Paso

Background

Researchers studied the effect of climate data on pavement vulnerability to early failure and accelerated maintenance schedules to understand how higher temperatures and increases in precipitation could affect maintenance requirements and sought design solutions to improve pavement performance under climate change. The main research question was whether certain thresholds of pavement suitability breached before their normal lifespan with intensified climactic conditions.

Innovations

The I-30 Frontage Road was tested which consists of a 4-in. asphalt concrete wearing surface, 15 in. of cement treated base, and a semi-infinite subgrade. Typical maintenance activities are warranted when the International Roughness Index (IRI) reaches 100 and the study found that the IRI will reach this threshold on average approximately 1 year earlier than normal when considering climate effects. When considering thresholds for wearing surface rutting, the study found that maintenance could be required up to 6 years earlier in a pavement life cycle than typically planned for in maintenance cycles.

Contribution

The study found that current maintenance cycles for pavements may not be capturing the anticipated influence of climate change on accelerating pavement rutting and cracking that will result in pavements falling below desired performance targets sooner than anticipated. The authors studied the effects of a few mitigation strategies and found that increasing the asphalt concrete thickness, utilizing new materials that perform better under climate conditions, and changing binder grades were found to be cost beneficial and yielded long-term benefits. Figure 30 outlines a few of the proposed design changes to improve long-term performance under climate changes.

Pavement Designs for Climate Adaptation

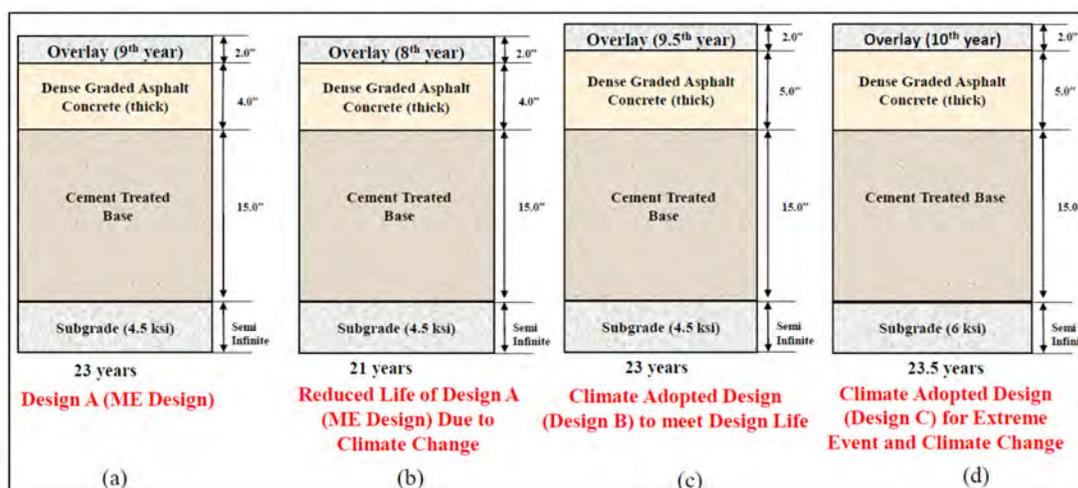


FIGURE 30 Various pavement designs for climate adaptation.
(Source: University of Texas at El Paso)

PAVEMENT ADAPTATION STRATEGIES

HEATHER DYLLA

Federal Highway Administration

Background

Environmental factors contribute to pavement distresses, i.e., blowups, buckling, rutting, and thermal cracking. The Long-Term Pavement Performance Program Impact of Environmental Factors on Pavement Performance reports 36% of total damage for flexible pavement and 24% of total damage for rigid pavements are caused by environmental factors. Pavements are designed using climatic data; however, engineers typically assume stationarity conditions which ignores anticipated changes due to climate change. The current U.S. DOT strategic plan commits to increased effectiveness to ensure infrastructure is resilient to extreme weather with an emphasis on improving pavement resilience by addressing it in asset management and project development to reduce impacts to operations and safety over the lifespan of roadways.

Innovation

Various FHWA tools were reviewed including the CMIP Climate Data Processing Tool that can greatly reduce the time and resources needed to obtain and develop relevant climate projections for temperature and precipitation variables. The VAST guides agencies through assessing climate vulnerabilities, evaluating adaptation options, and incorporating information into agency decision-making. When considering future conditions, the Adaptation Decision-Making Assessment Process was reviewed which is a risk-based approach to aid in the decision-making process to determine which project alternative best meets the needs when considering life-cycle costs, resilience requirements, and regulatory and political settings. When these tools are applied to pavements decision makers can monitor trends, evaluate vulnerability, and estimate future conditions.

Contribution

Several case studies that studied the effects of climate on pavements and two examined the effects of climate stressors on pavement design for new construction and maintenance needs of existing pavement sections.

In Texas, a section of SH-170 near Dallas was studied to determine the effects of climate change on pavement design. Climate models suggest a 4° to 6 °F temperature change expected and a decrease in the Thornthwaite Moisture Index leading to risks of invasive vegetation growth as roots under pavement seek moisture. Increases in pavement voids due to soil shrinkage was also a potential impact. The study findings recommended the use of higher steel concentrations in the continuously reinforced concrete pavement to address anticipated climate changes.

A section of existing two-lane rural asphalt highway with seasonal load allowances and restrictions was also studied in Piscataquis County, Maine to determine how freeze–thaw conditions could affect pavement maintenance requirements. The study location already has seasonal load allowances and restrictions due to the freeze–thaw cycles normally occurring. The researchers studied the anticipated pavement performance using mechanistic–empirical (ME)

pavement performance prediction models with projected climate data for temperature and precipitation. The study findings revealed that increasing in rutting and cracking due to anticipated climate changes would require increases in pavement thickness and modified polymer binders and it is anticipated that longer seasonal restrictions may be warranted due to earlier spring melts having a direct impact on the trucking industry.

This study reviewed the ongoing efforts to better understand how climate changes may affect pavement performance and design. An ongoing study to develop guidance document to incorporate sustainable practices into pavement design is expected in 2021. A guidebook on incorporating resilience into the planning process should be released in 2020.

PROJECTED IMPACT OF CLIMATE CHANGE TO ASPHALT PAVEMENT PERFORMANCE IN THE UNITED STATES

ANNE STONER

Texas Tech University Climate Science Center

Background

Engineering assets that are built to withstand certain environmental conditions are typically designed based on the assumption that there is some variability within the climate system. Extreme heat can severely damage pavements, causing excessive expansion of concrete slabs and reduced asphalt binder effectiveness.

Innovation

This study examined the impact of climate change on pavement performance for 24 sites in four different climate zones using AASHTOWare Pavement ME Design software. The software needs hourly information for five climate variables as input:

- Temperature,
- Precipitation,
- Wind speed,
- Relative humidity, and
- Percent sunshine.

Daily climate variables were obtained from a global climate model, GFDL-ESM2G, and a future scenario, RCP8.5. Figure 31 highlights some of the anticipated changes in Interstate pavement performance under climate changes.

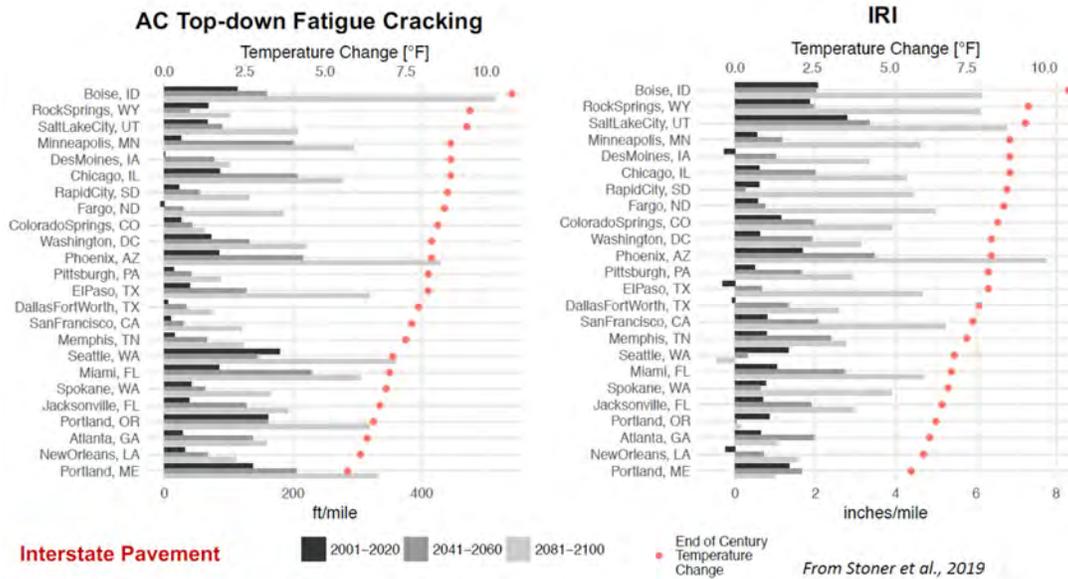


FIGURE 31 Anticipated changes in Interstate pavement performance when considering climate change. (Source: Texas Tech University Climate Science Center)

Contribution

This study utilized the capabilities of AASHTOWare Pavement ME Design to better understand the effects of climate change nationwide on pavement performance. Science has shown that climate is already changing and will continue to do so, the increase in temperature and rainfall will have a negative effect on both Interstate and primary road flexible pavement. Northern locations show the largest increase in permanent deformation. These results can provide key insights into how individual locations can alter the design, materials, and performance grade binder to optimize the performance and lifetime of the pavement in a changing climate.

Tools and Methods

CAROL LEE ROALKVAM

Washington State Department of Transportation, Moderator

This moderated panel discussion will explore ways to approach the assessment of climate risk as well as presenting useful tools and methods. The panel will reflect on how these approaches can be used to improve the resilience of transportation assets.

CITY SIMULATOR: AN INNOVATIVE TOOL FOR TRANSFORMATIVE RESILIENCE IN TRANSPORTATION SYSTEMS AND BEYOND

STEPHEN BOURNE

Atkins North America

Background

City Simulator is an ArcGIS Desktop add-in intended to help planners forecast the impacts of natural disaster and climate. Cities continue to grow while the costs of natural disasters continue to mount. This tool was designed to help planners visualize the combined effects of urbanization and climate change, identify their most-vulnerable assets, and evaluate alternative plans of action.

Innovations

City Simulator seamlessly integrates with the ArcGIS Desktop application. The user can incorporate a community's asset inventory, land use, building footprints, floodplain, and other data into an open map. The tool ingests Coupled Model Intercomparison Project (CMIP5) LOCA climate projections. On the graphic user interface (GUI), the Driver Forecast tab enables the user to select one of three climate drivers, minimum temperature, maximum temperature, or precipitation, as well as one or more GCM and emissions scenarios. Under the Scenario Builder tab, the user can define a range of years to run a simulation; and, the user has the option of incorporating physical countermeasures, infrastructure improvement measures or policy measures. The Simulation Tab is where the user can load and start a simulation. In addition, a drop-down menu makes available a wide variety of metrics, such as productivity, population, trips made, trips disrupted, vehicle miles and streets flooded. In short, the tool models the impacts of SLR, hurricanes, wildfires, droughts, heat waves, and more. It can produce reports summarizing economic loss, storm damage, changes in carbon footprint, population, and economic growth.

Contribution

City Simulator simulates a virtual city, complete with utilities, roads, rail, buildings, and lakes and streams. It uses agent-based modeling to simulate a virtual population of people living, working, commuting, shopping, and recreating. Using the latest GCM projections, planners can

stress test proposed countermeasures and quantify the change in resilience through measuring the reduction in loss and recovery time.

CLIMATE RISK ASSESSMENTS FOR TRANSPORTATION ASSETS: LESSONS LEARNED AND RECOMMENDED PRACTICES

DONOVAN JACOBSEN
Transport Canada

Background

Canada has felt impacts from climate change through road closures, flooded runways, shoreline erosion, and power outages. Transport Canada sponsored an initiative called TARA (Transportation Assets Risk Assessment initiative) that is grounded in the Pan-Canadian Framework on Clean Growth and Climate Change. TARA was formally launched on October 13, 2017, and funded with \$16.35 million over 5 years to better understand climate risks to federally owned or managed transportation assets. TARA funds risk assessments and research into the impacts of climate change on federally owned transportation assets as well as the purchase of data, equipment, technology, software, and training needed to study the impact of climate change on federally owned transportation assets.

Innovations

The objectives of TARA include the following: to increase the resiliency of federally owned transportation assets by giving decision makers the information they need to make informed decisions, to support research and analysis that helps identify and remedy gaps and or barriers to assess risk, and to mainstream the assessment of climate risk by normalizing the practice as part of asset management planning or the design of new infrastructure.

TARA has sponsored projects for all modes of transport, including 14 aviation assets in seven provinces, 15 marine assets in six provinces, and six surface assets in four provinces. Transport Canada has learned several lessons through the implementation of the risk assessment process.

First, the process is not as simple as plugging data into a model. Several decisions must be made before an assessment can begin, including which tool to use and what are required inputs and desired outputs.

Second, many tools share the same workflow: (1) risk identification; (2) risk analysis; (3) risk evaluation; and (4) risk treatment and adaptation measures. However, different models may emphasize different factors, such criticality, vulnerability, interdependencies, or engineering resilience. To ensure success, analysts should define the scope of the analysis to consider what assets should be analyzed and in relation to which climate stressors? Similarly, which emission scenarios should be chosen—RCP 4.5, RCP 8.5? In addition, success requires input from the ground; i.e., transportation operators, maintenance, engineers, etc. Information concerning the immediate and cumulative impacts of extreme weather is typically anecdotally based.

Last, what is the expected outcome of the risk assessment? Frequently, expected outcomes include decision-making tools, capital recommendations, engineering solutions and

simple integration with existing plans. However, the actual outcome may be limited to a better understanding of a system's vulnerability and recommendations for further analysis and planning. To enhance any risk assessment, one should consider mapping the projected risk over time and include different emissions scenarios, incorporate asset life cycle, and establish confidence levels for all outputs. Also consider identifying the acceptable risk tolerance and level of service when discussing projected risk with management.

Contribution

Transport Canada developed a climate risk assessment program, TARA, which has funded a multitude of climate change-focused risk assessments for all modes of transport. Through managing this program, Transport Canada has identified many of the key considerations necessary to conducting a successful risk assessment, including determining what tools to use, what inputs to use, defining the assets and threats to be analyzed, defining the desired outcomes, and consulting with operators to acquire the ground truth on impacts to transportation assets.

FLOODCAST: A FEDERATED DATA VISION FOR DOT FLOOD RESILIENCE

MATHEW MAMPARA

Dewberry

Background

Every year in the United States, widespread flooding results in loss of life as well as damage to private property and infrastructure. At the same time, extreme precipitation events are increasing in intensity due to climate change. While many state DOTs have bridge flood monitoring programs and use inundation mapping to assist in designing their transportation system, so far there has not been adequate integration of existing weather and climate tools to assist DOTs in planning, managing risk or emergency response. NCHRP Project 20-59(53), "FLOODCAST: A Framework for Enhanced Flood Decision-Making for Transportation Resilience," was launched to address this gap.

Innovations

Dewberry consulting group has completed development of a prototype tool, called FloodCast that attempts to strengthen local flood response through real-time flood analysis. Dewberry conducted a literature review and identified key needs concerning meteorology, hydrology and hydraulic, asset management, and communications transfer. DOTs identified a need to be able to access meteorological data from NOAA, NWS, and other sources, through a central data collection system. DOTs also identified a need to have rapid translations of stream flow predictions from the National Water Model into estimations of flood extent and depth. In addition, asset management data needs to include the necessary design attributes to support flood risk assessments. Finally, there is a need for an automated communications system to disseminate flood estimates, and there should be a data system for incident management personnel to record data on historically flood-prone areas.

Contribution

The FloodCast tool enables DOTs to rapidly estimate impending flood conditions using real-time meteorological data and on-the-fly hydraulic modeling. Users can identify threatened assets, record actual damages, and communicate damage estimates to emergency responders and the public.

IMPROVING THE RESILIENCE TO NATURAL HAZARDS ON NORWEGIAN PUBLIC ROADS: A PRESENTATION OF THE RESPONS PROJECT

MARTINE FREKHAUG

The Norwegian Public Roads Administration

Background

Norway is mountainous and has a long “snow season.” As ski tourism increases so does the risk to snow avalanche. In addition, a significant portion of the road and rail system is exposed to avalanche-prone terrain. The RESPONS project is intended to address this threat to the roadway network by facilitating preparedness and awareness.

Innovations

RESPONS is an avalanche warning system that incorporates field observations of snowpack and machine learning to estimate the potential for an imminent avalanche and produce a static atlas of high-risk avalanche areas. The atlas is used to warn asset managers and the public as well as inform roadway workers about hazards in their area. In addition, RESPONS plays a major role in community outreach. RESPONS is incorporated into interactive exhibits to teach about avalanches and what the NPRA is doing to protect the transportation system.

Contribution

The RESPONS program provides the Norwegian community with a tool for identifying high-risk snow avalanche areas. The program incorporates real-time observations to produce graphic visualizations for early warning and education.

SESSION QUESTIONS AND DISCUSSION

Q. How can we get the most out of our tools?

A. You get what you want if you know the question you want to answer. Relevant to interact the practitioners and end users of the tools. End users should be able to provide helpful input all the way through creation. Visualization is harder, but you need to be able to visualize it and bring in all stakeholders and leaders to act after witnessing it. Videos help, but sometimes tools are thinking too big and it's a good idea to simplify it.

- Q. Massachusetts DOT, which manages coastal assets and has vulnerable bridges, wants to use lidar data to check, but the bridge's elevation data is missing, what do they do?
- A. It's not just "where" is that data, it is what data is in there? Correct effort is to use federal asset managers to inform missing data. Local communities might have what you need, but lidar data is expensive to process to assess site-specific locations containing a gap.
- Q. For uncaged streams, what has the verification? Are there post-processing procedures for errors and data smoothing?
- A. State DOTs help with validation with rating curves. USGS and NOAA might have the data discreetly but tapping into a DOT's data can make new advancements in next generation hydrology factors.

There is currently an evaluation of the National Water Model and its biases and errors.

POLL

How Many Need a One-Stop Place for All Tools?

A number of participants indicated that they do need such a one-stop place. Tool awareness and training might be the way to limit gaps in information and a tool directory would really help DOTs know what's already out there.

Assessing Increased Coastal Flooding Due to Relative Sea-Level Rise, Part B

SCOTT L. DOUGLASS

South Coast Engineers, Moderator

Communities in almost every coastal state are experiencing problems with more-frequent, more severe road flooding at high tide and during smaller storms. This increased flooding is due to relative SLR and has been called nuisance flooding, sunny day flooding, high-tide flooding, storm-tide flooding, chronic flooding, recurrent flooding, and king tide flooding. The four presentations in this session show how this increased flooding due to relative SLR should be quantitatively assessed.

EVALUATING THE IMPACT OF RECURRENT FLOODING ON ROAD NETWORK ACCESS IN A COASTAL LOCALITY

PAMELA BRAFF

Virginia Institute of Marine Science

Background

Recurrent flooding can make local streets difficult or even impossible to cross for several hours at a time, preventing access to and from neighborhoods by residents and emergency services. In working with the localities along the Virginia Middle Peninsula, researchers discovered that flooding and access to public roadways was an area of concern. The geography of coastal Virginia is made up of a series of peninsulas connected by bridges and tunnels. There are often few alternative routes, if any. The closure or flooding of a main roadway can result in long and complicated detours. Using Gloucester, Virginia, as a case study the researchers developed an approach to quantify the impacts of observed and future projected flooding on road network access in coastal localities.

Innovations

The researchers began their investigation by collecting NOAA tidal gauge data. The benefit of using the tidal gauge data is that it captures not only the water level variability due to regular tidal cycles, but also due to such events as high tide flooding, nor'easters, and storm surge. The next step was to compare the recorded water levels with known elevations of roads and properties.

The researchers also wanted to study how recurrent flooding would change over time due to SLR. In this region SLR is expected to reach 1.5ft by 2050 and 4.2 ft by 2100. Based on the combination of tide gauge data and SLR projections, the researchers summarized the average annual flood duration by elevation in the county. This information was brought into GIS to visualize potentially impacted roads and buildings. Roads were considered flooded if the water level was at least 4 in. above the road level, and buildings were considered flooded if the water level exceeded 2 ft above the first-floor elevation.

Figure 32 depicts the expected change in hours of flooding per year in which water is expected to impede the roadway network. The population growth in this area has been concentrated in the southeast which as can be seen in the figure, more hours of flooding are anticipated annually as time passes.

Contribution

This project demonstrated how tidal gauge data and projections of SLR can be merged in a GIS to show the advance of coastal flooding over time. This information can be shared with the public to encourage policy makers to consider limiting development in flood-prone areas as well as making improvements to vulnerable infrastructure.

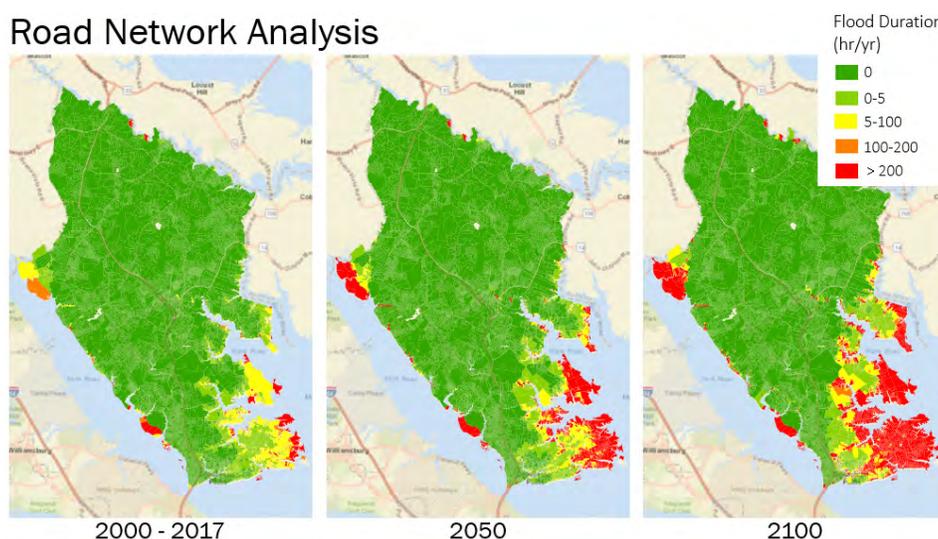


FIGURE 32 Road network analysis. (Source: Virginia Institute of Marine Science)

DATA PREDICTIVE APPROACH TO ESTIMATE NUISANCE FLOODING IMPACTS ON ROADWAY NETWORKS: A NORFOLK, VIRGINIA, CASE STUDY

SHRADDHA PRAHARAJ
University of Virginia

Background

According to the U.S. EPA in 2016, the frequency of flooding in the northeast Atlantic Coast has increased by 75% and 125% in the southeast Atlantic Coast. Jacobs et al. (2018) reported that the total annual travel delay in 2018 was 100 million vehicle hours. It is projected to reach 160 million vehicle hours in 2020 and 1.2 billion vehicle hours by 2060. A literature review revealed that few researchers in the past have used empirical data to assess resilience and instead relied on projections. The goal of this study was to show the value in using empirical data, including crowdsourced data, to assess resilience.

Innovations

The study area for this project was Norfolk, Virginia. The researchers collected the following datasets:

- Virginia DOT continuous count station data;
- Traffic volumes from Virginia DOT;
- Traffic demand data from the Hampton Regional Roads Transportation Demand Management (HRRTDM);
- StreetLight trip counts; and
- Hydrologic data from NOAA and Norfolk City.

These datasets were input into a series of machine learning algorithms to estimate the travel delay on flood days versus nonflood days. A description of the data models used for traffic volume estimation is provided in Figure 33.

For the study period, March 2017 to August 2018, there was an average 2.89% decrease in network wide vehicle hours of travel (VHT) on flood days versus nonflood days using Virginia DOT CSS data to validate the results. Traffic volume on principal arterials declined by 13% and on freeways by 10% on flood days. Similarly, average speed declined by 7% on principal arterials and by 5% on freeways. These values were statistically significant and within the 95% confidence interval.

Graphing maximum rainfall intensity on the *x*-axis and percent VHT reduction on the *y*-axis produced a trend line with an R^2 of 0.7325. However, graphing maximum tide level from mean sea-level on the *x*-axis and percent VHT reduction on the *y*-axis produced a trend line with an R^2 of 0.0004. It was hypothesized that rainfall-induced floods impact on transportation may be spatially more homogeneous while the impact on transportation from tidal floods may be more location specific. Thus, the limitation of the tested methodology is that it could not distinguish

Model Type	RMSE	NRMSE	High Importance Variables	Low Importance Variables
Random Forest Model 1 with roadway and traffic characteristics	Train: 679.80 Test: 1419.09	Train: 0.026 Test: 0.058	• Posted SL • TOD	• Per lane capacity • StL trip count • Number of lanes • Type of day
Random Forest Model 2 with roadway, traffic, and hydrologic variables	Train: 683.20 Test: 1315.40	Train: 0.026 Test: 0.054	• StL trip count • Time of day	• Per lane capacity • Posted Speed Limit • Type of day • Tide level • Rainfall
Streetlight Data model	5067.53	0.253		
Linear Regression	2384.43	0.085	• Rainfall • Tide level • Flooding • # lanes	• Posted SL • TOD • StL trip count • Per lane capacity • Type of day • Segment speed
Classification and Regression Trees (CRT)	2512.22	0.157	• StL trip count • Posted SL • TOD	• Rainfall • Tide level • Flooding • # lanes • Per lane capacity • Segment speed • Type of day

FIGURE 33 Data predictive model for traffic volume estimation.
(Source: University of Virginia)

spatial heterogeneity because the flood effects were aggregated across the city's entire road network. In addition, the flood data used had low temporal resolution and limited spatial coverage.

A second run of the data models included temporally disaggregated, crowdsourced incident data (WAZE). For this second run, only a small portion of the roadway was studied.

The results from this second run showed that the only statistically significant changes in VHT were observed during nighttime off-peak periods (6:00 p.m. to 6:00 a.m.). Variations can be found within each time period and within workdays and nonworkdays. The high degree of variability can be attributed to different types of environmental conditions, such as rainfall intensity, peak rainfall, and ground saturation conditions, during flood events.

Contribution

Machine learning algorithms can be used to analyze empirical flood and traffic data, producing statistically significant results that show the effects of nuisance flooding on traffic volume. City planners could improve the available data for this approach by installing low-cost, low-power rain gauges and sensors throughout the city to reflect the spatial heterogeneity of rainfall events. In addition, the methodology could be enhanced by incorporating a traffic demand model to reflect changes in upstream trip generation and downstream changes in route selection to reflect the distribution of transportation across traffic zones.

IMPROVED SEA-LEVEL RISE MAPPING FOR CLIMATE VULNERABILITY ASSESSMENTS

CHRISTOPHER DORNEY

WSP

Background

Most readily available SLR datasets are mapped using a mean higher high water (MHHW) tidal datum and transportation agencies frequently rely on these datasets. However, MHHW datasets do not show the full extent of tidal flooding that will be experienced for a given amount of SLR over the course of a year. Higher tides will inundate a larger area than MHHW mapping shows and to a greater depth. Using MHHW-based SLR mapping for a systems level vulnerability analysis can underestimate transportation network exposure. Showing only the assets that are inundated on average half of the days of the year misses all assets that are inundated less frequently, but still multiple times a year. There is a need to consider higher thresholds of tidal flooding for adaptation planning purposes.

Innovations

An alternative approach to mapping tidal flooding is to create maps that show the hours per year of tidal flooding. The key steps to this approach include:

- Obtain tidal predictions;
- Obtain SLR projections;

- Determine mapping increments;
- Calculate future tidal elevations;
- Analyze additional flooding metrics;
- Map future tidal inundation; and
- Assess asset exposure.

Hourly tidal predictions for 2018, 2040, 2070, and 2100 can be obtained from NOAA. Tidal predictions include consideration of astronomical effects (position of the sun, Earth, and moon) but do not account for SLR and do not account for storms or other meteorological anomalies that can affect tides.

Five mapping increments were selected by the research team. The increments were well spaced to ensure that the different maps are distinguishable. The chosen increments are as follows:

- 1 h of flooding per year (considered a high threshold for exposure analysis);
- 50 h of flooding per year (considered an intermediate value for analysis);
- 250 h of flooding per year (considered an intermediate value to ensure good spacing);
- 527 h of flooding per year (a common reference point); and
- 1,254 h of flooding per year (a common reference point).

An Excel spreadsheet was used to calculate future tidal elevations. The model applied SLR to the predicted hourly tides for each horizon year and scenario. The model also calculated the elevations corresponding to the selected increments and provided for a given elevation the number of events per year and their average and maximum durations. Fifty high-resolution flood depth rasters were generated to map future SLR, one for each tidal elevation (for all horizon years, all SLR scenarios, and all hourly increments). The method for producing the rasters is NOAA's modified bathtub approach.

To assess asset exposure, this project assessed the depth of flooding for roads, railroads, airports and utilities to ensure no false positives for bridges. "Do nothing" costs were calculated for each asset if no adaptation is undertaken and depth–damage functions used to estimate losses.

Contribution

Mapping projected inundation by showing the number of hours a location is flooded per year ensures that locations that are inundated less frequently are included. By combining projected SLR with tidal data, future flood elevations, as well as the number of flooding events per year, and average and maximum durations, can be calculated. Overlaying maps of projected flood duration with transportation asset layers enables planners to estimate the direct impact of flooding to their assets.

ASSESSMENT OF HIGH TIDE FLOODING OF COASTAL ROADWAY

DAVID KRIEBEL

Naval Academy

Background

The speaker provided a series of definitions for frequent flooding:

- Nuisance flooding: flooding that causes public inconveniences such as frequent road closures, over-whelmed storm drains, and compromised infrastructure (NOAA).
- Recurrent flooding: flooding that happens repeatedly in the same areas, typically leading to economic losses (VIMS).
- Chronic flooding: flooding that occurs more than 24 times per year or every 2 weeks on average.
- King tide: a colloquial term for an especially high tide, such as a perigean spring tide. King tide is not a scientific term, nor is it used in a scientific context (Wikipedia).
- High-tide flooding: a generic term for flooding associated with high tide events overtopping coastal infrastructure thresholds (Kriebel).

At the United States Naval Academy, there are two bellwether roads at low elevation that can be monitored to assess the increase in flood frequency: McNair Road and Ramsay Road. Both roads sit at elevation over 2 ft and frequently flood. Between 1930 and 1969, there were 41 floods in 40 years. Between 1990 and 2010 there were 41 floods in 10 years. In 2018 there were 41 floods in 1 year. A mere difference of 1-ft elevation (of SLR) can mean the difference between zero floods and hundreds of floods per year.

Innovations

This study demonstrated a five-step process for assessing coastal flooding:

Step 1. Acquire NOAA tide gauge data. Use the hourly water levels from the NOAA tide gauges. Remove the linear trend due to past relative SLR and identify the high-tide amplitudes.

Step 2. Graph the number of high tides that exceed specific elevations. Count the average annual number of high tides exceeding different elevations.

Step 3. Shift the curve to the right for other elevations. Project into the future by adding relative sea level. Shift the curve to the right to reflect the higher sea level. Assume the same distribution of high tides will continue.

Step 4. Determine threshold elevations. Apply an elevation threshold for the site of interest. The graphic below is for McNair Road at over 2.0 ft elevation NAVD 88. Estimate the number of future high tide flood events.

Step 5. Convert to time bases to project into the future. Apply SLR scenarios to the year 2100.

Figure 34 shows a forecast of future high-tide flood events on McNair Road using the NOAA intermediate SLR scenario.

These projections can be used to assess mitigation measures. Figure 35 shows how the frequency of flooding on McNair Road changes if the roadway was raised 2 ft, as shown the number of flood events drops from about 25 per year in 2020 to 0. Flooding does not become an issue again until approximately 2060.

Contribution

Planners can estimate the number of days of flooding per year at a given site by adding SLR projections to local tidal data. This same methodology can be used to assess hypothetical mitigation options, for example, raising the elevation of a road. Increasing the flood threshold can result in a large reduction in future flood events.

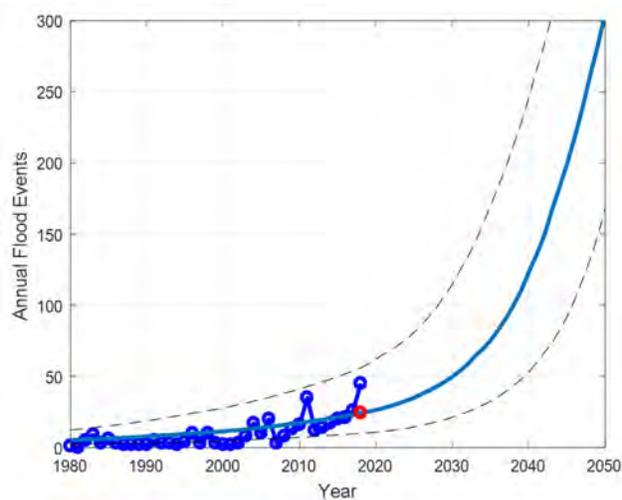


FIGURE 34 Forecast high-tide flood events on McNair Road using intermediate SLR scenario.
(Source: Naval Academy)

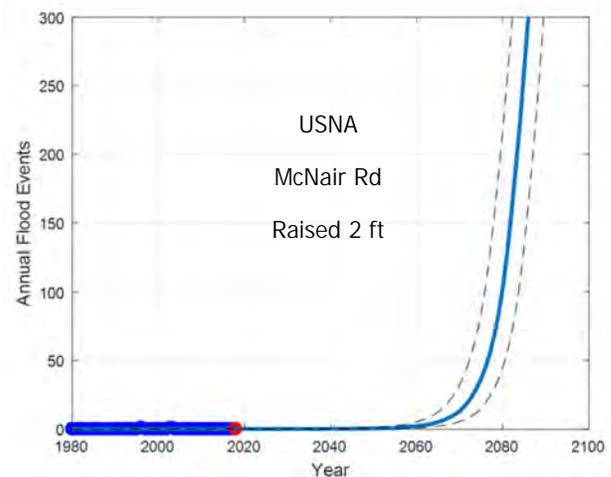


FIGURE 35 Hypothetical effect of raising McNair Road 2 ft.
(Source: Naval Academy)

Managed Retreat, Part A *Is It Even an Option?*

LEAH DUNDON

Vanderbilt University, Moderator

This panel focused on control of adaptation decisions and the challenges that, in some cases, may prevent managed retreat from being considered. The panel focused on the law and policy side of the issues and included a case study discussion that brings to life the policy challenges of having meaningful discussion of retreat.

MANAGED RETREAT AND INFRASTRUCTURE PLANNING: LONG-TERM CHALLENGES OF COASTAL COMMUNITIES FROM A POLICY AND LEGAL PERSPECTIVE

THOMAS RUPPERT

Florida Sea Grant College Program

Background

Managed Retreat, or Managed Relocation, was implemented in Florida with the Florida Sea Grant in 2010. The Florida Sea Grant College Program addresses infrastructure impacts from extreme weather events and flooding. Initially, the agency decided to conduct analyses on SLR, as there was no local government assigned to address this issue. In the United States, due to the separation of government powers, courts have withdrawn from telling local governments to implement changes in their area, the need to preserve the discretionary power of the legislative branch leads to a multibillion-dollar question: what is maintenance versus upgrade?

In the case of *Jordan et al. v. St. Johns County*, 2011, a roadway that was the only access to houses in the county was washed away. It was built in the 1950s and less than 10 years later, the Atlantic Ocean was causing erosion on the roads. Florida DOT decided it would be better to relocate the road instead of building it back. In 1979, Florida DOT went to the county and offered the road to the county in order to service the three homes on the roadway. The new road alignment of SH-A1A was built, but in 2007, erosion began to occur, and in 2010 an absolute breach of the land occurred. The claims of the lawsuit were that the county was taking the homeowners private property rights; however, over one 5-year period the county spent a quarter of a million dollars per mile per year, which is 25 times the average per mile per year cost. The county won the lawsuit and the property owners appealed. The courts responded by saying that laws state that the county must provide “reasonable level of maintenance” that results in “meaningful access.” This left the county with the question of “How do you fight the Atlantic Ocean?”

Innovation

Varying legal responsibilities between four southern states (Florida, Georgia, North Carolina, and South Carolina) were analyzed. This analysis was aimed at states, counties, and municipalities, as there are differences across these states as to whom the responsibility of roadway maintenance resides. For example, North Carolina has almost no county roads while Georgia has mostly county-owned roads.

Contribution

With policy solutions, the goals were to work toward an adaptive duty to maintain road systems, an adaptive authority to abandon, and state-level duties and authorities to deal with state–county–city patchwork to provide consistency within the process. At a minimum this would allow better adaptation options at the local level. This leaves the question of “Should state DOTs be at the table with local governments in discussions about future relocation and abandonment?”

MANAGED RETREAT

JIM PAPPAS

Delaware Department of Transportation

Background

Delaware is the lowest-lying state by average in the country and as such state agencies plan and design projects for flooding and SLR, prepare adaptation recommendations, set greenhouse gas mitigation goals, and maintain a state-level cabinet committee on climate and resiliency.

Innovation

In Delaware, SR-54 east of Fenwick has repeated flood events and serves as an evacuation route. An elevating solution was set up by constructing a viaduct over low marshy areas to raise road above the flooding elevation. In this area, the Delaware DOT could not raise the roadway using fill because of impacts to the adjacent wetlands. Instead a 2,400-ft-long viaduct was constructed at the cost of \$16 million dollars.

In response to Hurricane Sandy damage which resulted in SR-1 being covered with sand after approach embankments eroded, the agency constructed a sheet pile seawall. The wall was 800 ft long and had 65 tiebacks and cost \$1.4 million to install but is anticipated to keep the roadway open and reduce potential detours which can add 30 to 40 min to travel time, which is unacceptable from an emergency perspective.

By contrast, Old Corbitt Road with average daily traffic of only 340 vehicles and is often overtopped with changes in the daily tide was abandoned by the agency. An existing bypass route only slightly increased travel time by 2 to 3.5 min which was deemed acceptable by Delaware DOT. When looking at options for this project, Delaware DOT went to emergency responders in the area for their advice about abandoning the bridge. The emergency responders were for the idea since the tides were swift and emergency rescues had occurred at the bridge.

Delaware DOT then went to the local government, who were also in favor of abandonment of Old Corbitt Road, however, residents were not happy with the idea. The cost to abandon or elevate the road would have cost \$2.5 million and would not have any federal resources for the project. In addition, an anticipated \$2 to 3 million in utility relocations would be required. Ultimately, the roadway was abandoned, and barricades were placed to prevent anyone using the road.

Contribution

Delaware DOT has been and continues to be challenged by SLR, and decisions about SLR are made on a case-by-case basis. Delaware needs policies that detail how they will spend their capital to protect and maintain assets affected by SLR, in addition, these policies must line up with statewide policies for all agencies.

BROADER PERSPECTIVE ON STATE AND LOCAL GOVERNMENT ACTIONS AND CHALLENGES RELATED TO MANAGED RETREAT, AND THE GEORGETOWN CLIMATE CENTER'S FORTHCOMING "MANAGED RETREAT TOOLKIT"

KATIE SPIDALIERI

Georgetown Climate Center

Background

The Georgetown Climate Center (GCC) works to provide both mitigation and adaptation strategies and resources to deal with SLR and climate change. In the coastal zone, an analyst may juggle local, state, and federal laws all at once depending how far inland a study area lies or how far toward the ocean. For example, open water to the beach is covered federally by the Clean Water Act and the Rivers and Harbors Act, beaches are covered by state coastal management and wetlands laws, and upland is covered by local zoning ordinances, floodplain ordinances, and local coastal programs. It is helpful to understand this mix of agencies and policies when considering what stakeholders need to be brought to the table to discuss managed retreat.

Innovation

One example of a coast plan is called a Special Area Management Plan (SAMP). Under the Federal Coastal Zone Management Act, states can create a SAMP to apply increased management in an area to balance future development and resource protection. In 2018, Rhode Island was the first state to tackle this with the Shoreline Change SAMP, this modeled impacts along the entire coast particularly from SLR and coastal erosion, to provide guidance to the both state and local governments and other state agencies on how to potentially incorporate both climate change issues for future development decisions. Retreat is included as a potential option within SAMP for the purpose of locating and designing infrastructure, either not locating infrastructure in particular areas, or making sure it is elevated if it is located in low-lying areas.

In terms of infrastructure planning, resiliency requirements of the FAST Act allow states and local governments to consider potential retreat strategies into decision-making, particularly

to low-lying roads. Hampton Roads, Virginia, Long-Range Transportation Plan: Transportation and Strategies includes an example of this. The study states that “Once the inundation analysis is complete, staff plans to recommend that the Hampton Roads Transportation Planning Organization Board modify its Project Prioritization Tool to give points to projects that improve or provide an alternative to existing roadways projected to be inundated in the sea-level rise/storm surge study.” In this, authors identified retreat as a potential option to relocate critical infrastructure to higher ground.

A feasibility study was performed by the Hawaii DOT Office of Planning, which consisted of a literature review of case studies both domestically and internationally identifying efforts that could be used in Hawaii. As a result, five different components that cut across all different types of retreat situations were identified. In addition, Hawaii assembled four different scenario profiles ranging in different types of developments as well as environmental factors and physical risks in the state. This will help Hawaii to consider different retreat options. Hawaii DOT has determined, at this point, it is too early to move forward with any type of managed retreat plans.

Buyouts are usually the first thing people think about when thinking about managed retreat. In Charlotte–Mecklenburg County, North Carolina, their stormwater services department has been acting to create buyouts in both pre- and post-disaster context. The county has a local funding source that enables them to approach buyouts holistically, they then work with the community to decide what to do with the land.

Ecosystems on the coast, infrastructure, and other structures can create a phenomenon called “coastal squeeze,” where ecosystems are facing a barrier of sea-level rise on one side and a structural barrier on the other side. Resilient SR-37 in Bay Area California is a partnership between the North Bay MPO, four counties, and Caltrans. The agencies work together to think about prioritizing projects for transportation, ecosystems, and resilience into one project design plan to redesign this area.

Retreat is not only thinking about moving people out of the way but also where to locate such communities. Receiving communities, can be within the same area, other counties or even other states. It is important to think about proactive investments, not just in housing, but also infrastructure investments that may be needed. Louisiana’s Strategic Adaptations for Future Environments (LA SAFE) program is trying to think proactively using flood data as well as demographic data to prepare the region for shifts in population migration to higher ground areas.

The following should be considered:

- Authority:
 - Local authority and
 - State agency roles.
- Compliance with state and federal laws:
 - Transportation requirements,
 - Coastal Act,
 - Floodplain requirements, and
 - Wetlands regulations.
- Constitutional questions:
 - Takings.

In the case, *Lucas v. South Carolina Coastal Council*, Lucas purchased a shorefront property and shortly after the state passed a setback law that covered his entire property and would prohibit development. The Supreme Court ruled that this was a *taking*, but a special type of taking called a *per se taking*, which means Lucas would be deprived of all the economically beneficial uses of his property.

The *Penn Central Transportation Co. v. New York City* case showed that if a regulation will not rise to the level of the *per se takings* there is a rule called *regulatory takings*. If a regulation ultimately would not deprive a property owner of all economic uses of the property but inhibit it enough that it would constitute a taking, the government would not be able to enact the regulation without proper compensation. This also depends on a balance of three factors applied on a case-by-case basis of the public purpose served and the effect of the regulation on the owner. This effect includes the potential decrease in value of the entire property and the property owner's investment backed expectations in the property.

A takings example was described for Chatham, Massachusetts, when the local government created an overlay district which prohibited any new development in the 100-year floodplain area. A property owner wanted to sell their property, but the sale was contingent on being able to develop. This case went the Massachusetts Supreme Court where it was decided it was neither a *per se taking* nor a *regulatory taking*. It was found that Chatham had a public purpose to set this land aside. This established that local governments can restrict development in hazard areas if it is reasonable.

Contribution

GCC's Managed Retreat Toolkit is in development, the primary audience is state and coastal policy makers who want to make sure this appeals to a broader audience. This will be available in spring 2020. The toolkit is intended to include the following:

- Legal and policy considerations;
- Planning (e.g., CZM, long-range plans);
- Buyouts and acquisitions;
- Regulatory tools: limiting new development in at-risk areas;
- Infrastructure;
- Ecosystems and migration corridors;
- Preparing "receiving" communities;
- Equity and community engagement; and
- Funding and financing.

Managed Retreat, Part B *When, Whether, and How?*

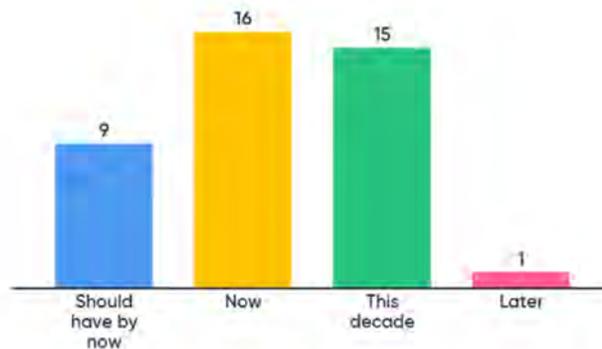
MARK ABKOWITZ

Vanderbilt University, Moderator

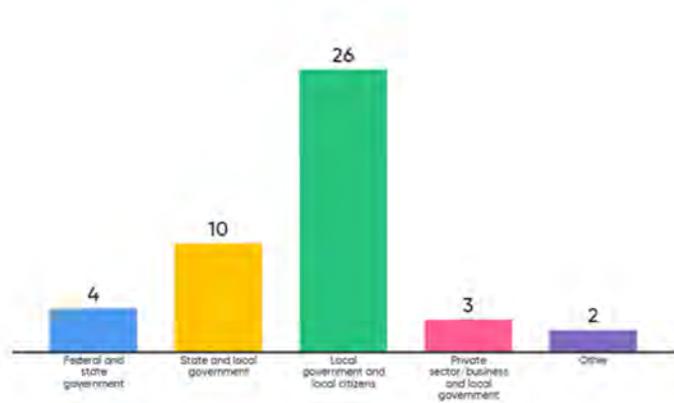
SLR, increased frequency, and intensity of flooding, and other extreme weather events have sparked a growing recognition that managed retreat must be among the solutions considered, in some locations, to protect human life, livelihoods, and public and private infrastructure investment. This plenary session featured immediate input from the audience using smart phone survey software. It was intended create a framework for charting a path forward in this emerging area of resilience that would be of benefit to researchers and practitioners. During this session, the audience was asked several questions regarding the use of managed retreat. Several graphs were provided that included the findings of the real-time survey.

Participants were asked: “How soon will coastal communities need to face the decision of utilizing managed retreat?” Figure 36 reveals that most of the participants felt this decision would need to be made now, in the near future, or should have already been made.

Next, participants were asked to consider what agencies and parties are the most critical to engage when seeking a successful managed retreat. Figure 37 reveals that the most noted agencies and parties to engage include local government and local citizens, while state and local government agency engagement were also noted as being critical to successful managed retreat programs.



**FIGURE 36 Participant findings from Survey Question 1:
How soon will coastal communities need to face this decision?**

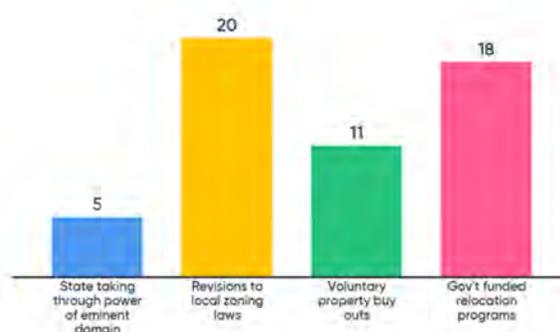


**FIGURE 37 Participant findings from Survey Question 2:
What is the most critical collaboration needed between stakeholders for managed retreat to occur successfully?**

Next, participants were asked about the types of mechanisms that should be used to implement managed retreat. Figure 38 shows that participants felt that revisions to local zoning laws and government funded relocation programs could be effect followed by voluntary property buyouts.

Participants were next asked who should initiate the discussion of managed retreat within a community. Participants noted that local mayors or governments or the state government should be the lead agency in this regard as shown in Figure 39.

Participants were asked what their greatest concern was regarding migrating populations. Figure 40 shows that participants are concerned most about the ability of communities to absorb migrating populations and provide adequate housing. Jobs were also noted as a concern.



**FIGURE 38 Participant findings from Survey Question 3:
What legal or political mechanisms should be utilized to effect managed retreat?**

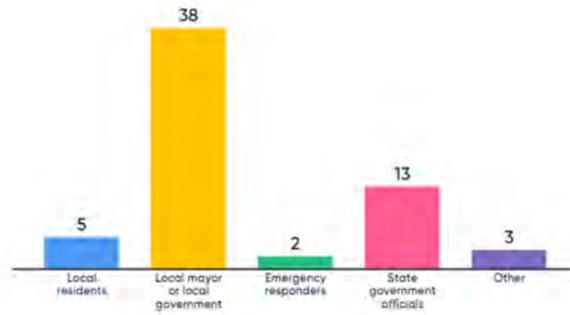


FIGURE 39 Participant findings from Survey Question 4: Who should initiate the discussion of managed retreat in a community?

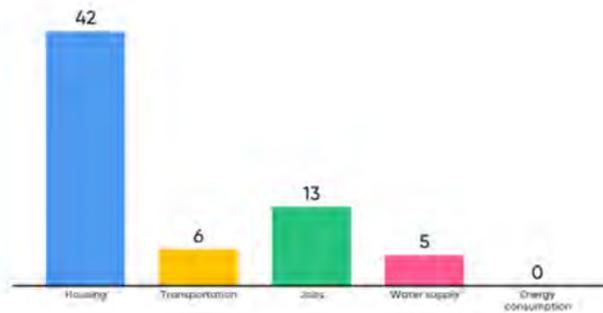


FIGURE 40 Participant findings from Survey Question 5: What is your greatest concern about the ability of another community to absorb the influx of the migrating population?

Shareable Lessons from Natural Disasters

DAVE CLAMAN

Iowa Department of Transportation, Moderator

This session will present lessons learned for incorporating and assessing resiliency for infrastructure from extreme weather events. The presentations will provide case studies and examples for incorporating resiliency into infrastructure design/repair and for integrating/assessing resiliency into project planning/prioritization.

THE HISTORIC 2019 MISSOURI RIVER FLOOD AND IOWA DOT'S RECOVERY AND RESILIENCY

DAVE CLAMAN

TAMARA NICHOLSON

Iowa Department of Transportation

Background

Historic flooding was reviewed for events in Iowa in 2011 and 2019 on the Missouri River Basin. The 2019 flood event occurred in March when a 30° to 40°F temperature swing, 12 to 24 in. of snowpack, and 2 to 3 in. of rainfall fell on March 14. The result was devastating including 13 major levee breaches, 47 mi of Interstate impacted, and three major Missouri River crossings damaged.

Innovation

Design innovations were considered to address damages to highways including the use of a commercial product intended to protect embankments from flood scour that is buried under typical embankment material. The authors provided positive results from the use of this product in areas that had begun to receive the treatment after the March flood event and experienced another flood event in June of 2019. The treatment appears to have performed well and protected the embankments from flooding. Another innovative solution considered for temporary protection in areas where levees had failed in March included a temporary water-filled barrier that can be used to control and divert water. Iowa DOT is also considering traditional resiliency solutions such as grade raises, protective dikes, and hydraulic capacity increase.

Contribution

In response to the flood events in 2019, Iowa DOT saw a need to capitalize on the investments already made to date in the state to identify vulnerable corridors and better understand the overall impact of events to operations. Through the FHWA ER Program, Iowa DOT has begun to address some of the failures that occurred in 2019 with more resilient designs to reduce future

losses from similar events. Following a process developed by Colorado DOT and AEM Corporation after its 2013 flood event, Iowa is working to identify betterments that are selected with the intention of reducing risks to vulnerable locations from future flood events, as shown in Figure 41.

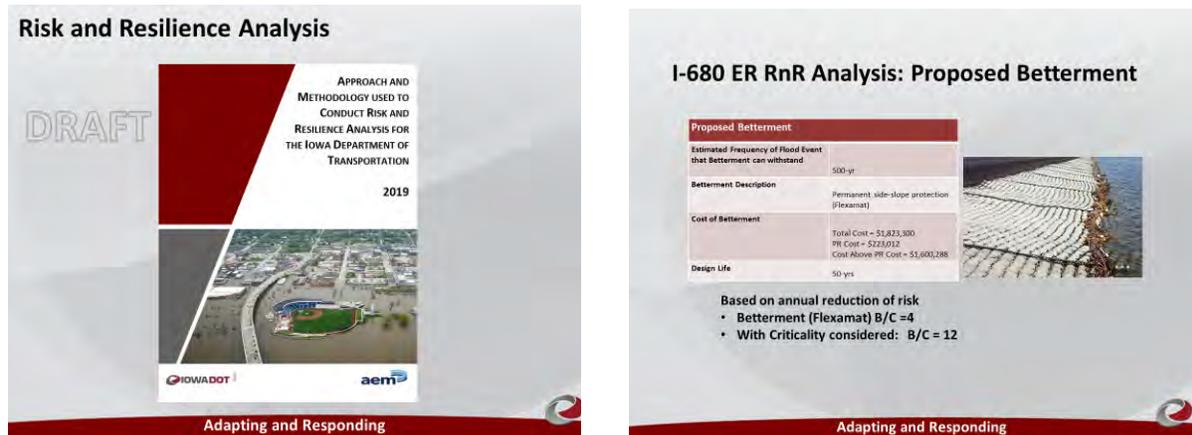


FIGURE 41 Iowa's approach to betterment analysis for FHWA ER eligible highways. (Source: Iowa DOT)

TRANSPORTATION SERVICE PLAN FOR DISASTER SURVIVORS

ERIC PLOSKY

Volpe National Transportation Systems Center

MATT CAMPBELL

Federal Emergency Management Agency

JAMIE SETZE

Capital Region Planning Commission

Background

This study focused on the short- and long-term transportation needs of disaster survivors. The authors studied areas impacted in the Baton Rouge MPO, which experienced a major flood event in 2016. The study involved a survey sent to 15,000 survivors who returned to the area approximately 5 months after the flood event. One-third of respondents reported not having access to a vehicle after the event and more information was gathered to determine what could be done prior to events to improve transportation needs of survivors of disasters.

Some of the challenges to improving transportation needs of survivors included:

- Lack of access to personal information data from FEMA;
- Difficult to target outreach efforts;
- Survivors are often scattered and move frequently; and

- Traditional transit options are not optimal post disasters.

Innovation

This study sought to better understand how to plan for transportation needs prior to disasters. Several items identified in the study that could be helpful to planning agencies to better prepare for these needs upstream of events as shown in Figure 42.

Contribution

The lessons learned through this study include understanding how origins–destinations may have changed post-disaster as well as how to empower transit agencies to respond immediately post-disaster and identify data needed to reimburse transit agencies before disasters to ensure proper reimbursement. The authors also suggest transportation needs be identified beyond vehicle replacement and transit and instead consider alternative transportation modes such as ride sharing, private, and for-hire passenger carriers. In the mid- to long-term horizon, the authors suggest efforts should be made to expand service between major cities.

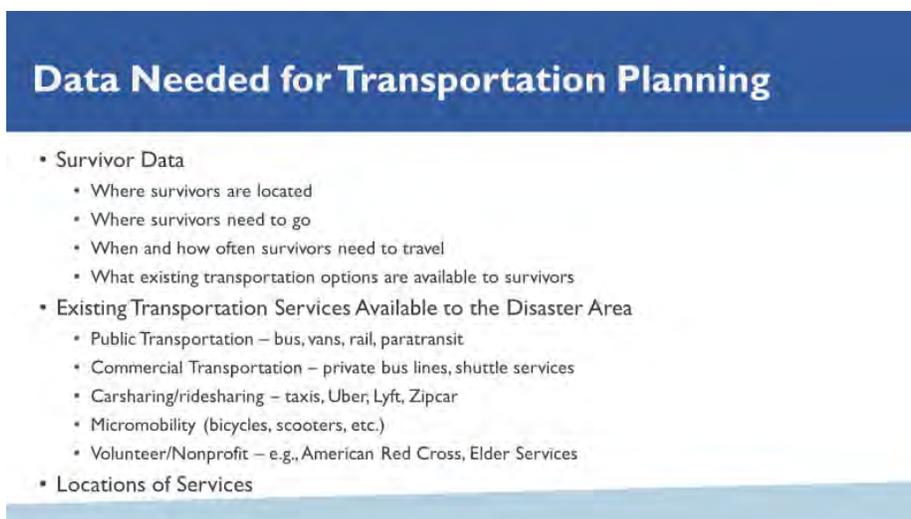


FIGURE 42 Identified data to plan for transportation needs prior to disasters.
(Source: Volpe)

2019 OKLAHOMA FLOODING RESILIENCE ASSESSMENT

REBECCA LUPES

Federal Highway Administration

Background

FHWA was interested in a broad overview and general understanding of transportation resilience-related impacts and opportunities related to various natural and other hazard events. To help accomplish this, the agency tested out an approach of having a small team of FHWA, state DOT, and contractor subject matter experts conduct a “Rapid Resilience Assessment” of affected locations post-disaster.

From May 18–30, 2019, 6 to 16 in. of rain fell along and northwest of a line from near Okmulgee, Oklahoma, to near Bentonville, Arkansas, while 3 to 5 in. of rain fell southeast of this line. Heavy fall and early spring rains had saturated soils, filled groundwater tables, and filled streambeds, leaving no place for storm water to go. The high rainfall areas included most of the tributary watershed of the rivers and streams in Oklahoma and neighboring Kansas that experienced flooding in late May through the first half of June. The continuing rainfall combined with reservoir releases as levels rose contributed to widespread flooding in Oklahoma.

In July 2019, approximately 6 weeks after the flood event, FHWA compiled a team of FHWA Headquarters, Resource Center, and Oklahoma Division Staff as well as Oklahoma DOT staff, and a contractor team to conduct field assessment of several sites damaged by the event. Subject matter experts, including hydraulics, geotechnical, and bridge and structures professionals analyzed the damage to the locations which suffered damage from flooding. The team visited 11 sites in 3 days.

Innovations

The multidisciplinary team approach worked well, stimulating several discussions on river morphology, asset damage history, and construction experience.

Oklahoma DOT’s roads demonstrated several resilience practices. The SH-74 bridge at Skeleton Creek has a substructure composed of driven H-piles at both abutments and drilled shafts at all three piers. The drilled shafts were constructed with a depth that extends approximately 15 ft below the rock layer. There was scour, which was to be expected, but the drilled shafts maintained structural stability.

In wide floodplains, roads can act as a barrier during flood events. In these instances, Oklahoma DOT has used a “fuse plug” approach which can work well to provide hydraulic relief. A fuse plug is a dip to allow floodwater to overtop the roadway before it overtops the bridge. A fuse plug was used north of the SH-74 Bridge as shown in Figure 43. In this instance, although the fuse plug was inundated during the flooding, the road did not experience overtopping flow because of a berm to the west of SH-74 which blocked flow. However, the lower elevation of the fuse plug makes the road impassable without the benefit of relieving hydraulic pressure on the bridge. The DOT might consider analyzing the fuse plug elevation to reduce the amount of water pushing on the bridge which may extend the service life of the bridge. Consideration could also be given to lowering the elevation of the berm equal to or lower than the roadway elevation to allow the fuse plug to operate as intended.



**FIGURE 43 Fuse plug used north of bridge to improve resilience.
(Source: Oklahoma DOT)**

Contribution

FHWA is assessing the lessons learned from the approach and is interested in feedback on how to make something like this most helpful from a state DOT perspective, including thoughts on timing: after response and initial recovery efforts are complete, but soon enough see damage and provide information for repair or reconstruction. While the pilot study was a narrowly focused assessment, additional information is under consideration for future efforts such as damage and repair costs, travel impacts (delay, detour length) and environmental projections.

HIGHWAY INFRASTRUCTURE RESILIENCE AND POST-HAZARD RESPONSE: BRIDGES AND TUNNELS

SISSY NIKOLAOU
WSP Inc.

Background

Extreme events observations constitute a class of risk in the life span of bridges and tunnels, including effects to highway facilities, vehicles–drivers, and to the community–environment at large. Evaluating this risk requires the support of research-quality historical data and incorporation of results in a consistent format that can assist in informed decision-making in all service stages (1), including planning (2), construction (3), and emergency response (4). In developing resilient infrastructure systems, the factor of learning from post-event evaluations is essential, yet still overlooked. Failures, but also successes of a transportation network, can reveal its resilience, defined as the emergent property of what this engineering system does, rather than a static property the system has (5). Information from assessing highway facilities

after extreme events coupled with risk analysis, can lead to improved design frameworks that incorporate a recursive process of sensing, anticipation, learning, and adaptation, with resilient implications in the adaptive management of complex, coupled systems (6). Recognizing these needs, FHWA has initiated an effort for improving resilience of highway structures through post-hazard assessment with initial findings presented in this session.

Innovations

The development of a unified, applicable engineering framework that can be adopted by state and local officials that supports informed decision-making for short- and long-term resilience goals against natural and other hazards, applicable to all stages of highway bridges and tunnels projects, and creation of a nationwide database with information that can be used to quantify resilience and guide future investments. The framework supports an enhanced definition of multihazard resilience of a highway infrastructure system as an aggregate of (1) the ability of its built components to anticipate, absorb, prepare for, and adapt to changing conditions throughout the life cycle and achieve rapid recovery by ensuring life safety; (2) maintaining defined levels of functionality for the system, its components, and supported supply chains; (3) and using collected data and technologies to quantify this ability and improve it for future events.

Contribution

The presented findings from this ongoing work can improve the state of practice, offering:

1. Thorough review of relevant literature;
2. Objectives of a resilience framework for highway bridges and tunnels;
3. Guidelines for PDI (post-event damage inspection) and PEI (post-event engineering investigation) evaluation of highway structures that support resilience, and
4. Tools—procedures for improving risk-based decision-making.

The two categories of post-event evaluation were presented, specifically: PDI—which provides damage indexes, access restrictions, and recommendations for continued operations with teams deployed rapidly, hours to days after an event—typically consisting of bridge inspectors, first responders, maintenance personnel, and emergency management and maintenance personnel; and PEI, that identifies performance and causes of failure/nonfailure, documents lessons learned, and develops design-type recommendations for improvements. PEI teams can be deployed hours, days, or weeks after an event, and include structural engineers and national subject matter experts. The project includes and proposes improvements in developed field assessment guidance to support rapid initiation and execution of PDIs, including *NCHRP Synthesis 497: Post-Extreme Event Damage Assessment and Response for Highway Bridges* (7), NCHRP Project 14-29, “Assessing, Coding, and Marking of Highway Structures in Emergency Situations” (8), and *NCHRP Research Report 833: Assessing, Coding, and Marking of Highway Structures in Emergency Situations* (9). Efforts in developing PEI guidance are ongoing, as currently PEIs are case-specific with limited general guidance, because of the broad spectrum of subjects and parameters involved, and the need of specialized knowledge.

The goal at the end of this FHWA project and its contribution to practice are to provide a framework or guidance document and training materials to state and local transportation authorities in support of informed decision-making for short- and long-term resilience goals against natural and other hazards.

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Communications and Making the Business Case for Resilience

ELIZABETH HABIC

Maryland Department of Transportation, Moderator

How can you communicate the importance of resilience to stakeholders? And how do you make the business case for resilience investments? This session will include an overarching speaker to set the stage and two or more case studies on this essential topic.

COMMUNICATING CLIMATE PROJECTIONS, RISKS, AND UNCERTAINTY: SOLUTIONS TO KEY CHALLENGES

BRAD HURLEY

ICF

Background

The purpose of this presentation was to recommend strategies for effectively communicating climate change. Some examples of consideration when discussing climate change are as follows: First, metrics: when describing projections of SLR, what units should be used? In the United States people are more familiar with traditional English units than metric. In addition, many people visualize elevation change in terms of height which is usually expressed as feet and inches. Second, benchmarks: when talking about SLR, a benchmark should be provided for comparison; for example, SLR is projected to increase 3 ft by the year 2050 in comparison to the year 2010. Third, visualization: how can climate change be represented graphically? A map of inundated coastal areas might be useful for urban planners. However, a photograph of high-water marks on the wall of a public building would be more meaningful to a building manager.

Innovation

To help clients develop strategies to communicate climate change, ICF developed the “creative brief.” The creative brief asks clients a series of questions. What are your objectives? What does success look like; that is, what is the outcome you want? Who do you need to help you accomplish that? What is your target audience? What information do your audiences need to achieve the desired outcome? How can you most effectively provide that information?

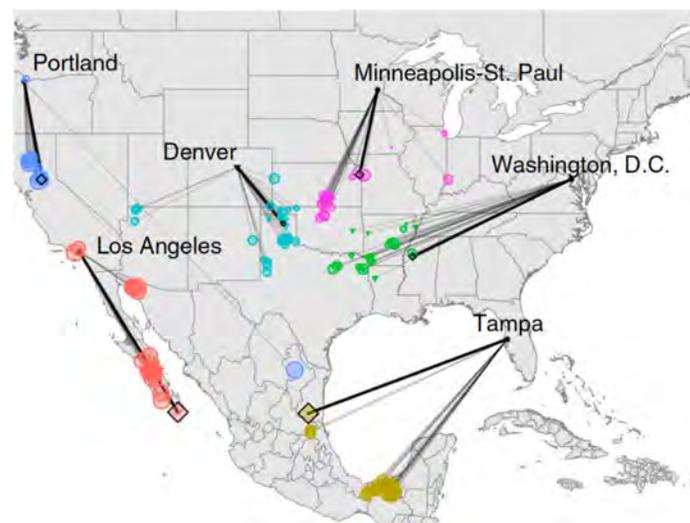
Communicating probability can be particularly confusing. When discussing probability, one cannot assume that the audience is knowledgeable about the mathematics of probability. For example, many people erroneously assume that if a 100-year flood occurs today, they will not have to worry about another flood of such magnitude for another 100 years. Rakow (2015) proposed a seven-category taxonomy for expressing uncertainty, ranging from general, qualitative descriptions to precisely quantitative as shown in Figure 44.

Table I. A Seven-Category Taxonomy for the Degree of Precision in Uncertainty Statements.

Category	Statement Specifies	Examples
Possibility	What event(s) can/might occur	Sea levels may rise. You are at risk of stroke.
Comparative possibility	Which of two events is more likely	Floods are more likely here than there. Surgery will reduce your risk of stroke.
Categorical possibility	How likely an event is (verbal label)	This is a high-risk area for flooding. You have a low risk of stroke.
Relative probability	Comparison of risks (numeric ratio)	Floods are 3 times as frequent here as there. Surgery will halve your risk of stroke.
Absolute probability	Numeric probability of a risk	There is a 1-in-75 annual risk of flooding. Your 5-year risk of stroke is 8%.
Comparative probability	Absolute probabilities for different risks	The annual risk of flood is 1 in 25 here, but 1 in 75 there. Surgery reduces your 5-year stroke risk from 8% to 4%.
Incremental probability	Probability difference between risks	The annual flood risk is 2.7% higher here than there. Surgery reduces your 5-year stroke risk by 4%.

FIGURE 44 Taxonomy for degree of precision in uncertainty statements. (Source: ICF)

A suggestion to improve understanding is to use the “twin track” approach. Combine a qualitative description with a quantitative one; for example, pair “very unlikely” with “less than 10% probability.” Care should be taken to put expressions of probability in proper context. For example, the phrase a “doubling of risk” may seem large at first if one is not aware that the actual probability is only one-in-a-million. Comparative statements can help clarify measures of severity; for example, the total number of acres burned by wildfire equals the total area of the state of Kansas. A novel technique of visualizing climate change is the climate-analog map that shows today’s climate at a given location may be similar to the climate of a distant location far into the future; for example, the climate of Portland, Oregon, today, may be similar to the climate of Sacramento, California, by the year 2080. The map included in the Figure 45 shows lines that connect cities to their analog locations. Diamonds indicate contemporary analogs, that is, where the climate today represents the city’s climate in the year 2080. The varying size of connected circles shows increasingly poor analogs.

**FIGURE 45 Use analogies. (Source: ICF)**

Analogies can be useful, but one should exercise caution because analogies can overlook significant differences as well. If the climate of Portland will more closely resemble Sacramento in the future, does that necessarily mean, then, that planners should adopt Sacramento's climate change adaptation measures?

Finally, to ensure more effective communications with the target audience, it is advisable to interview audience members and learn from them what they hope to learn and what they need to make informed decisions.

Contribution

This presentation offered strategies for improving communications about climate change. Communications are more effective if speakers take the time to learn from their target audience, consider what metrics to use, express probability clearly, use benchmarks and comparisons, and combine with meaningful graphics.

CLIMATE COMMUNICATION PILOT PROJECT

Tracey Frost

Caltrans

Background

FHWA selected Caltrans to participate in the FHWA Resilience and Durability to Extreme Weather Pilot program. As a response, Caltrans used grant money to launch its Climate Communications Pilot project to improve communications with stakeholders engaged in the resilience pilot.

Innovations

The communications plan was developed with the intention of using it statewide. The plan was separated into four parts: goals, audiences, messages, and strategy. A survey was developed to obtain feedback from stakeholders and local partners. The target audience for the surveys included internal representatives such as division chiefs from construction, traffic management, project management, freight, external affairs and traffic operations, district chiefs from planning, environmental, design, hydraulics, and the District 4 Sea-Level Rise Task Force. The surveys have recently been completed. Feedback about the quarterly resiliency meetings and the vulnerability pilots was found to be helpful.

In turn, the districts have been sharing the vulnerability assessments with external partners from the private sector, academia, local, county and state government, and members of the public. As a result, district representatives have received a lot of inquiries from the media. This ties in with the survey question, "What challenges do you face in communicating about potential climate change threats and solutions with your audiences?" It became apparent that there was a need for internal coordination on messaging about climate change.

With regard to external coordination and messaging, the following needs were identified: a need to communicate priorities, activities, and cost-sharing, a need to understand the

audience's knowledge and viewpoints, a need for help with tailoring messages, a need to coordinate messages with external partners, and a need to connect Caltrans' goals with the state and partners.

The question, "What are your audience's informational needs?" revealed the following data needs:

1. Guidance on integrating climate risk into daily asset management;
2. Information about what other districts and agencies are doing;
3. Adaptation strategies;
4. Impacts of climate change on transportation systems;
5. Climate change projections, such as SLR;
6. Potential transportation system vulnerabilities; and
7. Information on the intersection of greenhouse gas reduction and climate change adaptation.

The survey question, "What kinds of activities and/or channels do you use to communicate with your audiences?" revealed a wide variety of passive and active methods. Active methods included meetings, teleconferences and workshops. Passive methods included email, webinars, reports, transportation planning scoping information sheets, social media, etc.

The question, "Are there any tools or resources that you are aware of that would be helpful to you in your communication?" yielded responses about both existing and needed tools. Existing tools include external tools, such as Caladapt.org, California Air Resources Board data, Metropolitan Transportation Commission Vital Signs, the NOAA sea-level rise viewer, and Vulnerability Assessment Reports. A resource portal and consistent messaging on adaptation and mitigation measures were among identified needed resources.

Finally, the question, "Any other comments or suggestions for enhancing climate change?," revealed that survey takers believe climate change communications need to look at the big picture, climate change has to be expressed as a priority, and there is a need to build connections with external advocacy organizations and individuals interested in climate change. Currently, Caltrans hopes to finalize the communications plan by spring 2020.

Contribution

Caltrans' Climate Communicate Pilot project demonstrated the value of engaging internal and external stakeholders. Using surveys are helpful in identifying the tools and information needed to effectively communicate clear and consistent climate change messaging.

CLIMATE CHANGE AND COMMUNITY ENGAGEMENT: A CASE STUDY IN FRESNO COUNTY, CALIFORNIA

ANNIKA RAGSDALE
WSP

Background

The Fresno Council of Governments (FCOG) in California was awarded a Caltrans Adaptation Planning Grant through Senate Bill 1 to collect Fresno County stakeholder and public input, assess vulnerabilities of the Fresno County transportation system and users, develop a range of adaptation strategies for the county, compile findings into a report for use by FCOG, stakeholders, and the public. FCOG was the project lead and convened regional stakeholders. VRPA Technologies, Inc., led the community engagement efforts; and, WSP processed findings from engagement results and incorporated them into the vulnerability assessment.

Innovations

The public outreach plan included a public forum and materials that provided clear and concise project information. The plan allowed the public and community members to inform the development of the vulnerability assessment and provided the opportunity to involve a broad range of community members and minority, low-income, and disadvantaged communities. In addition, a Vulnerability Assessment Working Group was formed. The group met three times per week during the project in order to provide local policy and technical guidance. Representatives came from community-based organizations and cities/emergency services.

The working group developed a survey, the Fresno County Regional Transportation Network Vulnerability Assessment, to learn about the public's concerns and experience with extreme events, recommendations for adaptations, as well as their transportation needs. The surveys were in English and Spanish and administered at public events, such as the Reedley Street Faire and the San Joaquin Carnival. The "pop-up" surveys were supplemented with mapping exercises that enabled participants to pinpoint locations where heat waves, flooding, wildfire and poor air quality are a problem. An online survey tool was implemented to ask questions similar to the paper survey questions. The working group received 241 survey responses, 63 online and 178 from the paper surveys. Of all Fresno County respondents, 86% reported they were concerned about climate change. Out of the 86%, most were concerned about chronic conditions, such as extreme heat, drought and poor air quality. Out of all the respondents, 43% reported having had weather affect their travel.

Contribution

This project demonstrated the effectiveness of using surveys in collecting information about people's concerns, knowledge, and experience with climate change in their local area. Online and pop-up surveys proved to be more effective than holding public meetings. The pop-up surveys in Spanish were very effective in reaching low-income people while the online surveys tended to connect with middle-income people.

SESSION QUESTIONS AND DISCUSSION

Q. What's an alternative to the return period descriptor? Could it be "percent chance of happening over a 30-year mortgage?"

A. Alternatives to return period certainly exist and might be better descriptors.

Q. Has anyone thought of questions they wished to ask after the survey was done?

A. None jumping out at them, but they originally had 25 questions and went down to seven after review. Districts were talking about communication, surveys are hard, interviews are back and forth and better for them.

Q. How did some districts react?

A. Some were skeptical, others had some power playing sustainability managers who were glad to get on board. The necessity forces the hand of skeptical districts. One example, county officials in an eastern Maryland county once believed the county would not witness SLR impacts; however, the county experienced great impacts due to SLR in 2013. These impacts stressed the county assets and people, and as a result its officials became more willing to come on board.

Approaches to Addressing Multiple Hazards Within a Larger Modal Project

Rawlings Miller
WSP, Moderator

A transportation system is exposed to multiple hazards. Innovative approaches are emerging that assess system vulnerabilities and develop resilience recommendations to cope with the changing environment. This session will explore these innovative approaches and present project-based examples.

MULTIHAZARD RISK ASSESSMENT FOR ROAD NETWORKS

MARGREET VAN MARLE
Deltares

Background

Usually risk is estimated in combination with vulnerability, hazard, and exposure. Exposure refers to the road infrastructure that is in harm's way. Hazards are the source of risk, such as flood or landslide; and vulnerability measures how much damage to the road is caused by a hazard. Hazard maps are important tools in risk analysis with an ideal hazard map including both intensity and probability; for example, a flood map should show flood depth and return period. However, in many places in the world there is a lack of good hazard maps. Common examples include maps with susceptibility but no return interval, hazard maps that are very coarse and not suitable for analyzing road infrastructure, or no hazard maps at all. This project demonstrates how to conduct a risk analysis in a data-poor environment.

Innovations

This project addressed two case studies. The first case study is Albania and the second, the Netherlands. The Albania case study demonstrates what to do when the hazard map lacks a return period. Fortunately, the researchers were able to access event history data and had access to the national road network GIS layer, the European Landslide Susceptibility Map (ELsus) and a 3-year landslide inventory. The landslide inventory was classified into three intensity classes and correlated to the susceptibility map to estimate the likelihood of occurrence per kilometer.

Through workshops with stakeholders, the annual repair cost for primary roads was estimated. The risk data was mapped to identify those segments most at risk. Recommendations for mitigation were determined through a second set of workshops and included retaining walls, stepped slope embankment, and slope protection. To determine the economic viability of the recommended mitigations, a B/C analysis was conducted that also reflected road criticality and traffic data. It was determined that long stretches of road with high vulnerability required a lot of investment and yielded a low B/C ratio. In contrast, corridors with high economic damages and short sections yielded a high B/C ratio.

In the Netherlands case study, embankments along a corridor were studied for erosion potential and instability. No hazard maps or event history was available. Given this was a data-poor situation, a semi-quantitative approach was taken. GIS was used to map the following factors: presence of embankment, distance between embankment and the road, slope, embankment elevation, and soil type. The most sensitive locations to embankment failure were identified from these factors. Expert opinion was used to estimate the consequences and risk.

Contribution

This study demonstrated how to do a risk analysis for roadway infrastructure when data is scarce. The Albania case study showed that event history can be used to estimate return periods while expert opinion can provide estimates of damages and repair costs. The Netherlands case study demonstrated what can be done when no maps exist at all. In the latter case, relevant susceptibility factors were superimposed to create a susceptibility map. The susceptibility map helps analysts identify which assets are most at risk. Again, expert opinion can help provide quantitative analysis with estimates of number of closure days, travel demand, etc.

ADVANCING FLOOD RESILIENCE CONCEPTS TO DESIGN: BOSTON'S CLIMATE-RESILIENT DESIGN GUIDELINES FOR PROTECTING PUBLIC RIGHTS-OF-WAY

FRANK RICCIARDI

Weston & Sampson

Background

The city of Boston has prepared climate-resilient design standards and guidelines to address both acute and chronic flooding due to SLR and storm surge to protect the public rights-of-way.

Many neighborhoods in Boston are grappling with flooding due to SLR. Boston is the world's 8th most-vulnerable city to financial loss due to SLR and the amount of development. Eastern Boston frequently floods when there is a king tide, extreme precipitation or a nor'easter, and it is anticipated that there will be more than 40 in. of SLR by 2070.

Massachusetts's Governor Baker signed an Executive Order that required every state agency and municipality to conduct a risk and resilience assessment by the end of 2018 and draft a full resiliency action plan by 2020. Governor Baker also provided funding for municipal vulnerability planning grants.

Innovations

The *Climate Resilient Design Standards and Guidelines for Protection for Public Rights-of-Way* is a 112-page guide that presents design, operations and maintenance (O&M) and cost considerations necessary to advance conceptual flood barrier ideas to implementation. The Guidelines has three overarching themes: (1) take incremental action while planning long-term solutions; (2) manage projects with multiple jurisdictions and private owners, and (3) maintain mobility and access while protecting critical infrastructure.

The guide provides information on example flood barriers that can be used to fight SLR and storm surge including vegetated berms, harbor walk flood barriers, raised roadways and temporary flood barriers. All samples assumed a barrier height of four feet for flood protection to year 2070. The Guidelines also includes an approach for barrier selection, permitting strategies, methods to increase the reliability of the barriers, approaches for incremental adaptation if funding is limited, and the estimated value of the barriers in terms of their social impact, equity, and cobenefits.

Design criteria for heat, storm surge, and extreme precipitation are also provided and projections for these climate stressors for different design time frames, ranging from 2030 to 2100. The recommended design timeline is to design for at the minimum 2070 conditions with the ability to achieve an additional 2 ft of flood protection in the future with some simple design adjustments.

The guideline suggests nine design considerations: climate design adjustments and timelines; site-specific boundary constraints; stormwater; utilities; structural; geotechnical; accessibility and transportation; ground water; and vegetative. In addition, the Guidelines includes graphics for each type of sample barrier with engineering details; and each graphic addresses the nine design considerations and future flood elevations.

Contribution

The city of Boston has prepared a resilient design standard and guidance document to address both acute and chronic flooding due to SLR and storm surge to protect the public rights-of-way. The Guidelines provide climate design adjustments for design of flood barriers and a process for evaluating design, operations, maintenance, and cost considerations.

Presentation Questions and Discussion

- Q. The soil from dredges is often used build islands to protect a harbor. Was there any discussion of doing this in Boston Harbor?
- A. The sediment in Boston Harbor is not of the best quality. This was not discussed as an option.

FLOOD RESILIENCE FOR BOSTON'S BLUE LINE SUBWAY

INDRANI GHOSH

Weston & Sampson

Background

Massachusetts has been a resiliency pioneer across disciplines toward climate change and taking design steps to address risk. One such asset system risk pair is Boston's Blue Line subway that acts as a thoroughfare for metro transit in Boston. The goals for the project were to identify current and future vulnerabilities to flooding at Aquarium Station to Maverick Portal including potential points of ingress into the system, potential storm surge inundation points, and current brackish-saline groundwater intrusion; and recommend conceptual resiliency options.

Innovations

Many different types of ingress exist for flooding to enter a complex asset system such as the Blue Line subway with multiple vulnerable entry points for the threat including vent shafts and manholes. Using geospatial modeling it was possible to simulate future flood risks and possible at-risk assets in the future. Hydraulic modeling was used to analyze possible flow rates into the system in the subterrain environment.

Contribution

Vulnerable assets were identified, and their risk qualified for the future. The project was able to identify chronic and acute risks for the future, prioritizing resilience for the concern of public health and safety, with an emphasis on flood protection for the future. Recommendations were sorted into different categories of prioritization: short-term action needed for the Aquarium Station, Aquarium emergency egress replacement, the Maverick Portal (mid-term), and additional analyses to advance designs.

Adaptation strategies were also generated and included:

- Policy and operational planning: emergency planning, O&M, redundancy, and planning studies;
- Retreat: remove exposure/sensitivity, relocate critical infrastructure onsite, relocate off-site, and elevate critical infrastructure above flood level;
- Protect: block flood from impacting critical infrastructure, flood barriers, backflow preventers and flood gates, reinforce windows and walls; and
- Accommodate: allow flood but reduce damage to critical infrastructure, increase drainage capacity, install additional pumps, and wet flood proofing.

The final product included a poster sized list of proposed studies, O&M solutions, and engineering solutions to tackle the challenge that were color coded and time-scaled the project goals for short, mid, and long-range goals. These are done across all possible points of resilience and even shows examples of physical work to help improve resilience through an integrated investigation approach for a small-scale system of assets such as a single metro station. It has potential for scaling up toward larger projects.

Presentation Questions and Discussion

Q. What assumptions do you start with? How do you pick an RCP scenario?

A. We held meetings with all state agencies in the greater Boston area to come up agreed-upon design criteria.

UNDERSTANDING RESILIENCE THROUGH THE DESIGN AND IMPLEMENTATION OF STRESS TESTS FOR LARGE-SCALE INFRASTRUCTURE SYSTEMS

JUAN CARLOS LAM

WSP USA & ETH Zurich

Background

The terms systems, resilience, and stress tests are widely used in the field of transportation resilience. Many infrastructure managers, however, do not know how to apply the concept of resilience and have difficulties in understanding how to make investment decisions and where to start investing. The question this presentation will try to answer today is whether a resilient system can be defined?

In a stress test, a model used to estimate consequences is conditioned on representing one or more uncertainties in the model with values that are considerably worse than the corresponding median or mean values. The study area is in the eastern part of Switzerland in Canton Graubunden, a region continuously affected by flood events and landslide events. The network in the study area is comprised of approximately 600 km of roads (approximately 373 mi), including approximately 50 km (approximately 31 mi) of national roads and about 120 bridges. For the analysis the system was broken into smaller segments based on estimates of how the researchers thought a hazard might affect a particular segment, resulting in the network being divided into approximately 75,000 different elements.

Innovations

The model was developed to demonstrate how the system performs without making predictions. It was developed to model a rain event, a flood event, a mudflow event, local scour, inundation, reduction of speed, reduction of capacity, and restoration needs in terms of cost and time. Potential consequences were also modeled including direct cost, which is the cost of restoring the network or indirect costs, which is cost to the user.

There is a lot of uncertainty in this approach given there are a lot of different ways all these different kinds of events could occur. Instead of looking at one chain of events, it is suggested that multiple chains of events and running many simulations would provide a more realistic estimate of outcomes. The result is a distribution of potential outcomes and the analyst can count the number of simulations out of the total that show the system exceeding a certain value to obtain an overall performance metric. In this approach, every assumption in the model can be treated stochastically and a distribution of values generated.

There are two schools of thought about how to assess system resilience: (1) estimate the consequences and calculate the effect on users who want to use the system as they would on any given day and (2) alternatively, reduce demand after a hazard with some people choosing to telecommute or stay home. It is also anticipated that there will be a change in traffic patterns with perhaps more people going to hospitals and more emergency response vehicles on the roadway network.

Output from the simulations demonstrates the performance of the network over time by calculating the change in average travel time. Increased travel time indicates degradation of

performance and for the 100 simulations completed only 49 simulations showed adequate performance.

Contribution

Key findings show that quantitative methods and tools to determine the state of resilience of infrastructure systems are feasible. These methods and tools can integrate scientific advances and state-of-the-art practices. The use of stress tests to challenge modeling assumptions helps to better understand system performance when these are subjected to hazard events. There is a large need to generate better information leading to improved management decisions to make systems resilient.

Presentation Questions and Discussion

- Q. How easily can this model be repeated and at what scale—city, state, region, or continent?
- A. First you have to define what you are trying to do, but the described framework can be scaled up or down. The level of detail you put into the model depends on what scale you are modeling.

Integrating Resilience in Transportation Planning, Part B

TOM JACOBS

Mid-America Regional Council, Moderator

Resilience touches all aspects of transportation policy, planning, design, finance, operations, and management. In these Part A and B sessions, panelists identify natural and climate mitigation and adaptation strategies that can be mainstreamed into transportation planning programs and projects.

INTEGRATING NATURAL HAZARD RESILIENCE INTO THE TRANSPORTATION PLANNING PROCESS

HEATHER HOLSINGER

Federal Highway Administration

Background

FHWA works with state agencies on implementing federal transportation guidelines. The issue of resilience to extreme weather is important to FHWA and its partners. Communities across the United States are experiencing extreme weather events that damage roads and bridges; cost large sums to repair; and disrupt travel. Some recent examples include the 2017 landslides along Highway 1 in California, the 2012 Waldo Canyon Fire in Colorado, the 2011 Missouri River flood in Iowa that blocked I-680, and the flooding of the Battery Park Underpass in New York City following Hurricane Sandy.

Innovations

The U.S. DOT Strategic Plan for fiscal years 2018–2022 included the development of new tools to aid in improving the resilience of transportation infrastructure. FHWA is currently developing resources for state DOTs and MPOs. FHWA has also developed case studies, a fact sheet (January 2017), a white paper (May 2018), and is in the process of developing a handbook on integrating resilience into the transportation planning process. In addition, FHWA has sponsored three peer exchanges. The purpose of the peer exchanges was for staff from MPOs and state DOTs to learn from peers about best practices for integrating climate resilience into the planning process, including assessing risks, developing adaptation options, and prioritizing projects for implementation.

Currently, FHWA is sponsoring 11 resilience pilot studies. Partners engaged in this pilot program include Caltrans, Utah DOT, Corpus Christi MPO, Tampa Bay Transportation Management Area Leadership Group (TMA), Pennsylvania DOT, Massachusetts DOT, U.S. Navy, Atlanta Regional Commission (ARC), Bi-State Regional Commission (Western Illinois and Eastern Iowa), Mid-America Regional Council (Kansas City, Missouri), and Houston–Galveston Area Council (H-GAC).

As an example, the goal of the ARC pilot is to integrate threats of extreme weather on transportation assets and users into the pilot and engineering process, using ARC's vulnerability assessment framework. A critical concern for the region's transportation system is loss of access due to flooding. ARC plans to assess existing platforms and deploy a screening level GIS-focused hydrological tool for this pilot. The objective of this tool is to highlight current and future asset vulnerabilities to flooding for future in-depth hydrological and engineering analysis. With respect to heat-related effects on the human body, ARC staff plan to interact with the public health staff of the Centers for Disease Control and Prevention (CDC) to relate expected heat conditions to likely health-related impacts.

The goal of the Bi-State Regional Commission's pilot is to conduct a vulnerability assessment and determine strategies to mitigate near-term and long-term effects of extreme weather events in the Quad Cities, Iowa-Illinois metropolitan planning area multimodal transportation system.

Finally, the goal of the H-GAC pilot is to assess the vulnerability and risk of its transportation system to extreme weather impacts for the eight-county metropolitan area. The project will include the following objectives:

- Identify vulnerabilities in vital transportation assets (e.g., roadway, freight, transit, bicycle-pedestrian, connections to airports) and current-projected mobility;
- Categorize the vulnerabilities of corridor segments;
- Determine the potential effects on performance, mobility, the economy, and livability;
- Determine the transportation asset risk and replacement and maintenance costs;
- Pilot a replicable assessment process for jurisdictions to utilize within the MPO region;
- Determine the effects of changing climate on precipitation and financial impacts to transportation assets; and
- Collect and process climate data and make projections.

Contribution

FHWA has made available a wide array of resources to help state DOTs and MPOs incorporate resilience into their transportation plans as well as conduct extreme weather vulnerability studies. Resources include peer exchanges, a white paper, a handbook, and funding for pilot resilience and studies.

INCORPORATING RESILIENCE INTO TRANSPORTATION PLANNING AND ASSESSMENT

SARAH WEILANT
RAND Corporation

Background

In 2019, the RAND Corporation published *Incorporating Resilience into Transportation Planning and Assessment*. This work was sponsored by TRB under the auspices of NCHRP Project 08-36, Task 146, “Economic Resilience and Long-Term Highway/Transportation Infrastructure Investment.” This presentation summarizes some of the key points of the research.

Innovations

The definition of resilience varies across transportation entities, but it usually reflects the ability to adapt, recover, and respond to a variety of disruptions. A resilient transportation system contributes to the wellbeing of its community. The RAND Corporation took a two-pronged approach in tackling the NCHRP resilience project. The first prong involved meetings with stakeholders at state DOTs and MPOs to learn the role that resilience plays in practice. The second prong consisted of a literature review and a study of existing metrics for resilience. The outcome of the research was a framework for addressing resilience, summarized by the acronym, AREA (absorptive capacity, restorative capacity, equitable access, and adaptive capacity). The components of the AREA approach are defined as follows. Absorptive capacity is the ability of the system to absorb shocks and stresses and maintain normal functioning. Restorative capacity is the ability of the system to recover following a shock or stress quickly and to return to normal functioning. Equitable access is the ability of the system to provide the opportunity for access across the entire community during a shock or stress and during undisrupted times. Adaptive capacity is the ability of the system to change in response to shocks and stresses to maintain normal functioning. Figure 46 summarizes sample inputs and metrics for the AREA logical model.

Planners should consider the following when analyzing the resilience of their own system. Consider the benefits of investment in times of both normalcy and disruption. Engage stakeholders and decision makers to help weigh the tradeoffs that come with prioritizing options. Broaden the asset data to include human and equipment assets, use the logic model to guide expansions, and identify the criticality of these new assets. Expand hazard data to consider a wider array of hazards than just natural and determine whether they are systemwide or if they influence only a subset of assets. Use the indicators to assess the resilience of the system in a way that acknowledges the interaction of the criticality and exposure of the assets. Finally, use an established critique, such as a multi-criteria decision analysis, economic analysis, B/C analysis, or life-cycle cost analysis, to facilitate prioritization.

Contribution

This project gives transportation planners a conceptual model for characterizing their entire system and defining the goals they wish their system to achieve. The AREA model provides a way to develop a set of strategies for building greater resilience into the transportation system.

Logic Model Category	AREA Category	Categories of Metrics
Inputs	Absorptive Capacity	Exposure metrics
	Restorative Capacity	Available response resources
	Equity	Availability of public transit; availability of alternative mode choices
	Adaptive Capacity	Availability of alternative routes and alternative mode choices
Activities	Absorptive Capacity	Maintenance metrics
	Restorative Capacity	Measures of community planning efforts; measures of communities' communication capabilities
	Equity	Measures of communities' communication capabilities
	Adaptive Capacity	Network expansion
Outputs	N/A	Intensity of route use; measures of transportation system's state of repair; reliability metrics; intensity of route use
Outcomes	N/A	Measures of congestion, travel time, and travel speed; measures of transportation system safety; reliability metrics; accessibility metrics

FIGURE 46 Capacities and measures of resilience. (Source: RAND)

A RESILIENCE MEASURE FOR PRIORITIZING TRANSPORTATION NETWORK RECOVERY

Yuan Chi Liu

University of Delaware (in support of Sue McNeil)

Background

This project attempts to determine the optimum time for scheduling the repair of a transportation network following a natural hazard. While determining the optimal repair strategy can be computationally intensive, this project reduces the computational effort by using a modified network robustness index (MNRI). For each link in the network, the repair option is selected from multiple options using incremental B/C analysis. This method has been shown to produce results close to the results produced by a near-optimal heuristic algorithm.

Innovations

The MNRI is based on the Network Robustness Index (NRI) first proposed by Scott et al. (1). According to Scott, the NRI measures the importance of a link in the network as the change in travel-time cost associated with rerouting all traffic in the system should that segment become unusable. The MNRI models two scenarios, pre-event where the network changes from undisrupted to disrupted when one link is closed and post-event where the network starts out as disrupted until the closed link is repaired. The potential repair strategies are evaluated using incremental B/C analysis. First, alternative strategies are ranked by their initial cost. Second, the incremental benefits are compared in terms of travel cost saving with the cost for the candidate alternatives. If the incremental cost-benefit ratio is greater than one, the candidate alternative is substituted. The process is repeated for each alternative. This process was tested with a case study based in Chur, Switzerland. A total of 29 road segments were disrupted and three repair

alternatives were modeled. The three scenarios were (1) budget constraints, (2) budget and crew constraints, and (3) no constraints. In all three scenarios, total costs estimated by the MNRI were close to the results produced by a heuristic model.

The project produced the following recommendations for planners who wish to apply this approach to making good recovery decisions. First, planners need a good network model to compute disruption. Second, planners need a library of repair strategies and estimated costs. Third, planners need tools to compute the MNRI. Fourth, planners need to define crew and budget constraints. Future research based on this project could include studying the tradeoffs when additional resources are available to reduce disruption and studying the transition from initial recovery strategy to an optimal strategy.

Contribution

This project showed that it is possible to evaluate post-disaster repair strategies using an incremental B/C ratio comparison in lieu of more computationally intensive modeling. The methodology can help planners develop strategies for minimizing the time of recovery and the impacts of disruption.

Reference

1. Scott, D. M., D. C. Novak, L. Aultman-Hall, and F. Guo. Network Robustness Index: A New Method for Identifying Critical Links and Evaluating the Performance of Transportation Networks. *Journal of Transport Geography*, Vol. 14, No. 3, 2006, pp. 215–227.

SESSION QUESTIONS AND DISCUSSION

- Q. In the definitions used for resiliency, it is often mentioned to include adaptation and recovery, does anyone's definition include the reduction of risk and vulnerability so that a disruption to service won't happen?
- A. The risk can be divided down to consequence probability, the exposure can be reduced, but this is usually an expensive solution. Things have changed over the past decades, and we change building codes over time to reduce exposure accordingly. They looked at all definitions trying to find the broadest one, and each agency will define it for themselves. It comes down to their goal.
- Q. What data should DOTs procure?
- A. Agencies need to know the locations of their assets and risks they face.

Resilience Initiative for National Transportation Systems

Laurie Radow

Chair, TRB Standing Committee on Critical Infrastructure Protection, Moderator

Extreme weather and other effects of climate change on TSO and planning can occur in damaging combinations of threats and impacts, as increased hillside precipitation and sediment runoff can follow increased wildland fire incidence and intensity. This session will present for discussion several techniques for characterizing these sorts of cascading events and for incorporating them into transportation planning and operations.

Using Dutch Highway Network Climate Stress Test Results for Performance Management, Policy Development, Planning Infrastructure, and Prioritizing Renovation and Maintenance

Kees van Muiswinkel

Rijkswaterstaat – Ministry of Infrastructure and Water Management

Background

The Netherlands has approximately 17 million inhabitants, 451 km (approximately 280 mi) of coastline with an estimated 60% of the population living in flood-prone areas. The primary driver of potential flooding is high river discharge from abroad that can occur with the release of water from international catchments. To address these challenges, the Climate Change Adaptation Policy seeks to make the Netherlands as climate proof and water resilient as possible by 2050. Within the presentation, an overview of a seven-step approach to reach this goal was described and as shown in Figure 47.



FIGURE 47 Delta plan on spatial adaptation. (Source: Ministry of Infrastructure and Water Management)

Innovations

The Ministry has performed stress tests on highway assets to identify vulnerable assets from flooding, heat, and drought. The results of the stress test are used to provide input to maintenance staff to prioritize critical locations. Stress test results are also used to create dialogue around identifying adaptation solutions consistent with performance goals of safety, mobility, and quality of life. Stress tests also give insight to support necessary changes in design of infrastructure to address vulnerability that is used as input for the replacement and renovation program.

Contribution

Stress tests have served to raise awareness, urgency, and the necessity of adaptation in the agency. Efforts are now being made to mainstream adaptation efforts at all levels of the agency to support efforts to become more climate proof and water resilient by 2050.

SESSION QUESTIONS AND DISCUSSION

Q. How do you start to train people to be cross-cutting?

A. The CEO of the Netherlands is aware of climate change adaptation which is helpful to gear the message to the audience.

1. Did you have a problem with the “will my house flood” app in terms of insurance premiums?

A. No, we did not have any problems with property values decreasing or insurance increasing.

Projections and Downscaling

Developing and Applying Precipitation and Temperature Projections, Part 2

BRIAN BEUCLER

Federal Highway Administration, Moderator

This session includes a panel and group discussion with people who generate the projections and actually use them. In addition, lessons on how to deal with uncertainty. Where do you get the projections? Tools and techniques to predict storms, precipitation and flows utilizing climate projections for transportation planning and risk-based asset management.

ESTIMATING PROJECTED PRECIPITATION FOR DESIGN OF RESILIENT INFRASTRUCTURE

ROGER KILGORE

Kilgore Consulting and Management

Background

The objective of the NCHRP Project 15-61, “Applying Climate Change Information to Hydraulic Design of Transportation Infrastructure,” is to develop a design guide of national scope to provide hydraulic engineers with the tools needed to amend practice to account for climate change.

Innovations

The guide outlines a 10-step process for estimating projected 24-h precipitation quantiles. The process uses a lower and higher emissions scenario and multiple GCMs to allow for the estimation of confidence limits. Finally, it adjusts historical rainfall frequency curves with modeled ratios. The 10-step process is provided as follows:

1. Determine the historical observed 24-h precipitation rainfall frequency curve (RFC) (or single AEP quantile, if only one quantile is required) for the site.
2. Select baseline and future periods for analysis, as appropriate for the plan or project.
3. Identify the future scenarios and downscaled GCM outputs of interest from the most appropriate database of high-resolution climate projections.
4. Determine the number of grid cells required to adequately cover the watershed of interest.
5. Acquire the daily precipitation values and extract an annual maximum series (AMS) for each grid cell for the selected future scenario and downscaled GCM output dataset. Adjust the AMS to unconstrained point values with a real reduction factor and an unconstrained 24-h correction factor appropriate for the location.

6. For each grid cell, compute the 24-h precipitation RFC (or single AEP quantile) for the baseline period and for the future period from the AMS from Step 5, using an appropriate statistical distribution.
7. Repeat Steps 5 and 6 for each individual downscaled GCM output identified in Step 3. The result of this step is a set of estimates for a 24-h RFC (or single AEP quantile)
8. Compute the ratios of the modeled (downscaled GCM output) future 24-h precipitation RFC (or single AEP quantile) to the modeled baseline 24-h precipitation RFC (or single AEP quantile) for all grid cells and simulations.
9. Estimate the projected 24-h precipitation RFC (or single AEP quantile) from the historical observed 24-h precipitation RFC (or single AEP quantile) from Step 1 and the ratio(s) from Step 8.
10. Repeat Steps 5 through 9 for each future scenario identified in Step 3.

Contribution

The objective of this research was to develop a design guide of national scope to provide hydraulic engineers with the tools needed to amend practice to account for climate change. The design guide includes the following content:

- How to estimate projected 24-h quantiles based on future or baseline ratios from high-resolution climate datasets and adjust historical quantiles with those ratios.
- How to estimate projected sub-daily precipitation from the projected 24-h quantile and assume historical patterns in sub-daily relations.
- How to use confidence limits in evaluating project design.
- Recommendations for more complex methods for high-risk projects.

Presentation Questions and Discussion

- Q. Did you compare the difference between historical baseline and modeled baseline climate data?
- A. This analysis was not done. We compared projections of future climate to projections of baseline climate. That's why we used ratios between future and past rather than differences.

USING CLIMATE MODEL DATA FOR RESILIENT HIGHWAY PLANNING AND DESIGN: THE FHWA CMIP TOOL

ROB KAFALLENOS

Federal Highway Administration

Background

The CMIP Tool was named after the Intergovernmental Panel on Climate Change World Climate Research Program project of the same name. The CMIP Tool is currently a spreadsheet model and was designed to ingest downscaled climate data and calculate temperature and precipitation variables used in transportation analysis.

Innovations

The FHWA CMIP Tool is being redesigned as a web-based tool to run on a server and thus not tie-up a user's computer. It will run faster than the old tool and will use CMIP5 models and refined locally constructed analogs (LOCA) downscaled datasets. The new tool is expected to be released in early 2020. Sample temperature outputs include annual averages, the hottest temperatures of the year, 95th and 99th percentile temperatures, and the number of days and consecutive days per year and season above 95°F, 100°F, 105°F and 110°F. Sample precipitation outputs include 95th and 99th percentile 24-h precipitation, annual and seasonal precipitation, annual maximum 24-h precipitation, and the largest seasonal 3-day precipitation. It will also produce precipitation projections in terms of annual exceedance probabilities or return periods (24-h duration only) and the new user guide will include more information on selecting models, scenarios, and using confidence limits.

It was also noted that the FHWA publication *Hydraulic Engineering Circular No. 17: Highways in the River Environment Floodplains, Extreme Events, Risk, and Resilience* (2nd edition) also addresses climate change specifically. Chapter 5 gives a primer of climate change science. Chapter 7 includes risk and resilience analysis framework with five levels of analysis, where Level I used only historical data and Level 5 uses projected discharges and confidence limits plus expertise in climate science and land use.

Contribution

The updated CMIP Tool will enable planners and engineers to easily process downscaled climate data and calculate a variety of temperature and precipitation variables that are meaningful to transportation analysts.

Presentation Questions and Discussion

Q. How does the tool compute its values?

A. First you select what GCMs you want to use, then the tool will calculate the ensemble average of whatever GCMs you choose.

Q. Climate is not stationery. How do you address that?

A. The tool leverages existing models that give return periods which are adjusted with output from climate models.

A PROCESS FOR EFFICIENT, SCIENTIFICALLY INFORMED CLIMATE DATA DOWNSCALING FOR LARGE-SCALE ASSET CLASS RESILIENCE ASSESSMENTS: THE ARIZONA DOT APPROACH

STEVE OLMSTED

Arizona Department of Transportation

Background

In 2014, Arizona DOT was awarded a \$250,000 FHWA grant to conduct a pilot climate change study. The objective of the study was to identify hotspots where highways are vulnerable to climate-related threats such as extreme heat, freeze–thaw, snow and winter precipitation, wildfire, flooding, landslide, and slope failure. The project focused on the Interstate corridor connecting Nogales, Tucson, Phoenix, and Flagstaff (I-19, I-10, and I-17). Challenges included the fact that Arizona has a diverse topography, ranging from +0 to +8,000 ft in elevation and a diversity of climate zones: desert, grassland, chaparral, and forest.

Arizona DOT’s assets include

- Arizona:
 - 140,000 maintenance lane miles,
 - 7,800 bridges, and
 - 1 International border.
- Arizona DOT:
 - 30,000 maintenance lane miles connecting those 140,000 maintenance line miles,
 - 4,700 bridges,
 - 10 maintenance and construction districts, and
 - 1,500 facility buildings.

Innovations

Arizona DOT began the project by conducting a half-day scientific stakeholder workshop to obtain input from the Arizona science community. The participants discussed data sources, methodologies, and other information to inform the assessment, including:

- Spatial and temporal resolution,
- Selection of GCMs,
- Emissions scenarios,
- CMIP3 versus CMIP5, and
- Sources of bias.

Figure 48 provides a summary of the data sources and outputs selected by the stakeholder participants.

The FHWA CIMIP5 tool is a spreadsheet tool that processes downscaled CMIP5 climate data to output a series of temperature and precipitation climate variables relevant to transportation planners. The tool is limited to processing four grid cells at a time. The Arizona

Parameter	Specification
Projections and Historical Data Source	Downscaled CMIP5 Bias Corrected Constructed Analogs (BCCA) daily projections with accompanying historical data
Emissions Pathway	Representative Concentration Pathway 8.5
Downscaled General Circulation Models (GCM)	NorESM1-M, HadGEM2-ES, CSIRO-MK3.6, CanESM2, MPI-ESM-LR, MPI-ESM-P, GFDL-ESM2M
Horizontal Spatial Resolution	1/8° (~7.5 mile or ~12km)
Temporal Resolution	Daily for 1950-2000 (backcastings from models in addition to historical data), 2025-2055, and 2065-2095
Model Outputs	Temperature (daily maximum and minimum) and precipitation (daily total)

FIGURE 48 Data selection. (Source: Arizona DOT)

DOT pilot study area, encompassed over 450 grid cells. Arizona DOT solved this problem with a custom batch processing tool written in the *R* programming language. The modified tool not only batch processed climate data but also fitted generalized extreme value (GEV) distributions for extreme rainfall events (1% and 2% change).

Arizona DOT batch processed climate data for two time periods, 2025–2055 and 2065–2095. The tool output the following climate variables for each GCM and RCP scenario.

- Number of degree-days > 100°F;
- Number of degree-days > 110°F;
- Performance grade (PG) binder high-temperature grade; and
- PG binder low-temperature grade.

In addition, the tool output the median values from the full GCM ensemble as well as the maximum, minimum, and interquartile range.

Vulnerability for roadways was estimated by first calculating the mileage of roadway by AASHTO functional class. Next, vulnerability was calculated with weighted multiplication and the summation of PG temperature change and mileage of roadway by functional class; e.g., interstates were weighted more than U.S. or state routes. The hazard for a given roadway segment was quantified by calculating the difference between high-temperature PG grade from historical climate records and future high-temperature PG grade. The impact of a hazard for a given roadway segment was calculated by multiplying the number of users on each road times the weighted factor for the assigned functional class. It was assumed the delay to a user was greater on an Interstate than on a U.S. route, etc.

Contribution

Arizona DOT modified the FHWA CMIP Tool to batch process CMIP5 climate for a large study area. The tool outputted a series of climate variables relevant to transportation planners, and fit

GEV distributions for extreme rainfall events. ADOT was able to use the output climate variables to estimate the vulnerability of roadway to future temperature change.

Presentation Questions and Discussion

Q. Is the goal to produce a statewide database that can be downloaded to assist in design or evaluation of pavements?

A. Yes, the ultimate goal is to have an open-source statewide dataset.

Q. Looking at arid environments like the southwest, peak flows can increase dramatically after a drought. How do you address that?

A. USGS is installing cigar-sized flow sensors at cross-sections of various washes to help collect additional flow data.

Q. What is the trigger for doing a probabilistic analysis?

A. When the output of a model, such as HEC-RAS, produces unrealistic results for a high-priority site, we do additional, probabilistic modeling.

INTRODUCING STAR-ESDM: HIGH-RESOLUTION CLIMATE PROJECTIONS FOR IMPACT ANALYSIS

ANNE STONER

KATHERINE HAYHOE

Texas Tech University Climate Science Center

Background

GCMs divide the Earth into grid squares at a very coarse resolution. Downscaling is the process of taking coarse climate data and transforming it with physical or empirically based models to a finer temporal and spatial resolution. There are two categories of downscaling methods: statistical and dynamical.

Dynamical downscaling uses output from a GCM as input to a regional-scale model. This method is computationally very demanding. In contrast, statistical downscaling uses the statistical relationships between large-scale variables, such as atmospheric pressure, and a local variable, such as wind speed, at a given location. The derived statistical relationship is applied to the GCM data to derive local variables from the output of the GCM. Texas Tech University Climate Science Center has developed a new method of statistical downscaling.

Innovations

The research team introduced a set of empirical–statistical downscaled climate projections produced by the new Seasonal Trends and Analysis of Residuals Framework (STAR). The empirical–statistical downscaling model component, STAR-ESDM, uses signal processing techniques to decompose the temperature or precipitation time series into three separate components: (1) the long-term trend; (2) static and dynamic climatologies; and (3) static and

dynamic diurnal anomalies. The ESDM then downscales global climate model output to the spatial and temporal resolution of any observational dataset; here, station-based NOAA Global Historical Climatology Network observations across North America and 1/16th degree gridded observations (Livneh et al. 2013) covering the contiguous United States. The ESDM is trained for each individual high-resolution grid cell or weather station with each component of the signal being individually bias-corrected. In the case of daily anomalies, they are transformed using a nonparametric Kernel Density Estimation function into a probability distribution that closely resembles historical observations initially but that changes over time as the GCM's distributions change, yielding the downscaled and bias-corrected future projections for the location of interest, whether station or grid cell.

Evaluating this new method using the perfect model framework shows that it significantly improves on previous errors and biases at the tails of the distribution where extreme events are relatively rare but have a proportionally greater impact on infrastructure, agriculture, human health, etc. while retaining a high computational efficiency. STAR-ESDM output is currently available for daily values of minimum and maximum temperature as well as daily precipitation for CMIP5 and CMIP6 simulations corresponding to a historical total-forcing scenario and a lower and higher future scenario (RCP4.5 and RCP8.5 and SSP2-4.5 and SSP5-8.5) for the period 1950–2100.

Contribution

STAR-ESDM dataset provides gridded and downscaled CMIP5 temperature and precipitation at a 1/16th (~6 km) degree spatial resolution across the United States; 1/12th degree resolution across Canada; and point information for several thousand individual weather stations across North and Central America.

Managed Retreat, Part C

How Are the Hard Decisions Made?

ROB GRAFF

Delaware Valley Regional Planning Commission, Moderator

This panel focuses on transportation infrastructure in high-risk areas and approaches that are used now, and approaches that should be used in the future to evaluate the option of retreat. The panel discussed case studies of infrastructure retreat—abandonment and how costs and benefits of retreat are currently evaluated.

THE CASE OF LOUISIANA: TERREBONNE PARISH AND LOUISIANA'S STRATEGIC ADAPTATIONS FOR FUTURE ENVIRONMENTS

MATTHEW D. SANDERS

Louisiana Office of Community Development

Background

Louisiana's Strategic Adaptations for Future Environments (LA SAFE) has concluded that the average household in the six LA SAFE parishes has received over 28 times the national average in FEMA disaster recovery payments between 1978 and 2016. Louisiana is also losing land faster than it can be restored, even with full implementation of the Coastal Master Plan. As disaster events take place, populations are shifting from low-lying communities to toward higher ground locations. Future development decisions should incorporate the best understanding of risk and should contemplate outcomes for areas anticipated to experience a range of risks.

Innovations

In 2017, outreach and engagement began with a parishwide meeting to identify challenges and opportunities; community meetings to propose strategies; another parishwide meeting to evaluate vision and strategies; stakeholder roundtables and open houses to direct policy, program, and project development; and another parishwide meeting for project evaluation. Overall, there were 71 community meetings with 2,835 individual participants. LA SAFE combined the highest-rated community strategies with future flood risk and existing efforts in each parish to create draft projects.

Contribution

These meetings led to projects such as the Run to Retention Program which would purchase and clear abandoned properties to return these areas to their natural state to provide areas for collecting stormwater. In addition, the Stormwater Management Park which would build in stormwater management features to keep other parts of the park dry and serve as an educational resource to learn about wetland ecosystems.

MANAGED RETREAT AND INFRASTRUCTURE DECISION-MAKING

STACY CURRY

New Jersey Office of Emergency Management

Background

Woodbridge is in Central Jersey, Middlesex County, is approximately 23 mi² with a population density of approximately 4,225 per square mile with over 400 residential properties within the flood zone. Previous flooding in the area includes Hurricane Irene in 2011 and Hurricane Sandy in 2012. In 2013, FEMA granted New Jersey federal funds for buyouts that would focus on purchasing and removing clusters of homes to enhance flood mitigation. Two hundred residential properties within the flood zone applied.

Contribution

Challenges associated with the buyout included no-applicants, flips, and foreclosures. In addition, resident economics (i.e., moving expenses, appeal appraisals, no equity, and tenants/rentals), property maintenance, and neighborhood safety (i.e., increased police presence).

Some of the program's successes listed included involving "key players" such as FEMA, State of NJDEP, mayor and administration staff, the Office of Emergency Management, and community engagement. Because of these efforts, a restoration plan was developed that includes a "buffer zone" with planting, road removal and parks—passive recreation. In addition, funding for the project included grants and township budgets. Planning restoration early and embracing the importance of buyouts were listed as key takeaways from the project.

A CLIMATE-RESILIENT STATE TRANSPORTATION DEPARTMENT

TRACEY FROST

Caltrans

Background

Caltrans is one of the leading agencies tackling climate change considering both mitigation and adaptation. The agency is taking steps to fully integrate climate change into the transportation investment decision-making process from planning to project development. District Vulnerability Assessment Reports have been developed that project climate impacts on state highways and transportation assets and the agency is in the process of developing GIS maps with similar information consolidated. In addition, Climate Adaptation Strategy Reports are prioritizing assets at risk, developing adaptation strategies, and integrating these into Caltrans business practices.

Innovations

Caltrans is developing literature, including a summary report to give an overview of the natural environment and transportation infrastructure, a technical report to give background on data used to develop reports and an online viewer tool used to toggle stressors on and off to visualize locations of stressors. These tools will be available to all 12 Caltrans Districts soon.

In addition, Caltrans is looking at four different adaptation approaches to combat sea-level rise examples include projects such as rock slope protection along Highway 101 and includes a 3-mi realignment to protect a highway from erosion. Additional adaptation projects are as follows:

- Piedras Blancas in San Luis Obispo, Highway 1 realignment, aims to realign 2.8 mi of roadway up to 475 ft inland of the existing alignment. The project includes restoration of the existing highway to natural conditions and restoration of nearly 20 acres of off-site state parklands to mitigate impacts to disturbed areas.
- In the area of Del Norte and Humboldt County, residents have been in search of a permanent fix for Highway 101's Last Chance Grade. Its failure would have a \$1-to-\$1.5-billion negative impact on the regional economy and the highway is a lifeline for coastal communities.
- The proposed Gleason Beach Roadway Realignment aims to realign a section of SR-1 in order to maintain the only road connecting the communities of Bodega Bay and Jenner. This would realign approximately 1,000 ft of the existing SR-1, shift travel approximately 11 ft east, and would minimize armoring of the bluff.

Technical Solutions for Resilience

JENNIFER JACOBS

University of New Hampshire, Presiding

Resilience transportation networks require technical solutions that go beyond traditional practice by using existing tools in novel manners and creating new methods and tools to handle new challenges. In many cases, such as low-volume roads or increasing flood risks across a region, it is difficult to justify major infrastructure investments. In this session, a range of technical approaches will be discussed that focus on understanding and increasing the capacity of those systems. The focus is on practical applications that have been demonstrated to be effectively used by state DOTs.

INCREASED HIGHWAY RESILIENCE: USING CULVERT DIFFUSERS TO DECREASE HYDRAULIC LOSSES AND INCREASE CULVERT CAPACITY

ALEXANDER MANN

Maine Department of Transportation

Background

State DOTs face many resiliency challenges including climate change, development and changing land use, increase in high-flow events, budget constraints, and culvert failure and flooding. A review of hydraulic losses in culverts showed that inlets cause 0% to 25% of losses, pipe friction causes 0% to 25% losses, and outlets cause approximately 50% of losses. The use of outlet diffusers could reduce losses and increase culvert capacity.

Innovations

In 1926, David Yarnell experimented with diffuser designs at the University of Iowa and found that there was a 40% increase in capacity with the addition of a diffuser and that there was a decrease in the pressure in the culvert during operation.

Contribution

Both Caltrans and Maine DOT have used diffusers to increase pipe capacity. Maine DOT found that their testing indicated a greater than 50% increase in pipe capacity. The results of using a diffuser mechanism include increased pipe capacity, decreased inlet water level (reduced flooding), reduced outlet velocity reduces erosion, and increases pipe system resilience to high-flow events. Figure 49 provides additional information on the changes in pipe capacity with the use of diffusers.

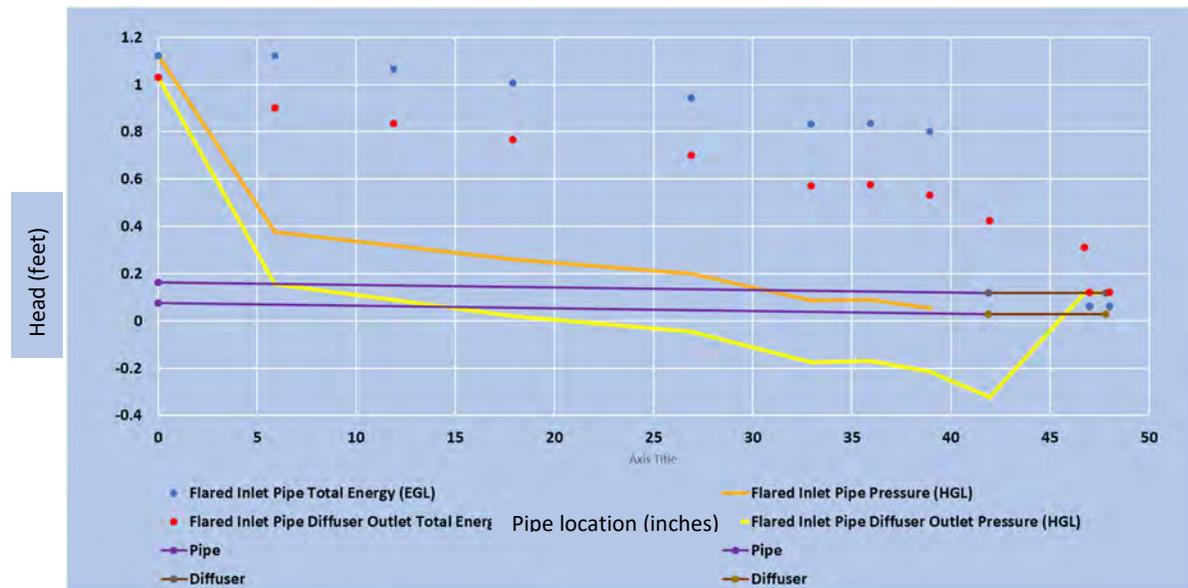


FIGURE 49 Improvements anticipated in pipe capacity and other benefits of diffusers.

APPLICATION OF 1D/2D HYDRAULIC MODELING FOR INVESTIGATION UTILIZING NORTH CAROLINA DOT INFRASTRUCTURE TO IMPROVE FLOOD RESILIENCY

JOHNNY MARTIN
Moffat & Nichol

Background

During the hurricane recovery efforts North Carolina DOT was required by the Governor’s Office to investigate its infrastructure to determine if any of the USACE recommended countermeasures could be immediately implemented to improve flood protection levels. The goals of this project included having permanent countermeasures implemented and to determine if additional alternatives were feasible. It was required that this project have no negative impact to the public or to Princeville Dike.

Innovations

In order to identify permanent countermeasures along the existing flood protection system, discussions were had with USACE and a Feasibility Report was completed. Because of the desire for quick implementation, culverts were investigated to install backflow preventers (flap gates). The permanent countermeasures were installed to nine out of 10 culverts identified in the USACE Study. For this project, permitting and construction was fast-tracked.

Contribution

The benefits of these permanent flood countermeasures include impediment of water from 39.9 to ~42.5 NAVD (North American Vertical Datum), reduced water entering Princeville, and improving the return period of a 25-year event to a ~70-year return period. A 1D/2D Model was created to run models in real time, with a full simulation taking approximately 2 weeks to complete. The model and incorporation of pipe and levee interconnectivity gives a better picture of the flood behavior and the vulnerability associated with the surrounding areas. These permanent countermeasures have improved flood resilience for the Town of Princeville from a 25-year event to a 50- to 70-year level event.

Cascading Events

JEFFREY ARNOLD

U.S. Corps of Engineers, Moderator

Hazards are like infrastructure, interconnected. Flooding leads to secondary effects of erosion, contaminated water, mold, clogged storm drains, downed power lines, etc. Cascading and connected events can impact local, state, regional, national, and international supply chains. The goal of this session is to demonstrate methods to simulate risk in disasters and potential cascading and connected hazards.

FRAMEWORK FOR INCORPORATING COMPLEX UNCERTAINTY SYSTEMS UNDER POST-DISASTER CASCADING INFRASTRUCTURE

YANFENG OUYANG

University of Illinois at Urbana–Champaign

Background

It is known that natural disasters cause great damages to the urban system, such as damaging critical infrastructure and posing a threat to the population. Such events are inevitable challenges for urban systems around the world and it appears that urban systems are not as reliable as expected when facing disruptions due to natural disasters. To analyze the disruptions posed to a modern urban system, ideally modern urban infrastructure system (power, water, transportation) should be considered and the urban population that it serves. This leads to a need for a Framework for Incorporating Complex Uncertainty Systems into disaster management planning. The goal of this project was to analyze and predict human behaviors under emergencies to assist in the decision-making process.

The framework consists of a critical complementary analytical tool to conduct qualitative analysis with multiple models and software, as well as large datasets. The framework was built on the backbone of the Human Infrastructure System Assessment–Transportation Analysis Simulation System (HISA-TRANSIMS) model.

Innovations

HISA models the human factor, that is, the human connection to the infrastructure. TRANSIM is an integrated set of tools developed to conduct transportation system analyses. TRANSIMS incorporates network topology and origin–destination trip tables to simulate real-time traffic flow.

The HISA-TRANSIM model is divided into three components. The first component is comprised of the input databases: (1) the Urban Tactic Planner database contains information about infrastructure network interconnectivity along with transportation network notations such as speed limits, turns and routing; and (2) the digital population database (DigPop) that acts upon

a principle of random realization combined with real representation of statistical census data and neighborhood-level detailed survey data.

The second component describes the urban dynamics by focusing on the activities of population, infrastructure, and transportation (Figure 50). The key motivations behind these activities are resource supply and resource demand. The population needs to obtain resources directly from infrastructure or indirectly via the transportation network, for example, gaining access to the water supply.

The resource availability model looks at how strong the support systems are for a given resource and how easily they can be disrupted. The public’s access to these resources is then interpolated from DigPop survey data, allowing for it to check for initial disruption in the damage zone that includes loss of functionalities and the ability to provide resources as a source. Then, it follows with a disruption propagation mechanism to check if support failure has occurred in which the source remains disrupted and thereby causes a cascade of failure. For example, the loss of a major power transmission pylon would lead to the loss of power substations and then proxy transformers in their ability to distribute power. Included in this analysis is also an inventory supply and demand model for commodities.

The third component is a traffic simulation model that takes an in-depth look at dynamic population transit modules as seen in Figure 51.

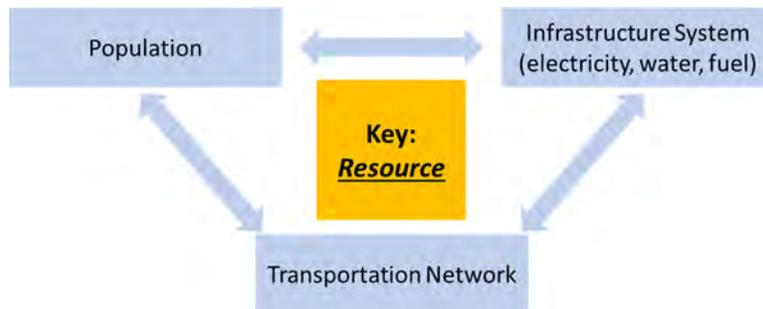


FIGURE 50 HISA-TRANSIMS component II–HISA simulation model.
(Source: University of Illinois at Urbana–Champaign)

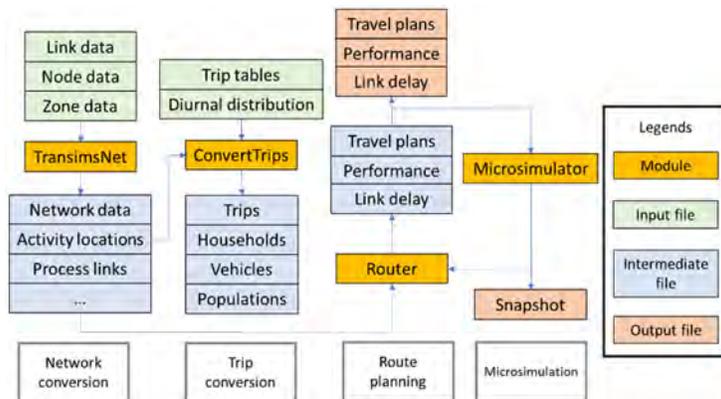


FIGURE 51 HISA-TRANSIMS component III–TRANSIMS Simulation Software.
(Source: University of Illinois at Urbana–Champaign)

The diagrams in Figure 52 present the complete HISA-TRANSIMS model with all three components.

Contribution

The project conducted a case study in the Manila National Capital Region, a megacity with a population of more than 24 million that contains 38% of the GDP of the Philippines. The study area is prone to major disruptions such as earthquake and typhoons, social issues, and terrorist threats. The current tool is a web app with the ability to draw zones of disruptions for electricity, fuel, transportation, and water. Figure 53 graphically shows the results of a simulation of a disruption that occurs at 12:00 a.m. on a weekday. From left to right, the maps show cascading failures within the water system, electric grid, and fuel infrastructures, respectively. Figures 53 through 55 illustrate the growing water shortage.

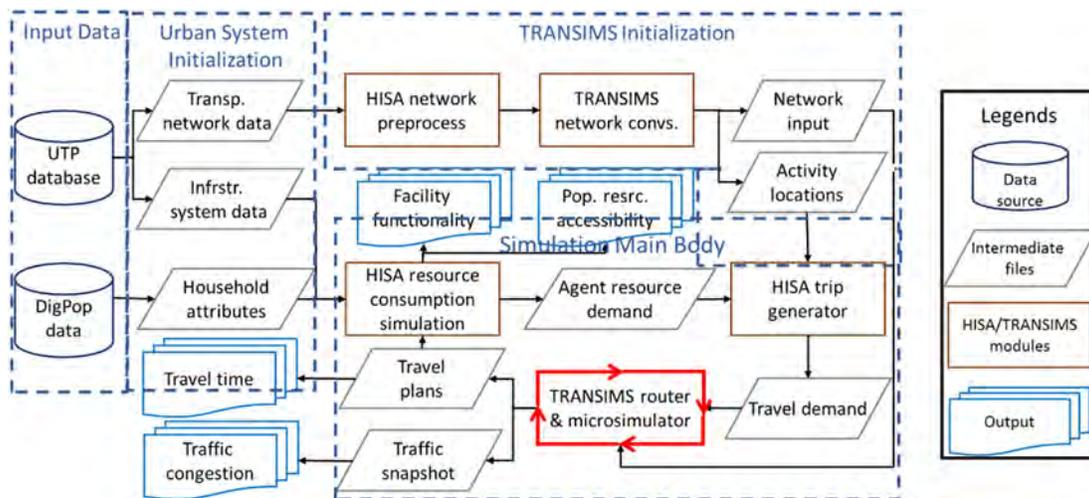


FIGURE 52 HISA-TRANSIMS: Single-period simulation workflow. (Source: University of Illinois at Urbana–Champaign) (NOTE: the model as illustrated is configured for a single-time period. However, it could be reconfigured to simulate multiple time periods.)

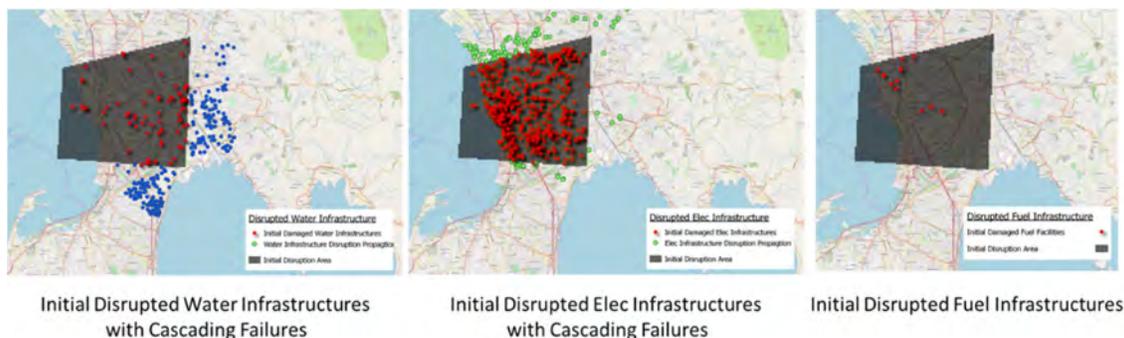


FIGURE 53 Case study output. (Source: University of Illinois at Urbana–Champaign)

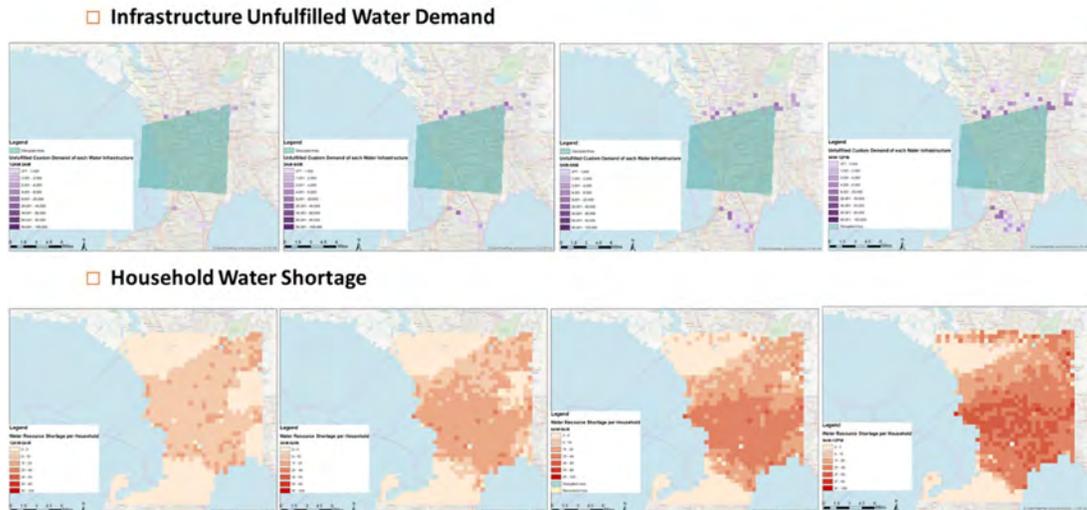


FIGURE 54 Case study output. (Source: University of Illinois at Urbana–Champaign)

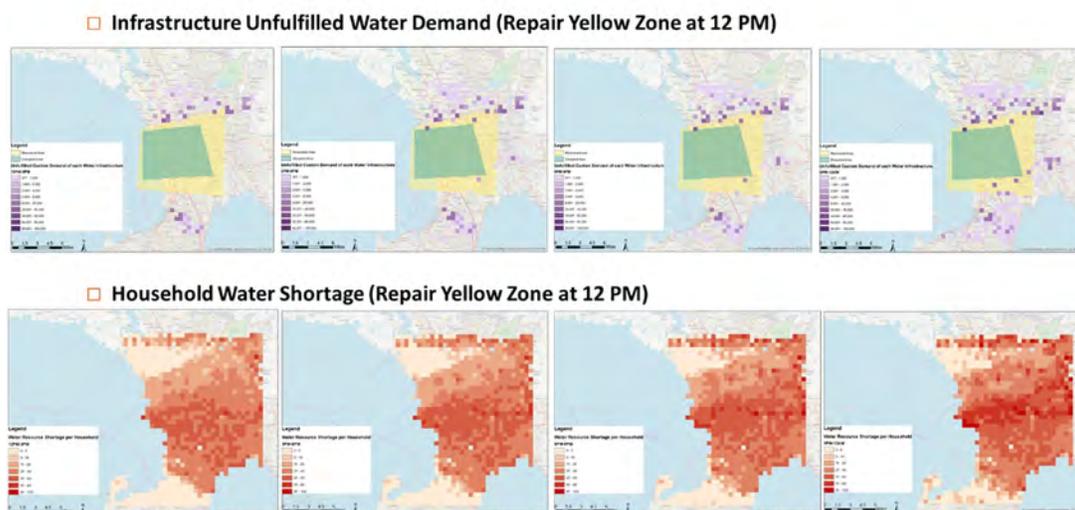


FIGURE 55 Case study output. (Source: University of Illinois at Urbana–Champaign)

In summary, the current work has led to a comprehensive simulation model that integrates infrastructure system dynamics, transportation activity, and community behavior. Disruption and recovery propagation have been modeled to capture the urban system interdependence and based on the framework of single-period simulations; however, multiple-period simulation is proposed to broaden the application of this model. Future work is focused on addressing uncertainty in the urban system (errors in human decision-making, herding effects, etc.) and more functionality to model evacuation and public transportation systems.

MESOSCOPIC MODELING OF MAJOR DISRUPTION SCENARIO IN AUSTIN, TEXAS, TO ESTIMATE BENEFITS FROM INTEGRATED CORRIDOR MANAGEMENT

MATTHEW MILLER

Texas A&M Transportation Institute

Background

The definition of resilience is expansive because it includes a need to withstand or bounce back to all hazards in all condition across the entire transportation system. When addressing the hazards of climate change, transportation has access to fund sources arriving from many agencies, the U.S. Department of Homeland Security and U.S. DOT comes to mind. Traffic operations obtain funding primarily from U.S. DOT and state funds including air quality, capacity expansion projects, and a variety of other sources. Operations focus on minor and major incidents because of their frequency. With suitable planning and an eye toward incorporating findings from research on responding to hazmat and natural disasters, operations can be expanded to respond to these activities. This requires planning and investing in these response strategies.

The response strategy discussed involves Integrated Corridor Management (ICM), which really serves as a coordinated effort to enable multiple response strategies in response to a given recurring (high frequency) non-recurring disruption event. Figure 56 illustrates the goals of ICM.

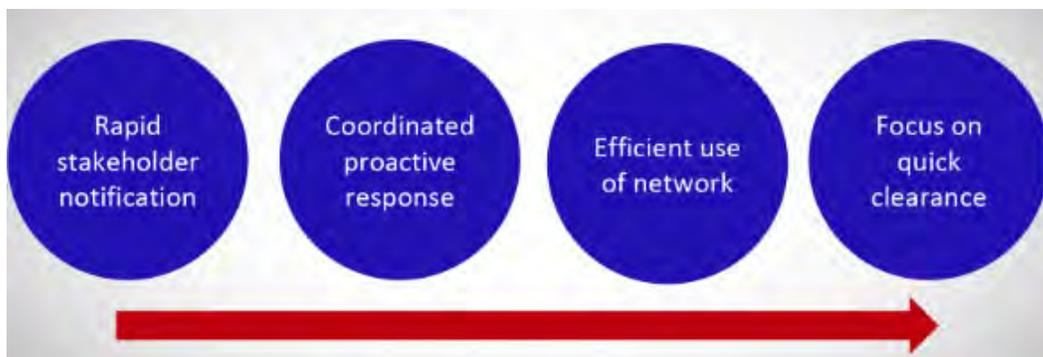


FIGURE 56 ICM goals. (Source: Texas A&M Transportation Institute)

Innovations

The Federal Transit Administration (FTA) defines ICM as “the integrated management of freeway, transit, arterial, and parking systems within a corridor using Intelligent Transportation Systems (ITS) technologies and innovative practices. It is the management of a corridor as a system rather than the management of the individual transportation networks (e.g., rail lines, bus routes, arterials, freeways) within a corridor, which is the current practice in the U.S.” ICM is comprised of four layers. The Traveler Information Systems layer includes NR incident data, traffic conditions, mode choice data, and alternate route data. The Pre-Planned Alternate Routes/Modes layer includes alternate route traffic delay monitoring, signal plans, toll waiver

response plans and transportation service scale-up. The ITS layer includes traffic condition-based traffic signal phasing, closed-circuit TV, speed sensors, and work zone queuing alerts. Finally, the Traffic Incident Management layer includes the HERO service patrol, vehicle location data, and Traffic Management Center (TMC) -based incident management controls and alerts. A decision-support tool with a GUI ties the four layers together.

This project leveraged the Dynus-T Dynamic Traffic Assignment Model, an anisotropic mesoscopic modeling (AMS) tool, to test the ICM system along a corridor. The AMS model is based on two intuitive concepts and traffic characteristics: (1) at any time, a vehicle's prevailing speed is influenced only by the vehicles in front of it, including those that are in the same or adjacent lanes; and (2) the influence of traffic downstream upon a vehicle decreases with increased distance. Data to run the model was gathered from the Capital Area MPO travel demand model. The data was converted to origin–destination (O-D) pairs. INRIS data was used to update and validate speeds for given historic events. The simulated scenario was for a full freeway closure based on the May 10–11, 2018, overnight full lane closure at the Oltorf Street Bridge. All vehicles exit to the frontage road. Upstream frontage road signals were adjusted to accommodate the new frontage flows. The ICM response plan would start at 5:00 a.m. dynamic messages signs (DMS) provided diversion routes. Green signals were extended on parallel routes. Tolls were relaxed from 5:00 to 7:00 a.m. on SH-45. Two ICM responses were modeled. First, ICM lite included the following. The TMC is notified, police and emergency services are notified, and the Safety Patrol was deployed. In addition, the city of Austin adjusted the signal timing at the intersection where the incident occurred. Second, full ICM included advanced traveler information; that is, DMS, radio, TV, Twitter, and WAZE. Alternate route information was provided. Signal timings were adjusted, and toll waivers were activated. The results of the modeling showed that travel time on I-35 during the simulated closure was greatly reduced when using ICM as compared to the base.

Contribution

This project demonstrated that ICM improves the ability to adapt and recover from a major incident. While the ICM processes and procedures were originally developed for major corridors, they can be applied to any roadway.

REGIONAL-SCALE SIMULATIONS OF EARTHQUAKE IMPACTS CONSIDERING MULTIPLE FIDELITY MODELING APPROACHES

MATTHEW SCHOETTLER

UC Berkley

Background

The Natural Hazards Engineering Research Infrastructure (NHERI) is a distributed, multi-user, national facility that provides the natural hazards engineering community with state-of-the-art research infrastructure. The more than \$60 million infrastructure research projects funded by the NSF, NHERI enables researchers to explore and test ground-breaking concepts to protect homes, businesses, and infrastructure lifelines from the impacts of earthquake, wind, and water hazards,

enabling innovations to help prevent natural hazards from becoming societal disasters. The NHERI's SimCenter is the center for computational modeling and simulation. SimCenter conducts regional-scale simulations of earthquake impacts considering multiple fidelity model approaches. SimCenter's goals include

- Developing a computational framework that supports decision-making to enhance community resilience to natural hazards in the face of uncertainty;
- Designing the framework to be sufficiently flexible, extensible, and scalable so that any component can be enhanced to improve the analysis and thereby meet the needs of a user group;
- Seeding the framework with connectivity to existing simulation tools and data so it can be readily employed and improved as users identify new needs;
- Releasing tools/applications built using this framework that meet the computational needs of researchers in natural hazards engineering; and
- Providing an ecosystem that fosters collaboration between scientists, engineers, urban planners, public officials, and others who seek to improve community resilience to natural hazards.

Innovations

The projects had to be flexible, scalable, extensible, and seeded with open-source framework, along with releasing streamlined toolsets as standalone products. It took an ecosystem of designers of resilience and collaboration between all in communities, looking to the test outcomes to describe resiliency curves for the future.

The natural hazard simulation framework includes the following characteristics: (1) performance-based engineering methodology, (2) uncertainty quantification, (3) multifidelity modeling capabilities, (4) extensible to include earthquake, hurricane, and tsunami threats, (5) scalable: local-to-high-performance computing (HPC) in the cloud, (6) regional simulations, and (7) artificial intelligence enabled.

The framework has been tested doing simulations for earthquakes in San Francisco, California, and Anchorage, Alaska, as well as hurricanes in Atlantic City, New Jersey. Each simulation requires the following workflow. Asset description, hazard description, asset and hazard modeling, response estimation, and damage and loss estimation. As an example, for the Anchorage earthquake simulation, the asset description consisted of the NBI, AADT, and detour distance in kilometers. The hazard description included the earthquake scenario description. The asset and hazard modeling step involved stochastically simulating spectral acceleration and leveraging the HAZUS bridge fragility curves. Response estimation consisted of the modeled probability of failure. Finally, the damage and loss estimation consisted of the estimated direct losses and bridge repair down time.

Contribution

The SimCenter is able to use stochastic modeling in combination with asset inventories, ground motion maps, and loss ratios to realistically estimate the anticipated direct and indirect losses from a seismic event. The software used by the SimCenter is open source. In addition, the SimCenter is open for collaborations and pilot studies.

SESSION QUESTIONS AND DISCUSSION

Q. Why were only two vulnerabilities shown?

A. We chose to show 50% of the file for presentation.

Advancing Resilience at National, State, Regional, and Local Levels

TRACEY FROST

California Department of Transportation, Moderator

This is a panel and group discussion on a prioritization tool for transportation assets, lessons learned in indicator-based vulnerability assessments, addressing climate change impacts on U.S. Forest Service transportation assets, and approaches adopted in the Netherlands to assess the resilience of the Dutch highway network to natural hazards.

THE U.S. FOREST SERVICE TRANSPORTATION RESILIENCY GUIDEBOOK: ADDRESSING CLIMATE CHANGE IMPACTS ON U.S. FOREST SERVICE TRANSPORTATION ASSETS

BENJAMIN RASMUSSEN

Volpe National Transportation Systems Center

Background

The Volpe Center worked with the U.S. Forest Service to develop a guidebook, *U.S. Forest Service Transportation Resiliency Guidebook: Addressing Climate Change Impacts on U.S. Forest Service Transportation Assets*,¹ that focuses on resiliency and climate change for transportation assets typically managed by the U.S. Forest Service. The motivation for this guidebook came from regional and headquarters staff of the U.S. Forest Service who wanted a resource to help its regional staff and forest-level engineers and planners address climate issues and document emerging issues related to climate resilience of its transportation infrastructure. The goal was to provide a framework for assessing vulnerability of typical U.S. Forest Service facilities such as low-volume, unpaved roads and trails that also recognized the limited funds for construction and maintenance available. The guide focuses on a specific set of stressors:

- Temperature change;
- Extreme storms and flooding;
- Unstable slopes and erosion;
- Tree mortality;
- Wildfire; and
- Changing visitation and use patterns.

The Volpe Center staff utilized available FHWA resources but recognized the limitations of the applications of some of these resources to low-volume, unpaved roads and trails. Some of the FHWA resources included are (<https://www.fhwa.dot.gov/environment/sustainability/resilience/>):

- Vulnerability Assessment and Adaptation Framework;
- Resilience Project Pilots;

- HEC-17: Highways in the River Environment—Floodplains, Extreme Events, Risk, and Resilience;
- HEC-25: Highways in the Coastal Environment: Assessing Extreme Events; and
- FAQ: Emergency Relief Program and Resilience.

Innovations

Building on previous work completed for FHWA, the authors gathered additional input from field staff including an advisory committee of U.S. Forest Service staff and staff from FHWA's Western Federal Lands. The guidebook was field tested through a workshop in 2018 with representative staff where the guidebook was applied, and suggestions made to improve the final product. The guidebook has four primary sections including identifying vulnerability, reducing vulnerabilities, implementation opportunities, and appendices that include climate projections for each Forest Service region.

Contributions

The new guide seeks to close an information gap between guidance aimed at higher volume transportation facilities and provide guidance for agencies, in particular the U.S. Forest Service, who manage low-volume, unpaved roads and trails.

Note

1. <https://www.volpe.dot.gov/FS-Transportation-Resiliency-Guidebook>

BEST PRACTICES AND LESSONS LEARNED IN INDICATOR-BASED VULNERABILITY ASSESSMENTS FOR TRANSPORTATION

CASSANDRA BHAT

ICF

Background

This presentation focused on the development and application of the Indicator-Based Vulnerability Assessment for Transportation, which is a scoring process to help screen transportation assets to determine their vulnerability to climate stressors. There are three typical vulnerability assessment tools including those developed from stakeholder input, scoring methods, and engineering-based assessments. The indicator-based method developed through this study draws on multiple indicators including exposure indicators (e.g., days above 95°F, sea-level rise, flooding); sensitivity indicators (e.g., past experience, truck traffic); adaptive capacity indicators (detour length, disruption duration, etc.).

Innovations

The process developed has been applied in multiple locations including MPOs and state DOTs for a range of stressors and assets. Some of the key lessons learned from the application include taking care when selecting indicators such as avoiding redundant indicators; using high-quality data; engaging engineers and asset owners; and capturing the impact to the system users. The authors also recommended groundtruthing the findings with maintenance and asset owners to ensure the findings resonate with people who manage such assets daily.

Contribution

This presentation provided an overview of a new scoring-based process to help screen transportation assets to help prioritize those assets most vulnerable from identified climate stressors. The process is applicable to help screen highway assets but engineering informed assessments are needed to determine applicable adaptation strategies to reduce asset vulnerability from identified stressors.

STRESS TESTING THE DUTCH NATIONAL HIGHWAY NETWORK

THOMAS BLES

Deltares

Background

This presentation provided an overview of the ongoing “Delta Programme Spatial Adaptation” underway in the Netherlands in which a stress test was conducted to determine which assets are vulnerable to climate threats. Next, a determination will be made as to what level of risk is acceptable. Then adaptation strategies will be identified to make the road network more resilient as well as stakeholders to execute the strategy.

Risk values are considered for both the present day as well as 2050 considering expected climate changes while the authors note they have not incorporated changes to the roadway network, changes in traffic demand, economic growth, or technological changes.

Innovations

The study provided a series of risk estimates for a large range of potential stressors with and without climate change. The graphic in Figure 57 provides an overview of the type of information generated in the study.

Risk – effect of climate change

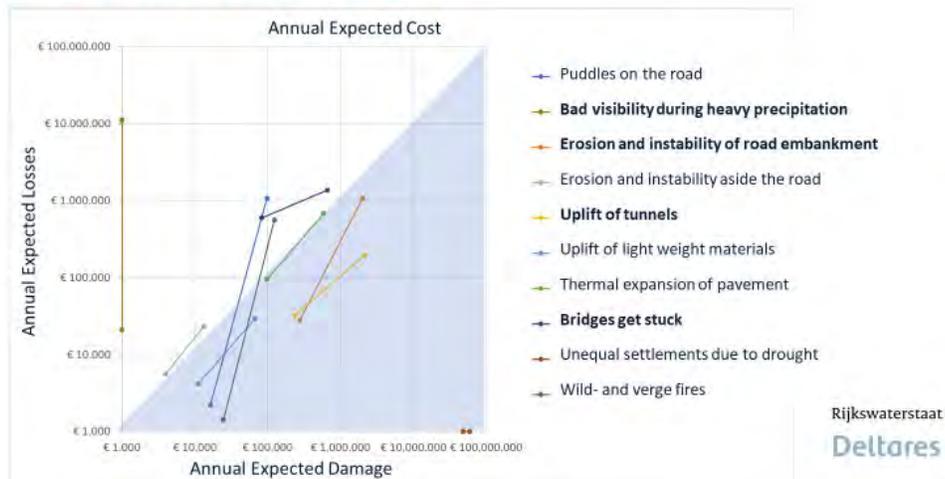


FIGURE 57 Anticipated losses to highway assets. (Source: Deltares)

Contributions

The overall strategy provided by the “Delta Programme Spatial Adaptation” process provides a planning level approach to identify assets that are or are anticipated to be at risk from climate stressors and provides cost estimates of the anticipated losses to infrastructure and the traveling public. Next, the Dutch Highway Program will consider what are acceptable levels of risk, or how resilient do various highways need to be now and in the future? Finally, strategies will be developed to work toward making the highway network more climate resilient.

SESSION DISCUSSION AND QUESTIONS

Q. Did the New York State study consider system redundancy in their modeling of criticality?
A. No, they did not.

Q. Did the U.S. Forest Service consider woody runoff?
A. Yes, as well as areas of future study.

Q. Did the Dutch study take into supply chain impacts?
A. No, they did not.

Q. Did the Dutch study take into account the age of assets in the analysis?
A. Yes, for culverts.

Q. Do the Dutch engage warning systems if you can't address a problem area?
A. Yes, we do have a wreath of warning systems.

TRANSPORTATION ASSET CRITICALITY PRIORITIZATION TOOL FOR NEW YORK STATE

ALAUARAH MOSS

Dewberry

Background

This study sought to develop an asset criticality prioritization tool for New York State and sought to move beyond traditional criticality frameworks. To capture additional components of criticality, the research team reviewed existing criticality frameworks and methods that capture the role that rural transportation infrastructure plays. For example, FHWA’s Planning for Transportation in Rural Areas guidance is intended to contribute to a better understanding about how “rural” is defined, as well as provide examples of successful rural transportation planning efforts from several states. The guidance stresses the importance of considering safety, economic, and environmental components of criticality.

Innovations

The research team built upon the information gathered through a review of multiple criticality frameworks and conducted a survey to fine tune the factors and categories of importance to respondents in New York State. The survey findings led to an expanded compilation of factors for consideration in the criticality model as shown in Figure 58.

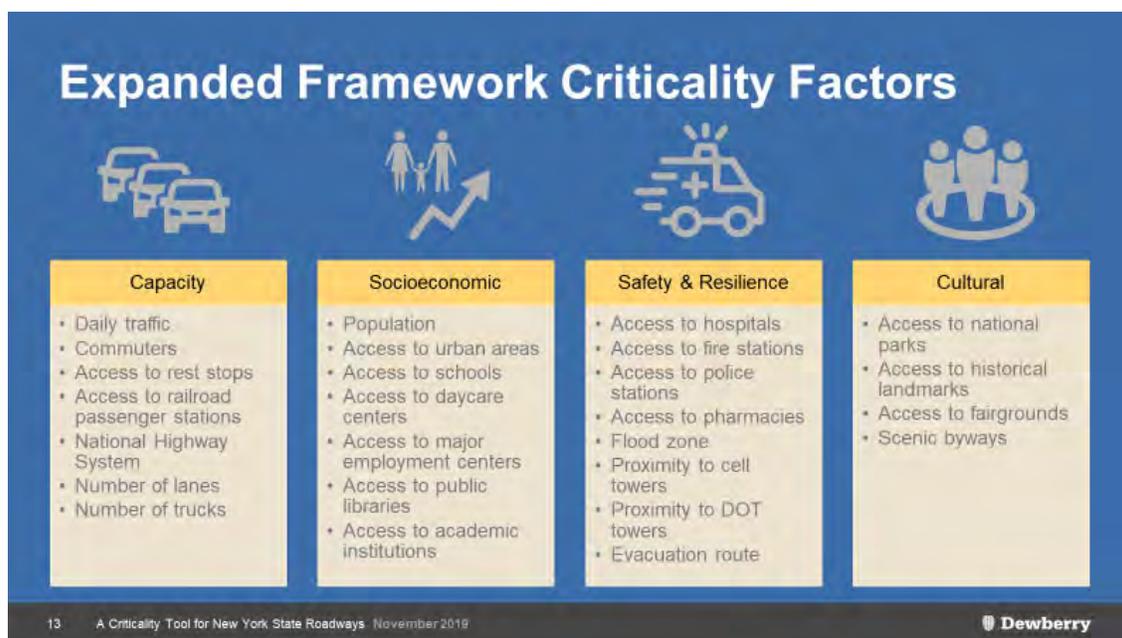


FIGURE 58 Expanded framework criticality factors. (Source: Dewberry)

Contribution

The research team built an online GIS-based criticality tool that allows for the user to compare various scenarios including filters for analyzing rural roadways only. The maps generated are viewed as being defensible, transparent, documented, and reproducible. Use cases were developed for New York DOT headquarters, regions, and MPOs in the state. A screenshot of the tool is shown in Figure 59.

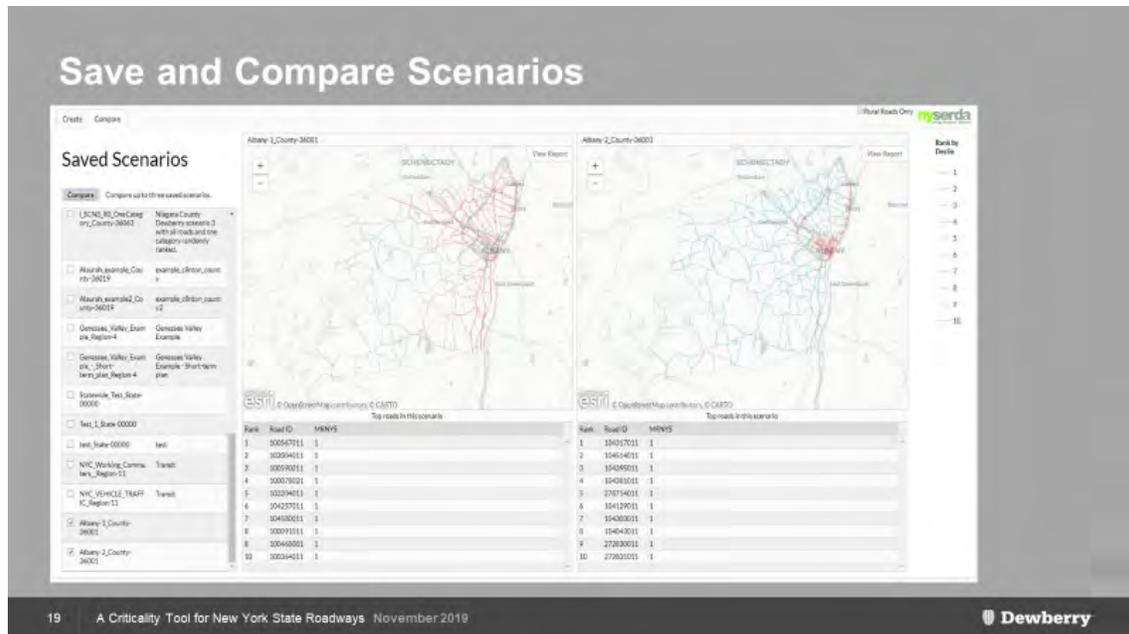


FIGURE 59 Online criticality tool. (Source: Dewberry)

Recovery for More Resilient Roads

WILLIAM ANDERSON

Transportation Research Board, Moderator

The best preparedness plan is a good recovery plan. Panelists will discuss practical approaches to managing transportation systems to return to safe operations following a disruption caused by a disaster.

ASPHALT PAVEMENT RESILIENCY: FINDINGS OF THE 2019 NCAT WORKSHOP

BENJAMIN BOWERS

Auburn University

Background

On September 10–11, 2019, the National Center for Asphalt Technology (NCAT) conference was held in Dallas, Texas. Participants included representatives from government agencies, industry, and academia. The goal of the workshop was to discuss and define resilience as it relates to asphalt pavements as well as to discuss case studies. This conference was part of a project sponsored by the National Asphalt Pavement Association.

FHWA Order 5520 defines resilience as the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions. Figure 60 summarizes the conference panel’s approach to applying the FHWA resilience definition to asphalt pavements.

Innovations

The 2019 NCAT Conference presented case studies that showed the value of proactive resilient design as well as the benefit of close cooperation between contractors, DOTs, and other stakeholders in facilitating the rapid rebuild of damaged assets. In addition, the conference produced a gap analysis for research and implementation needs. Several case studies were highlighted in the conference as summarized here.

Prepare and Adapt	Withstand and Recover
Perpetual pavement design	Fast construction
Adaptable materials for climate extremes	No cure time, open to traffic almost immediately
Porous asphalt systems	Resilient designs to protect critical corridors
resilient adaptation can be built into long term maintenance schedules	Recyclable (e.g., crushing old, “failed” roadways and reusing)

FIGURE 60 Defining resilience. (Source: Auburn University)

Case Study 1: Iowa—Flood, 2019

This study focused on the flooding that occurred in 2019, overtopping the intersection of I-29 and I-680. This intersection suffered significant flooding in March 2019, and again in May of 2019. The flooding was attributed to rapid snowmelt and heavy rainfall. Figure 61 summarizes the time schedule of events and repairs.

The contractor worked around the clock, and the governor waived the low bid requirement.

Case Study 2: Alaska—Earthquake, 2018

This case study was presented by Amanda Gilliland of the Transtec Group. Alaska is unique in the extremes that it experiences, including extreme temperature fluctuations, flooding, and earthquakes. Alaska DOT must consider resilient design regularly. On November 30, 2018, a magnitude 7.0 earthquake caused severe fracturing of the pavement on Vine Road, southwest of Wasilla. The response time was only 4 days. The DOT wrote contracts as the contractors were working on repairs. A team effort was required to make this rapid response happen.

Case Study 3: Alaska

On Alaska's North Slope is an excellent example of resilient design. Since the road floods every year, the bridge and roadway were designed to be submerged and withstand ice. PND Engineers, Inc., worked with the DOT in designing and constructing these innovative submersible bridges on the North Slope of Alaska, which saved the DOT approximately 50% (\$10 million) over the cost of elevated bridges for the crossing of two river channels in a floodplain nearly 2 mi wide. Extreme environmental conditions, design vehicle weights approaching 4 million pounds, impact loading from river ice 5 ft thick, and discontinuous permafrost soil conditions posed interesting and unusual design and construction challenges. The permanent crossings allow passing flows to go through and across the Spine Road by using a combination of submersible low-water bridges and paved low-water crossings.

The conference also addressed other problems, including ground water rising into the pavement structure due to SLR, extreme temperature fluctuations, and cascading effects; e.g., a tornado or hurricane results in a need for demolitions of structures and a huge debris pile.

Status	Flood 1 (Dates)	Flood 2 (Dates)
Closed	3/14/2019	5/31/2019
Water Receded	3/27/2019 (Debris cleared for testing)	6/10/2019
Contractor Mobilized	3/30/2019	6/10/2019
Open	4/2/2019	6/12/2019

FIGURE 61 Response. (Source: Auburn University)

Contribution

The conference concluded with lessons learned. First, relationships between the DOT, contractors, and other stakeholders should be established in advance of a disaster. Second, let the DOT and contractor work together to solve problems. Third, rapid contracting can allow damaged roads to re-open quickly. In the case of flooding in Iowa, the contractor was offered incentives to hasten the pace of reconstruction.

Questions that came out of the conference included whether planners should be looking at broad approaches to enhancing resilience or specific solutions for acute problems. Do planners need a new design method, or should they adopt practices from neighboring DOT's?

The conference identified the following research gaps:

- Guidance:
 - Development of action plans–best practices;
 - Delivery method; and
 - Policies for DOT rapid response.
- Temporary materials–tools for enhanced protection;
- Designing for failure and rapid rebuilding;
- Groundwater intrusion due to SLR;
- Future temperature–climate models; and
- Climate model integration into pavement models.

Future implementation needs include:

- Educational tools;
- Use of maintenance cycles to build in resilience;
- Downscaling and the use of climate model data for pavement design and binder selection;
- Examining specific implementation modes such as pavement management systems; and
- Funding. DOTs need funding to build in resilience into the system and a need to combine emergency repairs with resilient rebuilding.

The conference addressed specific questions concerning asphalt. Asphalt pavements have been proven to be resilient in that they can be reconstructed rapidly, and design considerations can be made with respect to temperature and climate. However, what about using porous asphalts. How far should a DOT go in beefing up structures to withstand hazards? How will potential moisture due to ground water rise be managed? Finally, if resilience is built into maintenance schedules (overlay without milling), how is it ensured that future cracking will not be induced?

Presentation Questions and Discussion

- Q. Do we need to add scenario analysis to these pavement workshops? For example, if we just assume that we should harden a road, what if an extreme event occurs and the hardened road fails? Now, we just have a more expensive repair to do.
- A. We did not run scenarios in the workshops. However, the goal should be in the future to run a number of strategies, such as harden versus gradual fill.

A POST-DISASTER DECISION FRAMEWORK FOR SELECTION OF BRIDGE REHABILITATION FOR DISRUPTED TRANSPORTATION NETWORKS

ERIC MERSCHMAN

MERHNAZ DOUSTMOHAMMADI

ABDULLAHI SALMAN

MICHAEL ANDERSON

University of Alabama

Background

During and immediately after a natural disaster, there is a large amount of chaos especially when no protocol is established. This lack of organization can lead to major inefficiencies in critical decision-making timeframes directly after a natural disaster. A poor repair plan can result in wildly different resilience curves costing taxpayers significantly over the restoration period. This study lays the groundwork to develop numerical methods for streamlining decision-making for DOTs to implement when evaluating a disrupted network. This study proposed the following question: can a travel demand model and a value model be used with multiple decision-making attributes to assist in evaluating a repair sequencing problem?

Innovations

The methodology proposed two replacement scenarios: (1) equal bridge repair times; and (2) different bridge repair times. Assumptions of the methodology included:

- Only one bridge can be repaired at a time;
- All destinations are constant and drivers will not cancel trips; and
- Cost is not one of the constraints. All bridges will be repaired.

The case study location was Mobile, Alabama. The scenario involved a hurricane impacting four bridges that span Dog River as described here:

Location	AADT
McVay Drive	13,000
Interstate 10	80,000
Alabama Highway 193	20,000
Alabama Highway 163	4,000

Travel time on impacted bridges was set to 9,999 min. Commercial vehicles and passenger cars were assigned independent trip tables. Commercial vehicles were given initial preference.

Delay is calculated as a function of the ratio of volume to capacity. The model ran 16 different scenarios. For each scenario a combination of one or more bridges was removed from the road network and two bridge repair scenarios were tested:

1. All bridges take the same time to repair: 60 days.
2. Different bridge repair times:
 - a. Bridge 1: 120 days;
 - b. Bridge 2: 60 days;
 - c. Bridge 3: 40 days; and
 - d. Bridge 4: 20 days.

Figure 62 shows the most economical repair schedule (orange) when using the same repair time schedule:

Similarly, Figure 63 shows the most economical repair schedule (orange) when using different repair times.

A proposed modification of the framework involves using value-based modeling to evaluate an optimal sequencing of repairs for multiple bridges due to a disruption. Value-based modeling involves multiple decision-making attributes to assist decision makers in evaluating the sequencing problem. The three proposed measures are (1) functional; (2) topological; and, (3) social. Figure 64 shows how the performance curve changes depending on the bridge repair sequence. In this case, repair sequence 14 is 2-1-4-3 and all the bridges are repaired at the same time.

Repair Schedule	Total Delay Costs In Million Dollars	Repair Schedule	Total Delay Costs In Million Dollars
1-2-3-4	40.92	3-1-2-4	54.54
1-2-4-3	41.54	3-1-4-2	64.93
1-3-2-4	55.76	3-2-1-4	37.68
1-3-4-2	66.26	3-2-4-1	37.66
1-4-2-3	51.14	3-4-1-2	58.83
1-4-3-2	61.02	3-4-2-1	48.31
2-1-3-4	25.22	4-1-3-2	55.66
2-1-4-3	25.84	4-1-2-3	45.78
2-3-1-4	23.30	4-3-1-2	54.79
2-3-4-1	23.39	4-3-2-1	44.28
2-4-1-3	24.58	4-2-1-3	34.91
2-4-3-1	23.94	4-2-3-1	34.28

FIGURE 62 Cost comparison—same repair time. (Source: University of Alabama)

Repair Schedule	Total Delay Costs In Million Dollars	Repair Schedule	Total Delay Costs In Million Dollars
1-2-3-4	59.23	3-1-2-4	65.04
1-2-4-3	59.89	3-1-4-2	64.14
1-3-2-4	68.67	3-2-1-4	31.66
1-3-4-2	67.83	3-2-4-1	31.07
1-4-2-3	57.8	3-4-1-2	41.32
1-4-3-2	63.94	3-4-2-1	31.64
2-1-3-4	27.05	4-1-3-2	51.92
2-1-4-3	26.72	4-1-2-3	45.79
2-3-1-4	22.78	4-3-1-2	48.76
2-3-4-1	22.19	4-3-2-1	27.25
2-4-1-3	23.62	4-2-1-3	22.99
2-4-3-1	21.87	4-2-3-1	21.23

FIGURE 63 Cost comparison—different times. (Source: University of Alabama)

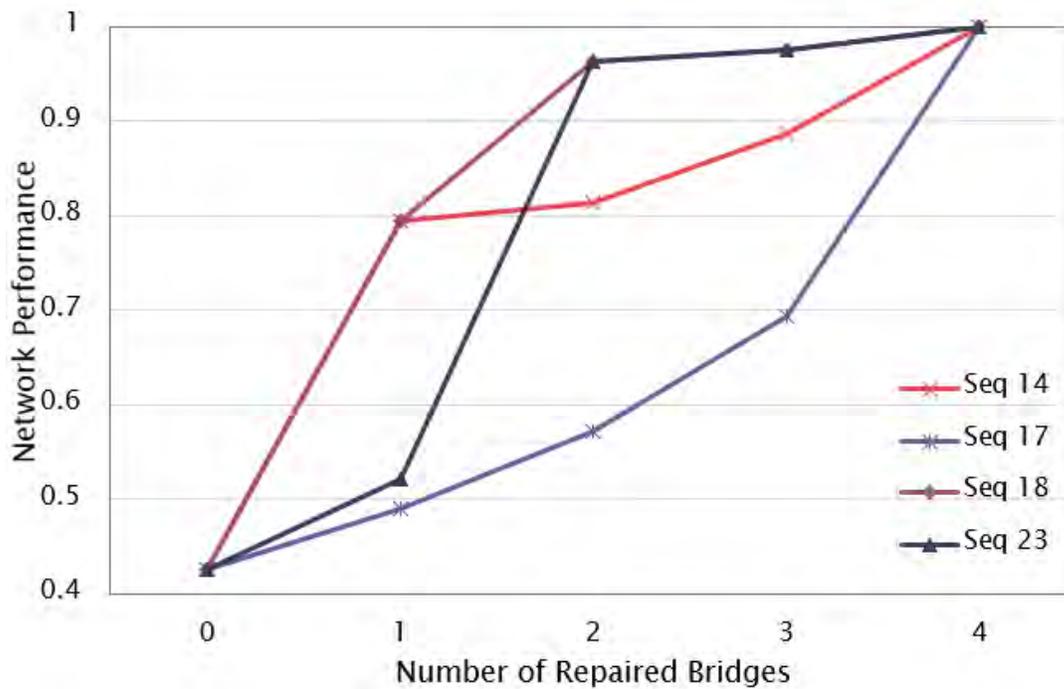


FIGURE 64 Performance curve. (Source: University of Alabama)

Contribution

Using travel demand modeling with the multiple attribute value approach shows that sequencing can have a significant impact on resilience after a natural disaster. What metrics are chosen has a large impact on how resilience is measured. An appropriate balance of metrics can lead to large increases in resilience while controlling the computational requirements. A large number of concurrent bridge (n) outages will increase the computational effort, but the probability of such an occurrence is low. Finally, a separate method will need to be developed when n is large.

Presentation Questions and Discussion

Q. Can you show me bridge number 2 to see what the traffic was?

A. Bridge number 2 was the Interstate bridge. It needed to be fixed first because of the high traffic volume. However, in other cases, a bridge could be prioritized because it is the only path that travelers can take where there are no other alternatives.

Q. What did Alabama do with your model? Was it incorporated into emergency response plans?

A. No. They studied the methodology to get an idea of how to do the analysis.

Q. Are there plans to do this for other cities, like Washington, D.C.?

A. Yes. There was a plan to do it for Jacksonville, Florida.

ROAD RESILIENCE AT THE WORLD ROAD ASSOCIATION

JURGEN KRIEGER

Federal Highway Research Institute

Background

The World Road Association (also known as PIARC) is a nonprofit established in 1909 as the Permanent International Association of Road Congresses. The PIARC authors develop best practices, provides service to low- to medium-income countries, and develop decision-making tools for matters concerning roads.

Innovations

PIARC has published many publications from the Strategic Plan 2016–2019 work cycle around five strategic themes:

- Strategic Theme A: Management and Finance;
- Strategic Theme B: Access and Mobility;
- Strategic Theme C: Safety;
- Strategic Theme D: Infrastructure; and
- Strategic Theme E: Climate Change, Environment and Disasters.

Strategic Theme E covers adaptation strategies for climate change. Issue E.1.1 investigates the state-of-the practice, current adaptation strategies for increasing the resilience of roads. The output is case studies. Under Strategic Theme E there are three technical committees. TC E.1 addresses adaptation strategies and resiliency, TC E.2 addresses environmental considerations in road projects and operations, and TC E.3 addresses disaster management.

The publication, *International Climate Change Framework for Adaptation for Roadways*, includes tables with qualitative descriptions of risk probabilities and severities. In addition, it describes adaptation strategies for a variety of climate change impacts.

Contribution

PIARC's publications from the Strategic Plan 2016–2019 work cycle elevates the treatment of climate change and environmental issues to the strategic theme level. Strategic Theme E gives guidance to road administrations on climate change adaptation to increase resiliency.

Post-Disaster Lessons Learned

Focus-Point Session

ANNE CHOATE
ICF, Moderator

Field perspectives from post-disaster recovery such as hurricanes in New Orleans (Katrina), New York (Sandy), Houston (Harvey), and Puerto Rico (Maria), including representatives from local and state agencies involved in specific locations.

Their comments are below:

HERBY G. LISSADE
Caltrans

California is prone to wildfires, earthquakes, flooding, draught, and many other disasters. Recently, this is visible in the severity of disasters in wildfires. November 8, 2018, a campfire in Paradise Park started a huge wildfire that last until November 25, 2018. Eighty-five people died; 153,000 acres burned; and 18,000 buildings destroyed.

To date, 8,043 Individual assistance applications have been approved and over \$97 million has been provided in grant dollars.

Some lessons learned: be aware of where your agency fits into other agency’s emergency response plans. Other noted recommendations are captured in Figure 65.

Communications and Coordination	Plans	Human Factor
<ul style="list-style-type: none"> ▪ Safety first ▪ Open lines of communication at all levels of government ▪ Coordinate resources ▪ Know where your staff are at ▪ Local communities have different levels of readiness 	<ul style="list-style-type: none"> ▪ EOP's and COOP ▪ Fuel ▪ Emergency communications ▪ Training ▪ Prepositioning of resources ▪ Short and long term recovery ▪ Document and photograph ▪ "The New Norm" 	<ul style="list-style-type: none"> ▪ What people will do during emergencies ▪ Engage law enforcement ▪ Don't assume ▪ Not all leaders have disaster experience ▪ Be engaged

FIGURE 65 Recommendations from post-disaster events. (Source: Caltrans)

JANE BROGAN

New York Governor's Office of Storm Recovery

Super Storm Sandy made landfall on October 29, 2012, damaging or destroying 300,000 housing units. Over 2 million utility customers lost power and over 2,000 mi of roadway were damaged or interrupted. The storm had a lasting effect on businesses and transit systems with major and long-lasting disruption to operations.

Recovery includes assistance from a \$4.6 billion Housing and Urban Development (HUD) grant focused on five primary program areas including housing, small businesses, community reconstruction, infrastructure, and rebuild by design.

Figure 66 presents the disaster response timeline to help others understand the time necessary to recover from large events.

Other lessons learned include plan for vulnerabilities and risks. Recognize the potential of events driven by SLR or climate change or extreme weather events now before the event occurs.

If an event should occur, work to build back better to be more resilient in the future. Recovery programs need to be more flexible to meet needs as well as comply with regulations.

The recovery process can be long, complex, and confusing when multiple government agencies are involved. Be prepared to set a reasonable pace of recovery recognizing funding constraints and timing and communicate frequently with all stakeholders.



FIGURE 66 Disaster response timeline.
(Source: State of New York, Office of Storm Recovery)

DREW RATCLIFF

Capital Region Planning Commission, Louisiana

August 11–16, 2016, a slow-moving unnamed storm settled over Louisiana with unprecedented rain amounts that led to 500-year flood events. Every railroad was closed in the area and portions of I-10 and I-12 were also closed. In addition, portions of the Red and Ouachita Rivers had extended closures limiting waterborne travel. The complications in freight movement led to the recognition of the Louisiana Supply Chain Transportation Council by the state to help prioritize investments and policies to reduce the risk of such impacts in the future. Key takeaways are captured in Figure 67.

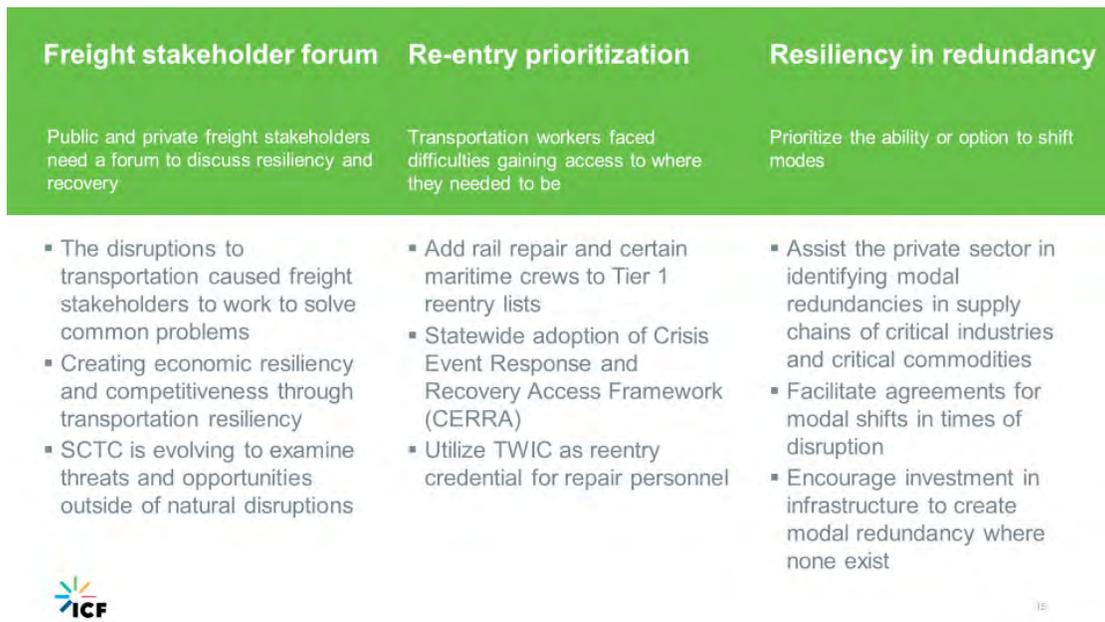


FIGURE 67 Key post-disaster takeaways. (Source: Capital Region Planning Commission)

SESSION QUESTIONS AND DISCUSSION

Q. What would be your single piece of advice to facilitate recovery?

A. Agencies need to build resiliency into design now.

It would also help to have a centralized office for resilience, which would facilitate coordination with stakeholders.

The development of a Resiliency Framework, with the help of experts drafted by FEMA.

Communication is key and have operational plans ready and understand what your agency’s role may be in other entities recovery plan

Q. How can DOT agencies access FEMA resources?

A. Agencies can look for grant opportunities. At this point, large-scale recoveries are not viable as the federal government wants to front end agency resiliency. In addition, agencies can

have B/C analyses completed for proposed projects. Coordination with locals who might have better luck with FEMA grants is another option.

Q. Who are the key players to coordinate with ahead of time?

A. Utilities are a major key player, it also helps to understand who all the players are ahead of disasters.

Q. When working with community in recovery or for resilience planning – how do you deal with a range of capabilities of local agencies?

A. Work with their hazard mitigation plans and try to support them and look for funding opportunities

We are trying to work at the watershed area level to assist local agencies

Q. Would renewable energy sources be helpful when power grid shuts down?

A. We have solar energy sources on some maintenance.

There is a white paper being developed on the topic but it can't solve the problem now.

Q. Our state legislature (Washington State) requested a working group to determine if the state needs a resiliency office. In your experience, how durable are these entities?

A. Florida just established one.

In Louisiana we have a 2-year funding stream established recently

There appears to be a need, but problem is long-term funding.

Q. You spoke about fires, what can you offer to address managed retreat?

A. We have a managed retreat program to restore wetlands that is all voluntary. Our lesson learned would be to establish a land bank as homes come available, buy them (New York).

Q. How do you draw in information/data?

A. Much of ours comes from FEMA CAT Teams.

Science and Data Update

Focus-Point Session

JEFFREY ARNOLD

U.S. Army Corps of Engineers, Moderator

This panel session provides discussion of the current and planned immediate future for climate science and observational data which can be used for transportation resilience planning and operations. Panel members include both data and modeling scientists as well as transportation practitioners who presented short descriptions of relevant new science products and transportation applications and answered questions from each other and the audience.

COMMENTS

ANA BUCHER

World Bank

Bucher noted that the challenge the World Bank is facing when addressing adaptation to climate change lies in project development and communicating this concept to different countries with varying levels of experience, data, and resources. The process of bringing science and data into operations has been lengthy. The World Bank learned from their member countries that they have specific needs in the data collection and analysis before applying research into policy making and practice. For the past 2 years, the World Bank has been developing a portal for data collection and dissemination. In order to do so, the staff have been working with different sectors to find out what are essential parameters for the portal. So, it has been a bottom-up approach with the parameter's development, and they go back to the member countries to start matching their needs with the data providers. The main lesson learned is that information at user levels requires a systems approach. There is a need to do a detailed analysis with consultants and engineers in order to understand such data requirements as flooding thresholds and the frequency of flooding events. The process has been unveiling downscaled data and gaps in the parameters that will help the World Bank in developing the portal.

Bucher noted the systems approach is about decision-making under uncertainty. Downscaled data doesn't necessarily give more useful information to plan better. It is necessary to struggle to determine what is needed at the user level. An example County "X" in Africa is considering investing in a new state-of-the-art road but using a systems approach with the portal may provide data showing a more affordable option and need for making its secondary roads resilient by providing flexibility in routing and rerouting. As the climate changes, the World Bank wants to integrate state-of-the-art Earth observations with its models and data tools to develop metrics and measure for the effectiveness of adaptation.

STACEY ARCHFIELD*United States Geological Survey*

Archfield talked about changes in hydrology and flood frequency. The USGS has a leadership role in determining flood frequencies estimates. Unlike other drivers like precipitation and temperature, where the signal is very strong to indicate that there is one direction, always increasing, the changes in flood frequency across the nation is more complex. The USGS sees a mix of increases and decreases. One hypothesis is there hasn't been a steady pattern of change in flood frequency. The guidance that USGS uses stresses the need to look for change, attribute that change to a driver then use that information to adjust. Otherwise, stationarity is the default assumption that is used. Archfield said that the way the USGS is using this information in cooperation with the FHWA to detect changes in flooding across the United States is not just in annual duration series, but also in partial duration series which allows for more than one flooding event to occur in any given year. They are also looking at changes to the largest floods. Through this research, they have now provided datasets for all those flood parameters through the USGS data portal. Now they are working on places where there have been statistically significant changes in floods in the United States, attributing causes to those floods using local knowledge, and tapping the nationwide network of hydrologic expertise. Is it a dam? Is it climate change? Is it land use change? Is it precipitation? That is the supplementary dataset the USGS will be developing in the next calendar year, 2020. Each gauge will have an attribution applied to it. The last piece of this project is tools for adjusting to change. One of their focuses is regression-based tools because that is one of the most commonly used.

STEVE OLMSTED*Arizona Department of Transportation*

Olmsted noted that they are fortunate in Arizona because they have been able to chip away not just at extreme weather but also had some space to engage in the climate change discussion for almost 8 years now. Arizona DOT has been fortunate to get leadership to rotate toward life-cycle analysis and asset management. The reality of life-cycle analysis and asset management created a great entry point for his interests and the agency's interests in blending science with engineering and technology with the goal of driving science-based decision-making. Arizona DOT also had a real desire to expand the knowledge base with environmental, resilience, and sustainability within a traditional entity such as Arizona DOT. Olmsted noted he has been asked "how do you advance this in a DOT setting?" His answer is that he tries to get one action item done per week. For an example of what Arizona DOT has accomplished, they did a FHWA Climate Change Vulnerability Pilot in 2014. In addition, they studied I-15, 322 centerline miles, from Mexico to Utah. Arizona DOT also used historical data up to 1999 to project into the future, out to 2049 and 2099, using historical data from 1950 to 1999 as a baseline. Another example, the Arizona Water Science Center from the USGS made a tremendous undertaking in customizing data collection tools with the focus of reinventing flooding reach-scale monitoring. The USGS and the Arizona Water Science Center has just finished building a cloud-based site for everything they have collected for Arizona that DOT engineers can consult. Arizona DOT has many ungauged reaches. They are now installing cigar-sized, wifi-connected sensors in cross-sections to monitor runoff in key locations for water crossing that are connected to bridge projects that are in our 5-year construction program. Last, FHWA has asked Arizona to host the national western states peer exchange. Olmsted noted that Arizona DOT is going to bring in all the USGS data chiefs.

ROUNDTABLE DISCUSSION

Archfield: Opening communication, understanding end users of data, and how support their needs are ways to continue to evolve the product. USGS couldn't foresee all the ways its data would be used. We need that feedback loop. We also need to make people aware of the data repositories that are already available.

Bucher: It's about trying to build this repository of information, and it's about the guidance, not just putting this information out there and making it accessible, but also targeting how the data can and cannot be used. It is necessary to try to learn what the USGS is doing and other institutions to see if it can be replicated and prioritized because it is not always possible to do the level of analysis that is required. What are the other options? We can use the systems approach to understand where we should enhance data access, capacity building, and guidance.

Olmsted: One of the things that has to change is an agency's comfort level with the available resources. There has to be an acceptable level of peer review, adoptability, and quality. During project scoping meetings there must be a level of trust in data selected to be used, whether it is from FEMA, USACE, or USGS.

Arnold: What is interesting is this focus on a systems approach. The last 10 years have been spent trying to understand what can be done in both current climate and in projections for the future climate. A lot of sensitivity testing is done to see how robust decision-making structures are against scenarios constructed for the future. But now it is necessary to integrate that testing into a large question of what else is going on inside the watershed, the watershed which has a road or multiple roads. My question for the group is: What is the appetite in your organizations for this systems approach?

Archfield: It is necessary to look at factors besides the climate. We have begun to isolate the effects of such things as urbanization. A more holistic picture of the watershed is needed and not just a narrow view of flood frequency, for which there is not the capacity to do that right now because the focus has been on attribution or historical changes.

Bucher: It is necessary to think about what are called "stranded assets" and how areas will be developed 10, 30, and 50 years from now. If people don't think in systems terms, they will not get a better ROI and the economics won't make sense in terms of investment. What is needed are improved data sets and data that are freely accessible for agriculture planning, urban planning, development planning, and transfer planning. Using a value chain approach to climate services, how can the impacts be understood in one component? It makes sense to build a cloud-based resource of information that is not only going to be for transportation but also agriculture and other applications.

Olmstead: Going back to the original question, yes, there is an appetite for this data. Arizona DOT's original foray in getting those types of data with its 2014 vulnerability assessment produced what it produced. The vulnerability assessment (provided) how many days under freezing, how many days over 100°F, how many days over 110°F. With precipitation, Arizona DOT looked at the 100- and 200-year storm and the assessment produced data that could be

mapped by region. Arizona DOT's first effort was just exploring those types of data sets. Six years later Arizona DOT is still seeking information on climate change and wants to use the new FEMA CMIP5 tool with the LOCA data capability.

SESSION QUESTIONS AND DISCUSSION

Q. Is there any value in comparing these methods—your regression-informed method versus a climate model, rainfall–runoff kind of method?

A. **Archfield:** Regression equations are based on historical data, they are based on statistics. It could be extreme precipitation or mean precipitation. Then that is related to a discharge statistic. That exists, first of all, for only some part of the country that have regression equations where precipitation data is a statistically significant variable. Where precipitation is not a statistically significant variable you are at a disadvantage if you are trying to force climate data in a certain way to get a discharge. In places where you do have precipitation that is statistically significant, there is a coefficient associated with that number that tells you the ratio between precipitation and discharge. Is it one-to-one? Is it two-to-one? We don't know that relationship outside the data that was used to create it. So, we don't know if that relationship will change in the future. That's when you get into uncertain ground when you try to extrapolate precipitation beyond the data for which the equation was developed. There are variances of regression equations with a moving window where you try to understand where you might weight more recent information than past information. One of the things we hope to learn is the limits of the applicability of these regression equations.

Arnold: The worst thing you can do is to treat projections of future climate as observations from the future. Understanding the limitations of those projections and how you can use them is important. Climate scientists don't run GCMs to serve us. They are interested in understanding what's going on with the climate. People must do a better job of explaining the limitations of climate model data outputs.

Bucher: What of the challenges we have is which GCMs should be used? The reality is a lot of the GCMs don't work well for the areas people work; and if all models are averaged, an event may happen that would never really happen.

Closing Plenary and Summary

CAROL LEE ROALKVAM

Washington State Department of Transportation, Facilitator

During the closing plenary session and working lunch attendees were asked to collaborate with their table partners to discuss ideas they learned from the conference that were new or challenging. Also, they were asked to identify any inspirational moments of the conference. Finally, participants were asked to identify any research or policy needs to implement improvements of resilience efforts in transportation.

Three general themes emerged from the discussions including:

- The need for better methods and tools to model the impacts of climate change and resilience.
- The need for methods to help agencies prioritize and fund resilience investments.
- The need for better communication tools to better explain decisions related to resilience and climate change.

Presentations and discussions over the course of the conference revealed a pent-up desire and need for more definitive, established means of modeling transportation resilience from a range of threats including sunny day flooding, geohazards, flooding, extreme temperatures, and more. Engineers and planners are also seeking methods to incorporate climate change models and predictions in their risk assessment models to better understand the potential impacts to transportation assets and service. As each of the two previous conferences focused on resilience have evolved (2016 and 2018), more ideas of how to model risk from external threats and stressors have begun to be developed, but with limited use and critique. Agencies want to be more responsive and more resilient, however, they lack the models, methods, and metrics to normalize the incorporation of risk and resilience into their everyday decision-making. Also, quantitative methods allow for B/C analyses of resilient solutions which many participants noted is lacking. Many agencies are attempting to pursue this work on their own, however, the industry as a whole would benefit from a central repository of methods, models, and established metrics to allow for ease of use. Specific points raised by the participants of the lunch discussion related to the need for better methods and tools to model resilience and the impacts of climate change included:

- Models that consider land use planning so future mistakes are avoided;
- Groundtruthing of models, including geohazard models;
- Resilience models that account for uncertainty, for example, it was noted that 90% of rainfall uncertainty is captured in existing models;
- Models to support B/C and economic assessment to demonstrate good resilient investment;
- Models to address sunny day and ground water flooding; and
- Models to capture behavioral changes in travel when failures occur from events.

A complement to the desire for methods, models, and metrics, is a desire to provide agencies direction as to how to prioritize investments to improve resilience and avenues to pursue funding to address resilience. The opening session of this conference provided some insight into potential legislation with the next U.S. transportation act through the PROTECT Grant Program. Without a dedicated avenue of funding and methods to help balance resilience projects against safety, operations, infrastructure health, and mobility needs, agencies with already constrained budgets will be left with little choice but to wait for failure to address needed resilience investments. Specific suggestions made by participants included:

- More time in future conferences should be dedicated to helping agencies understand how to prioritize and fund resilience projects;
- Additional guidance is requested to develop a framework agencies can use to incorporate resilience and sustainability;
- More information is requested on how to fund resilience work and how to engage staff in resilience efforts;
- Requests were made regarding how NOAA funding could be obtained to help agencies with modeling of events; and
- More information was requested to help agencies with contract language to address resilience.

One participant remarked that there are advantages from collaboration from scientific and engineering organizations. Also, as was noted in the speech by Alice Hill, the public is well aware of their “no more” moments” and agencies need guidance on communicating to the public about what efforts are being taken to reduce catastrophic failures and nuisance closures brought on by extreme weather and climate change. Another participant thought that the public does not understand or care that roadways are owned by different agencies, they just want to know that their service will not be disrupted and that efforts are being made to coordinate efforts to maintain service and address extreme weather and climate change impacts to infrastructure. Specific requests made by participants of the lunch discussion included:

- More information on how to engage the public, communities, and local governments in resilience planning and investment decision-making, and
- Additional methods on how to best communicate resilience needs to the public.

Finally, it was noted by many of the participants that the quality of research and presentations is increasing with each resilience and transportation conference and there is a desire to have additional conferences in the near future.

APPENDIX

Conference Program



2nd International Conference on
Resilience to Natural Hazards and Extreme Weather Events

Transportation Resilience 2019

NOVEMBER 13–15, 2019
NAS Building, Washington, DC

Hosted by
Transportation Research Board

With support from
Federal Highway Administration

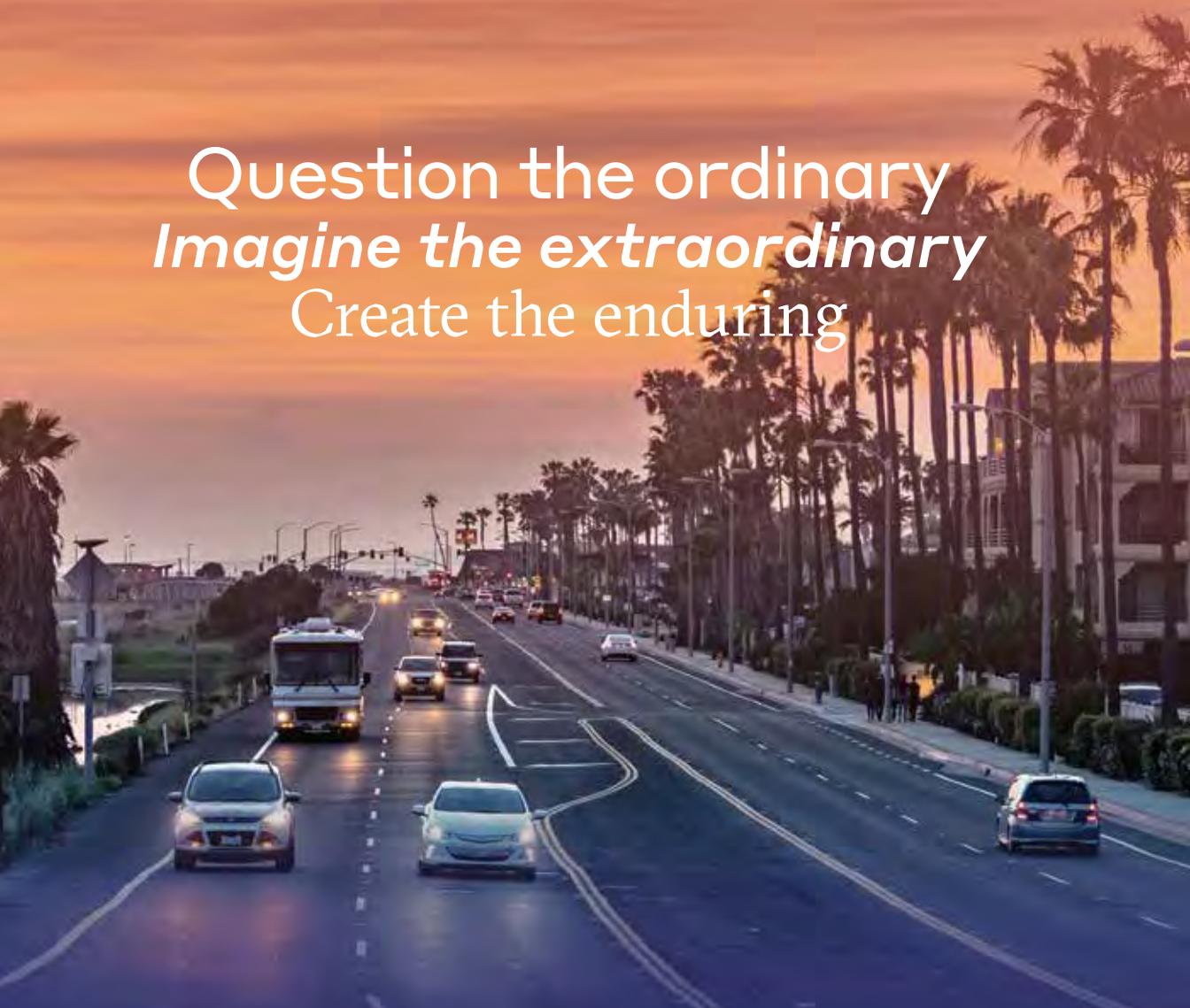
Organized by
Special Task Force on Climate Change
(A0020T)

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WELCOME LETTER

TR2019

We are delighted to welcome all of you to the National Academies of Sciences Building for the Transportation Resilience 2019 (TR2019) conference. TRB, a division of the National Academies of Science, Engineering, and Medicine, has organized this conference with support from the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO). The conference aims to focus on proactive, transformative, and recovery practices making our transportation networks and systems resilient to extreme weather events and other nature hazards.

This international conference, entitled Transportation Resilience 2019, is the 2nd International Conference on Transportation System Resilience to Natural Hazards and Extreme Weather Events. This conference will provide transportation professionals with information on emerging best practices and state of the art research results on how to adapt surface transportation networks to the potential impacts of natural disasters and extreme weather events. The conference will examine efforts to integrate resilience in all aspects of the transportation sector, including planning and programming, capital improvements, and operations and maintenance. The conference will promote international dialogue on research, implementation, and lessons learned on this important topic, with benefits that are expected to extend beyond the transportation sector.

This conference builds on the successes of the first conference held in 2015 and the *2018 Transportation Resilience Innovations Summit and Exchange (Transportation RISE)*. As attendees and presenters, your contribution will help make this conference a success. This is going to be an incredible forum for an exchange of ideas and learning more about the latest thinking on transportation resiliency.

We hope you find the conference motivating, enlightening, and enjoyable.

Welcome to Washington, D.C.

Michael Culp,
Federal Highway
Administration,
Co-Chair, TRB Planning
Committee

Carol Lee G. Roalkvam,
Washington State Department
of Transportation
Co-Chair, TRB Planning
Committee

Kees van Muiswinkel,
Rijkswaterstaat,
The Netherlands
Co-Chair, TRB Planning
Committee

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Kees van Muiswinkel, Ministry of Infrastructure and Water Management, Rijkswaterstaat, Co-chair

Carol Lee Roalkvam, Washington State Department of Transportation, Co-chair

Mark Abkowitz, Vanderbilt University

Jeff Arnold, U.S. Army Corps of Engineers

Vicki Arroyo, Georgetown Climate Center

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Tom Jacobs, Mid-America Regional Council (MARC)

Robert Kafalenos, Federal Highway Administration

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Constantine (Costa) Samaras, Carnegie Mellon University

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SCHEDULE AT A GLANCE

WEDNESDAY, NOVEMBER 13		
TIME	EVENT	ROOM
7:00 AM	Registration Opens	Great Hall
7:00 AM	Continental Breakfast and Coffee	West Court
8:30 AM	Opening Plenary—Welcome Remarks (PS01)	Kavli Auditorium
9:00 AM	Plenary Session: Prioritizing Resilience at State DOTs—Progress and Challenges (PS02)	Kavli Auditorium
10:00 AM	Transition Break—15 minutes	
10:15 AM	Technical Sessions—Period One Integrating Transportation Resilience into Asset Management (TS001) Regional and Multi-Sectoral Approaches to Resilience (TS002) Bridges and Culverts (TS003)	NAS 120 NAS125 Member Room
11:45 AM	Lunch	
12:45 PM	Focus-Point Session: State of Play of Proactive Adaptation (FPS01)	Kavli Auditorium
1:20 PM	Transition Break—10 minutes	
1:30 PM	Technical Sessions—Period Two Frameworks and Methods to Address Coastal Resilience—Part A (TS004) Transforming Design for Resilience—Part A (TS005) Approaches to Addressing Multiple Hazards within a Larger Multimodal Program (TS006)	NAS 120 NAS125 Member Room
3:00 PM	Networking Break—30 minutes	
3:30 PM	Technical Sessions—Period Three Integrating Resilience in Transportation Planning—Part A (TS008) Transforming Design for Resilience—Part B (TS009) Projections and Downscaling—Part A (TS010) Innovative Collaboration for Resilience to Extreme Weather Events (TS011)	NAS 120 NAS125 Member Room Board Room
4:00 PM	Registration Closes	Great Hall
5:00 PM	Poster Session and Networking Reception	Great Hall

THURSDAY, NOVEMBER 14		
TIME	EVENT	ROOM
7:00 AM	Registration Opens	Great Hall
7:00 AM	Continental Breakfast and Coffee	West Court
8:00 AM	Technical Sessions—Period Four Economic Analysis to Support Resilience—Part A (TS012) Nature-Based Solutions for Coastal Highway Resilience (TS013) Geotechnical Aspects in Transportation Resilience (TS014) Causality and Surrogates: Bridge Vulnerability and Resilienc (TS015)	NAS 120 NAS125 Member Room Board Room
9:30 AM	Plenary Session: Leading the Way to Great Resilience: Policy-Makers Talk About the Future (PS03)	Kavli Auditorium
10:30 AM	Transition Break—15 minutes	

SCHEDULE AT A GLANCE, *continued*

THURSDAY, NOVEMBER 14, <i>continued</i>		
TIME	EVENT	ROOM
10:45 AM	Technical Sessions—Period Five Economic Analysis to Support Resilience—Part B (TS016) Pavements Resilience (TS017) Tools and Methods (TS018) Assessing Coastal Impacts to Nuisance Flooding and Sea Level Rise—Part B (TS019)	NAS 120 NAS125 Member Room Board Room
2:00 PM	Managed Retreat (Part A)—Is It Even an Option? (TS020)	NAS 120
12:15 PM	Lunch	
1:15 PM	Focus-Point Session: Managed Retreat—When, Whether and How? (FPS02)	Kavli Auditorium
1:50 PM	Transition Break—10 minutes	
2:00 PM	Technical Sessions—Period Six Sharable Lessons from Natural Disasters (TS021) Communications and Making the Business Case for Resilience (TS022) Approaches to Addressing Multiple Hazards within a Large Modal Project (TS023)	NAS125 Member Room Board Room
3:30 PM	Networking Break—30 minutes	
4:00 PM	Technical Sessions—Period Seven Integrating Resilience in Transportation Planning - Part B (TS024) Resilience Initiative for National Transportation Systems (TS025) Projections & Downscaling —Part B (TS026) Managed Retreat and Infrastructure Decision Making (Part B)—How Are the Hard Decisions Made? (TS027)	NAS 120 NAS125 Member Room Board Room
5:00 PM	Registration Closes	Great Hall
5:30 PM	Committee Meetings: TRB Special Task Force on Climate Change (A0020T) AASHTO Committee Meeting on Transportation Systems Security and Resilience	NAS 120 Board Room

FRIDAY, NOVEMBER 15		
TIME	EVENT	ROOM
7:00 AM	Registration Opens	Great Hall
7:00 AM	Continental Breakfast and Coffee	West Court
8:30 AM	Technical Sessions—Period Four Technical Solutions for Resilience (TS028) Cascading Events (TS029) Advancing Resilience at National, State, Regional and Local Levels (TS030) Recovery for More Resilient Roads (TS031)	NAS 120 NAS125 Member Room Board Room
10:00 AM	Transition Break—15 minutes	
10:15 AM	Focus-Point Session: Lessons Learned from Post-Disaster Response (FPS03)	Kavli Auditorium
11:15 AM	Focus-Point Session: Science and Data Update (FPS04)	Kavli Auditorium
12:15 PM	Closing Plenary and Working Lunch: Collecting Your Thoughts	West Court
1:45 PM	Conference Concludes	
2:00 PM	Committee Meetings: Standing Committee on Critical Infrastructure Protection (ABR10) Standing Committee on Emergency Evacuation (ABR30)	NAS 120 Board Room

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COMMITTEE MEETINGS

THURSDAY, NOVEMBER 14, 2019

5:30 PM–7:00 PM, *NAS 120*

TRB Special Task Force on Climate Change (A0020T)

5:30 PM–7:00 PM, *Board Room*

AASHTO Committee on Transportation Systems Security and Resilience

FRIDAY, NOVEMBER 15, 2019

2:00 PM–3:00 PM, *NAS 120*

Standing Committee on Critical Transportation Infrastructure Protection (ABR10)

2:00 PM–3:00 PM, *Board Room*

Standing Committee on Emergency Evacuation (ABR30)

WEBCAST AND RECORDING STATEMENT—CROWD RELEASE

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DAILY GEOSCIENCE DEMONSTRATION: STREAM TABLE

Provided daily by FHWA:

West Court

Whether confronted with acute flood damages or chronic river uncertainty, understanding the scale and type of instability is essential for long-term transportation management. This small scale stream demonstration will provide an opportunity to see river geomorphic processes in action. Attendees will gain a hands-on knowledge of morphologic response of rivers to practices like channel straightening, culvert removal, or bedload mining. A greater knowledge of river stability could result in reduced flood-related road damage costs and increased river and road stability.

CONFERENCE PROGRAM

WEDNESDAY, NOVEMBER 13, 2019

7:00 AM–4:00 PM, *Great Hall*

Registration Open

7:30 AM–8:30 AM, *West Court*

Continental Breakfast and Coffee

8:30 AM–9:00 AM, *Kavli Auditorium*

OPENING PLENARY

Opening and Welcome Remarks (PS01)

Kicking-off the conference with an overview of the program given by the leadership of the TR2019 Planning Committee:

Carol Lee Roalkvam, Washington State Department of Transportation;
Michael Culp, Federal Highway Administration (FHWA); and
Kees van Muiswinkel, Rijkswaterstaat—Ministry of Infrastructure and Water Management

Following, welcome remarks will be offered by the three convening organizations: Neil Pedersen, Transportation Research Board; Thomas Everett, U.S. Department of Transportation, Federal Highway Administration (FHWA); and Jim Tymon, American Association of State Highway Transportation Officials (AASHTO).

Moderator: Carol Lee Roalkvam, Washington State Department of Transportation
Environmental Services Office

9:00 AM–10:00 AM, *Kavli Auditorium*

PLENARY SESSION

Prioritizing Resilience at State Departments of Transportation— Progress and Challenges (PS02)

State Departments of Transportation face threats to their statewide systems on a daily basis. Whether nature- or man-made, disasters can close critical facilities on a moment's notice, disrupting the economic vitality and quality of life of communities. In this session, we'll hear from state departments of transportation leaders about their progress and challenges in becoming more resilient agencies; in their organizational approach and through all phases of infrastructure development and operations.

Moderator: Paula J Hammond, WSP Inc.

Edwin Sniffen, Hawaii Department of Transportation
Greg Slater, Maryland State Highway Administration
Ellen Greenberg, California Department of Transportation
Mike Russo, New Jersey Department of Transportation

10:00 AM–10:15 AM

Transition Break

10:15 AM–11:45 AM, NAS 120

Integrating Transportation Resilience into Asset Management (TS001)

This session explores approaches to address the impact of current and future environmental conditions on transportation assets or highway networks. These approaches, whether focused on an entire network, a corridor, or a specific group of assets, provide a better understanding as to how to appropriately plan, design, manage, and make infrastructure investments to increase system resilience.

Moderator: Nastaran Saadatmand, Federal Highway Administration

Integrating Extreme Weather Risks into Transportation Asset Management Plans and Practices

Robert Kafalenos, Federal Highway Administration

Prioritizing Infrastructure Resilience throughout the Transportation Capital Planning Process

Jon Carnegie, Rutgers University, Voorhees Transportation Center

Southeast Michigan Flooding Study: Assessing Risk & Building Resilience

Kelly Karll, Southeast Michigan Council of Governments

Maximizing the Resiliency from Your Capital Spend: Analysis Tools to Address Resiliency Goals Management

Ister Morales, Gannett Fleming, Inc.

Development and Incorporation of Quantitative Risk and Resilience Analysis Standards into Agency Decision Making

Aimee Flannery, AEM Corporation

10:15 AM–11:45 AM, NAS 125

Regional and Multi-Sectoral Approaches to Resilience (TS002)

The transportation network is not an isolated system. Cities and regions depend on it for safety and economic vitality, other sectors rely on it for access to their infrastructure, and transportation assets can sometimes serve as the first line of defense for protecting a community. This session will explore how transportation agencies are partnering with others to more holistically plan for the resilience of a region.

Moderator: Susan Asam, IFC

Regional Resilience and Infrastructure—Opportunities for Dynamic Adaptation

Niek Veraart, Michael Baker International

Safeguarding Assets When You Can't Get There From Here—Shared Challenges in the Nexus of Multimodal Surface Transport, Buildings and Mission

Ann Kosmal, U.S. General Services Administration, Office of Federal High-Performance Buildings

State Hazard Mitigation and Climate Adaptation Plannin

Steve Miller, Massachusetts Department of Transportation (MassDOT)

Enhancing Local Climate Resilience with State-level Transportation Risk Assessment

Judy C. Gates, HNTB

10:15 AM–11:45 AM, *NAS Members Room*

Bridges and Culverts—Assessment of Resilience for Planning (TS003)

High water is a predominant climatic hazard that impacts bridges and culverts. High water can damage foundation material, structural members, and approach embankment and roadway. High water can also exceed hydraulic capacity causing overtopping and traffic interruption, as well as potentially causing problems upstream of the bridge or culvert. Resilience planning requires techniques for assessing or analyzing many locations within a jurisdiction to estimate the effects of current and future waterway flows for prioritizing mitigation. This session presents some assessment techniques that are in use or under study.

Moderator: Derek Constable, Federal Highway Administration

Resilient Bridge Planning in Mozambique: Bridge Failure Risk from Flooding and Climate Change

Sebastian Young, University of New Hampshire, Department of Civil & Environmental Engineering

Resilient Bridge Planning: Failure Risk from Flooding and Climate Change

Kyle Kwiatkowski, University of New Hampshire

Evaluating the Performance and Resilience of Major Stormwater Infrastructure Systems under Climate Change and Land Use Uncertainty

Tania Lopez-Cantu, Carnegie Mellon University

Culvert Resilience Assessment: From Pilot to Practice

Charles Hebson, Maine Department of Transportation

11:45 AM–12:45 PM, *West Court*

Lunch

12:45 PM–1:20 PM, *Kavli Auditorium*

FOCUS-POINT SESSION: State of Play of Proactive Adaptation (FPS01)

Proactive Adaptation is about strategies to reduce future damages caused by extreme weather and sea level rise. This focus plenary will explore the current state of proactive adaptation in the U.S. and around the globe. The aim is to highlight successes and demonstrate the clear need for proactive adaptation based on recent disasters. Questions to be addressed include:

- *What is the policy advancement?;*
- *What are barriers and ways to overcome them?;*
- *How can we utilize science?; and*
- *How do you deal with uncertainty?*

Moderator: Kees van Muiswinkel, Rijkswaterstaat—Ministry of Infrastructure and Water Management

Alice C. Hill, Council on Foreign Relations

1:20 PM–1:30 PM, *Great Hall*

Transition Break

1:30 PM–3:00 PM, NAS 120

Frameworks and Methods to Address Coastal Resilience—Part A (TS004)

The built environment in high risk coastal areas is confronted by natural hazards such as severe storms, flooding, sea levels rising, and erosion. In this session panelist will present methods and frameworks to support decisions to reduce the ecological, structural, and economic risks of coastal hazards.

Moderator: David Kriebel, United States Naval Academy

Highways in the Coastal Environment: A U.S. Engineering Manual

Scott Douglass, South Coast Engineers

Strategies to Increase Resilience of Florida DOT's Facilities

Jennifer Carver, Florida Department of Transportation, and Carl Spirio, Jr., GHD

A Stepwise and Flexible Adaption Framework for Coastal Road Infrastructure Resilience to a Changing Climate

Jayne F. Knott, JFK Environmental Services LLC

A Framework for Selecting Sea Level Rise for the Design of Resilient Infrastructure

Roger Kilgore, Kilgore Consulting and Management

1:30 PM–3:00 PM, NAS 125

Transforming Design for Resilience—Part A (TS005)

This session will delve into the practical world of design, exploring lessons learned from various organizations who have updated their design approaches to include nature-based solutions, as well as translate climate science into design-level guidance.

Moderator: Susanne DesRoches, New York City Mayor's Offices of Resilience and Sustainability

Characterization of Resilience of Road Networks against Fluvial Flooding through Modelling Dynamic Evolution of Flood Control Infrastructure Networks

Baiherula Abula, University of Texas A&M

Flood Resiliency: The Added Benefit of Aquatic Organism Passage Using the Stream Simulation Design Methodology

Nathaniel Gardner Gillespie, United States Forest Service, United States Department of Agriculture

Improving Resiliency and Sustainability of Vulnerable Infrastructure by using Natural Stream Channel Design and Restoration: Three Case Studies

Thomas A. Graupensperger, Dewberry

1:30 PM–3:00 PM, NAS Members Room

Approaches to Addressing Multiple Hazards within a Larger Multimodal Program (TS006)

Public agencies are working to develop more resilient infrastructure systems to ensure access and limit disruptions to the traveling public. This session will explore various state,

regional and national organizational approaches to address hazards within a program-wide context.

Moderator: Paula J. Hammond, WSP Inc.

Arizona Department of Transportation: Designing, Funding, and Building Resilience into a \$1Billion Construction Program

Steven Olmsted, Arizona Department of Transportation

Assessment of Incorporating Climate Adaptation into a State Department of Transportation: Caltrans Experience

Tracy Frost, California Department of Transportation (Caltrans)

Development of a Concept for Resilience Management for Federal Highways in Germany

Martin Klose, Federal Highway Research Institute (BAST)

Colorado's Road to Resiliency

Johnny Olson, Horrocks Engineers, and Elizabeth Kemp Herrera, Colorado Department of Transportation

Flood Resilient Critical Infrastructure: Dutch Policy and The Role of the National Highway Network

Kees van Muiswinkel, Rijkswaterstaat—Ministry of Infrastructure and Water Management

3:00 PM–3:30 PM, *Great Hall*

Networking Break

3:30 PM–5:00 PM, *NAS 120*

Integrating Resilience in Transportation Planning—Part A (TS008)

Resilience touches all aspects of transportation policy, planning, design, finance, operations, and management. In these Part A and B sessions, panelists identify natural and climate mitigation and adaption strategies that can be mainstreamed into transportation planning programs and projects.

Moderator: Heather Holsinger, Federal Highway Administration

Transportation Planning, Cultural Resources Management, and Climate Resilience

January Tavel and Tait Elder, ICF

Understanding the Coupled Impact of Urbanization and Climate Change on Watershed Planning

Tom Jacobs, Mid-America Regional Council, and Stacy Hutchinson, Kansas State University

Implementing a Risk Based Decision Tool in Long Range Transportation Planning in Federal Land Management Agencies in Alaska

Amit Armstrong, Federal Highway Administration

3:30 PM–5:00 PM, NAS 125

Transforming Design for Resilience—Part B (TS009)

As Part 2, this session will continue to explore the practical world of design, exploring lessons learned from various organizations who have updated their design approaches to include nature-based solutions, as well as translate climate science into design-level guidance.

Moderator: Josh DeFlorio, Port Authority of New York & New Jersey

Port Decision Makers' Barriers to Climate and Extreme Weather Adaptation;

Elizabeth L. Mclean, University of Rhode Island

Supporting Stormwater Infrastructure Decisions under Uncertainty through a Spatial and Temporal Analysis of Engineering Standards

Tania Lopez-Cantu, Carnegie Mellon University

Addressing Resilience at Road/River Intersections Using the Geomorphic Approach

Salam Murtada and Kevin Zytkovicz, Minnesota Department of Natural Resources, Ecological and Water Resources

3:30 PM–5:00 PM, NAS Members Room

Projections and Downscaling: Developing and Applying Precipitation and Temperature Projections—Part 1 (TS010)

This session will consist of the following:

- *Panel and group discussion involving those who generate the projections and the people who actually use them.*
- *How to deal with uncertainty, including where do you get the projections; how to apply them; and provide examples of building taking into account climate projections.*
- *Highlight tools and techniques to predict storms, precipitation and flows utilizing climate projections for transportation planning, and risk based asset management.*

Moderator: Jeffrey Arnold, U.S. Army Corps of Engineers

Risk Assessment & Resiliency for Design Rainfall

Allison Wood, Huitt-Zollars

Breaking the Mold: Changing the Practice of Processing Climate Projections for Transportation Planning

Rawlings Miller, WSP Inc.

Informing Neighborhood-Scale Decisions: Advances in Climate Impact Downscaling

Thomas Wall, Argonne National Laboratory

NCHRP 15-61: Incorporating Future Climate Projections into the Infrastructure Design Process

Anne Stoner, ATMOS Research & Consulting

3:30 PM–5:00 PM, *NAS Board Room*

Innovative Collaboration for Resilience to Extreme Weather Events (TS011)

This session will focus on the theme of innovative collaborations for climate action and enhanced resilience to climate change and extreme weather events in the transportation sector. Presentations will feature examples of how different agencies, local governments, and other stakeholders are working together across jurisdictional boundaries and multiple sectors and silos to improve collaborative decision-making in ways that better address climate change causes and impacts in transportation.

Moderator: Annie Bennett, Georgetown Climate Center

Innovations from Partnerships in Research and Practice—The Infrastructure & Climate Network (ICNet)

Jennifer Jacobs, University of New Hampshire

Working towards Resilient Transportation in the Tampa Bay Region

Allison Yeh, Hillsborough County Metropolitan Planning Organization, and Sean Sullivan, Tampa Bay Regional Planning Council

Collaborating for Transportation Resilience and Recovery in the Portland-Vancouver Region

Kim Ellis, Oregon Metro

Collaborative Efforts toward Increased Agency Resiliency

Melissa Savage, American Association of State Highway and Transportation Officials (AASHTO)

5:00 PM–7:00 PM, *Great Hall*

Poster Session and Networking Reception

Smart Adaptive Infrastructure for Transportation Sustainability and Resiliency

Xiong (Bill) Yu, Case Western Reserve University

Compound Flood Impacts on Transportation System during Hurricane Irma

Vidya Samadi, University of Southern California

A Strategic Management Framework to Improve Resilience and Adaptivity during Transportation Planning

Yilun Xu, Alliant Engineering, Inc.

Lessons Learned from Testing Vehicular Traffic Signal Assemblies at Hurricane Level Winds

Ionnis Zisis, Florida International University

Spatial Analysis of Environmental Influence on Wet Roadway Crashes

Michael Crimmins, Villanova University

WEQUAL: A Research Project to Support Green Infrastructures

Stefano Rignanese, Maccaferri Inc.

Transportation Fuel Resilience through Diversification in Tampa Bay Florida

Caley Johnson, NREL

Seven Strategies for Climate Resilient Infrastructure

Douglas Mason, Millennium Challenge Corporation

Efficiency and Resilience in Transportation: Quantification and Tradeoffs

Igor Linkov, U.S. Army Corps of Engineers

A Pilot Project under a Transformative Resilience Framework

Anabela Simoes, Lusofona University

A Mechanistic Approach to Quantify Asphalt Pavement Resilience to Flooding

Fan Gu, National Center for Asphalt Technology at Auburn University

Using Coastal Road Failures to Improve Resiliency

Garland Pennison, HDR Engineering

Climate Change and Airport Pavement Design Approaches for Coral Atoll Islands: Experiences from Tuvalu

Asif Faiz, Faiz and Associates, LLC

Resilience Activities and Research Needs in State Departments of Transportation

Sue McNeil, University of Delaware

Dynamic Evacuation Planning Based on Traffic Micro-Simulation Modeling

Mohammad Jalayer, Rowan University

Inventories of Inland Transport Networks and Nodes Vulnerable to Climate Changes in the UNECE Region

Piet de Wildt, Rijkswaterstaat—Ministry of Infrastructure and Water Management

Resilience to Extreme Weather of Transportation Operations, Maintenance, and Emergency Management

Hunter McCracken, Battelle

Collaboration between the Community Collaborative Rain Hail and Snow Network and NM Department of Transportation for Extreme Precipitation Events

Dave DuBois, New Mexico State University

Climate Change and the Challenges of Creating a More Adaptive and Flexible Pavement Engineering Paradigm

Andrew Fried, North Carolina State University

Resilient Recovery Actions in Maritime Transportation; Dredged Hole #86, Atlantic County, New Jersey

Kimberly McKenna, Stockton University Coastal Research Center

Resiliency: A Planning Focus

Steven Humphrey, Muller Engineering Company

Infrastructure Protection Resources

Christina Miskis, SFRPC

Beyond the Weather: Enhancing Mobility with Resilience in Tulsa, Oklahoma

Paulina Baeza, INCOG

Private Sector Best Practices in Resilience Planning

Scott Middleton, EDR Group

Freight Transportation System Resiliency—Employing Strategic Asset Management Methodology in Southeast Texas

Erik Stromberg, Lamar University

Climate Resilient Tunnels Provide for Robust Storm Evacuation Routes

William Bergeson, Federal Highway Administration

Development of Advanced Technology for Slope Maintenance for Climate Change

Oil Kwon, Korea Institute of Civil Engineering and Building Technology

THURSDAY, NOVEMBER 14, 2019

7:00 AM–5:00 PM, *Great Hall*

Registration Open

7:00 AM–8:30 AM, *West Court*

Continental Breakfast and Coffee

8:00 AM–9:30 AM, *NAS 120*

Economic Analysis to Support Resilience—Part A (TS012)

This session explores approaches for evaluating and capitalizing on the economic value of adaptation improvements. Presenters discuss cost-benefit analysis of resilience measures from varying perspectives. A framework for cost-benefit analysis helps departments of transportation compare projects and programs impacted by extreme weather from the perspective of the agencies' own bottom lines. A case study of a highway in California considers the often-undervalued economic impact of roadway disruptions on businesses and communities. And an asset owner seeks to capture the value of risk reduction benefits to their insurance underwriters

Moderator: Rebecca Lupes, Federal Highway Administration

Reaping the Benefits of Resilient Design to Reduce Property Insurance Premiums

Joshua DeFlorio, Port Authority of New York & New Jersey

Resilience Economics at the Facility and Program Scales

Scott Middleton, EDR Group

NCHRP 20-101: Evaluating the Costs and Benefits of Adaptation

Laurel McGinley, Dewberry

8:00 AM–9:30 AM, *NAS 125*

Nature-Based Solutions for Coastal Highway Resilience (TS013)

Natural and nature-based features such as wetlands, reefs, beaches, and dunes, can protect roadways from erosion and flooding while offering environmental benefits. Building on work from the US Army Corps of Engineers (USACE) and the National Oceanic and Atmospheric Administration (NOAA), the Federal Highway Administration (FHWA) conducted a research program to develop actionable information for transportation agencies to implement nature-based solutions to protect roadways. This work included a white paper, series of peer exchanges, pilot projects, and an implementation guide.

Moderator: Tina Hodges, Federal Highway Administration

Implementing Nature-Based Solutions for Coastal Highway Resilience

Bret M. Webb, University of South Alabama

Research and Pilot Projects under the USACE Engineering with Nature Initiative

Jeff King, U.S. Army Corps of Engineers

The Ecological Effects of Sea Level Rise

Trevor Meckley, National Oceanic and Atmospheric Administration

Delaware DOT's Analysis of Sea Level Rise and Storm Surge Vulnerability of State Route 1

LaTonya Gilliam, Delaware Department of Transportation

8:00 AM–9:30 AM, NAS Members Room

Geotechnical Aspects in Transportation Resilience (TS014)

This session will include a discussion of:

- *Geotechnical considerations in transportation resilience.*
- *Evaluation and management of weather elements effects on transportation geotechnical hazards (Geohazards) to maintain a resilient transportation system.*
- *The benefit of using GIS and data bases for the analysis of geohazards risk and development of transportation resilience approaches.*

Moderator: Khalid Mohamed, Federal Highway Administration

GIS Model for Landslide Susceptibility Due to High Precipitation Rain Storm

Hany Hassaballa, GeoDecisions, a division of Gannett Fleming Inc.

Geohazards, Extreme Weather Events and Climate Resilience—the Development of FHWA Guidance

Brian Zelenko, WSP USA

Case Study: MD 135 Rockfall Investigation and Back Analysis

Lijun Zhang, Maryland State Highway Administration

Resilience System to Natural Hazards in Norwegian Public Roads Administration (NPRA)

Martine Holm Frekhaug, Norwegian Public Roads Administration

8:00 AM–9:30 AM, NAS Board Room

Causality and Surrogates: Bridge Vulnerability and Resilience (TS015)

This session focuses on the relationship between changes in precipitation and the vulnerability of bridges to these changes. When examined comprehensively and in detail, this relationship can be simultaneously “compounding” and “confounding”. We will try to step the audience through the scour processes at work and statistical relations between precipitation, flow, velocity, flow depth and ultimately scour. We will look at uncertainties and other concerns such as channel instability, watershed characteristics, and bridge site geometry and how they complicate the picture. We will examine the ways floods are changing in the US and the significance of those changes. Finally, we will run through a project that strives to account for these changes so that bridges due for replacement can be built back in a resilient manner based on sound science.

Moderator: Brian Beucler, Federal Highway Administration

Scour and Extreme Events: Focusing on the Issues

Joe Krolak, Federal Highway Administration

Impacts of Flood Change on Bridge Scour Reliability

Chao Huang, Genex Systems

Detection and Attribution of Flood Change across the United States

Stacy Archfield, United States Geological Survey

Development of Site-Specific Hydrologic and Hydraulic Analyses for Assessing Transportation Infrastructure Vulnerability and Risks to Climate Change

Daniel Szekeres, Michael Baker International, and Donna Newell, NTM Engineering, Inc.

9:30 AM–10:30 AM, *Kavli Auditorium*

ROY W. CRUM DISTINGUISHED SERVICE AWARD

Presentation of the Roy Crum Award to Dr. Sue McNeil, Professor of Civil and Environmental Engineering and Public Policy and Administration, University of Delaware.

TRB is honored to present the Roy W. Crum Distinguished Service Award to Dr. Sue McNeil for her outstanding achievements in research in the areas of infrastructure asset management processes, brownfield redevelopment, and disaster response and preparation. The Roy Crum Award is among the highest presented awards from TRB. It recognizes exceptional achievement in the field of transportation research. It is named in honor of the memory of long-time TRB Executive Director Roy Crum.

PLENARY SESSION

Leading the Way to Great Resilience: Policy-Makers Talk About the Future (PS03)

Proactive adaptation, transformative resilience, and resilient recovery require investment and policy decisions to reduce loss of life, response and recovery costs, and socioeconomic impacts of future disasters. In this plenary session policy makers will highlight strategic and operational plans for improving community and transportation resilience.

Moderator: Vicki Arroyo, Georgetown Climate Center

Andrew Wishnia, Esq., U.S. Senate Committee on Environment and Public Works

Julie Rozenberg, The World Bank

Sue McNeil, University of Delaware

April Marchese, Office of Secretary of Transportation, U.S. Department of Transportation (Invited)

10:30 AM–10:45 PM, *Great Hall*

Transition Break

10:45 AM–12:15 PM, *NAS 120*

Economic Analysis to Support Resilience—Part B (TS016)

This second session on economic analysis includes presentations and discussion underpinning the importance of economic analyses. The session starts with views from the Office of the Secretary on U.S. Department of Transportation's current efforts to understand and incorporate the costs and benefits of resilience into long range planning and disaster recovery, followed with presentations on regionally assessing economic resiliency and making the business case for road and stormwater investments to combat sea level rise. The session ends with a review of economic tools for analyzing transportation projects incorporating resilience.

Moderator: Thomas Bles, Deltares

U.S. DOT's Tools to Augment Transportation Resilience and Disaster Recover

Alasdair Cain, United States Department of Transportation—Office of the Assistant Secretary for Research and Technology (OST-R)

Bouncing Back: Assessing Regional Economic Resiliency

Frederick Treyz, Regional Economic Models, Inc. (REMI)

Business Case for Road and Stormwater Investments to Combat Sea Level Rise

Cassandra Bhat, ICF

A Review of Economic Tools for Analyzing Transportation Projects Incorporating Resilience

Prerna Singh, Georgia Institute of Technology

10:45 AM–12:15 PM, NAS 125

Pavement Resilience (TS017)

Design and analysis of pavement infrastructure typically include the consideration of environmental conditions. However, conventional design methods rely on the assumption of the stationery climate mainly inferred from the historical data. Nevertheless, the design of resilient and robust pavement infrastructure necessitates additional guidance on how to incorporate the effects of future climate trends and extreme weather events into the design. This session is focused on pavement design methodologies that take into consideration future environmental considerations and potential pavement adaptations targeted towards improved resilience.

Moderator: Milena Rangelov, Federal Highway Administration

Developing Time-Depth-Damage Functions for Flooded Pavements

Jo Sias, University of New Hampshire

Resiliency Enhancement of Pavement Infrastructure to Mitigate Influence of Climate Change

Vivek Tandon, University of Texas, El Paso

Boosting Pavement Resilience

Heather Dylla, Federal Highway Administration

Projected Impact of Climate Change to Asphalt Pavement Performance in the U.S.

Anne Stoner, Texas Tech University Climate Center

10:45 AM–12:15 PM, NAS Members Room

Tools and Methods (TS018)

This moderated panel discussion will explore ways to approach the assessment of climate risk as well as presenting useful tools and methods. The panel will reflect on how these approaches can be used to improve the resilience of transportation assets.

Moderator: Carol Lee Roalkvam, Washington State Department of Transportation, Environmental Services Office

City Simulator: An Innovative Tool for Transformative Resilience in Transportation Systems and Beyond

Steven Bourne, Atkins North America

Climate Risk Assessments for Transportation Assets: Lessons Learned and Recommended Practices

Donavan Jacobsen, Transport Canada

FloodCast—A Federated Data Vision for DOT Flood Resilience

Mathew Mampara, Dewberry

Improving the Resilience to Natural Hazards on Norwegian Public Roads—A Presentation of the RESPONS Project

Martine Holm Frekhaug, The Norwegian Public Roads Administration

10:45 AM–12:15 PM, *Board Room*

Assessing Increased Coastal Flooding Due to Relative Sea Level Rise—Part B (TS019)

Communities in almost every coastal state are experiencing problems with more frequent, and more severe, road flooding at high tide and during small storms. This increased flooding is due to relative sea level rise and has been called “nuisance flooding,” “sunny-day flooding,” “high-tide flooding,” “storm-tide flooding,” “chronic flooding,” “recurrent flooding,” and “king-tide flooding.”

The four presentations in this session show how this increased flooding due to relative sea level rise should be quantitatively assessed.

Moderator: Scott L. Douglass, South Coast Engineers

Evaluating the Impact of Recurrent Flooding on Road Network Access in a Coastal Locality

Pamela Braff, Virginia Institute of Marine Science / MARISA

Data Predictive Approach to Estimate Nuisance Flooding Impacts on Roadway Networks: A Norfolk, Virginia Case Study

Shraddha Praharaj, University of Virginia

Improved Sea Level Rise Mapping for Climate Vulnerability Assessments

Christopher Dorney, WSP Inc.

Assessment of High Tide Flooding of Coastal Roadways

David Kriebel, United States Naval Academy

2:00 PM–3:30 PM, *NAS 120* (Corrected)

Managed Retreat—Part A (TS020)

This panel will focus on control of adaptation decisions and the challenges that, in some cases, may prevent managed retreat from being considered. The panel will focus on the law and policy side of the issues, and include a case study discussion that brings to life the policy challenges of having meaningful discussion of retreat.

Moderator: Leah Dundon, Vanderbilt University

Broader Perspective on State and Local Government Actions and Challenges Related to Managed retreat, and GCC’s Forthcoming “Managed Retreat Toolkit”

Katie Spidalieri, Georgetown Climate Center

Managed Retreat and Infrastructure Planning: Long-term Challenges of Coastal Communities from a Policy and Legal Perspective

Thomas Ruppert, Florida Sea Grant Program, University of Florida Extension

Managed Retreat (Part A)—Is it Even An Option?

Jim Pappas, Delaware Department of Transportation

12:15 PM–1:15 PM, *West Court*

Lunch

1:15 PM–1:50 PM, *Kavli Auditorium*

FOCUS-POINT SESSION: Managed Retreat—When, Whether and How? (FPS02)

Sea level rise, increased frequency and intensity of flooding, and other extreme weather events have sparked a growing recognition that managed retreat must be among the solutions considered, in some locations, to protect human life, livelihoods, and public and private infrastructure investment. This plenary session will feature immediate input from the audience using smart phone survey software. Together we will create a framework for charting a path forward in this emerging area of resilience that will be of benefit to researchers and practitioners.

Moderator: Mark Abkowitz, Vanderbilt University

1:50 PM–2:00 PM, *Great Hall*

Transition Break

2:00 PM–3:30 PM, *NAS 125*

Sharable Lessons from Natural Disasters (TS021)

This session will present lessons learned for incorporating and assessing resiliency for infrastructure from extreme weather events. The presentations will provide case studies and examples for incorporating resiliency into infrastructure design/repair and for integrating/assessing resiliency into project planning/prioritization.

Moderator: Dave Claman, Iowa Department of Transportation

The Historic 2019 Missouri River Flood and Iowa DOT's Recovery and Resiliency

Dave Claman and Tamara Nicholson, Iowa Department of Transportation

2019 Oklahoma Flooding Resilience Assessment

Rebecca Lupes, Federal Highway Administration

Highway Infrastructure Resilience and Post-Hazard Response—Bridges and Tunnels

Sissy Nikolaou, WSP Inc.

Transportation Service Plan for Disaster Survivors

Eric Plosky, Volpe National Transportation Systems Center; Matt Campbell, Federal Emergency Management Agency; and Jamie Setze, Capital Region Planning Commission

2:00 PM–3:30 PM, *NAS Members Room*

Communications and Making the Business Case for Resilience (TS022)

This session will include an overarching speaker to set the stage and two or more case studies.

Moderator: Elizabeth Habic, Maryland Department of Transportation

Communicating Climate Projections, Risks, and Uncertainty: Solutions to Key Challenges

Brad Hurley, ICF

Climate Communication Pilot Project

Tracey Frost, California Department of Transportation (Caltrans)

Climate and Community Engagement: A Case Study in Fresno County, California

Annika Ragsdale, WSP Inc.

2:00 PM–3:30 PM, *NAS Board Room*

Approaches to Addressing Multiple Hazards within a Large Modal Project (TS023)

A transportation system is exposed to multiple hazards. Innovative approaches are emerging that assess system vulnerabilities and develop resilience recommendations to cope with the changing environment. This session will explore these innovative approaches and present project-based examples.

Moderator: Rawlings Miller, WSP Inc.

Quantitative Multi-hazard Risk Assessment for Road Networks

Margreet van Marle, Deltares

Understanding Resilience through the Design and Implementation of Stress Tests for Large-scale Infrastructure Systems

Juan Carlos Lam, WSP Inc. & ETH Zurich

Advancing Flood Resilience Concepts to Design: Boston's Climate Resilient Design Guidelines for Protecting Public Rights-of-Way

Frank Ricciardi, Weston & Sampson

Flood Resilience for Boston's Blue Line Subway

Indrani Ghosh, Weston & Sampson

3:30 PM–4:00 PM, *Great Hall*

Networking Break

4:00 PM–5:30 PM, *NAS 120*

Integrating Resilience in Transportation Planning—Part B (TS024)

Resilience touches all aspects of transportation policy, planning, design, finance, operations, and management. In these Part A and B sessions, panelists identify natural and climate mitigation and adaption strategies that can be mainstreamed into transportation planning programs and projects.

Moderator: Tom Jacobs, Mid-America Regional Council

A Resilience Measure for Prioritizing Transportation Network Recovery

Sue McNeil, University of Delaware

Incorporating Resilience into Transportation Planning and Assessment

Sarah Weiland, RAND Corporation

Integrating Natural Hazard Resilience into the Transportation Planning Process

Heather Holsinger, Federal Highway Administration

4:00 PM–5:30 PM, *NAS 125*

Resilience Initiative for National Transportation Systems (TS025)

Extreme weather and other effects of climate change on transportation system operations and planning can occur in damaging combinations of threats and impacts, as increased hillside precipitation and sediment runoff can follow increased wildland fire incidence and intensity. This session will present for discussion several techniques for characterizing these sorts of cascading events and for incorporating them into transportation planning and operations.

Moderator: Laurie Radow, Chair—TRB Standing Committee on Critical Infrastructure Protection (ABR10)

Transportation in the UK's Third Climate Change Risk Assessment

David Jaroszweski, University of Birmingham

Using Dutch Highway Network Climate Stresstest Results for Performance Management, Policy Development, Planning Infrastructure and Prioritizing Renovation and Maintenance

Kees van Muiswinkel, Rijkswaterstaat—Ministry of Infrastructure and Water Management

Infrastructure Resiliency: Climate Adaptation Efforts on National Forests System Lands Enhancing Accessibility and Controlling Costs

Joseph Burns, U.S. Forest Service, U.S. Department of Agriculture

Resilience: A DOT Imperative

Deborah Matherly, WSP Inc.

4:00 PM–5:30 PM, *NAS Members Room*

**Projections and Downscaling—Part B
Developing and Applying Precipitation and Temperature Projections,
Part 2 (TS026)**

This session will consist of the following:

- *Panel and group discussion involving those who generate the projections and the people who actually use them.*
- *How to deal with uncertainty, including where do you get the projections; how to apply them; and provide examples of building taking into account climate projections.*
- *Highlight tools and techniques to predict storms, precipitation and flows utilizing climate projections for transportation planning, and risk based asset management.*

Moderator: Brian Beucler, Federal Highway Administration

Estimating Projected Precipitation for Design of Resilient Infrastructure

Roger Kilgore, Kilgore Consulting and Management

Using Climate Model Data for Resilient Highway Planning and Design: The FHWA CMIP Tool

Rob Kafalenos, Federal Highway Administration

A Process for Efficient, Scientifically-informed Climate Data Downscaling for Large Scale Asset Class Resilience Assessments: The Arizona DOT Approach

Steven Olmsted, Arizona Department of Transportation

Introducing STAR-ESDM: High-Resolution Climate Projections for Impact Analysis

Anne Stoner, Texas Tech University Climate Center

4:00 PM–5:30 PM, *NAS Board Room*

Managed Retreat and Infrastructure Decision Making—How Are the Hard Decisions Made? (TS027)

This panel will focus on transportation infrastructure in high risk areas and what approaches are used now, and should be used in the future, to evaluate the option of retreat. The panel will discuss case studies of infrastructure retreat/abandonment and how we currently evaluate the costs and benefits of retreat.

Moderator: Robert Graff, Delaware Valley Regional Planning Commission

Retreat: The Case of Louisiana, Terrebone Parish, and Louisiana Strategic Adaptations for Future Environments (LA SAFE)

Mathew Sanders, Louisiana Office of Community Development

Managed Retreat and Infrastructure Decision-making

Stacy Curry, Woodbridge, New Jersey Police Department

The Case of California Coastal Communities: Moving Portions of Highway

Tracey Frost, California Department of Transportation (Caltrans)

FRIDAY, NOVEMBER 15, 2019

7:00 AM, *Great Hall*

Registration Open

7:00 AM–8:30 AM, *West Court*

Continental Breakfast and Coffee

8:30 AM–10:00 AM, *NAS 120*

Technical Solutions for Resilience (TS028)

Resilience transportation networks require technical solutions that go beyond traditional practice by using existing tools in novel manners and creating new methods and tools to handle new challenges. In many cases, such as low volume roads or increasing flood risks across a region, it is difficult to justify major infrastructure investments. In this session, a range of technical approaches will be discussed that focus on understanding and increasing the capacity of those systems. The focus is on practical applications that have been demonstrated to be effectively used by state departments of transportation.

Moderator: Jennifer Jacobs, University of New Hampshire

Building Climate Resilience into Low-Volume Roads

Gordon Rex Keller, Geness Geotechnical and Matt Lauffer North Carolina
Department of Transportation

Increased Highway Resilience: Using Culvert Diffusers to Decrease Hydraulic Losses and Increase Capacity

Alexander W. Mann, Maine Department of Transportation

Application of 1D/2D Hydraulic Modeling for Investigation Utilizing North Carolina Department of Transportation Infrastructure to Improve Flood Resiliency

Johnny Martin, Moffatt & Nichol

8:30 AM–10:00 AM, NAS 125

Cascading Events (TS029)

Hazards are like our infrastructure, interconnected. Flooding leads to secondary effects of erosion, contaminated water, mold, clogged storm drains, downed power lines, etc. Cascading and connected events can impact local, state, regional, national, and international supply chains. The goal of this session is demonstrate methods to simulate risk in disasters and extenuate potential cascading and connected hazards.

Moderator: Jeffrey Arnold, U.S. Army Corps of Engineers

Framework for Incorporating Complex Uncertainty Systems under Post-Disaster Cascading Infrastructure

Yanfeng Ouyang, University of Illinois at Urbana-Champaign

Mesoscopic Modeling of Major Disruption Scenario in Austin, Texas to Estimate Benefits from Integrated Corridor Management

Matthew Miller, Texas A&M University

Regional-scale Simulations of Earthquake Impacts Considering Multiple Fidelity Modeling Approaches

Matt Schoettler, University of California, Berkeley

8:30 AM–10:00 AM, NAS Members Room

Advancing Resilience at National, State, Regional and Local Levels (TS030)

Panel and group discussion on a prioritization tool for transportation assets, lessons learned in indicator based vulnerability assessments, addressing climate change impacts on U.S. Forest Service Transportation assets, and approaches adopted in the Netherlands to assess the resilience of the Dutch highway network to natural hazards.

Moderator: Tracey Frost, California Department of Transportation (Caltrans)

Transportation Asset Criticality Prioritization Tool for New York State

Alaurah Moss, Dewberry

The U.S. Forest Service Transportation Resiliency Guidebook: Addressing Climate Change Impacts on U.S. Forest Service Transportation Assets

Benjamin Rasmussen, Volpe National Transportation Systems Center

Best Practices and Lessons Learned in Indicator-Based Vulnerability Assessments for Transportation

Cassandra Bhat, ICF

Stress Testing the Dutch National Highway Network

Thomas Bles, Deltares

8:30 AM–10:00 AM, *NAS Board Room*

Recovery for More Resilient Roads (TS031)

The best preparedness plan is a good recovery plan. Panelists discuss practical approaches to managing transportation systems to return to safe operations following a disruption caused by a disaster.

Moderator: William “Bill” Anderson, Transportation Research Board

Using Delay from a Travel Demand Model to Determine the Best Post-Disaster Bridge Repair Schedule

Mehrnaz Doustmohammadi, University of Alabama

Asphalt Pavement Resiliency: Findings of the 2019 NCAT Workshop

Benjamin Bowers, Auburn University

A Post-Disaster Decision Framework for Selection of Bridge Rehabilitation for Disrupted Transportation Networks

Eric Merschman, University of Alabama

Road Resilience at the World Road Association (PIARC)

Jürgen Krieger, Federal Highway Research Institute (BAST)

10:00 AM–10:15 AM, *Great Hall*

Transition Break

10:15 AM–11:15 AM, *NAS Kavli Auditorium*

FOCUS-POINT SESSION: Lessons Learned from Post-Disaster Response (FPS03)

Field perspectives from post-disaster recovery such as New Orleans (Katrina), New York (Sandy), Houston (Harvey), and Puerto Rico (Maria), including representatives from local and state agencies involved in specific locations.

Moderator: Anne Choate, ICF

Jane K. Brogan, Chief Policy & Research Officer, Governor’s Office of Storm Recovery (NY)

Drew Ratcliff, Regional Disaster Recovery Manager, Capital Region Planning Commission (LA)

Herby G. Lissade, P.E., Office of Maintenance Technical and Field support, California Department of Transportation (CALTRANS)

11:15 AM –12:15 PM, Kavli Auditorium

FOCUS-POINT SESSION: Science and Data Update (FPS04)

This panel session will provide discussion of the current and planned immediate future for climate science and observational data which can be used for transportation resilience planning and operations. Panel members will include both data and modeling scientists as well as transportation practitioners who will present short descriptions of relevant new science products and transportation applications, and will answer questions from each other and the audience.

Moderator: Jeffrey Arnold, Climate Preparedness and Resilience Programs, U.S. Army Corps of Engineers

Ana Bucher, The World Bank

Stacey Archfield, United States Geological Survey

Karuna Pujara, Maryland Department of Transportation.

12:15 PM–1:45 PM, West Court

CLOSING PLENARY AND WORKING LUNCH: Collecting Your Thoughts

We want to hear from you. During this working lunch we ask that you talk with your lunch table partners: What did you hear that was new or challenging? Were you inspired by anyone? What are your ideas and needs that TRB, AASHTO, or FHWA may initiate as a future action?

PARKING FOR MEETING PARTICIPANTS

NAS Building

Limited parking is available for meeting participants in the visitors parking area of the NAS building. Parking is provided on a first-come basis, and overflow is directed to public parking garages.

The public parking facilities closest to the NAS Building are Colonial Parking (20th Street, NW, between E and F Streets) and Columbia Plaza (23rd and Virginia Avenue, NW).



Keep this Statement for your records.

Transportation Research Board

Professional Development Hours Credit Statement for Registrant Records

Many licensure and certification agencies require the demonstration of continuing professional competency. Your attendance at this workshop and meetings entitles you to earn Professional Development Hour (PDH) units. This form is for your use in maintaining a record of the PDH units you have earned. Complete this form and retain it. Please do not return it to TRB. We recommend that you save the entire Workshop Program for your records should the licensure or certification agency request information from you. Reporting is done on an honor basis, and members are responsible for maintaining their own records.

The table below shows the professional development hours (PDH) that can be earned for the continuing education activities included in the Transportation Research Board Technical Sessions and Events at the Sixth International Conference on Women's Issues in Transportation on the Insights, Inclusion, and Impact: Framing the Future of Women in Transportation, Irvine, California, September, 10-13, 2019.

Dr. Ann M. Brach
Director, Technical Activities

Transportation Resilience 2019

Description: The Transportation Resilience 2019: 2nd International Conference on Transportation System Resilience to Natural Hazards and Extreme Weather Events will provide transportation professionals with information on emerging best practices and state of the art research results on how to adapt surface transportation networks to the potential impacts of natural disasters and extreme weather events. The conference will examine efforts to integrate resilience in all aspects of the transportation sector, including planning and programming, capital improvements, and operations and maintenance. The conference will promote international dialogue on research, implementation, and lessons learned on this important topic, with benefits that are expected to extend beyond the transportation sector. The conference will build on the content from the 1st International Transportation Resilience Conference held in September 2015 and the Transportation RISE conference in October 2018.

Learning Objectives:

By the end of the conference, attendees will have:

- Greater Awareness and Understanding of state-of-the practice information on incorporating resilience strategies into system performance activities
Vetted Resources and Data for measureable progress and performance of transportation resilience strategies and approaches
Identified Solutions in planning and design to advance sustainable and resilient transportation systems
Latest Policies and Standards to advance transportation resilience to natural hazards impacts
Exchanged Ideas with Peers from the private sector and every level of government

The Professional Development Hours (PDH) Tracking Sheet of eligible sessions and events is on the reverse side of this page.

William B. Anderson
Senior Program Officer, Transportation Research Board

Name _____ Date _____

Signature _____

Professional Development Hours (PDH) Tracking Sheet

<i>Wednesday, November 13, 2019</i>				
<i>Event</i>	<i>Time</i>	<i>Duration</i>	<i>PDHs</i>	<i>Attended</i>
Welcome Remarks and Opening Plenary Session – Prioritizing Resilience as State DOTs – Progress and Challenges (PS01 & PS02)	8:30 a.m. – 10:00 a.m.	1.5 hours	1.5 PDHs	
Technical Sessions – Period One Integrating Transportation Resilience into Asset Management (TS001) Regional and Multi-Sectoral Approaches to Resilience (TS002) Bridges and Culverts – Assessment of Resilience for Planning (TS003)	10:15 a.m. – 11:45 a.m.	1.5 hours	1.5 PDHs	
Focus-Point Session: State of Play of Proactive Adaptation (FPS01)	12:45 p.m. – 1:20 p.m.	0.5 hours	0.5 PDH	
Technical Sessions – Period Two Frameworks and Methods to Address Coastal Resilience - Part A (TS004) Transforming Design for Resilience - Part A (TS005) Approaches to Addressing Multiple Hazards within a Larger Multimodal Program (TS006)	1:30 p.m. – 3:00 p.m.	1.5 hours	1.5 PDHs	
Technical Sessions – Period Three Integrating Resilience in Transportation Planning - Part A (TS008) Transforming Design for Resilience - Part B (TS009) Projections and Downscaling – Part A (TS010) Innovative Collaboration for Resilience to Extreme Weather Events (TS011)	3:30 p.m. – 5:00 p.m.	1.5 hours	1.5 PDHs	
Poster Session and Networking Reception	5:00 p.m. – 7:00 p.m.	2 hours	1 hours	
Total hours:				
<i>Thursday, November 14, 2019</i>				
<i>Event</i>	<i>Time</i>	<i>Duration</i>	<i>PDHs</i>	<i>Attended</i>
Technical Sessions – Period Four Economic Analysis to Support Resilience – Part A (TS012) Nature-Based Solutions for Coastal Highway Resilience (TS013) Geotechnical Aspects in Transportation Resilience (TS014) Causality and Surrogates: Bridge Vulnerability and Resilience (TS015)	8:00 a.m. – 9:30 a.m.	1.5 hours	1.5 PDHs	
Plenary Session: Leading the Way to Great Resilience: Policy-Makers Talk About the Future (PS03)	9:45 a.m. – 10:30 a.m.	0.75 hours	0.5 PDH	
Technical Sessions – Period Five Economic Analysis to Support Resilience – Part B (TS016) Pavements Resilience (TS017) Tools and Methods (TS018) Assessing Increased Coastal Flooding Due to Relative Sea Level Rise - Part B (TS019)	10:45 a.m. – 12:15 p.m.	1.5 hours	1.5 PDHs	
Focus-Point Session: Managed Retreat – When, Whether and How? (FSP02)	1:15 p.m. – 1:50 p.m.	0.5 hours	0.5 PDH	
Technical Sessions – Period Six Managed Retreat (Part A) – Is it Even an Option? (TS020) Sharable Lessons from Natural Disasters (TS021) Communications and Making the Business Case for Resilience (TS022) Approaches to Addressing Multiple Hazards within a Large Modal Project (TS023)	2:00 p.m. – 3:30 p.m.	1.5 hours	1.5 PDHs	
Technical Sessions – Period Seven Integrating Resilience in Transportation Planning - Part B (TS024) Resilience Initiative for National Transportation Systems (TS025) Projections & Downscaling – Part B (TS026) Managed Retreat and Infrastructure Decision Making (Part B) – How are the Hard Decisions Made? (TS027)	4:00 p.m. – 5:30 p.m.	1.5 hours	1.5 PDHs	
Total hours:				
<i>Friday, September 13, 2019</i>				
<i>Event</i>	<i>Time</i>	<i>Duration</i>	<i>PDHs</i>	<i>Attended</i>
Technical Sessions – Period Eight Technical Solutions for Resilience (TS028) Cascading Events (TS029) Advancing Resilience at National, State, Regional and Local Levels (TS030) Recovery for More Resilient Roads (TS031)	8:30 a.m. – 10:00 a.m.	1.5 hours	1.5 PDHs	
Focus-Point Session: Lessons Learned from Post-Disaster Response (FPS03)	10:15 a.m. – 11:15 a.m.	1 hours	1 PDHs	
Focus-Point Session: Science and Data Update (FPS04)	11:15 a.m. – 12:15 p.m.	1 hours	1 PDHs	
Closing Plenary and Working Lunch: Collecting Your Thoughts	12:15 p.m. – 1:45 p.m.	1.5 hours	1.5 PDHs	
Total hours:				

SAVE THE DATE: NATIONAL CONFERENCE ON TRANSPORTATION ASSET MANAGEMENT
JULY 11-14, 2020
BOSTON, MA



VISIT OUR WEBSITE: <http://trb.org/publications/2020AssetManagement>



The 13th National Conference on Transportation Asset Management (TAM) provides an opportunity for all practitioners involved in their agency's asset management initiative to build core competencies and generate new ideas.

- Looking for both practical and innovative presentations.
- Selected abstracts will be featured in either poster or technical podium sessions.
- Presenters will be required to register and attend the conference to be included in the final program.

Presentation tracks and crosscutting issues:

- ◆ Track 1: Implementation
- ◆ Track 2: Data Governance/Tools
- ◆ Track 3: Managing Risk
- ◆ Track 4: Partners and Peers
- ◆ Track 5: Sustaining Asset Management in your Organization
- ◆ Crosscutting Issue 1: Transit
- ◆ Crosscutting Issue 2: Resilience



2ND INTERNATIONAL CONFERENCE ON
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The National Academies of **SCIENCES • ENGINEERING • MEDICINE**

The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, non-governmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

The **National Academy of Engineering** was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. John L. Anderson is president.

The **National Academy of Medicine** (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the **National Academies of Sciences, Engineering, and Medicine** to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The National Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

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The **Transportation Research Board** is one of seven major programs of the National Academies of Sciences, Engineering, and Medicine. The mission of the Transportation Research Board is to increase the benefits that transportation contributes to society by providing leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied committees, task forces, and panels annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

Learn more about the Transportation Research Board at www.TRB.org.



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