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Measuring and Managing Freight System Resilience Workshop

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Measuring and Managing Freight System Resilience Workshop

April 6–8, 2021

Sponsored by
Office of Freight Management and Operations
Federal Highway Administration

Alison Conway
Rapporteur
The City College of New York

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Preface

Convened virtually on April 6–8, 2021, the Measuring and Managing Freight System Resilience Workshop brought together 113 participants to discuss challenges and strategies for ensuring freight system resilience in the face of disruptions caused by major natural hazards. Sessions held over three afternoons brought together freight and emergency management experts to discuss four major disruption types—hurricanes, wildfires, floods, and the COVID-19 pandemic. Case study presenters and response panels spanned all modes and explored a wide variety of resilience-related topics, including: communications; data needs, sources, and analysis tools; infrastructure investments; operational adaptations, and enhanced interparty collaborations.

This report details the workshop program. It provides summaries of invited speaker presentations, panel discussions, and audience inputs. The final chapter summarizes key takeaways and identifies areas of future research to support advances in practice for measuring and planning for freight resilience and managing freight systems during and after extreme events. A copy of the full program, including detailed speaker biographies, is available on the event website. A compilation of related videos is also available online.

Special acknowledgments to the Transportation Research Board staff Tom Palmerlee, Rhonda Levinowsky, Bruce Millar, and Kate Debelack for their support and organizational expertise. Thanks to the Federal Highway Administration Office of Freight Management and Operations for supporting this event.

The views expressed in this summary are those of individual workshop participants and do not necessarily represent the views of all workshop participants, the planning committee, the Federal Highway Administration, or the Transportation Research Board.

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Introduction

Safe, efficient, and reliable freight transportation systems are critical to support economic health and basic quality of life in the United States. When large-scale events disrupt freight systems, supply chains can fail, and populations are at risk of losing access to basic necessities and to critical goods flows needed to support infrastructure and economic recovery. To address these concerns, the Measuring and Managing Freight Resilience Workshop was convened virtually by the Transportation Research Board (TRB) on April 6–8, 2021. Sponsored by the Federal Highway Administration (FHWA) and organized by a volunteer planning committee, the event brought together agency, industry, and academic experts in freight systems planning and operations and emergency response to address the challenge of ensuring freight system resilience in the face of disruptions caused by major natural hazards.

The workshop program was organized around four types of disruptive events: hurricanes, wildfires, floods, and the COVID-19 pandemic. Following an opening session that set the stage for the workshop, an expert panel was convened for each event type to share experience in planning for freight system disruptions, managing systems and stakeholders in real-time during an event, and restoring freight infrastructure and operations following an event. Case study presentations were followed by response panels, audience questions, and open discussions to highlight challenges faced and best-practice approaches to planning, response, and mitigation. In the following chapters, the presentations and discussions related to each type of event are detailed.

Together, these panels revealed an extensive list of lessons learned to inform future practices. Discussions also identified emerging challenges - such as interdependencies between transportation, energy, and communications systems - that will need to be addressed collaboratively in the coming decades, as well as critical gaps in data, communications, and technology that must be addressed through research. The last chapter summarizes these key takeaways and future research needs.

Opening Session

WELCOME AND INTRODUCTION

Joseph L. Schofer, *Northwestern University*

Major natural hazards like hurricanes, wildfires, and floods cause broad-scale disruption and destruction. Such events are becoming increasingly common, and their impacts on the logistics systems are of particular concern because the essential functioning and safety of our society and our economy depend so much on the timely and reliable movement of freight. These assaults on freight infrastructure and services are natural experiments that test the resilience of the systems we build and operate.

The focus of this 3-day workshop is to learn from these experiments how we can better respond to and protect our transportation systems in the future. Over the next 3 days, we will hear about four different disruptions—hurricanes, floods, and wildfires, as well as the COVID-19 pandemic—each from multiple perspectives. Afterwards, a panel of experts will offer their insights on what was experienced. Then, we will discuss together to derive some lessons learned, some good practices, as well as some ideas for research and data needs to boost freight system resilience.

This workshop is sponsored by the U.S. Department of Transportation's (DOT's) FHWA Office of Freight Management and Operations. The event was planned over the last year by an expert committee. The committee is grateful to the members of the TRB staff Tom Palmerlee, Rhonda Lewinowsky, Bruce Millar, and Kate Devlin, who provided the advice and good work to make this event happen.

We have an exceptional opportunity to have with us Robert Hampshire, who is the newly appointed principal Deputy Assistant Secretary of Transportation for Research and Technology. His qualifications are particularly appropriate for that new appointment. Prior to joining U.S. DOT, Hampshire was Associate Professor at the Gerald Ford School of Public Policy at the University of Michigan. In his prior research, he has applied operations research, data science, and systems analysis approaches to analyzing novel transportation systems and studying environmental impacts, equity, and access to opportunity. Hampshire earned his PhD in Operations Research and Financial Engineering at Princeton University. Robert, we are delighted to have you with us.

OPENING REMARKS

Robert Hampshire, *U.S. Department of Transportation*

Joe, I want to thank you and the Planning Committee for this workshop. I want to thank TRB, from Neil Pederson, to Susan Shaheen, to the staff and all those employees at TRB that helped make this workshop happen. I'm really honored to be here. I grew up in TRB as a researcher and a graduate student, so it's always a great honor to be here. I want to thank Pat Hu, our Director of the Bureau of Transportation Statistics (BTS) at U.S. DOT. It's a true honor to work side by side

with those colleagues and help lead them in implementing the missions of the Biden–Harris Administration and the DOT.

Since January 2020, I have served as the Acting Assistant Secretary for Research and Technology at U.S. DOT. My office is excited to engage the research community, the TRB community, and the transportation community as a whole on the priorities for this administration. In my role, we coordinate research across all the modes of transportation at the DOT, from pipelines to rail, to freight, to airlines. Many of these intersect and contribute to freight resilience.

We are coordinating and making sure that the research and technology mission really implements, accelerates, and supports the key priorities of this administration. The number one goal of the administration is to support COVID response. We're now administering 3.5 to 4 million doses of the vaccine per day. The freight system has played a key role in accomplishing this. A second goal is to provide access to better paying jobs through the American Jobs Plan, which is a component of the Building Back Better initiative. "Better" sometimes has to do with technology and research, but "better" also often has to do with building back more equitably. Promoting racial justice and equity is another key goal of the administration, and a theme I'll return to later in my remarks. We know that in the United States and the broader context, transportation plays a key role in our desire, and voters' desire, to advance racial equity in the United States, closing the wealth gap, and expanding affordable housing. It is connecting us to opportunity. A final goal is living up to our climate responsibility. This administration, this president and vice president signed Executive Orders on the first day related to getting us through the climate crisis and related to racial equity, and so you'll hear those themes come back in my remarks. Those areas are not separate, they are interrelated. These goals—Building Back Better, racial equity, climate, and COVID—form a system.

We are here today thinking about resilience. Let's take a broad view first of resilience at the individual level, community level, even national level of the ability to prepare for, absorb, respond to, and adapt to adverse events. My remarks will be in the context of natural disasters, particularly those related to climate change.

The key role that we have to play in freight system resilience is to have the ability to resist and rebound from disruptions. In the last decade, resilience has become a fundamental paradigm. We are thinking about the risks and safety threats ranging from climate to natural disasters, but also other things like economic threats. Here we are in a pandemic, thinking about resilience as well in that context of migration and globalization. So, there are many factors for which this lens of resilience is so salient.

Agencies view resilience in preparing for incident response and also as part of system performance. My remarks will focus on climate and racial equity. We know, of course, that in the last 10 years there have been an unprecedented number of natural disasters in the United States and around the world. Even just last week we saw the *Ever Given* wedged in the Suez Canal. By many reports, it was blown sideways because of a sandstorm, and it caused delays in global freight travel. Was this sandstorm climate related or not? As more and more of these incidents occur, the preponderance of evidence leads us towards climate-caused disruptions, from bomb cyclones in the Midwest, to five of the largest fires in California history, to the record snowstorms that we just had in February that disrupted the power grid. Many of these events are also occurring during the COVID-19 pandemic, meaning that the system is experiencing compounding stressors on our physical systems, social systems, and particularly our freight system. We need to consider not just individual events, but possibly multiple events happening simultaneously.

How fast we recover from these compounding stressors depends on how quickly we can get supplies and goods to those in need. Disruptions of this type have significant economic impact on services and producers. Diversions can overwhelm highway and rail capacity, so you start to really think about multimodal congestion and bottlenecks from rail, to freight, to ports. You have compounding stressors that are stressing multimodal systems. There, at that intersection of these systems, is where there is a lot of work to be done. What is interesting is, of course, the unintended consequences of all this happening during COVID. Given the great work of BTS, we know that at the same time that passenger travel has dropped, freight and commodity flows have increased dramatically. What you see is compounding stressors for multimodal systems during a time in which freight activity has increased. So we have major challenge ahead.

I want to pivot again to COVID, because whenever we have an event like this, be it a pandemic or a natural disaster, the first thing we should consider in terms of freight resilience is what I call a shift. By shift, I mean we need to find ways to fix the inefficiencies in the system. Here is a simple example. In preparation for this meeting, I was discussing with colleagues something we've all probably done before: we order things from Amazon, and then in a given day, three different drivers show up to our homes to deliver packages. What is going on? You think about efficiency, and you think about performance. What does that mean when you have these compounding stressors in a multimodal system where you still have in the last mile three or four different drivers showing up to my home all in the same day? In some ways, fixing the inefficiencies that are in the system now will remove redundancy that can sometimes help if you are in a disaster, but at the same time it can exacerbate the performance.

Lessons from the recent recovery operations emphasize the need for disaster preparedness along with longer-term goals directed to building resilience. That also includes what I call adaptation measures. The next part of strengthening our resiliency is adapting. How we frame adaptation has moved further from a focus on how vulnerable an area is to broader, wider social and economic drivers of vulnerability and people's ability to respond. We certainly see this during COVID with fragile systems. Those who are already in underserved communities—places that were already fragile—we see now that COVID and other natural disasters magnify that disadvantage. So in our definitions of resiliency, we really do have to take a view of understanding the underlying drivers of this fragility, because some of those are mirrored in our systems that we use to deliver services, including freight.

Here, I want to pivot a little bit and talk about equity. We'll focus on equity because the focus on resilience in the transportation planning community often ignores equity concerns related to resource deficits really faced by low-income and minority communities. There has been research in the last few years and historically about the role of resilience of a system or network like the transportation system in the underlying resilience of the communities that are being served by that network. From a research perspective, and also in practice, these need to be linked together in a much more systematic way. We've seen the magnifying impact of disasters over the years. We can just go back to Katrina or Sandy. First, the hurricane hits New Orleans and low-income African American residents are hit the hardest. Well, why didn't they leave? Well, they couldn't. They didn't have vehicles, for example.

When you think about service deserts and where Walmart and other service outlets are, those oftentimes are freight hubs or nodes for delivering of services. After a disaster, supply chain interruptions increase the cost of doing business in certain areas. And so, there's a certain point that businesses may decide that the cost of disruptions to their supply chain outweighs the cost of relocating an outlet. As a result, businesses simply leave altogether, and the region suffers. If we're

talking about low-income communities, or even rural communities, where they rely heavily on some of the industry, this has the potential to wipe out large swaths of the economy. We've seen this over the years with various disasters in that interaction with the supply chain.

Sometimes we focus on the idea that a place will bounce back after a disaster, but why bounce back when we can bounce forward? We should prepare for disasters and disruptions in supply chains before they happen so they are not so brittle. Something that we have seen over and over again is that equitable communities can be more resilient. So, this is a hypothesis that I'll put forward and that other researchers have said: that equitable communities are more resilient. I think that's an empirical question that there's evidence towards that my colleagues at the University of Michigan and colleagues around the country have been investigating. The charge that I have for you all is "how does this notion of equity interact with resiliency?" We're finding that in communities and certainly for the supply chains and services that serve those communities, we need to keep that in mind as well.

Last, let me move again to the climate element to talk about improving freight. The administration is refocusing on climate and getting back to living up to our climate responsibilities. We are looking to build and utilize a variety of transportation modes that not only reflect the transportation labor market patterns and needs of our community, but cut down on our carbon footprint. Our goal—the North Star—is decarbonizing our transportation system by 2050. The DOT, Department of Energy (DOE), the Environmental Protection Agency (EPA), and many other government agencies have been charged to decarbonize by 2050. In that lens, we've done lots of work inside the DOT with our DOE partners, particularly around improving the system by switching to biofuels or synthetics, even hydrogen for long haul. Here we're talking about long haul, or even maritime, moving to synthetic or sustainable fuel sources. We are also looking at pipelines as well as we work on getting to net zero as a multimodal freight system. To do so, we need to find efficient measurements of multimodal resilience. As we talk about moving to synthetic or other more sustainable fuel sources, we want to look at the life cycle, along with the entire supply chain. When you look at the supply chain disruption in the aftermath of hurricanes, or natural disasters, the resilience of the supply chain depends on the effects specifically at bottlenecks and on lead times more than on other aspects of the supply chain. You have to measure the resiliency of the freight system, but particularly as it depends on particular nodes. I know many of us, and many of you, have looked into that, but I think having that measurement, together with a multimodal perspective can help move the needle, particularly as the science and evidence suggest that we're going to see more and more natural disasters, not just individually, but together.

So let me wrap up and close out here. One of the administration's largest priorities, as I mentioned at the beginning, is this idea of Building Back Better. A key part of Building Back Better is a system that is also resilient, both from a system performance perspective, and from the perspective of providing equitable outcomes for communities and people. That nexus and the hypothesis that equitable communities are also more resilient is one I wanted to challenge and test, and I think there's evidence towards that effect that interacts very closely with freight and how we measure freight. I look forward to continuing this conversation and dialogue in this workshop. When it comes to measuring resiliency and freight, I want us to keep in account equity, the multimodal nature of freight, and also the compounding stressors from multiple disasters that can affect systems at the same time. And so I look forward to what comes out of this this workshop in this community. It is an honor to encourage you in this work and let you know that it is important, and is something that is on the agenda for this administration.

Hurricanes
Regional Disasters, Impacts, and Responses

The Wednesday afternoon panel focused on experience and lessons learned in planning for, responding to, and mitigating against hurricane impacts. Moderator Juan Carlos Villa introduced three presenters: Edward Emmett, Bethann Rooney, and Katherine Chambers, who shared case studies from recent hurricane events. Case study presentations were followed by a response panel moderated by Casey Wells, Texas DOT, that featured John Esparza, Tom Lambert, and Katherine Chambers commenting from the perspectives of the trucking industry, a transit agency, and a federal agency. At the end of the session, the audience had the opportunity to ask questions and discuss key findings with all presenters and discussants.

HURRICANE CASE STUDIES

Juan Carlos Villa, *Texas A&M Transportation Institute, Moderator*
Alison Conway, *City College of New York, Recorder*

Edward Emmett, *Baker Institute for Public Policy, Rice University*

Emmett served as the County Judge for Harris County, Texas, from 2007–2019. County Judge is a position created by the Texas legislature post-September 11, 2001 (9/11), to designate a single authority to oversee both homeland security and emergency management. Judge Emmett discussed lessons learned from Hurricane Harvey (August 2017), as well as from two other storms, Hurricane Katrina in New Orleans (August 2005) and Hurricane Rita in Houston (September 2005) which informed practices during Harvey.

During Hurricane Katrina in New Orleans, many people were not evacuated, at least in part because assets were not repositioned to safe locations prior to the storm; for example, school buses parked in low-lying areas were floating in floodwaters. Given the devastation of Hurricane Katrina on New Orleans, when Hurricane Rita hit Houston, it was difficult to convince residents not to leave, even if they were not in harm's way. Direct storm impacts were minimal, but the disaster occurred when many people tried to evacuate at the same time. More people died from the evacuation than from the storm impacts.

Hurricane Harvey did not hit Houston as a typical hurricane, but rather as the largest rainstorm in the region's history. The storm made landfall in Rockport (about 185 mi southwest of Houston), so no Houston evacuation was expected or planned. By the time the rain started, residents could not leave. Rain overwhelmed the transportation network. State and Federal Emergency Management Agency (FEMA) assets had traveled to where the storm hit, and were stranded by roadway flooding. Thirty-six emergency sites needed supplies, but the Red Cross could not set up shelters. Drivers were initially flooded in. Ultimately, volunteer drivers were identified, some from Houston Metro. Trucks had been moved out of harm's way, but were difficult to reposition with the entire region underwater. A furniture store and UPS, among others, provided trucks to supply the shelters. Volunteers with boats were sought, an action that was not typical, as volunteers are not usually engaged in rescue operations. Private boats,

including a group of volunteers that called themselves the Cajun Navy, responded to this request. San Jacinto County (two counties north) requested state help to supply a shelter, but state assets were unavailable but Harris County responded.

Emmett identified a number of key lessons learned from Hurricanes Katrina and Rita that informed practice during Hurricane Harvey. These include

- Evacuate those that you need to, and convince others to stay where they are.
- In case of a mass evacuation, develop a quickly implementable plan for contraflow lanes.
- Plan ahead for response necessities:
  - Develop a plan for fuel distribution,
  - Have a restroom staging plan, and
  - Prepare points of distribution for ice and water.

Emmett also identified a number of key lessons learned from Hurricane Harvey:

- There is no way to prepare for that kind of rainstorm, but as soon as it is clearly happening, it is important to get key assets needed for recovery out of harm's way (as Houston Metro did with its buses).
- Median barriers worked like dams and exacerbated flooding by preventing water from flowing across highways.
- Culverts were not big enough for rainwater flows, disrupting rail transit.
- Because trucks were pre-positioned in a location (the site of the hurricane landfall) that became inaccessible due to flooding, the "entire commercial world" came to a stop. There is a need for freight systems with alternatives.
- We need to respond faster in recovery. To do so, put the right people in the right positions, and give them the authority to act.

Bethann Rooney, *Port Authority of New York and New Jersey*

Rooney began her presentation by introducing the Port Authority of New York and New Jersey (PANYNJ), which manages all international transportation modes in the New York City region, as well as systems connecting the states of New York and New Jersey. Their system includes airports (JFK, LaGuardia, and Newark), tunnels, bridges, a bus terminal, a rapid rail system, and port facilities. Port facilities include Port Newark (which was built in the WWII era) and Elizabeth Marine Terminal (which was constructed after containerization in the 1950s), as well as other facilities in Staten Island, Brooklyn, and Jersey City.

In preparation for Superstorm Sandy, PANYNJ was anticipating a heavy rain event, but with a significant storm surge due to tide and moon phase. The agency implemented its hurricane and heavy weather plan starting on Thursday, and stood up its emergency operations center on Sunday. On Sunday morning, the National Weather Service informed PANYNJ to expect a 6- to 10-ft surge (on top of 5-ft tidal variance); the agency was not prepared for a surge of that height. Facilities were closed to all but essential personnel; by noon Monday, everyone was off the port. The storm hit at about 8 p.m. on Monday night with record surge more than 10 ft above the mean high-water mark at 15 to 16 ft of water. During the storm, there was not much to do but sit and

wait and see what happened. After waters receded, managers found standing water in buildings, raw sewage, water main breaks, pipeline breaks at adjacent facilities, rail track upended, security systems destroyed, and fence lines gone. It looked like Armageddon.

Specific impacts on freight operations included

- Many of 40,000+ on-site containers were toppled like matchsticks. Many were destroyed by water pressure, and others were in the water. These had to be counted manually before reopening the harbor.
- Automobiles, which were parked on the pavement, not stacked, were flooded; 12,000 were destroyed.
- Electric cars and drayage trucks spontaneously combusted from contact with salt water, leading to fires all around the facility. Over 150 brand new $200,000 drayage trucks were destroyed.
- In the 2 mi2 between the port and Newark Airport is the I-95 Corridor (New Jersey Turnpike) and rail and pipeline facilities, including a main thoroughfare for chlorine distribution, which was inundated with water.
- Seventy-two cranes (costing $18 million each) used for loading and unloading ships had to have motors taken out, cleaned, dried, and lubricated; the time required to fix them delayed recovery.
- A 110-ton barge was lifted onto the dock; other barges were lifted onto the New Jersey Turnpike. Another barge broke in half and floated to the middle of the harbor.
- Fifty-seven vessels were diverted to other east coast ports.

Leadership anticipated it would take months to get back into operation, but actual recovery was much faster. PANYNJ immediately assessed damage. The biggest impediment to recovery was the port's prioritization by utility companies. Although operations were vital to regional recovery, the port was considered lower priority for restoration than other facilities (e.g., hospitals, nursing homes, dense residential areas). By the end of the week, the U.S. Coast Guard (USCG) reopened the port to vessel traffic. However, PANYNJ first needed to assess the capacities of the port facilities and transportation network to distribute cargo and ensure that security measures were in place. The first vessels returned to the port by the following Sunday, and the port was reopened for limited truck and rail access by Monday. Across the agency, recovery is still ongoing today (e.g., tunnel repairs).

Rooney noted that it is critical that PANYNJ be able to sustain its own operations so that it can be part of broader supply chain recovery efforts. She noted that part of this is making sure that employees can come to work, and that their families are taken care of so that they can focus on recovery efforts. She shared a number of key lessons learned from the recovery period.

- Having a good emergency communications plan infrastructure in place is critical; keep paper copies of contacts, maps, forms, etc.
- Have a game plan to get essential personnel out of their neighborhoods and on site.
- Provide sufficient advanced information and industry will respond.
- Emergency broadcast messages must be concise enough for both e-mail and text formats.
- Qualifications of personnel responding to assist in recovery is more important than the number responding.

- Availability of traffic and street lights is critical to recovery; work can be done on a 24-h basis versus daylight hours only.
- Must document baseline power requirements for each facility and each tenant beforehand; will facilitate procurement of temporary generators.
- Procure additional fuel supply in advance of an event; can't do anything without the fuel and electrical grid.

Looking ahead, planning and rebuilding is considering climate risk (including sea level changes as well as temperature and precipitation changes). Specific actions include

- Ensuring that local and regional emergency response plans include recovery of the supply chain.
- Agencywide construction guidelines for climate resilience, which are updated on an ongoing basis.
- An asset management system that prioritizes critical infrastructure elements based on impacts (impaired, directly affected, disabled), which enables informed decision-making about protection, retrofits, elevating assets, etc.
- Policies and procedures to raise equipment to higher levels (e.g., traffic signal control panels, refrigerated cargo).
- Upgraded crane tie-downs, which are put in place in advance of heavy winds (30 to 35 mph).

Katherine Chambers, *U.S. Army Corps of Engineers*

Chambers began her presentation by defining resilience as a four-step process occurring over time (Figure 1). Her presentation focused on one of these steps, adaptation and evolution, from a federal agency perspective. Along with partners at the National Oceanic and Atmospheric Association (NOAA) Office of Coastal Management, Chambers co-led the Resilience Integrated Action Team (R-IAT), established in 2014 by the U.S. Committee on the Maritime Transportation System (CMTS). CMTS is a coordinating board for over 25 agencies involved in management and operation of the nation's marine transportation system (MTS). The CMTS tasked the R-IAT with a review of lessons learned from the 2017 hurricane season and this request has extended for subsequent hurricane seasons. For each hurricane, the R-IAT was asked to gather information from regional stakeholders and discuss the challenges faced, successes, and lessons learned. The group published findings in a report on the 2017 hurricane season (*1*). This effort was repeated for the 2018 and 2019 hurricane seasons (*2*), and a report on balancing the COVID-19 pandemic with the challenges of the 2020 hurricane season is forthcoming.

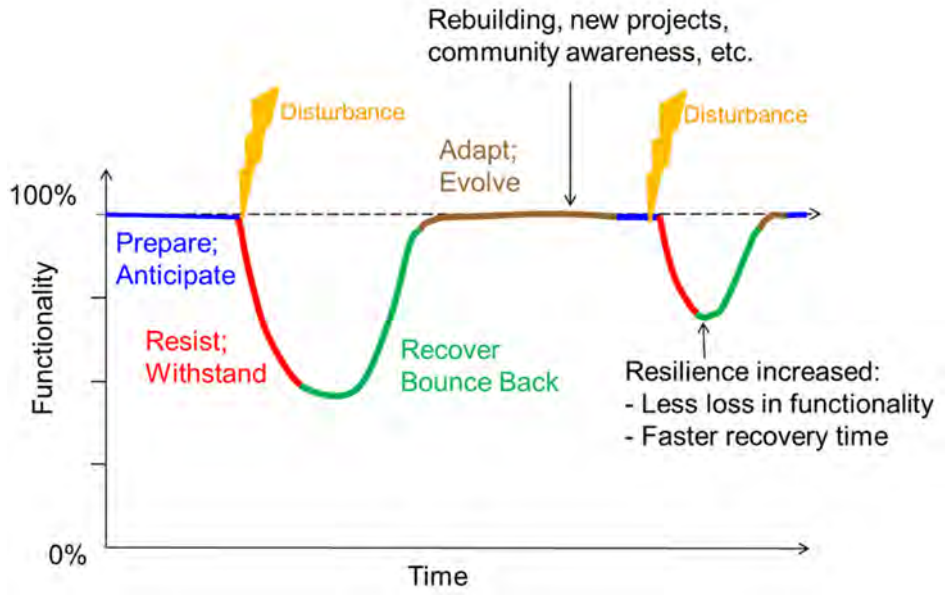

FIGURE 1 Components of resilience (*3*).

Chambers summarized lessons learned from six hurricanes, three during 2017 and three in 2018–2019. She noted that while this discussion focuses on impacts, there are also many successes described in the team's published findings. During the 2017 hurricane season, at least 45 ports in the lower continental United States and territories were impacted by three storms: Harvey, Irma, and Maria. Key challenges identified from these events:

- Harvey:
  - Occurring in August 2017, this storm primarily affected southeast Texas and southwest Louisiana. Four days of rain from the stagnant storm resulted in catastrophic flooding in the Houston Metro area and throughout east Texas.
  - There was a general lack of data, and limited availability of condition or status information from the Port of Houston and other Gulf Coast ports.
  - A lacking reporting structure created bottlenecks when first responders were continually asked to share reports or provide status updates, both to other agencies and to the public.
  - There was no centralized location for information communication.
- Irma:
  - In September 2017, U.S. territories impacted by Hurricane Irma included Puerto Rico, the U.S. Virgin Islands, and Florida.
    - Although it did not make landfall, the storm caused widespread damage in Northern Puerto Rico and the U.S. Virgin Islands.
    - Florida landfall resulted in widespread residential and agricultural damage in central and southwest Florida and the Florida Keys.
  - There were major power outages exacerbated by issues with debris removal.
  - There was a need to balance demands for space in crowded waterways for commerce, tourism, and emergency response, especially in the U.S. Virgin Islands and Puerto Rico.

  - Due to the changing storm track, there was difficulty pre-positioning equipment in Florida.
  - Available resources and funds were constrained because this event immediately followed Harvey and occurred while wildfires were ongoing in the west.
- Maria:
  - Hurricane Maria made landfall as a Category 4 storm causing widespread wind damage and flooding throughout Puerto Rico. Response was challenged by geographic constraints as well as enduring communications and utility outages.
  - The same challenges that occurred during Irma also occurred during Maria.
  - Although the Port of San Juan was open, there was a lack of storage capacity because the roads into the port were cut off and electricity was not moving. As a result, goods could not leave the port.
  - Due to utility failures, response had to start on paper; by the time power was restored, there were hotel conference rooms full of boxes of paper forms. Significant effort was needed to enter these into spreadsheets.
- Florence:
  - Hurricane Florence made landfall in North Carolina in September 2018. Heavy rain resulted in dam failures and widespread inland and coastal flooding in North and South Carolina. The storm also spawned tornadoes in southern Virginia.
  - Uncertainty in the location of landfall made it difficult to pre-position assets.
  - After landfall, there was a narrow window of opportunity to respond before inland flooding began.
  - Restoring the port to full navigational depth was a challenge due to downed bridges and debris, and strong currents prevented divers from investigating the debris.
  - National response was cut off and utilities (including cell service) were unreliable for several days; responders relied on radios.
  - Having a MTS professional co-located with FEMA enabled much more rapid communications.
  - The USCG's Common Assessment and Reporting Tool (CART) was only as good as the information feeding it; there is a need to validate that information.
- Michael:
  - Michael was a rapidly moving storm that quickly destroyed a very isolated area.
  - There were many communications issues due to downed cell service.
  - It was difficult to coordinate surveying assets along the intercoastal waterway.
  - There were uncertainties in projection of impacts as the storm moved across the southeast.
- Dorian:
  - In September 2019, Dorian devastated the Bahamas, but produced considerable uncertainty in where it would make U.S. landfall. This required widespread planning for potential landfall from Miami to Morehead City, North Carolina.
  - Ultimately, the storm made landfall in North Carolina's Outer Banks. Hurricane and tropical storm force winds and spawned tornadoes caused building, tree, and utility damage in North and South Carolina and Florida.

Chambers provided several examples of how data can be used to visualize impacts. The four port conditions during an impending hurricane are:

- Whiskey. Gale force winds expected to arrive within 72 h. Ports are open to all traffic.
- X-Ray. Gale force winds are predicted to arrive within 48 h. Ports are open to all traffic, but oceangoing vessels greater than 500 tons must prepare to depart the port.
- Yankee. Gale force winds are predicted to arrive within 24 h. Ports are closed to inbound traffic and oceangoing vessels greater than 500 tons are required to depart the port.
- Zulu. Gale force winds are predicted to arrive within 12 h. Ports are closed to all inbound and outbound traffic.

Figure 2 shows a series of heat maps developed using vessel Automatic Identification System (AIS) data; they depict these conditions during Hurricane Harvey. Vessels can be observed leaving the port after declaration of Yankee. During port closure, no vessels are observed. Upon reopening, queuing at the harbor is evident. Figure 3 shows net vessel counts at affected ports during different phases of Hurricane Florence.

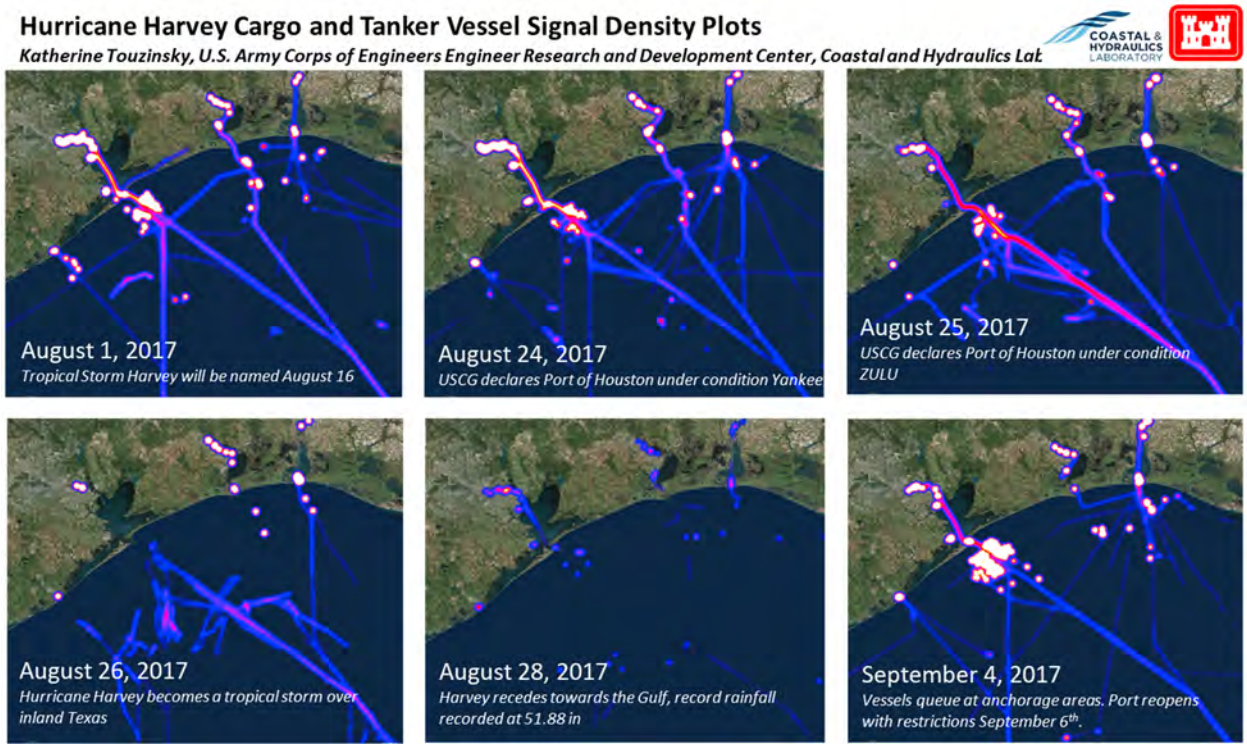

FIGURE 2 Hurricane Harvey cargo and tanker vessel signal density plots (*4*).

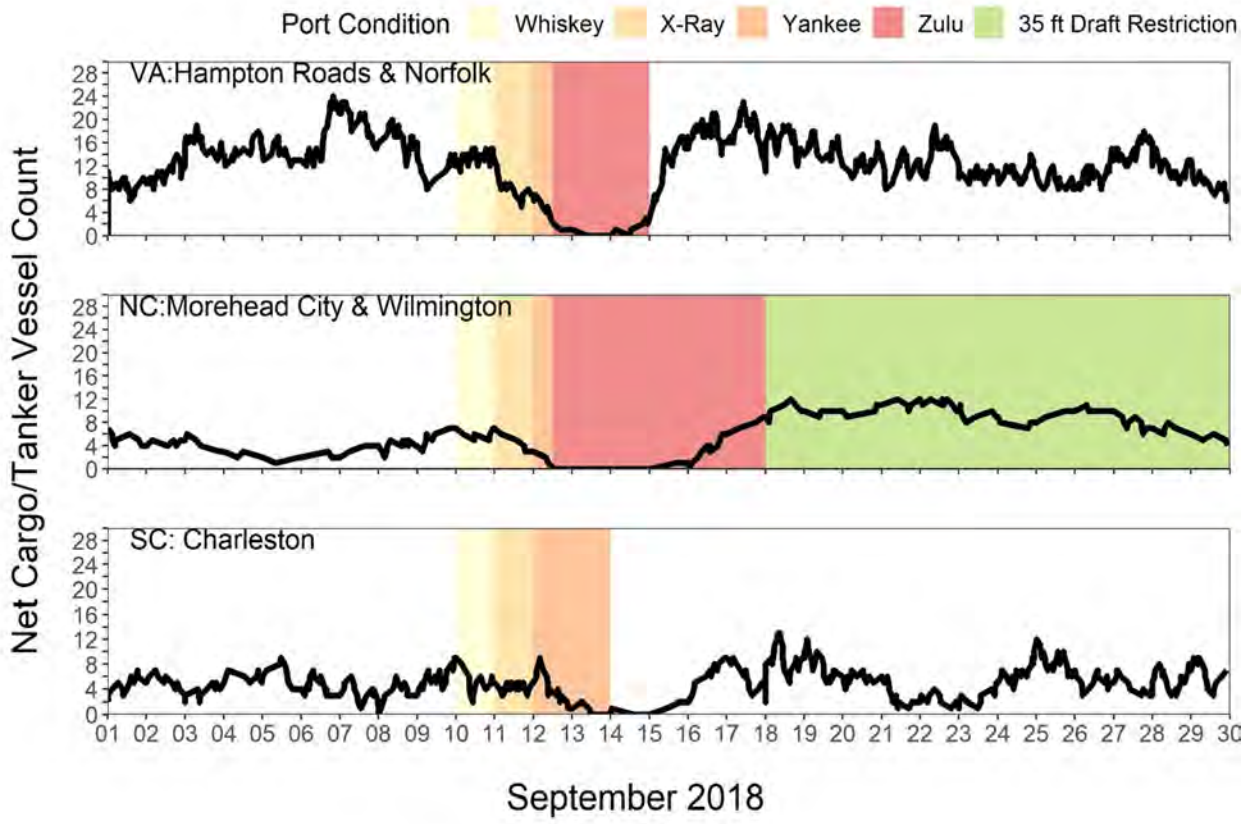

FIGURE 3 Hurricane Florence impacts on port traffic for Hampton Roads and Norfolk, Virginia; Morehead City and Wilmington, North Carolina; and Charleston, South Carolina.

Chambers identified a number of best practices for response and recovery identified from both the 2017 and 2018–2019 reviews:

- Good communications are critical; examples include:
  - Holding a kick-off meeting at the start of the hurricane season.
  - Conducting full-scale hurricane exercises.
  - Establishing area–port coordination committees.
- Interagency efforts for navigation channel reopening are constantly being coordinated and improved.
- Advanced tabletop exercises combined with local knowledge can be effective in establishing lines of coordination and to inform pre-prioritization of recovery assets.
- Co-locating and working together during a storm is very effective.
- Sharing useful tools across agencies (e.g., the USCG's CART) tool can pay dividends.
- Rapidly deployed unmanned aerial systems (UAS) have improved pre- and post-storm assessment capabilities, and electronic aids to navigation (e-ATONs) can also be implemented more quickly than analog systems.

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HURRICANE RESPONSE PANEL

Casey Wells, *Texas Department of Transportation, Moderator*
Alison Conway, *City College of New York;* **Karla Diaz Corro** *and* **Sanjeev Bhurtyal**, *University of Arkansas, Recorders*

John Esparza, *Texas Trucking Association*

Esparza presented a response to the hurricane panel from the perspective of the trucking industry. He primarily focused on the importance of communications. He noted that during Hurricane Harvey, the Houston TranStar Center served as a “central nervous system” to coordinate response across agencies, but that for trucking, it is not possible to coordinate in that way. For trucking, logistics is how they survive. When a storm “throws a curve,” everything can come to a complete stop, and disruptions can have multiplying effects. To illustrate this point, he provided an example of a company operating during Hurricane Harvey. The company, which hauls fuel, had a fleet of 125 tank trucks and employed 100 drivers. In the 12 to 24 h after the storm hit, the company was trying to fulfill the region’s need to transport pre-positioned fuel. However, due to the flooding, only 26 of these trucks were available, and of those, only 11 could make it to the intended destination to pull fuel from a rack. When they arrived, only three of these trucks were able to pull fuel from the rack because other trucks had already pulled the daily allocation for the intended receiver.

He noted the importance of sharing experience across the trucking industry, recognizing that during Harvey and other events, carriers that had been through previous events were more effective in their response. He noted that Texas Trucking Association (TXTA) served an important function, enabling companies to communicate with each other. Recognizing the importance of this, TXTA has developed a Crisis Communications Plan as an association to help smaller companies and has begun to conduct related educational programming. He highlighted the importance of establishing methods of communication when utilities fail to check in with and ensure the welfare of employees, as well as to communicate with relevant authorities managing emergency response.

He also noted that trucking cannot do it alone; effective response requires collaboration with multiple stakeholders and efficient and effective movements by all modes. He discussed the importance of communications in coordinating resources, highlighting the role of the American Logistics Aid Network (ALAN), which serves as an intermediary between industry and disaster relief organizations to request equipment and services. One example of the type of help the trucking industry was able to provide to ALAN was the sanitizing and repurposing of tankers to haul water to hospitals in South Texas and in the state's metropolitan areas when their water was cut off. He reiterated the importance of keeping lines of communication open to effectively engage volunteers.

In addition to communications, he touched on two other themes. First, he noted that trucking companies continue to learn from events ("necessity is the mother of invention") and are daily adjusting ways in which they operate to better prepare for future events (e.g., loss of power, storm), including through the development or adoption of new technologies. Second, he echoed earlier comments by Chambers and Rooney about the importance of pre-positioning supplies. He provided examples including stockpiling bottled water and storing fuel—both diesel for trucks and gasoline for employees—to ensure continued operations.

Thomas Lambert, *Houston Metro*

Lambert discussed the role of a transit agency in supporting the broader community in recovery and response, as well as the need to prepare the organization itself to assist the community. He thanked the panelists for framing the issues, and reiterated Esparza's point that institutional knowledge needs to be retained and is important to transfer to others moving forward. He complemented Emmettt and Houston Mayor Sylvester Turner for strong and transparent leadership, which provided critical clear messaging to the public during Hurricane Harvey.

He provided a timeline of Metro's storm preparations, which included:

- Participating in the launch of the Emergency Operations Center (EOC) at Houston TranStar, implementing early outbound park and ride services, and moving assets to higher ground prior to the storm.
- Monitoring events from TranStar.
- Suspending services.
- Maintaining volunteer operators at all facilities during flooding, and providing support to these staff.
- Assisting local and regional partners in transporting flood victims to safety and shelter.
- Restoring service as quickly as possible, starting with an assessment of all facilities. Out of 1,248 buses, only 20 were damaged. Facility damages were minimal, with the exception of electronic equipment in high-occupancy vehicle lanes.
- By mid-week, services were restored for medically important trips, and a day later, limited route service was restored. By the following Tuesday, all service were restored except those in areas still impacted by high water. These routes required adaptation.
- Recognizing that the storm had impacted many cars, the agency implemented a number of services, including free rides to school and free rides for parents to pick up kids from school.

Lambert stressed the critical importance of stakeholder communications before an event occurs. He noted that TranStar, Houston's combined traffic/emergency management center, was a partnership between the City of Houston, Harris County, the Texas DOT, and Houston Metro, and that the agencies jointly fund and operate the center on a daily basis. He provided several examples demonstrating the importance of existing partnerships, including:

- Prior to the storm the agency recognized that their buses did not perform well in high water. Working with partners from Harris County Transit, they were able to use school buses to evacuate neighborhoods. They had also secured 300 high-water rescue vehicles to support first responders. These vehicles could transport individuals to school buses, which then transported them to city buses for travel to a shelter.
- They also worked with the city and county to use Metro contractors to clear roadway debris.
- Texas DOT provided maps showing closed roadways and alternate routes, which enabled Metro to work with their police department to escort Red Cross vehicles to shelters, transport 15,500 people to shelters, and transport those individuals living in shelters for necessities such as groceries and pharmaceuticals.
- All communications were coordinated through the EOC managed by the Harris County Office of Emergency Management at TranStar. This enabled clear communication with the public and with employees.
- He noted that pre-positioning 120 buses to higher ground was done at the recommendation of maintenance staff. This saved the agency about $6 million in losses and allowed the buses to return to service.
- After sustaining about $15 million in damages, Metro worked with the Federal Transit Agency and FEMA to identify and secure funding to restore facilities. The agency provided about $2.3 million in services to the community during recovery.

In closing, Lambert reiterated the importance of having the right people in the right positions to be flexible and adaptable to changing conditions. He also emphasized that it is critical to pre-plan for emergencies so that when they occur, there are clearly defined roles for established partners.

Katherine Chambers, *U.S. Army Corps of Engineers*

Chambers offered additional insight on the panel from a federal perspective. She emphasized the importance of adaptation across multiple seasons, noting that best practices should be continually evaluated, and providing examples of lessons learned from the 2017 hurricane season that were applied as best practices during 2018–2019. Getting people in the room together who would not normally talk is also critical. While sharing after-action reports is common in some regions (e.g., Texas), it is not standard practice everywhere. She noted that data sharing is always a sticky subject, but there are some examples of successes. She again reiterated the importance of embedding experts in the MTS where possible.

In closing, she returned to the four-phase definition of resilience defined in her previous presentation to identify key themes during each step of preparation, resistance, recovery, and adaptation. To prepare, agencies should

1. Establish interagency relationships before an event;
2. Establish contracting mechanisms for emergency response operations;
3. Pre-prioritize specific infrastructure and services;
4. Identify staging and storage areas for equipment, fuel and supplies; and
5. Hold regular training and drills, involving local and subject matter experts.

During resistance and recovery, agencies should

1. Share data across agencies through interagency teams and data sharing platforms;
2. Regularly update data as response evolves (integrating new technologies as needed); and
3. Maintain a flexible workforce that can continue to operate during emergencies.

During adaptation, interagency after-action reviews should be conducted. Agencies should communicate with each other about challenges, successes, and lessons learned, and should have access to a common operating picture of vital information.

AUDIENCE DISCUSSION

Following both the case studies and the response panel, the audience had the opportunity to ask questions of the panelists. First, an audience member asked the panelists what we know about the utility of heavy-duty drones. Emmett noted that drones are extremely useful for conducting appraisals and investigating debris. He also noted that technologies in general are critical. For example, during Hurricane Harvey, it was difficult to keep track of where residents were placed after rescue. Now, in case of displacement, individuals are given radio frequency identification chips so that they can be located.

Panelists were next asked how to prepare for something you have never seen before. Several respondents emphasized the importance of having the right people in charge and preparing your staff to respond to uncertainties. Preparation includes mentally preparing staff to respond to emergencies, having everyone understand a common goal, conducting tabletop exercises to practice solving new problems, learning from experience in other locations, and coordinating with regional partners to define individual roles. It is important to let trained experts make decisions and act in an emergency, and to the extent possible, to limit second guessing from public officials and the media.

Panelists were then asked if planners with freight expertise were engaged in planning, response, and recovery, noting that sometimes freight planners and emergency planners “speak two totally different languages.” Rooney agreed that freight and emergency planners often do not “speak the same language”, but noted that after 9/11 the need for coordination between these groups in the New York–New Jersey region became obvious. For more than 20 years, these stakeholders have collaborated, especially on metropolitan planning organization freight plans. Ports had to be embedded in the freight plans, and that conversation has evolved to also include emergency response.

Next, panelists were asked to identify the top one or two challenges facing us as we work to implement lessons learned. A related question asked how we translate lessons learned from response into better planning to prevent disruptions from occurring in the first place. In response to

these questions, panelists identified a number of factors that could impede progress. These include difficulties in coordinating across agencies to maximize community benefits, partisan agendas, and the "invisibility" of freight to the general public. Several panelists identified a lack of political will to invest in solutions until a disaster occurs, although another panelist noted that if agencies can identify potential improvements in advance of an event before the timeline becomes intense, they may be able to take advantage supplemental funding that comes through during a disaster. Finally, a panelist noted that the ultimate goal of resilience planning is to serve and protect communities, and that doing so in the context of social justice, equity, the environment, climate, and other factors makes it a "wicked" problem to which there are no clear solutions.

An attendee asked panelists if agencies and supply chains were looking at (1) multimodal issues, like integration of resilience planning among roads, rails, ports, and airports and (2) potential long-term changes like integration of electric vehicles and changing weather and climate impacts. A panelist noted that it is the interest of each mode in the supply chain to coordinate with other modes to optimize overall system functionality, and that technology will play a role in enabling that coordination. Another panelist noted that intermodal facilities like ports already must coordinate across modes to maintain competitive operations, but that governments are not always privy to the details of this collaboration. This can result in uncertainties when considering investment decisions (e.g., investing in harbor deepening to accommodate larger ships without understanding planned landside capacity improvements). Schofer noted that intermodalism is a way to achieve some kind of redundancy, but that to take advantage of this during a disruption, we need to understand the system and how the pieces are connected. This process should not rely just on emergency responders, but also on people who really have strong domain knowledge.

Panelists ended the discussion noting that COVID has changed the discussion, increasing broad recognition of the important role of freight in supporting communities, but also establishing uncertainty in what will be the long-term impacts. As commuting patterns change, there may be an opportunity to re-envision the transportation system as a freight-focused system.

Schofer, with input from audience members, closed the session reviewing common themes discussed throughout the day. He noted that communication is at the core of responding. Knowing agency and industry partners prior to a disaster helps to facilitate collaborative response. Tabletop exercises are a difficult but effective way to do that. Learning from the experience of others is also important. For example, experiences during Superstorm Sandy revealed interdependencies and electric vehicle vulnerabilities that could inform planning in other locations. Having the right resources, pre-deploying them to the right locations, and being able to explain why we are doing so is also a critical function. Data and information sharing is important, and can be facilitated with common data language and shared databases. Given the complexity of freight systems, it is important to engage those with domain knowledge in emergency planning and response.

COVID-19
A Global Disruption

The first panel on Thursday afternoon discussed COVID-19 impacts on freight transportation systems. Moderator Joe Bryan introduced four presenters: Laura Mester, Adam Rod, Dan Horvath, and Josh Murphy, who shared COVID-19 case studies. The same presenters then had the opportunity to discuss common themes and lessons learned on a panel moderated by Alison Conway. At the end of the session, the audience had the opportunity to ask questions and discuss key findings.

COVID-19 CASE STUDIES

Joseph Bryan, *WSP, Moderator*
Alison Conway, *City College of New York;* **Jonathan Regehr**, *University of Manitoba, Recorders*

Following opening comments by Schofer, Bryan opened the panel, noting that COVID-19 presented a unique disruption to freight systems. Its global impacts are unprecedented in breadth and duration. While physical infrastructure has been unaffected, changes to the management of the system have been transformational. He then introduced the speakers.

Laura Mester, *Michigan Department of Transportation*

Mester discussed the impacts of COVID-19 on the funding and financing functions of Michigan DOT. In March 2020, the governor of Michigan issued an executive order suspending "all activities not needed to sustain or protect life." At the same time, goods delivery was transformed. With the state's transportation revenues almost entirely dependent on fuel consumption, immediate and ongoing demand changes imposed considerable uncertainties. This occurred during the budgeting cycle for 2021. The agency had to identify what resources were needed to support programs that typically receive funding from sources that were not constitutionally protected from state redistribution for other uses.

To maintain a balanced budget without impacting capital programs, the agency undertook a number of financial actions, including $95 million in administrative cuts, statewide employee furloughs (for 10 weeks, 2 days per week, which were covered under a state unemployment program), and initial issuance of the Rebuilding Michigan Program—one of the state's largest ever bonding programs ($800 million). Tax revenue from commercial traffic helped to sustain state operations, including both capital and administrative programs. The National Performance Management Research Dataset was used to map traffic flow; results indicated that trucks continued to use the same network during COVID-19 (Figure 4). Critical international border crossings remained open, but operations were affected by safety protocols. At the project level, utility coordination and community impacts had to be considered. Related financial and nonfinancial decisions are ongoing. With a national pandemic, there is "strength in numbers" as many states are facing the same challenges. Although responses varied by state, they learned

from each other coordinating with the American Association of State Highway and Transportation Officials (AASHTO). The federal response is addressing this as part of a long-term infrastructure program. While revenues may not completely rebound, the state can address challenges—especially freight investments—with creative solutions.

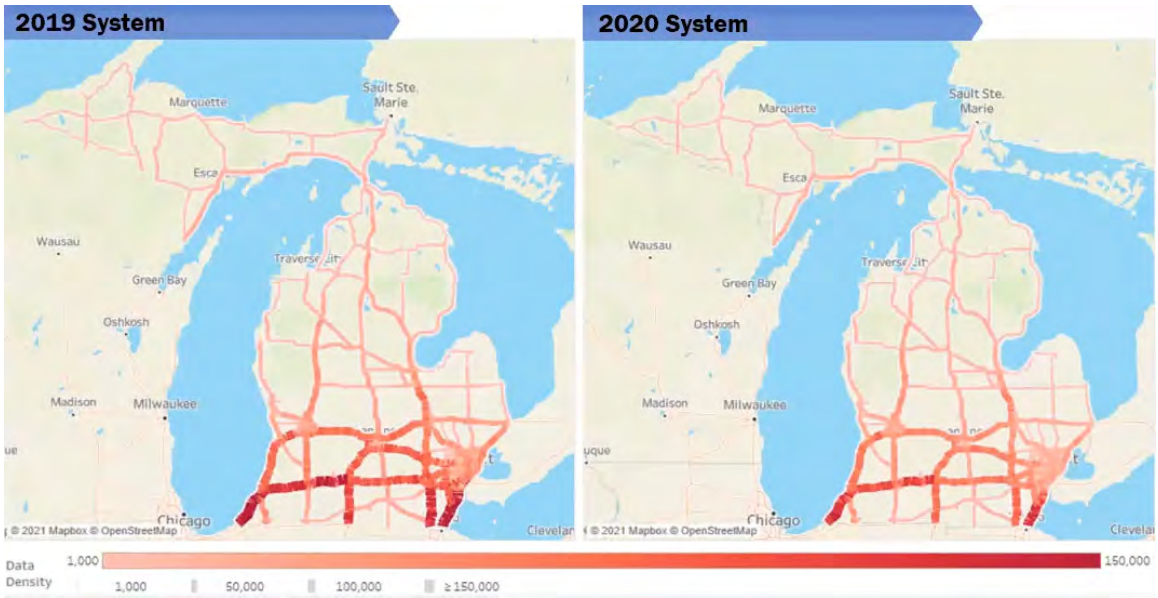

FIGURE 4 Michigan truck traffic flows, 2019 and 2020.

Adam Rod, *Chicago Department of Aviation*

Rod discussed COVID-19 impacts on air cargo operations at Chicago O'Hare Airport, which is managed by the Chicago Department of Aviation (CDA). The CDA is part of the city's government, but it operates like a self-sustaining corporation. The city of Chicago is historically a cargo hub for water and rail, and recent growth in air cargo continues this tradition. Chicago O'Hare is the top U.S. general cargo gateway by value. Even prior to the pandemic, traffic was growing due to its global capacity and reputation. The airport's recently completed capital program developed new and reconfigured runways for passenger and freight traffic. The current capital program aims to expand passenger terminal capacity and improve connectivity to highways and transit.

Under normal operations, cargo moves both via cargo planes and in the belly of passenger planes. During COVID, the latter was a challenge due to reduced passenger traffic (initially declined by 95%). Coronavirus Aid, Relief, and Economic Security (CARES) Act funds supported airlines and airports, but not concessions and other partners. At the same time that passenger travel was reduced, cargo volumes increased substantially; these included movements of pandemic-specific goods like personal protective equipment (PPE) coming from China. Prior to the pandemic, e-commerce was 10% to 15% of all retail transactions. By spring 2021 these increased by more than 50% compared to 2019. Several years' worth of projected growth was compressed into a few months. To meet demands, 150 airlines converted hundreds of passenger planes to freighters. Amazon began operations at the airport in 2020; activity has

since tripled. Strong cargo demand has resulted in more crowded operations on the airfield. The airport anticipates a substantial role in vaccine distribution over the coming months.

Rod summarized a number of key lessons moving forward. First, airports can no longer treat cargo operations as secondary. Second, airports will continue to recover and thrive, but support is needed for tenants. Finally, airports need more cargo capacity development, but must balance this with recovery efforts. Capital planning must remain prudent due to revenue losses.

Daniel Horvath, *American Trucking Association*

Daniel Horvath discussed COVID-19 from the perspective of the trucking industry, specifically addressing the issues identified and activities undertaken by the American Trucking Association (ATA) to support its members. The ATA is the largest trade association for the trucking industry in the United States. In March 2020, the ATA formed a task force to address emerging COVID-related challenges. In addition to basic issues like communications with members and staff, the ATA addressed several specific concerns that emerged for its members.

Despite the nation's reliance on the trucking industry for basic necessities, many state and local activity restrictions and shutdowns did not initially consider needs for goods movement. For example, in Pennsylvania, all rest stops were shut down, preventing drivers from accessing necessary services and from having a place to take rests mandated by hours-of-service regulations. New York City initially required those entering from out-of-state to quarantine for 14 days; it was not initially clear if this applied to truck drivers. In Utah, drivers were required to complete a survey listing every state they had visited in the last 14 days, a difficult challenge for a long-haul operator. These policies revealed a need to educate lawmakers at the state level about trucking industry operations. The #thankatrucker campaign helped to spotlight and provide recognition to the industry.

U.S. DOT was a great partner to the trucking industry in helping to obtain waivers to a variety of requirements (e.g., hours-of-service, expiring medical certifications for licenses) that were difficult to fulfill while rest areas and government offices were closed. The Cybersecurity and Infrastructure Security Agency (CISA) also designated truckers as essential workers, allowing them to continue to cross international borders. The trucking industry also played a critical role in vaccine distribution. During the initial phase of distribution, it was important to define temperature control requirements, as well as licensing and security requirements for drivers.

Throughout the pandemic, driver health was a major concern. ATA worked with hotel chains to identify facilities in case an out-of-state driver tested positive. When vaccines became available, truck drivers were designated by the Centers for Disease Control and Prevention (CDC) for prioritization in Group 1C—high priority, but not considered as critical as some other essential workers. Once states had vaccines available, distribution issues such as how a driver needing a second dose could obtain one out-of-state had to be addressed. ATA is currently working on establishing mobile vaccination clinics at truck stops and state-run facilities. The organization sought exemptions for team drivers to in-vehicle mask requirements. ATA is continuing to work on Occupational Safety and Health Administration (OSHA) standards.

Joshua Murphy, *National Oceanic and Atmospheric Association Office for Coastal Management*

After reviewing the four components of resilience, Murphy discussed the impacts of COVID-19 on the MTS. He noted that the data are still being examined, but so far, several impacts have been identified. Containerized and break-bulk cargo are down 25% to 27%, not including the cruise industry. Demand for petroleum fell "through the floor;" the industry stored unutilized petroleum in vessels anchored offshore of the Gulf and Pacific Coasts. Diminished activity began to rebound at the end of the summer and fall (Figure 5). He noted that in 2020, COVID was an exacerbating factor to a busy hurricane season with 30 named storms.

Successful risk mitigation measures identified from prior hurricane seasons included co-location and in-person meetings prior to the hurricane season. Those have been challenged by COVID. Agencies have been working on how to ensure virtual data flow, efficient and effective collaboration in a virtual environment, and use of tools like the Coast Guard's CART to enable clear information sharing across agencies. They have also been looking at new technologies such as virtual ATONs (vs. physical marks on channels) and autonomous underwater vehicles that can be used for surveying. The Resilience Integrated Action Team (R-IAT) is currently working with federal agencies to understand what is working, and what is not, for hurricane response during COVID.

COVID-19 PANEL RESPONSE AND AUDIENCE DISCUSSION

Alison Conway, *City College of New York, Moderator*
Jonathan Regehr, *University of Manitoba,* **Sanjeev Bhurtyal,** *University of Arkansas, Recorders*

Panelists participated in a moderated discussion of common themes, lessons learned, remaining challenges, and data and research needs. First, the panel discussed anticipated long-term transformational changes from the pandemic. Potential issues identified included continued work-from home for the basic workforce, use of virtual communications technologies for stakeholder coordination, continued digitalization of processes (e.g., paperwork for hazmat shipments), permanent changes to modified regulations (e.g., on-line license renewals), and new safety requirements on construction sites. A panelist noted that at airports, there is a renewed focus on freight; passenger airlines will be increasingly focused on goods movement, and airports will be looking at improvements for cargo handling.

Next, the panelists discussed the data sources used to measure changes and activity during the pandemic. Panelists noted that they used many of the data sources used under typical operating conditions to monitor activity. These include highway traffic monitoring data, airport passenger and freight traffic data, freight volume and tonnage data, vehicle inspection and violation data, and AIS data. Michigan DOT used gas consumption and revenue data to establish projections, and the ATA took advantage of real-time crowdsourced information from drivers. As a follow-up, the panelists discussed what information was needed, but missing. They identified timeliness of data as a problem (updates were needed daily), and noted difficulties measuring adapted–atypical operations and their impacts; for example, activities of transit agencies conducting food deliveries were difficult to measure, as were the economic impacts of trucking. One panelist pointed out that 2020 statistics would be of limited value for future projections, and another noted that there is a persistent gap in linking maritime and terrestrial data.

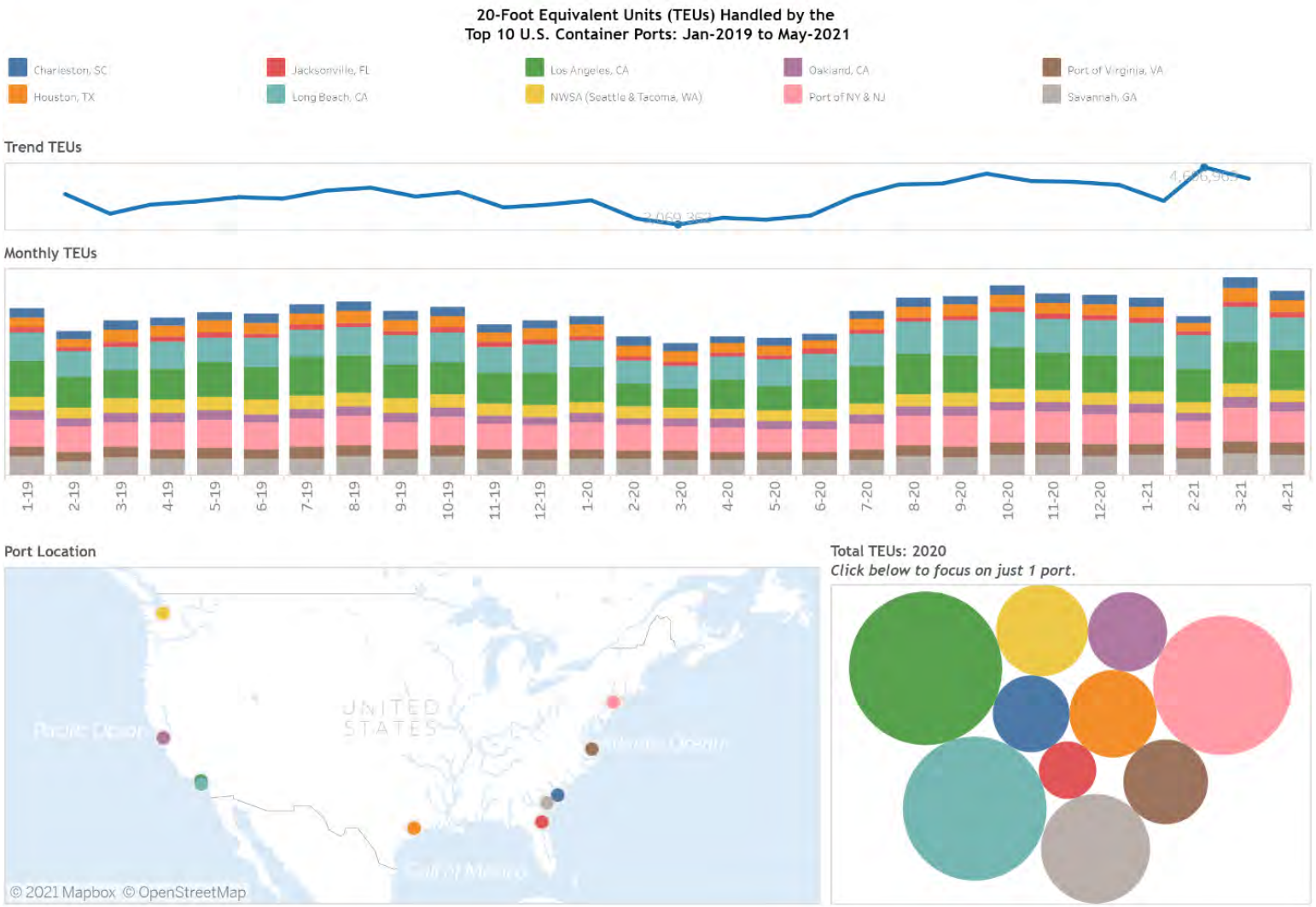

FIGURE 5 2019–2020 container port activity. (Source: BTS. Container Port Activity Dashboard. U.S. DOT, 2021.)

When asked how changes in passenger traffic affected the freight system, panelists noted that in air, cargo operations and passenger operations are typically segregated, although belly cargo was affected by reductions in passenger travel. On highways, collision frequencies and severities increased due to more speeding and driving under the influence; some highway routes became less congested for freight; and some construction projects could proceed more quickly, but neither of these is expected to remain a long-term impact. When asked if the pandemic has accelerated the push for automation, panel members noted that there is likely an increased role for automation in information collection (e.g., surveying), warehousing, and possibly in terms of driverless vehicles, but that drivers will likely still play an important role in the future.

Panelists provided several direct responses to audience questions:

- Michigan DOT's $95 million in cuts was achieved through furloughs and hiring freezes.
- Pre-pandemic trucking industry driver shortages were exacerbated by closure of training schools and delays in credentialing.
- Several states were proactive in supporting drivers. Nevada was the first to define drivers as frontline workers; Iowa and Arkansas both established programs to provide lunches to drivers at weigh stations; Texas provided critical support to resolve cross-border challenges; and New York was responsive to concerns about quarantine rules.
- Several states tried to amend their truck size and weight regulations to increase limits.
- Plane storage was a major challenge at space-constrained cargo hubs, and smaller trucks/vans are wreaking havoc at airports.
- The Ports of Los Angeles and Long Beach were identified as a bottleneck for containerized traffic; more coordination between ports is needed to improve resiliency.

Panelists identified two areas of future research needs:

- Airports need to better understand the e-commerce transformation, which is unlikely to subside post-COVID.
- Work is also needed on the safety impacts of regulatory waivers for trucks to better understand if changes should become permanent.

Wildfires
Impacts on Transportation, Logistics, and Infrastructure

The second Thursday afternoon panel discussed experience and lessons learned in planning for, responding to, and mitigating wildfires. Moderator John Contestabile introduced four presenters: Craig Hurst, Francisco Castillo, Eric Fredericks, and Monika Stoeffl, who shared case studies from wildfires in Colorado and California. Contestabile then moderated a response panel discussing common themes and lessons learned. At the end of the session, the audience had the opportunity to ask questions and discuss key findings.

WILDFIRE CASE STUDIES

John Contestabile, *Skyline Technology Solutions, Moderator*

Alison Conway, *City College of New York;* **Karla Diaz Corro**, *University of Arkansas;* **Sanjeev Bhurtyal**, *University of Arkansas, Recorders*

Contestabile opened the session. He noted that wildfires are unique from other types of events in that many of the routes around a wildfire in the western part of the United States will add hours (if not days) of travel. He also noted that wildfires seem to be increasing in frequency, intensity, and scale. He then introduced the session's three speakers.

Craig Hurst, *Colorado Department of Transportation*

Hurst discussed best practices from Colorado for understanding challenges before a wildfire emergency occurs. He noted that Colorado currently recognizes resiliency planning as more important than ever before, and that the state has recently increased their efforts to recognize resiliency opportunities and push for relevant projects. The Colorado DOT freight office, formed in January 2020, brings together planning and operations functions. The office has developed new ways to use existing in-house data to visualize freight system usage, particularly leveraging geographic information systems (GIS).

Hurst demonstrated several visualization techniques that Colorado DOT uses to understand truck movements and identify infrastructure deficiencies. In 2020, Colorado DOT issued more than 40,000 oversize and overweight permits. Because each issuance requires a customized route, the data is useful for visualizing routes and identifying resiliency issues. First, he shared a heat map of route usage in Colorado for 2020 based on single-trip permits (Figure 6). This information is used to identify the most heavily used roads. This information can then be overlayed on route information (e.g., weight-restricted bridges) to understand routing challenges (Figure 7). In everyday operations, it is useful for identifying detour routes, including for oversize and overweight vehicles, hazmat, and nuclear cargoes.

FIGURE 6 Colorado route use heat map.

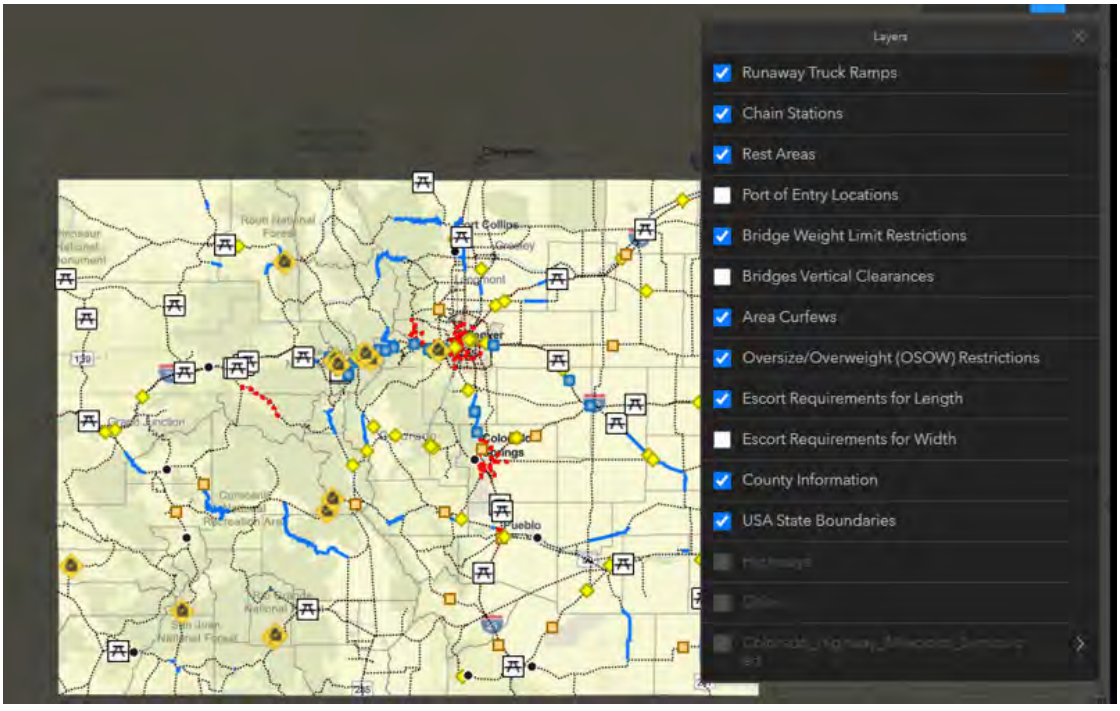

FIGURE 7 Overlay of restrictions.

This type of analysis has produced many benefits for daily operations, including reduced greenhouse gas emissions from more efficient routing and reduced maintenance costs by routing trucks on roadways designed for them. Because of related efficiency benefits, industry operators have been helpful partners. To better communicate benefits to operators, Colorado DOT developed its first public-facing freight website and a series of videos as part of their Mountain Rules Safety Campaign, and continues to test new technologies for real-time communications (e.g., in-cab messaging).

In 2020, Colorado experienced its worst fire season in history. Hurst discussed two specific fires from this period, the Grizzly Creek Fire and the Pine Gulch Fire. The Grizzly Creek Fire closed I-70 in Glenwood Springs, an area in the middle of the Rocky Mountains. This route is a critical artery to the western slope. Colorado DOT quickly identified that this was going to be a long-term closure and was going to affect the railroad that follows the same canyon as the highway. The Pine Gulch Fire—the second largest in the state's history—occurred just north of Grand Junction, near the state's northern border, on a route that is a significant connector to Utah and Wyoming.

During these two fires, Colorado DOT had to address a number of freight mobility issues. Commercial vehicles could not use the available detour route for I-70, which is difficult to navigate even in a passenger vehicle. During the Pine Gulch Fire, delivery of aviation fuels needed for firefighting aircraft to local airports was an unanticipated challenge. While the private sector is responsible for the fuel delivery, Colorado DOT played a role in addressing road closures that resulted in excessively long (16 h or more) delivery routes. These long routes extended 1-day trips to 2, which would create difficult-to-fill demand for more drivers. DOT also had to ensure safe routes for bulldozers and heavy equipment for firefighting operations.

With the addition of road closure information, Colorado DOT's existing GIS-based platform was useful for emergency response and wildfire planning. During the event, the system allowed Colorado DOT to identify a potential problem area where a route with planned long-term construction was the only alternative to a route closed by wildfire. The system was also used for routing of escorted aircraft fuel trucks through wildfire areas to maintain reasonable (and legal) travel times for drivers. Hurst is now approved to be located in the emergency operation center during events; a commercial vehicle call center will be made available to provide routing support for drivers. Colorado DOT is also using U.S. Department of Agriculture (USDA) tools to identify potential high-risk areas to start developing detour routes for all vehicle types, including hazmat. The agency works with Colorado State Patrol to identify temporary alternative hazmat routes.

Hurst closed with several key lessons learned from Colorado DOT experience. These include:

- Communications with neighboring states is critical. Cross-state problems can ruin a solution.
- Understanding statewide routing challenges before an emergency allows focus on a problem area during the event.
- When infrastructure weaknesses are identified, funding opportunities (e.g., National Highway Freight Program) can be leveraged to address them.
- Critical assets should be prioritized based on resiliency to optimize return on investment.
- Once data are in hand, visualization is critical to quickly and successfully communicate information.

Francisco Castillo, *Union Pacific Railroad*

Francisco Castillo discussed the experience of Union Pacific Railroad (UP) in addressing California wildfires. UP is the largest Class I railroad in the United States. Its 38,000 employees operate 33,000 mi of track in 23 states, mostly west of the Mississippi, and through 7,000 communities. Parts of its network are at risk from blizzards, floods, tornadoes, hurricanes, and wildfires. In California, UP operates a number of routes at risk from wildfires—two of particular concern are a coastal route and a route from Fresno to Oregon. The California Delta Fire ignited September 5, 2018, north of Redding. The fire covered 50,000 acres in Shasta, Trinity, and Siskiyou counties and destroyed at least 17 structures. The fire shut down I-5 twice, including once for 5 days, and even after reopening, many exits remained closed. The fire halted operations in UP's valley subdivision between Redding and Dunsmuir. Trains had to be rerouted or held at the northern California service unit.

Within UP, every group has a health and safety plan. Key items typically included in these are having a good communications plan in place with emergency response agencies (e.g., FEMA), state agencies, and local responders; participating in local drills; defining a process for information gathering; providing access to PPE; and identifying a team of individuals who, when events are expected, will monitor weather conditions and identify issues.

UP undertakes a number of fire prevention efforts that include working with locals to prevent fires in rail right-of-way (ROW); spraying rail infrastructure with herbicides to limit weed overgrowth; conducting joint meetings with local and state agencies; monitoring U.S. wildfire data; and staging resources. They conduct active risk assessments, using 11 variables to identify high-risk locations. Critical vegetation control management efforts include coordinating with local stakeholders; developing vegetation strategies; managing vegetation in the ROW as well as under infrastructure and on adjacent properties; mechanical cutting and mowing; chemical spray application; and use of a blower to remove dried vegetation.

Castillo identified a number of key lessons from the Delta Fire:

- UP regularly participates in meetings, which allowed for better coordination of resources and transportation needs during the event.
- Effective internal communications between departments were also key.
- UP was a proactive partner offering shared resources. UP crews assisted U.S. Forest Service firefighters with hi-rail vehicles and provided water car support to remote areas. These were used to keep roads and bridges wet for infrastructure protection.
- They also coordinated on rail traffic coordination to keep trains moving. This required inspections and careful scheduling, with consideration for periods of potential high wind and for water trains.

Eric Fredericks, *California Department of Transportation*

Fredericks began his presentation noting that nearly half of the largest wildfires in California history occurred within the last year, and that as a result, 4.2 million acres have burned. These fires are moving faster than before; at 15 mi per day it is difficult to contain them before they reach populated areas. Winds from wildfires have generated tornadoes. Conditions are exacerbated by the state's ongoing drought. The California Department of Transportation

(Caltrans) had 29 highways damaged, necessitating 35 repair projects and $209 million in wildfire infrastructure repair costs.

The wildfires produce a variety of impacts on supply chains. The poor air quality puts individuals' health at risk, including at major port facilities. Both Caltrans and transportation industry employees have lost homes. Trucks drivers were caught on closed roads and could not turn vehicles around. Road closures delayed deliveries; in the case of refrigerated goods, the product may be lost. Many trucks unable to find parking have to wait out events at the roadside, putting them at risk of getting hit while parked. Rural highways are heavily impacted as alternative routes during freeway closures. Traffic overwhelms many small towns, and pavements are damaged by unplanned heavy loads.

Utilities are also being shut off ahead of wind events because utility companies are liable for damage if their operations spark a fire. These impact traffic and operations. Maintenance stations go out. Traffic signals go to auxiliary power, and variable message signs go out; the latter cannot be replaced with mobile units because they can blow over. As the state pursues its zero-emissions targets, Caltrans needs to consider alternative routes in the provision of electric vehicle charging infrastructure, as well as to study the performance of zero-emissions vehicles when power to gas stations is lacking.

After a wildfire, mudslides and flooding can occur as a result of the altered landscape. The Montecito mudslides that resulted from the Thomas Fire shut down a primary route through the central coast in early January 2018. The mudslides left drivers in perilous conditions, pushed traffic into small towns, and prevented farms in a major agricultural area from reaching their largest market (in Southern California).

Fredericks identified a number of actions that Caltrans has undertaken in response. The agency shares information with drivers through a variety of mechanisms including: website maps, direct communications between Caltrans districts and truck stops, which display information on TVs in their lounges; distribution of brochures; and coordination of variable message signs with neighboring states. During events, the freight office provides information both to the Caltrans EOC and to the governor's EOC. They share reports with about 140 stakeholders, including Class I and short-line railroads and the warehousing industry, and collaborate closely with the Governor's Office of Business and Economic Development. Under new guidance from the California Wildfire and Forest Service Resiliency Action Plan, Caltrans is maintaining "defensible profile zones" by clearing brush. During one coastal event, the agency also worked with the National Weather Service (NWS) to predict areas of potential washout and conducted preplanned closures that likely saved lives. They are looking to expand this collaboration, but it is a challenge; because of the size of the state, they need to work with many different NWS offices. They are also looking into installing barrier gates that can swing open to allow trucks to turn around, which is not possible with concrete barriers, and considering installing rock structures and other hardening infrastructure. However, this is a challenge when resource demands for repairs are so high. Finally, Caltrans has published some roadway design guidance for evacuation routes.

Monika Stoeffl, *California Resiliency Alliance*

As executive director of the California Resiliency Alliance, Stoeffl discussed wildfire impacts from the perspective of private industry. Her remarks described impacts from several events

including the Blue Cut Fire (August 2016), the Delta Fire (September–October 2018), the Silverado Fire (October–November 2020), and the Grizzly Creek Fire (August–December 2020), among others.

Wildfires can affect a carrier's ability to access a pick-up point. During the Silverado Fire, a major grocery distribution center, which served about 20% of Southern California's grocery consumption, was located across the street from an evacuation zone. If the zone had expanded to include the distribution center, it would have had a large disruption on food access in the region. During the Delta Fire, the parking lot for a freight logistics company was located within an evacuation zone. It took several days to coordinate access through the roadblock to get the trucks out for use at other warehouses. Evacuation zones can also affect employees; when the 2018 mudslides in Montecito closed both a main route and residential streets for 12 days, employees living on one side could not get to the other side of the closure. This created challenges as warehouse could not move goods without drivers. Additionally, not all sectors are impacted equally. For example, goods that typically move in or through rural areas—such as agriculture and timber—may move on low-volume routes that are not necessarily prioritized in recovery and may remain closed for longer. Outside of direct wildfire threats and damages, one of the wildfire mitigation tactics used by utilities—public safety power shutoffs—can cause a loss of power to distribution centers, thereby disrupting commodity flows. On the West Coast, most gas stations do not have backup generators, and cell tower backup generation typically lasts only a few hours. As a result, power shut offs can also result in operational disruptions and communications failures. Another factor is poor air quality, which affects operations both for drivers and at distribution centers both directly and indirectly. Some ventilation systems rely on outside air intakes. Worker safety regulation, such as Cal/OSHA's indoor air quality requirements, may create other workplace challenges even hundreds of miles from a fire.

The National Highway System in the western United States generally has more isolated stretches with limited route alternatives compared to the east coast. This means disruptions to a route can cause significant challenges. With limited alternatives, trucks are rerouted onto longer routes. Conditions on these routes are also often congested because they were not designed for the detour flows. Restrictions for traveling through road closures are often confusing, with the vehicle types permitted to travel sometimes changing on an hourly basis.

Rail faces similar congestion challenges to trucks. When the Blue Cut Fire affected the Cajon Pass, a key channel serving the Port of Los Angeles, it caused backups as far away as Chicago. Wildfires can also affect both passenger and freight air transportation. When visibility is inadequate, planes are delayed or canceled. The size and duration of a fire will determine the extent of impacts. In addition, to support fire response, the Federal Aviation Administration (FAA) issues no-fly zones. These can affect flightpaths, especially when there are numerous no-fly zones in place at once. In 2020, there were a significant number of wildfires burning concurrently in the western United States. The no-fly zones were manageable due to reduced traffic, but in normal conditions, it might have created some traffic flow problems.

Simultaneous events and cascading failures are also a concern. Particularly for companies operating across multiple states, tracking impacts and updates from multiple events simultaneously can be a challenge. After an event, businesses and freight are often prioritized behind residents in getting reentry access to an evacuation zone. Evacuations also displace demand; businesses may need to reroute their products to new locations if populations are displaced; however, knowledge of where people are moving during an evacuation is often lacking.

AUDIENCE DISCUSSION

Following the case study presentations, the presenters addressed moderator and audience questions. Hurst discussed the growing role of freight in emergency planning in Colorado. Previously, freight was primarily considered in emergency planning for the purpose of moving goods into impacted communities; now, impacts on surrounding systems are also considered. He noted that within Colorado DOT, the freight office sits within the Division of Maintenance and Operations and reports directly to the individual in charge of emergency management; this structure provides an opportunity for ongoing collaboration. According to Fredericks, emergency planning and freight planning have not been historically linked in California, but dialogue has begun during the pandemic. This coordination is challenged by limited data acquisition since the freight unit does not house traffic operations units. Contestabile pointed out that freight planning generally suffers from a lack of data since most DOT data comes from the public not private sector. He also noted that organizational alignment of the freight office within the DOT will affect its role in emergency response. Stoeffl explained that while the transportation sector is recognized as important in event recovery, freight facilities are not usually prioritized for fuel (versus hospitals and buses).

Castillo discussed the factors that are considered in risk planning. Risk assessment is useful to identify high-risk hotspots. UP uses 11 risk factors and each is weighted in tabulation of a "fire risk factor." Examples of factors include elevation, surface vegetation, and adjacent properties.

Castillo also discussed UP participation in emergency response. Following earlier communications challenges, the railroad now has a representative in the EOC during an event to inform operational decisions. There is a desire to continue to improve relationships with other entities and agencies, although communications have recently improved, particularly at the statewide level. Specific desirable changes would include direct notifications from the state to key stakeholders; establishment of a trusting relationship in which agencies seek industry inputs on decisions that affect them; and providing access to roads into rail facilities.

Fredericks discussed the data and information needs for better planning. In California, many data-driven statewide resiliency assessments have been performed, and there are implementation plans, but freight has played a limited role. Recent efforts have focused on breaking down these silos. From a wildfire perspective, there might be more data available. With climate change, it is uncertain if wildfires will continue to occur primarily in western states. More states should consider wildfire plans and think about the resiliency and the aftermath, including large-scale power losses. Port data is a specific challenge. Ports are moving to zero emissions and shore power, but last summer during the power shutoffs, they had to stop using shore power plug-ins for ships. This has an impact on emissions. Power is at the root of wildfire-related discussions in California.

Stoeffl also addressed data needs, noting the importance of understanding movements across jurisdictions and state boundaries. It is important to understand flow patterns, as disruptions can have far-reaching impacts on neighboring and even distant states. When asked if the use of GIS in freight planning is "forward leaning," Hurst noted that data is tough to obtain and to communicate appropriately, and that using Colorado DOT's own permitting data has been a great resource. Layering this data with other vendor data adds value, and future intelligent transportation systems implementations should further improve usefulness for planning. In 2020 GIS was key for communicating across agencies and making real-time decisions. Hurst also

explained how Colorado's work with freight routing has influenced the state's asset management plans. Informed by work on route restrictions, the state approved a timber structure project to enhance nearly 150 structures—60 of which are located on freight routes—to remove weight restrictions, improve structural performance, and enhance the service life of the structures. This project will open up new routing opportunities and contribute to greenhouse gas reductions.

Missouri River Valley Floods, 2011 and 2019
Transportation and Logistics Disruptions and River Management

The final workshop day focused on experience from two Missouri River Valley flooding events in 2011 and 2019. Moderator Jeff Purdy introduced three case study presenters: Matthew Baker, Austin Yates, and Peter Skosey, who shared their experiences. Case study presentations were followed by a response panel also moderated by Jeff Purdy and featuring Jacob Nicholson, Brian Tuma, and Ted Sussmann. At the end of both panels, the audience had the opportunity to ask questions and discuss key findings with all presenters and discussants.

MISSOURI RIVER VALLEY FLOOD CASE STUDIES

Jeff Purdy, *Federal Highway Administration, Moderator*
Alison Conway, *City College of New York, Recorder*

Jeff Purdy opened the session by describing the two major flood events to be discussed. In 2011 Missouri River flooding was triggered by record snowfall in Rocky Mountains, followed by near-record spring rainfall. To prevent overflow, all of the major dams along the Missouri River released record amounts of water, which led to flooding that threatened numerous towns and cities along the river between Montana and Missouri. Between January and May 2019, the Missouri River and its tributaries in Nebraska and Iowa again experienced major floods that impacted 14 million people. During the wettest season on record, record snowfall was followed by quick temperature rise and rainfall. In March, heavy late-winter rainfall on frozen ground exacerbated the flooding, with ice flows causing significant damage to the infrastructure and to communities in Nebraska, Iowa, and other nearby states. Nearly 14 million people were affected by what was called “The Great Flood of 2019.”

Matthew Baker, *Nebraska Department of Transportation*

Baker discussed floods impacts and responses in the state of Nebraska. He began by noting that the conditions that created the 2019 event can occur annually; only a small difference in temperature prevented a similar event in 2020. He described the factors that led to the “perfect storm” in 2019: low temperatures for most of January and February leading to frozen ground and deep snowpack; a very rapid drop in barometric pressure (a “bomb cyclone”); blizzard conditions with 100-mph winds in the panhandle; heavy rains that immediately followed a blizzard on March 13; and increased river flows from rapid thawing. In about 24 h, 3,000 mi of state highways were washed away or closed.

This event caused widespread infrastructure damage, with the most severe damage occurring in the east. Ice floes deposited ice piles on roadways and caused structural damage, including bent girders, scoured abutments, and bridges unseated from their piers. Ice deposits remained on roadways even after the river receded, and a 3-million-pound bridge section was carried downstream and deposited on a sandbar. At a location on Highway 281, where an earthen dam previously channelized the river over a concrete spillway at a hydroelectric dam, both the

earthen dam and the concrete spillway were destroyed. Their simultaneous failure likely prevented a bridge from washing away. Overall, in Nebraska alone, 27 state bridges were damaged and about 200 mi of pavement required repairs. Once the waters receded, inspections were conducted, repairs began, and temporary detours were put in place.

Route closures resulted in operational and access challenges. I-80 closed because there was nowhere for traffic to go. This is a common occurrence that the state typically responds to with well-coordinated rolling roadway closures. Following a roadway washout, the community of Fremont was completely cut off by any means of transportation for close to a 48-h period. Multiple agencies worked together to find a highway that could provide access with minimal risk. The route still had water flowing over it, but debris was cleared and a convoy of trucks and supplies were finally able to be brought into the community. In another community in Northern Nebraska, a town implemented ferryboats to allow residents to cross the river and avoid hour-long commutes brought about by roadway closures. Many access routes to the Omaha area from the west and the south were cut off. While I-80 itself remained intact in this area, many commuting routes were disconnected or damaged. With closure of Highway 2, a primary connector to I-29, a large amount of traffic had to be rerouted onto a two-lane facility through small town unprepared for the heavy volumes. To address this, traffic signals were retimed. Messages were posted on direct message system boards, and information on alternatives was crowdsourced from websites.

To prepare for future events, Nebraska DOT's in-house meteorologist has developed a flooding forecast matrix. A minimum of nine criteria are taken into account to produce a flood threat level. The matrix can be applied to an individual location or a group of locations, based on where a storm event will occur. Nebraska DOT continues to be proactive to get detours in place and communicate this information to drivers in a timely manner to allow for rerouting before a vehicle reaches an area of a road closure.

Austin Yates, *Iowa Department of Transportation*

Yates started his presentation by reminding the audience that closures and detours have everyday impacts on residents and their commuting patterns. He then provided some historical background on the Missouri River. The river was channelized by the U.S. Army Corps of Engineers (USACE) to make it navigable (200 ft wide and 10 ft deep). To do so, they constructed wing dikes that slowed the water down and caused sediment to fall out of the water. Over the intervening decades, deposited sands turned into soil and ultimately prime farmland, establishing conditions that enable recurrent flooding at I-29. Six dams and reservoirs were constructed on the Upper Missouri under the Pick-Sloane Plan, which brought together two independently developed plans for watershed management. The most downstream of these, the Gavin's Point Dam, flooded severely in 2011; afterwards, USACE set back the levees and tied into the earthwork of the Missouri River Bridge. This created a pinch point.

On March 3, 2019, temperatures in Sioux Falls, South Dakota, were below zero and 13 in. of snow were on the ground; by March 13, temperatures were in the 50s and the snow was melted. Conditions in Omaha were similar; on March 8, temperatures were around freezing point with 7 in. of snow and then just a handful of days later, temperatures were in the 60s, all the snow had melted, and it was raining. Flooding occurred almost exclusively due to runoff that overran the rivers.

HDR Engineering was hired early in the flood to help run the agency's response. They developed a hydrodynamic model to simulate the event. Yates shared the simulation, which showed the following:

- On March 12, normal spring flooding occurred in the lowlands.
- On March 13, the Platte River flow started exceeding the Missouri River flow.
- On March 14, first levies failed. The biggest and worst failure occurred on March 15, south of Highway 34.
- By March 17, the Missouri River returned to its "bluff to bluff" location.

NWS hydrographs demonstrated that the river remained at flood stage in Omaha until November 7 and in Nebraska City (where all-time peak Missouri River flow had occurred) until December.

Yates provided an example from an east–west roadway to demonstrate severe flooding impacts. In Iowa, travel lanes are typically concrete with asphalt shoulders on a granular roadbed for slope. When floodwaters rise, they first fill the upstream ditch. The roads can remain open under this condition. However, when water reaches the travel lanes, it may close depending on the expected rise. If rise is limited and restricted to one side of the road, the DOT can convert the opposite side to a "head-to-head," operating one lane in each direction. If the water extends into the opposite lanes, the road can normally just close until the waters recede, and debris can be removed. However, if the water reaches a sufficient depth, it can reach a "flow transition." When the water reaches the downstream shoulder, a "hydraulic jump" occurs, and the previously laminar flow turns into a turbulent flow. This starts a chain reaction, washing away vegetation, penetrating the base, collapsing shoulders, and ultimately collapsing the pavement. Ultimately, 68 mi of Interstate were underwater.

The first step in response was getting partners on board and organized. Roads were broken into segments for damage tracking, and a website was set up to track the recovery, from closure through damage assessment, debris removal, and repair to reopening. Under normal circumstances, roadside cameras provide good coverage, but after a month under water, the fiber optics failed. Instead, the agency deployed camera trailers that operate on a cellular data connection. Since the cell towers are located in the bluffs, they were not affected by flooding. Due to a closed roadway segment, global positioning system (GPS) were sending vehicles onto a detour route that included two low tunnels inadequate in height for commercial vehicles. To immediately discourage drivers from using this route, the DOT input fictitious roadway closures into Waze, which propagated into Google Maps. They also created a new sign that was installed at multiple locations to remind drivers to follow the detour and not their GPS.

A critical freight and commuter connection on Highway 2 was underwater for a month. To keep traffic moving, DOT constructed a "causeway system" out of temporary barrier rail (TBR). The TBR consists of a layer of large rock that can let water flow through, a layer of drivable road rock, and fabric to keep those layers from mixing. At one location on a curve, pipes were also placed under saturated eastbound lanes to help them dry out. Running highway traffic over a gravel road was a challenge; it had to be maintained multiple times per day. Westbound lanes were reopened under a "pilot car scenario" with only one lane, but the TBR was lost when another round of flooding occurred. The Interstate had to be completely rebuilt. Four rounds of flooding occurred throughout the year in March, June, and September–October.

For resiliency, flexi-mat, an inexpensive material usually used for coastal protection, was

installed on I-680. It is essentially a net with concrete embedded in it. The flexi-mat "takes the beating" from the water so it does not wash away the downstream slope and vegetation. After its efficacy was demonstrated during June floods, it was installed all over the district. A section of I-29 was closed for a total of 100 days throughout the four rounds of floods, causing the GPS rerouting issue discussed previously. A cost-effective solution was to raise up only the northbound lanes and run head-to-head traffic.

Up north, there was a confusing situation with roadways names. Two different roadways were named I-680, making it difficult to communicate what was closed. In fall 2019, one was renamed I-880 to allow for better communication.

To address the "pinch point" on Highway 2, the roadway was elevated just east of the River Bridge to allow more water to go through. Many resources were allocated to this project, which was designated as high priority at all levels (the district office, DOT headquarters, Governor's office, and Transportation Commission). Design that usually takes 4 years was completed in a just a few weeks. The new levy tie was put in place by December 2019, more than a year and half earlier than planned. Additional improvements are ongoing at the Highway 2 interchange area, including raising bridges, reconstructing culverts, doing a grade raise, and building a dike to protect the interchange as well as truck stops, hotels, restaurants, and gas stations at the interchange area. This is a huge investment, but it is worth it because of the impact on freight.

Peter Skosey, *BNSF Railway*

BNSF Railway is one of the largest freight railroads in the country, with about 36,000 employees and many locomotives. It is a fully owned subsidiary of Berkshire Hathaway. Skosey shared a map of BNSF's network showing the location of the Napier subdivision between Sioux Falls and Lincoln. This is a key north–south corridor that was shut down by flooding. While alternative routes exist (e.g., via Wisconsin and Texas), these add substantial mileage.

In a typical year BNSF will spend about $3 billion on capital improvements; 80% of this is going directly to maintenance, including flood repair when necessary. Normally, this includes things like redoing rail, replacing ties, and resurfacing ballasts. In 2019, the railroad's Napier subdivision was hit hard by flooding, particularly due to a major dam failure. The subdivision was closed on March 15, at which point 60 mi of track were underwater and several bridges were destroyed. A bridge was lost—literally—and 73 culverts were damaged.

The railroad spent a fair amount of time and money replacing everything in close coordination with the Iowa DOT. This involved moving hundreds of tons of rock and lots of rock trucks, and required coordination with Iowa DOT to get access to I-29 even while it was closed because the BNSF corridor parallels I-29 and rock movements were needed to shore up the embankment. Over 500 rock trains brought in rock from all over the region. One hundred BNSF employees and 500 contractors were on site. Where possible, the grade was raised about 5 ft, and 100 4- to 6-ft culverts were put in place in locations where none had existed previously. Concrete bridges were also added. Four months after the flood, the subdivision reopened for service.

Skosey closed his presentation with a video about the event. It highlighted preparatory actions, including stocking ballasts, having trains ready to go, and having equipment in place in case of an emergency. The video noted that the event was historical in that over 1 million tons of materials were required. It closed with recognizing the motivation of employees, especially given the long duration of the event.

AUDIENCE DISCUSSION

Following the case study presentations, speakers addressed a few audience questions. Skosey stated that the railroad has ongoing conversations with local DOTs (to prevent the creation of "humped" crossings), and is working on coordination before, during, and after any event. Skosey also noted that BNSF has a close connection with customers; when floods occurred, the railroad immediately alerted those operating in affected subdivisions. They used e-blasts to customers, but also followed up individually with major customers. Baker noted that there were periods when Waze turned off because information flow was substantial enough to warrant detailed vetting to ensure accuracy. Yates discussed the potential benefits of having a regional authority, similar to the Tennessee Valley Authority that would manage the whole watershed, noting existing challenges such as private levees built in the 1970s that now have no clear owner.

MISSOURI RIVER VALLEY FLOOD RESPONSE PANEL

Jeff Purdy, *Federal Highway Administration, Moderator*
Alison Conway, *City College of New York;* **Karla Diaz Corro**, *University of Arkansas, Recorders*

Jacob Nicholson, *Iowa Department of Homeland Security and Emergency Management;* **Bryan Tuma,** *Nebraska Emergency Management Agency;* **Ted Sussmann,** *U.S. Department of Transportation Volpe Center and University of Hartford, Panelists*

Challenges

First, the panelists discussed challenges to preparedness, recovery, and response. According to Nicholson, knowing partners and maintaining relationships across jurisdictional boundaries is an ongoing challenge. New partners are needed as problems grow in size and scope. Communications, especially "rumor control," is critical to maintain consistency of information across stakeholders. Particularly when dealing with many small localities, miscommunication of resource needs or a failure to vet requests can result in inefficiencies and duplications. Communications between local jurisdictions can also be critical. Examples from Iowa include upstream locations providing early warnings in the case of a levee breach and sharing of strategies for communicating with the public. The duration of flooding and extent of catastrophic damage resulted in a cycle of bouncing back and forth between response and recovery. Finding the parties legally responsible for private levees was a challenge. Working groups and annual meetings with stakeholders, including industry partners and utility companies, are important to mitigation. Looking forward, there is a need for more information on private levee owners and on the cascading impacts of failures.

Tuma noted that Nebraska faced many similar issues to Iowa. For preparedness, the Nebraska Emergency Management Agency consults regularly with USACE, NWS, natural resource districts, city water–utility managers, and transportation planners at local and state levels. The agency's worst fears came to fruition when a period of rapid warming coincided with a moisture event, resulting in the worst flooding event in the state's history. Coordination

occurred several weeks before the event, including monitoring of conditions and communicating with local stakeholders. This enabled pre-positioning of supplies, standing up of resources, and preparations for flooding. After the initial event, damages were compounded by recurrent flooding, which occurred in July after many initial infrastructure repairs had been completed. County roads were especially challenging, resulting in considerable impacts on commuters, including those working in farming and manufacturing. Employers had to lodge employees and develop other work-arounds. Many unique issues related to agriculture had to be addressed. Wells were contaminated. The USDA assisted in burial of livestock carcasses. The EPA was engaged in handling chemical containers that had floated from agricultural production facilities, and propane cylinders from homesteads. Actual recovery costs exceeded $550 million, mostly for repair of local roadways and bridges. Rural areas do not have a large tax base to support these, so it is difficult to do repairs and wait for reimbursement. A long-term resiliency task force is still in place.

Sussmann noted that railroads are different from highways. They are not sealed from water entering like pavement but are open with ballast supporting the track. Drainage is critical, and floods demonstrated the importance of maintenance of drainage and ballast. Blocked culverts are a critical problem. Much of the infrastructure is old, meaning that embankments are often steep and culverts likely require maintenance to ensure proper flow. As a result, asset management is challenging requiring specific data on structural condition. Hardening the embankment interface is an important part of mitigation. During recovery, there may be questions about the strength of the embankment after it has flooded. For example, during Hurricane Katrina, rail provided critical access to evacuate stranded residents, but there were concerns if the tracks were safe for this purpose. It is difficult to answer these questions in the absence of data. It is important to conduct assessments before an event occurs, because it is difficult to capture this information during an event.

Financial Resources

Next, the panelists discussed the key considerations for ensuring reimbursements from FEMA or FHWA. Tuma explained that FEMA supports emergency work, such as immediate responses for life and safety and permanent infrastructure. Under infrastructure, areas relevant to transportation include “Category B” debris removal and “Category C” roads and bridges. He identified several critical issues for local and state authorities. FEMA will not cover a cost that is covered by insurance. Substantial documentation is required. Owners must prove that infrastructure has been maintained and provide photos of infrastructure prior to damage. They must also conduct damage assessment. FEMA will not cover federal highway infrastructure that is covered by FHWA. Work is sometimes required to determine which routes are eligible, especially in areas like game parks or natural resource districts. Nicholson added that in order for FHWA to activate funds, the governor needs to declare an emergency or disaster. Efforts may be needed to draft specific proclamations to activate funds.

Communications

The panel then discussed communications challenges between agencies, jurisdictions, and between the public and private sectors. Sussmann noted that during 2019 flooding, communications were eased by having a great point person at the railroad providing direct

updates on flood progress and the status of infrastructure in near-real-time. A consultant also provided updates on asset conditions, railroad performance, and traffic impacts. This success was contrasted by experience during the 2011 floods when communications were more challenging making it was more difficult to keep track of projects and monitor employees in the field. He also noted that asynchronous communications (e.g., texting) has sped up communications compared to prior methods (e.g., leaving a voicemail and waiting for a response). Nicholson noted that circular communications between state and local entities and private stakeholders are a challenge. He reiterated the need to vet and validate information, giving an example of a local EOC hearing about an Interstate reopening when it was not true and noting that similar issues have occurred with railroads. He noted that when partners who are not used to working together have to share information, it is important to get everyone on the same page to ensure information consistency. Tuma noted that it is important to ensure accurate and timely information on resource requests. Social media is effective to communicate, but can be both a source of and a means to correct misinformation. Social media can also provide a window into what people are experiencing across the state. Disaster victims want information quickly about how to access resources and begin the recovery process. Website enhancements can be used to provide situational awareness and link to resources.

Recovery

Next, the panel talked about restoring access to communities. Nicholson noted that during and immediately following a disaster, the safe restoration of transportation routes is always a priority, both to permit effective emergency response and access from first responders, and to allow for safe reentry of residents and businesses into the area. He provided an example of a small community of 400 residents that had been evacuated during the flood. Due to persistent high waters, residents could not reenter their homes for more than a month to recover property. A deliberate approach was needed to allow reentry. The state of Iowa deployed an incident management team and search and rescue forces to work with local officials. They developed rapid assessment teams that were a combination of engineers and inspectors, law enforcement, and local officials. They did external inspections for structural integrity issues, removed orphaned drums and hazardous materials, and coordinated with animal control to remove wild animals. They cleared every property in the community (about 100 structures). They cleared roadways of both large and small debris. For the latter, the DOT brought in magnet trucks. Emergency managers worked with law enforcement to implement 24-7 controlled access. Access was limited to one roadway in each direction. Emergency managers also coordinated with utility providers. Entries were conducted in planned stages by sector to prevent a “free for all.” The same types of actions were undertaken for rural residences, but these individuals typically had to wait much longer due blocked access routes and re-flooding.

Tuma described several communities in Nebraska that were physically isolated due to loss of transportation infrastructure and remaining floodwaters. Airboat operators provided services on a volunteer basis to extract stranded individuals or transport people in need of medical assistance. The state relied on the National Guard and aerial assets for airdrops of needed supplies. In some locations, high-wheeled vehicles navigated floodwaters to deliver medical supplies and food and move people out of harm’s way. Volunteers also offered private aircraft that could access local airports, again to move people out. The state conducted some livestock feeding operations using helicopters to drop hay bales. Helicopters were also used to

extract stranded individuals from rooftops.

Sussmann noted that having equipment pre-positioned and available for service is critical. In the Midwest, rail service is focused on freight so passenger services are somewhat limited. Railroads are particularly adept at maintenance. Rail infrastructure is built to easily accommodate maintenance and upgrades and railroads have specialized equipment for that purpose that can cover a lot of territory in a short amount of time. This equipment can be pre-positioned across the network because of the type of maintenance activities that occur. As the BNSF video demonstrated, continuously bringing these resources to bear in the 2019 flood areas and having equipment that can lift up the tracks, push out the flooded materials, and bring in the new ballast and increase the level of the tracks is impressive and unique to that type of infrastructure.

Partnerships

Finally, the panel discussed needed partnerships, and potential hurdles to putting them in place. Nicholson discussed the development of new partnerships with agriculture and with BNSF during the 2019 floods. The state of Iowa deployed aerial assets and even built a new road to feed livestock isolated by the flooding at large confined animal feeding operations facilities. Having effective partnerships allows emergency managers to get ahead of these types of issues; better preparation would be even more helpful. The state of Iowa also formed a special relationship and established new communications pathways with BNSF as a result of this event. BNSF worked closely with the state DOT, the state Department of Homeland Security and Emergency Management, and with local entities to ensure that their flood mitigation measures would not adversely affect communities. This communication is going to help make mutually beneficial response actions more impactful. Nicholson is not aware of any legal or regulatory procedural hurdles to implementing and maintaining these types of relationships. He noted that a commitment to preparedness, regular meetings and touch points among partners, and a willingness to openly communicate during the response to better coordinate actions are what is needed.

Tuma noted that there are standard partnerships that have always been in place, but that partnerships were taken to another level in 2019. He reiterated the roles of the USDA in addressing livestock issues and the EPA in cleaning up orphaned containers. He noted that standard partnerships with USACE and NWS on issues like weather reporting, water management, and levees were elevated by implementation of an Incident Management Systems Team. A joint field office in Lincoln housed over 600 FEMA employees during recovery. Volunteer organizations played a critical role not only during response but also during recovery. The Emergency Management Agency forged new working relationships with housing authorities and others entities engaged in meeting individual assistance requirements. A working relationship was also established with University of Nebraska's Extension Service that serve as an intermediary to Farm Service Agency representatives in each county. The Nebraska Preparedness Partnership is a public-private partnership that brings together corporate entities with the public sector to provide assistance during emergencies or disasters. It is largely built around resources, equipment, and personnel to assist with the response in the recovery. Their goal is to simply provide those resources because they want to take care of the communities that they do business in and in which their employees live and work.

Sussmann provided another example of coordination between railroads and DOTs. He

noted that while working on a project involving track additions, the selection of staging areas for materials was made in partnership with highway and other agencies because that work was being done partly as a capacity improvement but also partly as a flood mitigation. He noted that poor site selection can lead to adverse impacts on highways that might only be recognized in hindsight, so it is important to communicate and identify potential challenges up front to achieve a network that performs well for everyone.

AUDIENCE DISCUSSION

At the end of the session, participants addressed audience questions. First, the panelists discussed what data they wished they had, or what data they wished they had access in a more timely fashion. Tuma noted that damage assessments are critical in initial stages to demonstrate need for a federal disaster declaration. Nicholson noted that while a much stronger relationship was forged over the course of the event, he would have liked to have had advanced notice of railroads plans for mitigation and the rebuilding measures that they were putting in place, given the cascading impacts of material movements on local traffic. Sussmann noted that knowledge of flood stages would be informative to railroads. This information is publicly accessible but needs to be channeled into a format easily consumable by railroad operators. This data can be used to identify erosion and pinpoint potential structural problems in the railroad infrastructure and embankments.

Next, they discussed whether drones and other new technologies significantly improved assessment and recovery planning. Nicholson noted that in Iowa, drones were used for damage assessments. However, he pointed out that sometimes the federal protocols and requirements need to catch up to the technology. Federal regulations and requirements may require physical visits; sometimes drone footage is accepted as a replacement, and sometimes it is not. As a result, the state had to launch amphibious vehicles from search and rescue teams to visit homes as part of that damage assessment process but did use drones to get a sense of where these properties were for planning. Sussmann noted that when rivers rise, drones can be used to investigate and confirm water encroaching on the track structure along with any erosion, settlement, or other impacts without putting track inspectors at risk.

They then discussed actions to get businesses back up and running. Tuma noted that Nebraska typically brings in the Small Business Administration to do damage assessments and determine if businesses qualify for their loans, which are available to individuals, homeowners, and renters, as well as small business owners. Nicholson added that Iowa immediately recognized the importance of freight movement and of minimizing interruption to it given potential regional and national economic impacts.

Next, the panel summarized impacts to agriculture and agricultural goods movements as a result of flood closures and infrastructure damage. Tuma noted that the Nebraska Emergency Management Agency worked very closely with the University Extension office and their representatives in nearly all of the state's counties. The office works with Farm Service Agency representatives to leverage the USDA programs that are available for post-disaster help. The president can declare a disaster through FEMA using the National Disaster Relief Fund, but Secretary of Agriculture also has the authority to declare agricultural disasters, which opens up a new funding stream specifically for agricultural producers. This covers a wide range of issues, including restoring fence line and other materials, helping with feeding requirements of

livestock, and assisting with mitigation issues for flooded agricultural land.

When asked about the role of trucking companies and associations, Tuma noted that the trucking association has helped identify volunteer carriers to help transport commodities such as water at no cost. Nicholson noted that trucking associations not only can provide assistance with commodity movements, but can also serve as a sounding board in assessing the need for regulatory waivers or a governor's proclamation for hours of service or overweight and over length trucks that are hauling loads for disaster relief supplies. Tuma revisited the topic of damage assessments, noting that while the DOT is very good at coordinating these, local government entities may face delays due to staff resource limitations.

When asked what can be done about data sharing and whether there would be value in a centralized data repository, Tuma noted that EOCs typically run incident management software platforms that document everything about what is occurring in the event, the resource requests, etc. This is a proprietary system to the first responders and public safety agencies. However, part of preparedness and planning is having sessions to discuss these issues and understand each other's needs prior to an event. He noted that events are diverse and may impact infrastructure and businesses in different ways, so it's best to know who you can reach out to and how you can exchange information ahead of time. Nicholson added that there are practical limitations to having a single repository or system because every partner needs slightly different data or information. He also noted that having one single system that all users can authenticate into where information that is not public facing can be protected would also be a challenge. Private companies (e.g., railroads and utility companies) have proprietary and confidential information that they legally cannot share.

Finally, Tuma discussed the value of debriefings. He shared that after-action reporting is standard protocol in the emergency management business. Emergency support function coordinators that are assigned to the EOC will report, and will bring in volunteer organizations, academic disaster experts, and faith-based groups. They also engage DOTs, railroads, and public-private partners as needed.

At the end of the session, a discussion was opened for audience input. Avery Grimes added that while there's a lot of coordination that goes on between local fire departments, emergency responders, and railroads, it is typically focused on planning for hazmat type of events more so than on flooding. Jeff Purdy added that a current focus of FHWA’s freight office is emergency multi-state emergency response routing. A committee formed under the FAST Act called the Emergency Route Working Group put together recommendations. Feasibility studies are currently ongoing. FHWA is working with AASHTO to look at ways to expedite large response vehicles traveling across multiple jurisdictions.

Lessons Learned
Key Takeaways and Future Research Needs

At the start of each day's events, Schofer reviewed key takeaways from the prior day. At the end of the workshop, attendees were invited to participate in a roundtable discussion to identify lessons learned and key takeaways. Following the event, a planning committee debrief meeting was also held to discuss lessons learned from the event. The following sections summarize key takeaways for freight resiliency planning and operations and potential future research and activity needs derived from these discussions.

KEY TAKEAWAYS

Communications

Before an event occurs, it is important to build partnerships to understand each other's capabilities and resources. As Lambert noted in his presentation, stakeholders "should not be exchanging business cards" during a disaster. Relationships should include intra-agency communications between experts in freight planning and emergency management; interagency partnerships across levels of government, between relevant domains, and across jurisdictional boundaries; and partnerships between government and industry. Relationships can be built before an event occurs with regular meetings, as well as with drills and tabletop exercises. Better communications prior to an event can help to clearly define roles for partners in response. Getting to know partners pre-event can also inform development of communications strategies and tool such as data sharing platforms that enable clear, efficient, and effective information sharing with partners and the general public during an event. If possible, relevant agencies should co-locate during long-duration events. Ideally, agency freight staff and industry representatives should also locate in the EOC, both to provide inputs to decision-making and so that they can quickly communicate information to their teams. Virtual communications platforms can be useful but may be at risk from communications failures. Low-tech solutions such as radios may be required to maintain communications in the event of wireless and wired network losses.

Response Planning

Identifying critical infrastructure and assets prior to an event allows for rapid prioritization, damage assessment, and recovery actions. Freight mobility considerations should be explicitly incorporated into response plans, considering both the role of freight in community recovery and the anticipated impacts of disruptions on broader supply chains. Domain experts with understanding of the complexities of freight transportation systems and supply chains should be engaged in planning. It is important both to train staff and to have plans in place to support employees during an event; this might include having resources in place such as food and gasoline for personal vehicle use. When possible, stakeholders should pre-position equipment and supplies for response, and move the assets they will need to support community recovery out of harm's way.

Infrastructure Management

Infrastructure limitations (such as pavement, bridge, and culvert capacity limits and vehicle height and weight restrictions) and control system failures can hinder recovery. Information systems that detail infrastructure, technology, and communications assets can inform risk assessment and enable rapid interventions to aid response and recovery. Vehicle size and weight and culvert capacity limitations in high-risk areas or on critical response routes should be identified and prioritized for upgrade. Problematic infrastructure, such as highway median barriers that prevent drainage or truck turns should also be considered for replacement with more flexible solutions such as swinging gates. Both long-term and temporary solutions can mitigate impacts—for example, TBR and flexi-mat solutions used in Iowa during highway flooding.

Resilience should not only be considered on an asset-specific basis, but also at a system-wide scale. For example, dam releases for flood control may need to be coordinated along a watershed. Operational approaches that enable capacity management, such as highway contraflow lanes and alternative traffic control approaches, should be detailed in pre-event planning.

Funding to invest in hardening solutions can be limited by resource constraints when costs are high for basic recovery. It is difficult to keep political will focused on infrastructure investment when there is no active crisis. Identifying desired interventions in advance could possibly allow stakeholders to take advantage of supplementary funding opportunities when an event occurs, although many programs fund only restoration, not resilience building.

Data

Agencies use a breadth of data in emergency planning, response, and recovery. Many datasets used in everyday applications are useful to inform pre-emptive decision-making as well as post-event analysis; examples include truck permitting records to identify critical routes and restrictions, traffic performance monitoring data to understand flows, and AIS to investigate MTS response. Data from other domains can be leveraged with transportation data both for planning and in after-action studies; examples include using NWS data to identify potential high-risk areas and to recreate event timelines. GIS is very useful for layering new information such as road closures with existing and historic data. During an event, data is critical to establishing real-time situational awareness. Standardized tools for data sharing and uniform credentialing systems that enable access can help ease reporting burdens and facilitate information exchange.

Agencies face common data challenges. When power is unavailable, paper records may still be needed. When conditions are changing, real-time information is critical but often difficult to access, especially when utilities and communications networks fail. Crowdsourcing and social media can be effective means of monitoring conditions on the ground, although data quality needs to be considered. GPS-based real-time navigation systems that do not take into account data on current condition of links, or on volume or load-bearing capacities, can exacerbate infrastructure damage, delays, and risk to operators. Technology solutions such as camera trailers and UAS are useful during recovery to capture information in difficult terrain and where power or communications networks are limited.

Interdependencies

System interdependencies can also exacerbate impacts. Power failures can affect communications

and data sharing, and lacking fuel and power can delay response. Power recovery is typically not immediate after an event, as other users such as hospitals are often prioritized before transportation systems. As vehicles and facilities become increasingly electrified, understanding power system interdependencies will become even more critical.

RESEARCH NEEDS

Several general areas of future research need were identified during the workshop; these can be broadly categorized into: communicating the importance of freight resilience, developing and sharing best practices, improving data and information systems, and understanding the role of freight resiliency in broader policy discussions. Many specific research topics identified span the expertise of several TRB standing committees. Collaborations such as joint workshops, coauthoring of research needs statements, or establishment of ongoing joint subcommittees would be beneficial to advance work in these areas.

Communicating the Importance of Freight Resilience

Experience from recent events, particularly the COVID 19 pandemic, has revealed a need to educate policy-makers on (1) the role of freight to support emergency response and basic economic activity, and (2) the basic needs and functions of the freight industry. Research is needed to develop and share best practices on communicating freight fundamentals.

Developing and Sharing Best Practices

Both agencies and industry can learn from the experience of others. Development of a structured case repository would be helpful for agencies to identify past events that might inform their practices. Research is also needed to translate operational experiences into useful guidance for future events. Specific types of guidance that would be useful include identifying data needs, conducting pre-event trainings and tabletop exercises, identifying and prioritizing critical infrastructure elements, identifying mitigation alternatives and selection approaches, and conducting after-action assessments.

New risk-based approaches to freight systems and investment planning are needed. Research can inform methodologies and the design and implementation of related decision support tools.

Improving Data and Information Systems

Agencies face critical challenges in accessing timely data for decision-making and in sharing data between agencies, stakeholders, and modes. Research efforts are needed to establish standardized methods for data formatting and storage and to develop data architectures, technology platforms, and institutional arrangement that enable data sharing within and between agencies. Research is also needed to develop real-time data and information systems that can inform vehicle routing, traffic management, and asset management during an event.

Understanding the Role of Freight Resiliency in Broader Policy Discussions

Freight transportation systems and supply chains are complex, dynamic, and interdependent. Resilient freight systems must take into account climate risk; the health, safety and equity of communities and industry stakeholders; multimodal connectivity; potential for rapid changes in supply and demand; and interdependencies with passenger transportation and energy systems. Research is needed to better understand many of these factors. Some specific areas that need to be better understood include the impacts of facility closures or restrictions on supply chains; the effects of cascading power and communications system failures on freight systems and supply chain operations; and linkages between community vulnerability, supply chain organization, and the ability to respond to and recover from disruptions. Research could also investigate strategies to overcome political disinterest in or resistance to resiliency-related investments.

APPENDIX A

Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
AIS	Automatic Identification System
ALAN	American Logistics Aid Network
ATA	American Trucking Associations
ATON	Aid to navigation
Caltrans	California Department of Transportation
CARES	Coronavirus Aid, Relief, and Economic Security
CART	Common Assessment and Reporting Tool
CDA	Chicago Department of Aviation
CDC	Centers for Disease Control and Prevention
CISA	Cybersecurity and Infrastructure Security Agency
CMTS	Committee on the Maritime Transportation System
DOE	Department of Energy
DOT	Department of Transportation
EOC	Emergency Operations Center
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
GIS	Geographic information system
GPS	Global positioning system
MTS	Marine transportation system
NOAA	National Oceanic and Atmospheric Association
NWS	National Weather Service
PANYNJ	Port Authority of New York and New Jersey
PPE	Personal protective equipment
R-IAT	Resilience Integrated Action Team
TBR	Temporary barrier rail
TRB	Transportation Research Board
TXTA	Texas Trucking Association
UAS	Unmanned aerial systems
UP	Union Pacific Railroad
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard
USDA	United States Department of Agriculture

APPENDIX B

Workshop Attendees

Kwabena Aboagye
Tennessee Department of Transportation
Nashville, TN

Jill Angelone
Amtrak
Philadelphia, PA

Daniel Arellano
Caltrans
San Bernardino, CA

Felipe Aros-Vera
Ohio University
Athens, OH

Kenjana Aulia
Northwestern University
Evanston, IL

Matthew Baker
Nebraska Department of Transportation
Lincoln, NE

Jeannie Beckett
The Beckett Group
Gig Harbor, WA

Mark Berndt
Quetica
Bloomington, MN

Sanjeev Bhurtyal
University of Arkansas
Fayetteville, AR

David Bierling
Texas A&M Transportation Institute
College Station, TX

Julia Billings
Modern Mobility Partners
Atlanta, GA

Michelle Blake
Caltrans
San Diego, CA

Scott Brotemarkle
Transportation Research Board
Washington, DC

Joseph Bryan
WSP USA
Boston, MA

Jonathan Camp
Caltrans
Sacramento, CA

Francisco Castillo
Union Pacific Railroad
Sacramento, CA

Ryan Castle
Caltrans
Sacramento, CA

Katherine Chambers
US Army Corps of Engineers
Washington, DC

Qian Chen
Northwestern University
State College, PA

Holly Cohen
Florida Department of Transportation
Tallahassee, FL

John Contestabile
Skyline Technology Solutions
Glen Burnie, MD

Alison Conway
City College of New York
New York, NY

Trevor Daviscourt
Washington State Department of Transportation
Seattle, WA

Keegan Day
Amtrak
Philadelphia, PA

Karla Diaz-Corro
University of Arkansas
Fayetteville, AR

Paula Dowell
Cambridge Systematics
Austin, TX

Edward M. Emmett
Rice University Baker Institute for Public Policy
Houston, TX

Ronnie Escobar
Caltrans
San Bernardino, CA

John Esparza
Texas Trucking Association (TXTA)
Austin, TX

Harold Feinberg
Caltrans
Sacramento, CA

Josh Foster
Maryland Department of Transportation
Hanover, MD

Angela Fredericks
Caltrans
Sacramento, CA

Eric Fredericks
Caltrans
Sacramento, CA

Colin Fredrickson
Caltrans
Marysville, CA

Joseph Fuhr
Old Dominion Freight Line
Thomasville, NC

Jamaica Gentry
Caltrans
Sacramento, CA

George Avery Grimes
Patriot Rail
Jacksonville, FL

Megan Gutzmer
Amtrak
Philadelphia, PA

Robert Hampshire
U.S. Department Of Transportation
Washington, DC

Matt Hanson
Caltrans
Sacramento, CA

Sharika Hegde
Northwestern University
Evanston, IL

Adrian Hernandez
Northwestern University
Chicago, IL

Sarah Hernandez
University of Arkansas
Fayetteville, AR

Samuel Hiscocks
Iowa Department of Transportation
Ames, IA

Stephen Holliday
Louisiana DOTD/Office of Multimodal Commerce
Baton Rouge, LA

Daniel Horvath
American Trucking Associations
Arlington, VA

John Hourdos
University of Minnesota
Minneapolis, MN

Pat Hu
U.S. DOT - Bureau of Transportation Statistics
Washington, DC

Craig Hurst
Colorado Department of Transportation
Denver, CO

Liisa Itkonen
COMPASS
Meridian, ID

Jocelyn Jones
FHWA
Baltimore, MD

Simranjeet Kaur
Caltrans
Fresno, CA

Amy Kosanovic
Tennessee Department of Transportation
Nashville, TN

Carl “Jim” Kruse
Texas A&M Transportation Institute
Houston, TX

Cecile L’Hermitte
University of Waikato
Hamilton, New Zealand

Tom Lambert
Metropolitan Transit Authority of Harris County
Houston, TX

Peter Lemack
Applied Geographics, Inc.
Boston, MA

Rhonda Levinowsky
TRB
Washington, DC

Edward Lincoln
Caltrans
Marysville, CA

William Lusk
AASHTO
Washington, DC

Laura Mester
MDOT
Lansing, MI

Bruce Millar
Transportation Research Board
Washington, DC

Curtis Morgan
Texas A&M Transportation Institute
College Station, TX

Hunter Mulhall
COMPASS
Meridian, ID

Josh Murphy
NOAA Office for Coastal Management
Rockville, MD

Sheridan Nansen
Caltrans
San Luis Obispo, CA

Alison Nealon
Caltrans
Sacramento, CA

Max Ng
Northwestern University
Evanston, IL

Jacob Nicholson
Iowa Department of Homeland Security and Emergency Management
Winsor Heights, IA

Kara Oldhouser
Amtrak
Philadelphia, PA

Steven Olmsted
ADOT Environmental Planning
Phoenix, AZ

Thomas Palmerlee
Transportation Research Board
Washington, DC

Marygrace Parker
The Eastern Transportation Coalition
Greenwich, NY

Sherry Pifer
Texas Department of Transportation
Austin, TX

Eric Pihl
FHWA
Denver, CO

Cristina Popa
Northwestern University
Evanston, IL

Lia Prince
Tennessee Department of Transportation
Nashville, TN

Jeff Purdy
FHWA
Washington, DC

Frank Ramirez
GO-Biz
Sacramento, CA

Hector Rangel
Caltrans
Fresno, CA

Drew Ratcliff
Capital Region Planning Commission
Baton Rouge, LA

Suresh Ratnam
Caltrans
Eureka , CA

Meredith Raymer
Northwestern University
Evanston, IL

Jonathan Regehr
University of Manitoba
Winnipeg, Manitoba, Canada

Adam Rod
Chicago Department of Aviation
Chicago, IL

Bethann Rooney
Port Authority of NY & NJ
New York, NY

Justin Ryan
FL Department of Transportation
Jacksonville, FL

Joseph Schofer
Northwestern Univ
Wilmette, IL

Kristen Scudder
Delaware Valley Regional Planning Commission
Philadelphia, PA

James Shankel
Caltrans
Los Angeles, CA

Peter Skosey
BNSF Railway
Chicago, IL

Megan Smith
The MITRE Corp
McLean, VA

Austin Sos
Caltrans
Stockton, CA

Steven Stichter
National Academies of Science, Engineering and Medicine
Washington, DC

Monika Stoeffl
California Resiliency Alliance
San Francisco, CA

Sam Sturtz
Iowa Department of Transportation
Ames, IA

Theodore Sussmann
U.S. Department of Transportation/Volpe Center
Cambridge, MA

Bradley Trefz
Texas A&M Transportation Institute
College Station, TX

Bryan Tuma
Nebraska Emergency Management Agency
Lincoln, NE

Juan Villa
Texas Transportation Institute, Texas A&M University
Houston, TX

Elizabeth Welch
Cambridge Systematics
Austin, TX

Casey Wells
Texas Dept of Transportation
Austin, TX

Michael Williamson
Cambridge Systematics, Inc.
Fort Lauderdale, FL

Erika Witzke
CPCS Transcom Inc.
Washington, DC

Xiwen Xu
Northwestern University
Cary, NC

Austin Yates
Iowa Department of Transportation
Ames, IA

Yian Yin
Northwestern University
Evanston, IL

Yanlin Zhang
Northwestern University
Evanston, IL

Wenjuan Zhao
Washington State Department of Transportation
Olympia, WA

Kaiwen Zhou
Somerset, NJ

Huaqing Zhu
Northwestern University
Evanston, IL

Melissa Ziegler
CDM Smith
Knoxville, TN

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