Project No. NCHRP 20-117

SUMMIT/PEER EXCHANGE REPORT

Task 7 Report

---DRAFT---

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National Cooperative Highway Research Program
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of
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WSP USA
1015 Half Street SE, Suite 650
Washington, DC 20003

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Summit Planning Committee

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- Brooks D. Nelson, Corporate Citizenship Center

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Introduction

The Transportation Resilience Innovations and Summit Exchange (RISE) was held on October 8-10, 2018 in Denver, Colorado. The Summit was co-sponsored by the American Association of State Highway and Transportation Officials (AASHTO), Colorado Department of Transportation (CDOT), Federal Highway Administration (FHWA), Transportation Security Administration (TSA), and the Transportation Research Board (TRB). Over 450 participants attended sessions on a wide range of topics focused on how to make the transportation system more resilient.

Besides plenary and breakout sessions, the Summit included a poster session where state DOTs and other transportation agencies highlighted aspects of their resilience program. The posters represented a diverse set of activities across all the agencies that prepared them, illustrating how agency actions can enhance the resilience of the transportation system. In addition, a field trip to the nearby Eisenhower/Johnson Memorial Tunnels occurred one day prior to the opening session. The field trip focused on tunnel fire suppression technologies and featured presentations and participants from Australia and New Zealand. The Transportation Security Administration (TSA) also offered a workshop on vehicle ramming. Several AASHTO and TRB committees held meetings either the day before or the day after the Summit.

The Summit took advantage of several National Cooperative Highway Research Program (NCHRP) projects that were at the time in various stages of research on transportation system resilience. The Summit itself was part of NCHRP 20-117: *Deploying Transportation Resilience Practices in State DOTs.* This project was responsible for Summit organization and management, logistics, and follow-up research. Two other projects also used the Summit as part of their research design--NCHRP 20-59(54), *Transportation System Resilience: Research Roadmap and White Papers*, and NCHRP Project 20-59(55), *Transportation System Resilience: CEO Primer & Engagement.*

Summit Organization

The Summit was structured around three major conference themes that served as the foundation for session tracks, with a plenary session introducing key points of departure for each theme. The three conference themes were: 1) Enhancing an Organization's Capacity for Incorporating Resilience into Its Activities, 2) Recognizing Infrastructure Dependencies and Fostering Partnerships, and 3) Making the Case for Resilience. A conference track was also offered for state DOT officials to focus on resilience opportunities and challenges from a state-level transportation perspective. NCHRP provided funds to support two representatives from every state DOT in the country to attend the Summit (see inset A for the state DOTs and international transportation agencies that attended).

Overarching Observations

With 13 plenary session speakers and 29 breakout sessions, it is challenging to summarize all of the important observations and conclusions made throughout the Summit. However, a number of overarching observations were universally noted by almost all of the speakers and participants. These observations are presented below in no order of priority.

Transportation system resilience should be a concern for all transportation agencies and their partners - Although many reasons and examples were offered on why transportation agencies should be concerned about resilience, some of the more salient included the following:

- System disruptions and resulting impacts: A transportation system provides levels of mobility and accessibility that act as the foundation of a modern society. When this transportation system is disrupted, potentially serious short-term impacts could affect the economy,

Inset A: The following 44 state DOTs and transportation agencies from other countries attended the RISE meeting.

- Alaska Department of Transportation & Public Facilities
- Arizona Department of Transportation
- Arkansas Department of Transportation
- California Department of Transportation
- Colorado Department of Transportation
- Connecticut Department of Transportation
- Delaware Department of Transportation
- D.C. Department of Transportation
- Florida Department of Transportation
- Georgia Department of Transportation
- Hawaii Department of Transportation
- Idaho Transportation Department
- Illinois Department of Transportation
- Iowa Department of Transportation
- Kansas Department of Transportation
- Kentucky Transportation Cabinet
- Louisiana Department of Transportation and Development
- Maine Department of Transportation
- Maryland Department of Transportation/Maryland State Highway Administration
- Massachusetts Department of Transportation
- Michigan Department of Transportation
- Minnesota Department of Transportation
- Missouri Department of Transportation
- Montana Department of Transportation
- Nebraska Department of Transportation
- Nevada Department of Transportation
- New Hampshire Department of Transportation
- New Jersey Department of Transportation
- New Mexico Department of Transportation
- New York State Department of Transportation
- North Carolina Department of Transportation
- North Dakota Department of Transportation
- Oregon Department of Transportation
- Pennsylvania Department of Transportation
- South Carolina Department of Transportation
- Tennessee Department of Transportation
- Texas Department of Transportation
- Utah Department of Transportation
- Vermont Agency of Transportation
- Virginia Department of Transportation
- Wyoming Department of Transportation
- Washington State Department of Transportation
- West Virginia Department of Transportation
- Wisconsin Department of Transportation

<u>International Representatives</u>

- Ministry of Infrastructure and Water Management, Rijkswaterstaat, The Netherlands
- New Zealand Transport Agency
- Transport Canada

environment, and social interactions. If the system is viewed as consistently unreliable, long-term development patterns could also be influenced as industries and companies move to locations that are considered to have a more reliable transportation system. As stewards of the transportation system, transportation agencies are naturally concerned with avoiding such disruptions if possible, or at least mitigating the negative effects.

- High visibility of system disruptions - In most cases, transportation disruptions will inconvenience system users and those who rely on what the transportation system delivers; in the worst case, disruptions could result in fatalities and injuries. Thus, when such disruptions occur, political, public, and media attention is given to why the disruption occurred and, just as importantly, how the transportation agency will get the system back to normal and prevent such issues from recurring. The ability of transportation officials to deliver a fast recovery provides credibility to their agency's efforts and oversight of the system; alternatively, poor management of a disruption and of the subsequent recovery could invite scrutiny from other branches of government and loss of credibility.
- Increasingly interconnected world - Many of the infrastructure systems that states or communities rely on are interconnected such that a failure in one will lead to potential failures in others. The cascading effects of failure thus suggest that transportation agencies need to be aware of their reliance on the reliability of other systems (power, for example). This adds more complexity to developing a plan for agency response when the transportation system is affected by a disruption outside of the control of transportation officials.
- Vulnerability of cyber systems - The interconnectivity mentioned above certainly pertains to the reliance of transportation systems on reliable cyber networks. Several recent cyberattacks on public and private transportation organizations were discussed that resulted in loss of productivity and incurred substantial recovery costs. As was presented at the Summit, the transportation sector is considered the third most vulnerable sector to cyberattacks. Several speakers noted the need for transportation agency attention on this very critical part of day-to-day operations.
- Human-caused disruptions - World-wide, transportation systems are some of the top targets of terrorists, not only because of the impacts on the community and economy, but because of how visible the attacks are and how they will be covered by the press. Terrorist attacks in the U.S. against transportation systems are not as common as elsewhere, although there have been several, highly visible attempts (e.g., the New York subway). Because of the vulnerability of the U.S. transportation system, transportation agencies should be continually concerned about protecting transportation infrastructure and system users against foreign and domestic terrorist attacks.
- Future climate and extreme weather conditions - Several well-reported extreme weather events over the past 10 years (e.g., hurricanes, superstorms, floods, blizzards, droughts, and wildfires) have shown how vulnerable transportation systems are to natural disruptions. With the vast majority of climate science projections suggesting that such events are likely to get worse in the future, it is important for transportation agencies to consider asset vulnerabilities and risks in their planning, project design, operations/maintenance, and asset management. Most projects put in place today will still be around over the projected timeframe of expected dramatic changes in climatic conditions.

> Don't be limited by what you do in resilience by not having enough data or analysis tools….it is better to do something than nothing at all.
>
> -- Debra Nelson, New York Metropolitan Transportation Council

Creating a state DOT culture of resilience starts with agency leadership – The fact that 13 state DOT CEOs and over 100 other high-level state DOT officials attended the Summit attests to the interest and concern DOT leaders have for system resilience. As was noted by many speakers and attendees, the path toward a more resilience-oriented DOT starts with agency leadership. This might mean nothing more than expressing interest in the topic and then assigning responsibilities to others to carry it out, or it might mean direct and continual involvement by the CEO in the agency's activities. In some cases, the impetus for more concerted efforts at resilience came from within the DOT but did not get more broadly applied or implemented until the CEO or other top leaders supported the initiative. The key observation from all the state DOT CEOs who presented at the Summit was that they personally were supporting the effort as well as taking steps to institutionalize the activities and practices to last beyond their tenure as the head of the agency.

Most transportation agencies feel comfortable with their planning and implementing emergency response procedures – Many transportation agencies consider system resiliency solely from the perspective of operations and emergency response. Well-thought-out procedures and guidance have been available from many different sources (e.g., FHWA, Federal Emergency Management Agency (FEMA), TSA, and the like) for many years. When asked to identify the state DOT resilience-oriented actions or activities that their agency was most proud of or comfortable with, the vast majority of DOT officials noted their emergency response procedures.

However, a concern was voiced that transportation system resilience should be considered in all functional units within a transportation agency –DOT officials were asked what they would like to have more information on. Many responses indicated the need for guidance or information on how resilience concepts can be incorporated into everything the DOT does. Transportation agencies need to look at their own policies, structure, products, services, and capabilities from the perspective of the role of each in fostering a more resilience-oriented agency. It was, in fact, a major purpose of the Summit to foster this broader perspective on how resilience could be considered across a typical agency (see Figure 1). NCHRP 20-117 is developing a guidebook that will provide DOT officials with information on how to do this.

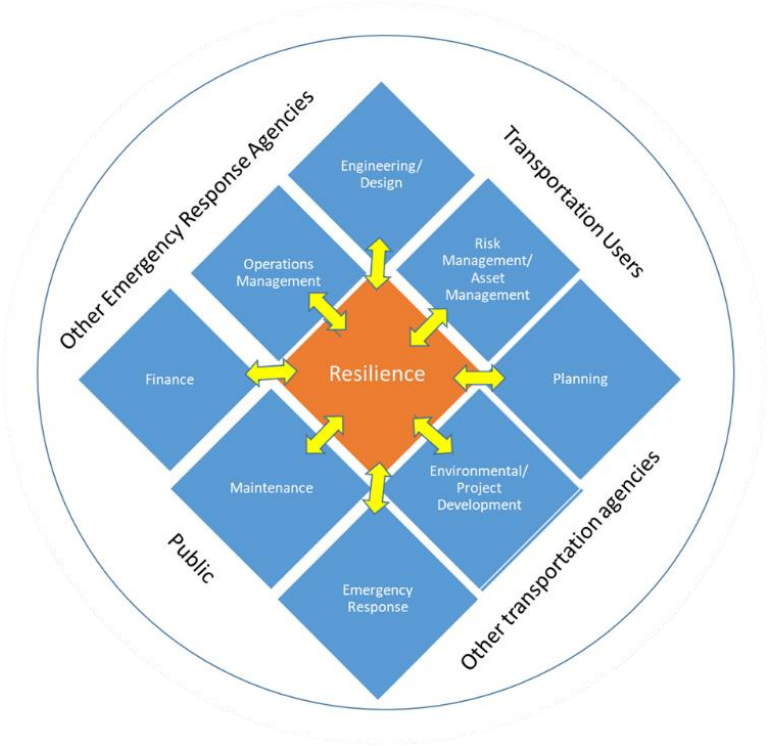

Figure 1: Resilience Considerations Should be Part of All DOT Functional Areas

Incorporating resilience concerns into decision-making processes is a key step for success – In discussing how one knows if resilience is being considered successfully by an organization, Summit participants offered many different ideas on how success could be measured (e.g., use of resilience performance metrics, implementation of resiliency projects or project characteristics, and the like). Most noted that even though system resilience is an important (and becoming increasingly more important over time) concern to transportation officials, the reality is that it will compete with many other goals and objectives. It was suggested that the most important step in institutionalizing resilience in agency efforts was to integrate such concerns into agency decision making and to make the case for why it deserves to be considered (see next observation). Decision making in this context included all agency decisions that could affect system condition and performance (e.g., policy formulation, planning, project development, operations and maintenance, asset management, and the like). One of the foundational "pillars" of including resilience into decision making was understanding how "risk" can be considered in a decision-making context. Doing so necessarily requires an understanding of the types of threats and hazards that will likely be faced and the vulnerability of system assets to such threats/hazards.

Many executive-level transportation officials recommended that the transportation planning process be one of the most important areas where risk and resilience needs to be included. Many of the Summit participants, especially those in very senior agency positions, felt that transportation planning was one of the most important functional responsibilities of their agency where risk and resilience concepts should be addressed. There seemed to be many reasons for this:

1. Planning provides the future context for decisions today and for those that will be made in future years. With a growing concern for system disruptions, planning is an obvious function where such considerations should occur.
2. Planning is often the source of much data and information describing what is happening on the transportation system. Adding additional requests for resiliency information would not be outside the norm for a transportation planning unit.
3. Many of the vulnerability assessments that have been conducted in the Nation follow a systematic process that is very similar to the usual steps in transportation planning, and thus the process steps will not be unfamiliar.
4. Planning is often the unit within an agency that leads interactions with other stakeholders (e.g., regional and local planning agencies, port authorities, transit agencies, transportation system users and with the general public). Planners are thus comfortable with the process of including others into transportation agency processes.
5. Federal requirements for performance-based program management have often led to the planning unit being responsible for identifying appropriate performance measures. To the extent that system resilience is to be part of these metrics, planners are probably best situated to do so.

6. Transportation plans are undertaken at various scales --- statewide, regional, corridor and site-specific. Transportation planners would thus be in the best position to incorporate risk and resiliency into all of these efforts whose primary intent is to inform decision making (see Figure 2 for an example from the Utah DOT at the corridor planning level).

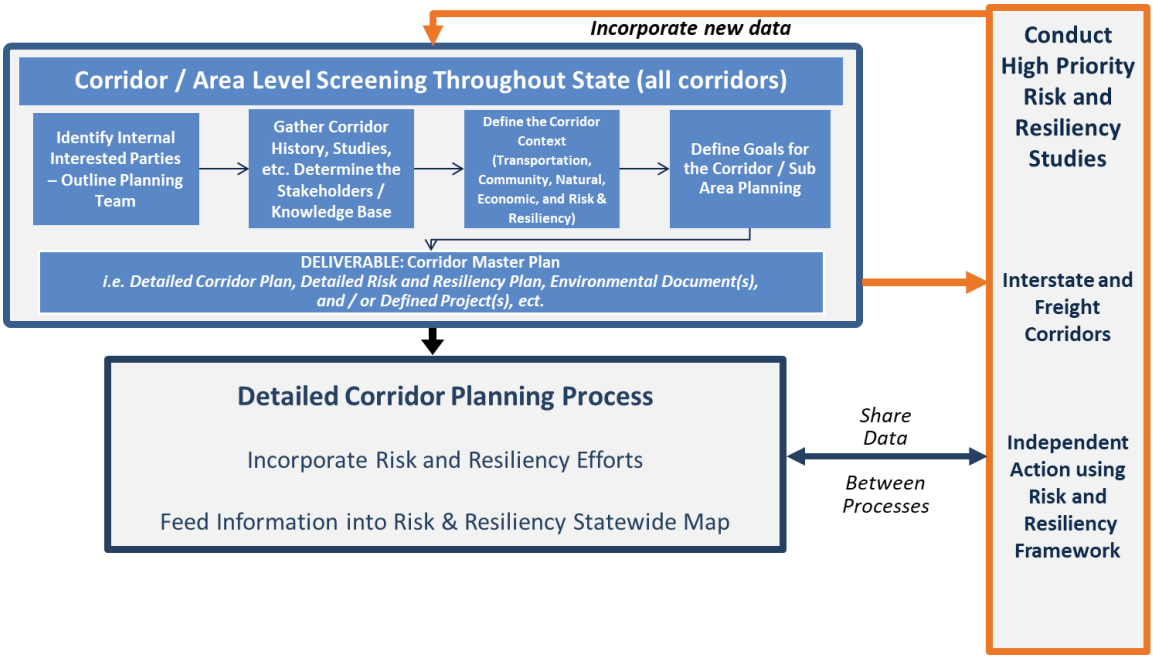

Figure 2: Incorporating Risk and Resilience into Corridor Studies, Utah DOT

There is an important need for developing information, tools, and data to "make the case" for resilience – In order to compete with other goals and objectives, transportation officials need to have information on the benefits of investing in resilience projects or in project characteristics that provide enhanced resilience for minimal costs. The desire was not only for information on benefits and costs for individual strategies and actions, but also on methods for comparing across different projects (it is interesting to note that the session on benefit/cost methods was one of the most attended of the Summit). This need also included increasing the understanding of how resilience and other performance characteristics could be viewed from a co-benefit perspective, and the types of metrics (system and system users) that should be included in the analysis.

> Leaders establish the resiliency culture in an agency…it is all about risk and resilience …. we are in it for the long game.
>
> -- Paula Hammond, WSP, Inc.

Transportation agencies cannot do it alone – Transportation system resilience, in all its manifestations, affects many different groups and organizations. Summit participants emphasized the importance of collaboration, coordination, and communication among all the parties involved in enhancing system resilience. One session, for example, talked about supply chain disruptions and how both public agencies and private organizations could improve system resilience in the context of goods and freight movement. Others noted the importance of collaborative arrangements among different levels of government and with relevant agencies at the same level for specific activities and responsibilities (such as emergency response).

Analysis frameworks exist…and are being used – Several Summit presentations focused on structured analysis frameworks that are being developed and/or used to provide transportation officials with a step-by-step process for considering resilience. In some cases, these frameworks were examining one particular function within a transportation agency (e.g., traffic incident response) whereas another was developed as a self-assessment tool for agencies to determine where they are today with respect to resilience activities and what they can do to enhance their capabilities. As additional frameworks are developed and existing ones are refined over time, transportation officials will have better information as part of their decision-making process to gauge the relative value of resilience actions. As climate science evolves and better and more cost-effective databases and models become available, transportation agencies will have to keep abreast of what these advances mean to their own capabilities.

Sharing best practices is one of the most effective means of enhancing professional capacity in resilience efforts – Summit participants viewed peer exchanges, case studies, and other means of sharing best practices as the best forms of learning about the state-of-practice. This is especially true in the U.S. where there is wide ranging applications of agency-wide resilience practices. Some states are proceeding across agency functional areas; others are focusing on only one area (in most cases, emergency response). The sense was that transportation agencies can learn a lot from what others are doing.

Training and professional development opportunities are critical resources to a resilience-oriented agency – Many DOT officials recognized that a greater consideration for resilience is not just a matter of having guides, design criteria, or analysis tools for doing so. It also requires staff who understand how to use this information…and perhaps as importantly, why they are doing so. The observation of the need for staff training and professional development in resilience topics cut across all four conference tracks.

The consequences of system disruptions often have greater impacts on disadvantaged populations and thus transportation agencies need to consider such impacts in resilience efforts – Studies have shown that, in many major disasters, those living in poverty or who have no way of leaving an impacted area often face much higher consequences (and thus risks) than other population groups. This includes not only the immediate impacts on the livelihood and survival of low income and disadvantaged population groups, but also the long-term impacts of the economic dislocations that follow a disaster. Some states (e.g., California and Colorado) described how social impacts are being considered when priorities are set for resilience-oriented projects. This is an important and growing concern for state DOTs.

The focus should be on what transportation systems enable, not on the transportation system itself --- Several sessions examined the challenges of incorporating resilience concepts into agency practice. In some cases, this was discussed in the context of how to convince legislators or other key stakeholders that funding should be allocated for such a purpose. In others, the context was how do you show the general public that the transportation agency is serving them. The message was clear----focus on what transportation systems do for a state, community, or society at large. Then show what will happen when transportation systems are disrupted. Focusing solely on transportation systems can miss the bigger picture of why a reliable, resilient, and effective transportation system is so important for a modern society.

> Creating a culture of resilience means planning our transportation systems to be more resilient, designing our projects to be more adaptive to change, constructing our projects to withstand more challenging stresses, and operating and maintaining our system to operate more reliably ----Mike Lewis, Colorado DOT

Keynote Presentation, Mike Lewis, Executive Director, Colorado Department of Transportation

Mike Lewis, Executive Director of the Colorado DOT, provided an overview of the challenges facing state DOTs with respect to system disruptions. He noted that since 1953 there has been a significant growth in the number of declared disasters in the U.S. In fact, the top five most expensive storms in U.S. history have occurred since 2012, with these top five causing more than $300 billion in damage. In Colorado, the 2013 flood disaster resulted in over $700 million in repair and reconstruction costs, projects which in a few cases CDOT is still in the process of delivering (in 2018). One of CDOT's regional offices had to suspend all work in its planned capital program for one year just so it could focus on flood-related repair work. Mr. Lewis also noted that although state DOT officials have focused on natural disasters, cyberattacks represent an ever-growing threat as well. CDOT faced such a serious cyberattack in early 2018 that caused significant disruption.

Mr. Lewis emphasized that effective state DOTs learn from their experiences. He compared the northeastern U.S. blizzard of 1978 to a similar storm in 2013 that also hit the northeastern U.S. High winds and 30" to 40" of snow in both instances had very different outcomes. The "Blizzard of '78" caused major interstates to be shut down for many days, closed schools and government offices for up to three weeks, and resulted in major economic losses. The 2013 blizzard, on the other hand, saw major interstates closed for up to 12 hours unlike in 1978. Economic losses were minimal. Why was there such a difference? According to Mr. Lewis, the National Weather Service did a post-mortem on both events and concluded that there were two major reasons for the different outcomes, 1) weather forecasting had improved over that time period, and 2) there was a much more coordinated and stronger government response. In other words, according to Mr. Lewis, the respective DOTs had learned their lesson from the 1978 storm and put in place coordination and communication strategies that resulted in a much less disruptive storm in 2013 …. greater coordination reduced the impact of a major storm.

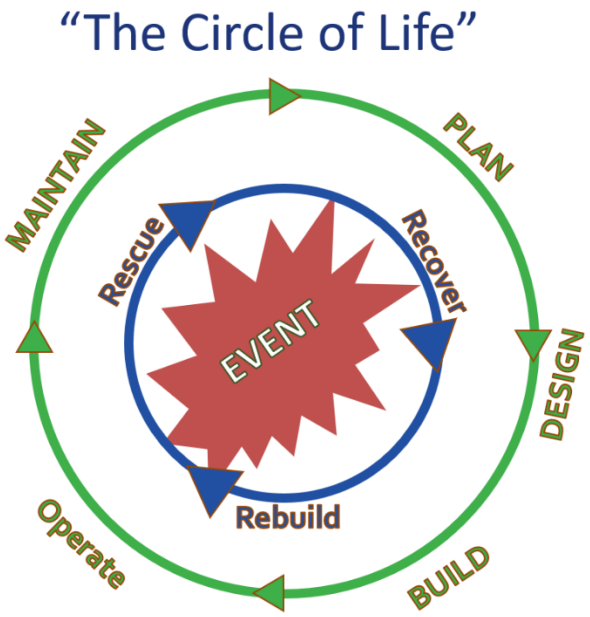

Figure 3: State DOT's Circle of Life and Disruption Response

Mr. Lewis introduced the concept of a "circle of life" to explain how he sees resilience incorporated into what state DOTs do. As shown in Figure 3, state DOT responsibilities include planning, design, building, operations, and maintenance---the typical functions within a DOT. DOTs do their jobs well…they have many years of experience in knowing how to produce transportation projects. Then some form of disruption occurs to the transportation system that, similar to the CDOT experience with the 2013 flooding, refocuses the energies of the agency. Mr. Lewis suggested that to minimize the disruption to the DOT, and to the state and its communities, the DOT needs to know how to plan transportation systems to be more resilient; how to design projects more appropriately for unforeseen events and actions; how to construct resilient projects; and how to operate and maintain transportation systems that promote resilient performance. In other words, "how do we develop a culture of resilience in our agency?"

Mr. Lewis described CDOT's efforts to "change mindsets," of thinking of system resilience as a key outcome of all the DOT's activities. CDOT has created institutional structures within the agency to act as continual champions for resilience. The agency has conducted resilience-oriented corridor studies to better understand where the risks are and the associated consequences of failure. It has incorporated system resilience into the statewide transportation plan. And it has developed a middle management staff that are committed to thinking creatively on what their unit can do to improve system resilience.

Mr. Lewis closed by noting that of all the risks to I-70, one of Colorado's most important interstates, winter storms is the one that closes the road most. He noted every year CDOT closes the road for some winter-related reason (130 times in 2017). CDOT has managed through operational strategies to reduce the number of 90+ minute closures from 30 five years ago to 0 today. Thus, CDOT has learned from experience how it can reduce the impact of winter closures. However, even with this progress, given the importance of the tourist industry to Colorado and winter travel along I-70, Mr. Lewis noted that CDOT still needs to identify a long-term plan to avoid road closures in the future. This can only be done if CDOT has a good idea of where the high-risk locations are.

Track on State DOTs and Resilience …. included sessions on:

- How Resilience Can Help You Sleep Better at Night
- How to Become Resilient (in State DOTs)?
- Resilience Starts at Home: How to Build on What You Are Already Doing and Fill Any Gaps?
- Making the Case for Resilience: How Do We Get What We Need?
- Make it Last: Incorporating and Sustaining Resilience in Agency Functions and Operations
- Incorporating Resilience into Decision making: Asset Management
- Developing an Action Plan and Implementation Strategy

The purposes of the state DOT track were to: 1) increase state DOT's understanding of resilience and how risks could be incorporated into DOT decision making, 2) learn about what others are doing, 3) exchange best practices, and 4) identify strategies to incorporate resilience in DOT functional areas.

A presentation by Paula Hammond from WSP, Inc. opened the session by presenting perspectives on resilience that she has found in her work throughout the country. She presented a 12-step analysis framework that agencies could use to determine where they currently are with respect to incorporating resilience considerations in agency decision making. Her major observations included:

- Resilience often has different meanings to different people.
- Resilience should be part of every functional area in a DOT (see Figure 1).
- Resilience should be part of the life cycle of assets, especially those assets considered most critical.
- A resilience strategy for a DOT is adaptive, collaborative, communications-focused, and results-oriented.
- There are ways a DOT can systematically identify areas of risk and develop risk mitigation strategies.

Presentations were made by several state DOT officials highlighting a project, study, or initiative they felt illustrated best practice. Some examples:

Colorado DOT (CDOT): CDOT conducted a risk assessment of 470 centerline miles of I-70 through Colorado between the Kansas and Utah borders. The intent was to take a proactive look at optimal near-term investments, and take whatever actions were necessary in advance of future events. Both owner risks and user risks were identified (the highest owner risk was rockfalls; and the highest user risks were flooding in addition to rockfalls). The study identified and prioritized potential mitigation measures using benefit/cost analysis. Interestingly, the study showed that 7 percent of the road segments composed 67% of the total risk in the corridor. The prioritization methodology considered road segment usage (e.g., average daily traffic and truck volumes), economic impact (e.g., on the tourism industry), social impact (e.g., social impact index), and system redundancy (e.g., detour mileage and time).

The information from the study was included in different types of CDOT decision making. For example, the top 10 high risk culvert locations were incorporated into project NEPA studies (this was considered important because designers using NEPA reports needed to know what issues should be addressed). The rest were compared to CDOT's geohazard plan, and if they were not in the plan, they were added. The list of culverts was given to the maintenance group, which gave high-risk culverts greater attention for debris removal and inspection. CDOT's asset management program, which includes 11 asset categories, was also examined to see where the investments in the corridor could "buy down the risk" associated with the critical culverts. Finally, when CDOT was identifying candidate projects for the new federal National Freight Program, the criteria for project selection included: safety, economic vitality, system maintenance, mobility, and enhancing resilience/reducing risk. The results from the I-70 study were incorporated into the latter component of the selection criteria.

At a broader agency level, CDOT's resilience strategy, program, and efforts were born in the aftermath of the 2013 floods. The state legislature and governor's office created a statewide resilience program focusing on communities and their ability to survive and recover from disasters. Debra Perkins-Smith from the CDOT made the point that the focus on "community" and not just infrastructure resilience has been a key element of the success of the state's and CDOT's efforts. CDOT's resilience strategy included adding a strategic objective to the statewide transportation plan stating that risk, resilience, and network redundancy concepts should be included throughout CDOT actions. According to Ms. Perkins-Smith, this "provided the support and rationale to take action."

Ms. Perkins-Smith concluded that major lessons from CDOT's experience with resilience included:

- Having state legislation, CDOT policy, and a statewide transportation plan with resilience mandates helped establish the foundation for subsequent actions.
- Success will depend on having management support at all levels of the agency.
- It helps if there are recognized "resilience champions" in the agency; even better if there are resources to promote their activities.
- Resilience needs to be engrained in all levels and parts of the agency.
- Resilience also needs to be considered throughout a project's life cycle.

Oregon DOT (ODOT): ODOT followed a strategy over many years of developing plans for responding to a Cascadia Subduction Zone earthquake. The motivation for the strategy was predicated on an estimate that there was a 37% chance of a major earthquake happening in the next 50 years, and that when it occurs it will have a devastating impact on the state's transportation system and on the economy. Three

main goals of ODOT's efforts were to: 1) support the survivability of the transportation system immediately following an event (short term), 2) ensure transportation facilities that were critical to life support following the event were available (mid-term), and 3) over the following years support statewide economic recovery (long-term). Over a period of 20 years since the magnitude of a Cascadia event was first recognized, the State of Oregon and ODOT have taken several steps to enhance transportation system resilience in anticipation of massive disruptions following the event:

- In the early 1990s, ODOT revised its bridge design criteria beyond those required by FHWA or other states to be more stringent in terms of seismic design. Performance-based criteria were established based on the concept that bridges should be functional after an earthquake (not like other criteria which focused on simply keeping the bridge standing).
- In the mid-1990s, ODOT assessed its entire inventory of state bridges against the design criteria to determine the degree to which bridges might be vulnerable. An initial investment in retrofitting bridges began in the late 1990s.
- In the early 2000s, ODOT commissioned a study on the economic impact of such an earthquake on the state' economy and found that there would be an estimated $350 billion economic cost. The study also indicated that investment in bridge strengthening and landslide mitigation would reduce this loss between 10% and 24% over the course of the eight years of the most economic impact. The study looked at three different scenarios of earthquake severity. Both costs to reconstruct road infrastructure and to the users forced to detour around closed roads were included.
- From 2012 to 2014, ODOT did a more detailed assessment of the costs of protecting bridges (slope stability strategies were considered as well). The estimated statewide cost was just over $5 billion. The study recommended ODOT replace 140 bridges, retrofit 580 bridges, and stabilize 1200 slopes.
- In order to assure rapid (national) response, ODOT undertook a criticality analysis of lifeline routes that could serve as major access routes into the state for relief coming from other states. Two state highways were identified as being critical to such relief. Efforts have been made and continue today to make both routes seismic-resilient.
- In 2017, the Oregon legislature provided ODOT with $138 million for seismic projects, much less than the $5 billion price tag estimated from the study.
- Given that ODOT was not likely to get anywhere near the funding necessary, it adopted another strategy, called the triage approach, wherein focus was given to how local roads (designed at much lower standards) could be used as access routes into the disaster area. In the southern part of the state (expected to be hardest hit), the triage approach showed that response capability could be provided for 15% ($35 million) of the cost that the prior study indicated was needed for safeguarding the state highway routes in this part of the state. This cost has been covered out of the $138 million provided by the legislature.
- Other efforts that reflect ODOT's efforts to enhance system resilience include: 1) stockpiling supplies and materials at two state maintenance facilities that will likely be needed to respond to an earthquake, 2) practicing the response to the major earthquake by using current responses to smaller-scale incidents to fine-tune protocols and procedures, 3) developing a post-earthquake continuity of operations plan, 4) hardening the Bend, Oregon airport which is expected to be the center of earthquake relief/response, 5) working with local governments to identify seismic vulnerabilities on their road networks, and 6) putting a redundant command

and control system in Bend to act as a back up to the one in Salem, Oregon (which is likely to be damaged).

Interestingly, ODOT followed a process similar to that outlined by Paula Hammond in her opening remarks but did so over a relatively long period---approximately 15 years from when the idea for some form of action was first considered.

Maryland DOT (MDOT): Pete Rahn, Secretary of the Maryland DOT (MdDOT), discussed his experience as CEO for three state DOTs with respect to system disruptions. As noted from this tenure in Missouri, his first year as Secretary saw a major snowstorm in January in St. Louis that stranded thousands of motorists on the regional interstate system. This was followed by a deadly tornado in February in the western part of Missouri that disrupted the local economy, followed in March by a major ice storm, which was followed in April by an earthquake in Illinois that caused Missouri DOT to inspect more than half of its bridges. This was then followed by a major Mississippi River flood in June. Throughout all of these disruptions, the DOT responded in very effective and resilient ways.

When Mr. Rahn became Secretary in Maryland, he was now responsible for many different business units. He realized that many of these business units had large databases with personal information that might be susceptible to cyberattacks. For example, there were over six million records with personal information in the Department of Motor Vehicle databases (DMV); over 1.2 million credit card files in the Toll Authority databases.

Given the potential public relations and operations disaster if these records were hacked, Mr. Rahn explored further how vulnerable his agency was to cyberattacks. Some key points for his agency:

- MdDOT discovered it had 228 computer programs and 44 databases that were on-line, and thus potential paths into the computer network.
- "White hat" cyberattacks (professional hackers hired to determine where the agency is vulnerable) were commissioned to see how easy it was to hack the DMV databases. The hackers found two "easy" paths into the databases, including an abandoned DOT website that no one remembered even existed.
- MdDOT was experiencing 8 million cyberattacks per month.
- An attack over a 4th of July holiday weekend against the state's traffic control system was thwarted with new firewalls put in place. If successful, the attackers could have controlled all the DOTs real-time traffic signals, message boards, and variable speed limit signs.
- MdDOT has "geo-fenced" (deny access to any electronic messages from)19 countries.
- MdDOT is now spending $3.7 million per year on cybersecurity.

MdDOT is developing an integrated framework that will provide a "dynamic defense" for all of its databases and computer programs. As noted by Mr. Rahn, he is willing to spend money on this even trading off capital or operations funds simply because of how important it is. He closed his remarks by saying, "if you are discussing organizational and system resilience, you have the responsibility to include cybersecurity in your discussions."

Utah DOT (UDOT): UDOT has adopted a set of risk management objectives including, 1) assess and prioritize physical threats; 2) quantify annual monetary risk to UDOT and travelers; 3) develop economical risk mitigation solutions; 4) provide a risk-based, fiscally-constrained input to the Transportation Asset Management Plan (TAMP), maintenance and project selection strategies; and 5) develop a repeatable risk management process. Similar to CDOT, Utah DOT conducted a risk assessment along I-15 at the asset level, specific to the risk circumstances associated with each asset. For example, a bridge was assessed for magnitude 50-, 100-, and 500-yr flood events as well as any other applicable threat such as an earthquake. The intent is to adopt the I-15 corridor risk assessment approach to other parts of the state.

We need to understand and communicate why transportation is important to our society…this should drive why we need to focus on system resilience -- Carlos Braceras, Utah DOT

Take-aways from the discussions in the state DOT track:

- Transportation planning is a key functional responsibility in a state DOT where system resilience needs to be considered. It occurs early enough in the decision-making process that resilience concerns and recommended actions can be passed onto other activities in the project pipeline. Some examples:
  - Caltrans: Caltrans has conducted Climate Change Vulnerability Assessments in every Caltrans district, identifying segments of the State Highway System that are vulnerable to climate change impacts including precipitation, temperature, wildfire, storm surge, and sea level rise. Caltrans is now looking at how to prioritize projects vis-à-vis climate change impacts.
  - Colorado DOT (CDOT): CDOT has taken steps to institutionalize resilience concepts in the five Colorado regions by examining planning process changes. This includes how to institutionalize a concern for resilience in every functional area – project planning, design, maintenance, budgeting, etc.
  - Pennsylvania DOT (PennDOT): PennDOT is conducting an extreme weather study to identify transportation system vulnerability and risk by PennDOT region.
  - Utah DOT (UDOT): The initial resilience focus was on corridors where it was felt resilience was more meaningful to the district offices and other stakeholders. UDOT also works with the state's MPO's to consider resilience in regional transportation planning.
  - Vermont Agency of Transportation (VTrans): The experience of Tropical Storm Irene was a wake-up call for Vermont. In particular, it highlighted transportation system vulnerabilities to extreme weather and potential future climate disruption. VTrans began its agency focus on resilience by introducing expected system vulnerabilities to the agency's Executive Committee, many of whom were surprised by the magnitude of system vulnerability. VTrans also worked closely with the Burlington metropolitan planning organization (MPO) to better define what system resiliency means to system operations in that region.
- Some state DOTs are integrating risk, vulnerability and resilience into project development --- some examples:

- Connecticut DOT (ConnDOT): Officials worked with the legislature to pass Coastal Zone zoning and corresponding enforcement to influence shifts in development and land ownership behavior patterns. The intent was to incentivize people to not build in designated coastal zones. A challenge in ConnDOT's climate change efforts is the lack of climate data at the local level. The DOT is also thinking about how to design for short-term weather events.
- Delaware DOT (DelDOT): The key concern for DelDOT is flooding, which has already affected many coastal roads. The short-term solution has been to raise road elevations through repaving projects. However, the long-term risk is sea level rise, so DelDOT is examining how to use betterment funding during project development to address needed improvements due to rising sea levels.
- Georgia DOT (GDOT): GDOT has focused on addressing bridge vulnerability from planning through design, e.g., using asset-based systems to identify risks for lifeline critical systems relating to access to energy sources, hospitals, etc. The emphasis is on taking care of critical assets first. A single database has been developed for all state agencies for extreme weather events. The desire is to have all relevant state agency employees see the data for the most critical transportation assets. Continuity of operations has received priority in agency planning.
- New Jersey DOT (NJDOT): Superstorm Sandy was a major challenge to the DOT in dealing with extreme weather events. NJDOT is now beginning to design beyond current standards to account for future threats to low-lying roads.
- New York State DOT (NYSDOT): NYSDOT is identifying corridors that were vulnerable to extreme weather threats and are designing beyond current standards to mitigate these vulnerabilities.
- Ohio DOT (ODOT): ODOT has established an internal team to examine weather and climate change impacts to the State Highway System.
- Tennessee DOT (TDOT): TDOT uses geological data, in combination with hydrology data, to manage the network vis-à-vis system operations expectations. Some roads are going to flood on a regular basis, so the idea is to help residents and businesses understand that these networks are not going to be available when certain conditions prevail.
- Texas DOT (TexDOT): The DOT is identifying all the roads in the state that have been inundated many times and how these roads feed into the State Highway System. DOT officials will prioritize where prospective projects could significantly improve long-term resilience.
- Utah DOT: UDOT is changing design criteria for corridors depending on identified vulnerabilities and risk levels.
- VTrans: The DOT is using scenarios analysis to examine climate change implications to project designs. Three scenarios for climate change have been developed---a relatively low level of change, a medium level of change, and an extreme level of climate change. The scenarios are used to examine needed design changes to assess the impacts on project performance of these different levels of climate change.
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- Some of the best examples of state DOT resilience efforts are found in system maintenance and operations strategies. Some examples:
  - Arizona DOT (ADOT): ADOT pre-positions equipment that can be used to recover system operations quickly. One of the challenges is providing rapid response to replace intelligent transportation system (ITS) signing.
  - ConnDOT: ConnDOT puts emphasis on tree maintenance and tree cutting; in addition, culverts on the National Highway System receive particular attention for drainage clearance.
  - Florida DOT (FDOT): FDOT pre-positions equipment, personnel, and materials proximate to where an expected event is likely to occur. FDOT has received public acknowledgment of its rapid response to major weather events. FDOT is also using highway shoulders as part of evacuation strategies, making sure evacuation routes (and shoulders) are free of obstructions.
  - Idaho DOT: Risks are addressed on a case-by-case basis. For example, avalanches are a significant problem in Idaho, so an upgrade to the avalanche monitoring system is being put in place.
  - TDOT: TDOT has implemented a program to keep culverts clear of debris.
- Several observations were made on institutional issues relating to system resilience and agency operations.
  - Disasters and other significant system disruptions should be viewed as an opportunity to improve an agency's resilience efforts. This includes a post-event assessment of what worked and what needs improvement …… to how assets can be better designed to withstand future hazards and threats. What steps can be taken so as not to perpetuate the rescue-recover-rebuild cycle that resulted in the original failure?
  - Set up administrative systems for handling disaster response and tracking costs/hours well ahead of time. Involve administrative staff in the response.
  - One state has added "resiliency/recovery" to every staff job description in the agency to sensitize staff to the importance of system resilience and make sure they are aware that they might be called upon when disasters occur.
  - Response and recovery times are often very limited. There often is not much time available to wait for decisions. Empower staff to make decisions; push such decisions as far down the chain of command as possible.
  - Some states have created "strike forces" to make repairs and get the system back in operation as quickly as possible. Tennessee, for example, has a 100-person recovery strike force for making repairs; the strike forces can deploy for 30-days and is self-sustaining.
  - Transportation agencies are not only responsible for its transportation system, but they are also employers. Some DOTs have established programs for helping employees and their families affected by a disaster (e.g., a hurricane). Louisiana, for example, provided affected employees with hotels and FEMA trailers post-Hurricane Katrina. Others have established protocols for "call-ins" after a disaster to make sure employees are okay.

- Several observations were made on the importance of partnerships.
    - Strong relationships with partners are critical for success. Success is more than just conducting training exercises. This includes proactive coordination with all stakeholder and partner agencies prior to a disaster.
    - Efforts should be made to improve communications and outreach to navigation providers like Google and Waze and jointly recommend how information dissemination can be better used during disruptions.
    - Partner with the tourism industry to get the "word" out on road closures (many travelers ask their hotels or tourist sites for this information).
- Other important observations included:
    - Cyber risks are important in today's world and will likely become even more important in the future (see later section on cyber security).
    - Remote monitoring technology is proving useful in response and recovery efforts (e.g., drones to monitor traffic, truck parking utilization., etc.)
    - More guidance is needed on how betterments can be part of federal Emergency Relief (ER) policies when reconstructing facilities.
    - Common sense and understandable communication is key to public understanding what is happening and what they should be doing---need to speak in language that "mom and dad" would understand.

Joyce Coffee of Climate Resilience Consulting, Inc. noted that although much of the discussion in the Summit has been on infrastructure, we need to be concerned about people and their welfare during times of stress. Some of her key points included:

- Environmental justice is the law. Environmental Justice Executive Orders, Title VI, and SAFETEALU require the consideration of equality in decision making. U.S. DOT enshrines this concept in its Principles of Environmental Justice. However, very few examples presented at the Summit consider social equity integration.
- One of the key findings of the 2018 World Economic Forum Global Risks Report, based on a global risk perception survey of over 1000 'educated elites," was that inequality and "polarization" now rank among the top three interconnected underlying trends influencing global risks.
- How do you integrate social equity as an important decision-making context for DOTs? Focus on communities!
    - Community-driven planning processes create stronger climate resilience solutions because communities most vulnerable to the effects of climate change have relevant direct experience and information that is not otherwise accessible to public bureaucracies.
    - Resilience planning at the community level can be an opportunity for net positive shifts in other systems and relationships.
    - Leverage goodwill. Most understand that a working transportation network is key for the restoration of services following a disruption.
    - We need to acknowledge the disproportionate economic impacts of extreme weather events. For example, a 2017 study published in the journal *Science* reported that the

poorest 1/3 of U.S. counties sustained much greater economic hardship from hurricanes, rising sea levels, and high temperatures than other counties.

- Resilience-oriented analyses should include data collection and analysis on:
  - Existing community groups and social networks.
  - Transportation's impacts on different social groups.
  - Historical inequalities and demographic characteristics of those who are mobility-disadvantaged.
  - Past agency efforts to recognize and address social impact issues.
- Strategies for successfully considering social impacts in resilience planning include:
  - Create allies before, during, and after emergencies.
  - Work toward a shift in agency culture by integrating community involvement in project development, which includes:
    - Community participation in decision making
    - Authentic and equitable partnerships
    - Increased awareness of systemic injustices
    - Solutions that address the root causes of vulnerabilities
    - Understanding of communities' unique transportation vision *and* implementation
    - Focusing on who is most vulnerable
  - Start with the community first:
    - Communicate information clearly
    - Secure buy-in from local leaders to be community liaisons
    - Designate focal point agency officials to be responsible for community dialogue
    - Maintain formal feedback channels/loops between public => agency => public
    - Make community concerns a call to action
    - Mainstream community stories to media
    - Map everything to the community
  - Show the intersection and relationships among top priorities – health, housing, small business, economic growth, safety, etc.
  - The key questions for agency leaders are:
    - "How do we engage community members in decision-making processes?"
    - "Does my office undergo racial sensitivity training?"
    - "How do we take steps to ensure that lower-resourced communities have access to emergency evacuation?"
    - "In what ways do we collaborate with other levels of government on social issues?"

- "How do we ensure a balance among environmental, economic, and social considerations?"

Each state DOT representative was provided a postcard and asked to answer two questions, 1) what actions/efforts are you currently undertaking that are examples of an agency commitment to transportation system resilience? and 2) what additional information would you like in order to improve your agency's resilience efforts? The responses to these two questions are shown in Table 1. Note that several states identified some of the same efforts (e.g., strong partnerships with emergency response agencies) and thus these responses are not repeated in the table. It is interesting to note that many DOT officials wanted to know more about how the concept of resilience can be integrated into all functional units within their agency. In addition, many state DOTs were interested in how project development and design might be made more resilience-focused.

Table 1: State DOT Input on Agency Resilience Efforts

State DOT	What are you proud of?	What would you like more information on?
1	Flood inundation mapping and how we use it to assess flood risks.	How routing companies like Waze and Google determine best network routes and how transportation agencies can work more closely with them during emergencies.
2	Keeping the public informed during disruptions	Designing for future environmental conditions, especially flood mitigation.
3	Collaboration with other agencies in emergency response	Organizing our entire agency along resilience lines and how to integrate into our decision-support systems.
4	Team approach; top leadership support; crisis communication plan; operations center action checklist	Training needs; succession planning; and staying ahead of technology curve.
5	Conducting an assessment of the critical state facilities	Integrating resilience into all of our programs and policies.
6	Adaptation in design and construction	Improving our emergency response preparation and training.
7	Strong operational planning for responding to natural disasters	Promoting resilience throughout the entire organization.
8	Statewide hurricane and winter plans	Getting involvement from all of our agency units.
9	Analyzing land use and growth risk to our transportation system as part of planning and environmental linkages; understanding operational resiliency, triggers, and decisions that affect system performance	Costs of raising elevations of state roads in high-risk areas.
10	Asset management and performance metrics that reflect resiliency concerns	Improving cybersecurity protection; how to conduct vulnerability/resilience studies.
11	Very strong relationships with emergency management agencies	Funding needed mitigation strategies; are statistical uncertainties in projections driving us to the most expensive strategies?
12	Working relationships with adjacent states; with emergency response agencies	Making procurement processes more in line with resilience needs.
13	Working relationships with other emergency response agencies	Adding resilience factors into preservation program.

14	Adaptive design approaches; use of technology in assessing asset condition	How to justify betterments in FHWA's Emergency Relief (ER) program; how others have modified project design guidance to further resilience goals.
15	Our flexible designs in roads and bridges in anticipation of natural disasters	Impact of connected/autonomous vehicles on transportation system resilience
16	Planning and designing for seismic events; disaster drills	Funding resiliency actions.
17	Use of social media during system disruptions	Improving information on disruptions to system users on.
18	Avalanche control	Building resistance and resilience into project designs in simple and practical ways.
19	Institutional shared service agreements that allow us to help local governments	Transitioning from a system operator to an all-hazards first responder.
20	Mapping of vulnerable areas to flooding and sea level rise	Using technology better to monitor potential disruptions and minimize impacts.
21	Asset management, risk management, and scenario planning (although not well-coordinated)	Training and workforce development; using after event reports; staff sharing.

Note: Many of the state DOT responses were similar, so not all states were listed in the table.

Track on Enhancing an Organizational Capacity for Incorporating Resilience into Agency Activities

…. included sessions on:

- Frameworks for Resilience Strategies: Part A
- Frameworks for Resilience Strategies: Part B, Dutch Experience with Resilience
- Considering Resilience in Transportation Planning: Laying the Groundwork How to Incorporate Resilience into Project Development
- Incorporating Resilience into Project Development: Risk-based Design
- How to Incorporate Resilience into Asset Management
- Capability Maturity Self-Assessment Tools/ Education and Training Needs
- TRB Executive Committee Resilience and Sustainability Task Force: Challenges, Recommendations, and the Way Forward

This series of sessions focused on efforts to enhance organizational capacity for considering resilience concerns in agency activities. Some sessions examined overall approaches or frameworks for such consideration, while others described efforts in specific functional responsibilities (e.g., planning, project development, and asset management). One session provided an overview of self-assessment tools that can be used by transportation officials to assess the current resilience status of their organization and to identify strategies for enhancing this status.

Frameworks: Heather Holsinger from FHWA noted that FHWA Order 5520 defines resilience as the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions. FHWA intends to integrate resilience into whole-of-transportation decision making. Its Extreme Weather Policy is encouraging states to identify the risks of climate change and extreme weather events to current and planned transportation systems. The FHWA is working to integrate a consideration of these risks into its planning, operations, policies, and programs in order to

promote preparedness and resilience; safeguard federal investments; and ensure the safety, reliability, and sustainability of the Nation's transportation systems.

Several examples of state DOT and MPO resilience analysis frameworks were offered by presenters, including:

Los Angeles County Metropolitan Transportation Commission (LA Metro)

LA Metro has undertaken a systematic effort to consider system resilience in many of its decision-making processes. The primary motivations for doing so included a statewide referendum providing funds to consider climate change adaptation projects, prospective bids for the 2020 Olympics and 2026 World Cup, a request from the policy board to accelerate 28 projects by 2020 ($100 billion in projects) that includes climate safe designs, and state "Climate Safe" legislation that required the state to incorporate climate science in the design, project planning, and engineering standards of relevant infrastructure systems. LA Metro has an investment budget of $120 billion over the next 40 years for transportation capital improvements, which includes preparing the LA region for a climate safe environment. Key observations on the LA Metro efforts included:

- Adaptation and greenhouse gas mitigation (GHG) strategies need to assess resilience vulnerabilities on low-income populations.
- Having a state "Climate Safe Infrastructure" policy provided an important policy foundation (justification) for moving forward.
- Having a permanent source of funding for climate science advancement and infrastructure adaptation is an important enabling factor for continued attention to climate-related system resilience.
- The engineering process needs to be reinvented; we cannot continue to design projects like we have done in the past given likely changed conditions in the future. This would entail staff training and new design codes and standards for engineering.
- Process standards and standard operating procedures (SOPs) will also likely have to change, such as needed changes in procurement procedures (e.g., thinking about materials and resources when procuring commodities, and a green procurement policy). The prospect of "change orders" has to be incorporated into requests for proposals (RFPs) for types of projects where climate risks might be discovered during the study.
- LA Metro has developed seven key metrics for tracking system resilience as part of its system resilience framework. These are in the form of a scorecard.
- Every project requires a sustainability plan, based on an environmental planning framework that has been in place for many years. This includes visioning workshops, and other opportunities for community input; partnerships with local sustainability councils (e.g., technical agencies, non-governmental organizations (NGOs), etc.), and the Greener Workforce Program (certifies sustainability professionals). Research and policy organizations are also part of the collaborative process. LA Metro plans on training up to 1500 people on Los Angeles climate change impacts by incorporating resilience strategies into the agency (850 people had already been trained over about 18 months).
- An example of LA Metro efforts included examining climate change impacts on bus stop design/service frequency and a station design. The expected service demand at a bus stop was overlaid with expected high heat maps to determine what mitigation was necessary in bus stop

design. In addition, the question was asked if more frequent service was necessary to minimize the amount of waiting in high heat conditions. The second example was the design of a transit station in which the "design storm" was revised to include a 100-year/500-year floodplain. The net present value of expected economic impacts of possible disruption showed that although there were increased costs to retrofit in the future versus building in a resilience strategy now, it was worth the investment today.

Atlanta Regional Commission (ARC)

David D'Onofrio from the ARC presented a resilience framework linking the types of decisions ARC and local decision makers have to make on how resilience factors can be considered when choosing projects. The framework also ties resilience to system performance measures. The framework is based on three important issues---exposure, sensitivity, and adaptive capacity.

ARC has also conducted a climate resilience study on water planning---how might climate change impact water quality? --- and identified actions to ensure water remains available to the region. In addition, ARC studied social equity, recognizing that poverty increases vulnerability to weather events.

Hillsborough (Tampa, FL) MPO

An important role for MPOs in system resilience is working with communities in integrating resilience concepts into local decisions. The Hillsborough MPO conducted a survey of 9,600 respondents seeking input on anticipated climate change in the region and steps government should take in response. Based on this input and a technical analysis of expected climate conditions in the Tampa region, the MPO developed three climate scenarios for a 2040 horizon. The long-range transportation plan showed the economic savings associated with investing in improved system resilience. For an investment of $31 million, an expected $112 million in losses could be avoided. The most cost-effective strategy was making such investment as part of ongoing maintenance and improvement programs.

Colorado DOT (CDOT)

The focus on system resilience began in Colorado in 2013 with the state response and recovery from major floods. With support from the FHWA, CDOT adopted an innovative approach to address resilience in planning and project development. Resilience concerns were expanded statewide through the Colorado Resiliency and Recovery Office (CRRO), which formed the Colorado Resiliency Working Group (CWRG) to bring all sectors of the state together to enhance collaboration, communication, and identify system resilience opportunities. A state-adopted Resiliency Framework (2015) was designed to be a tool for state agencies in addressing resilience in their own areas.

The State of Colorado adopted the following definition of resilience, "Positively adapting to, or thriving amidst changing conditions or challenges – including disasters and climate change – and maintaining quality of life, healthy growth, durable systems, and conservation of resources for present and future generations." Infrastructure was considered an important sector of a resilient Colorado.

CDOT adopted a roadmap to achieve a resilience mindset throughout the agency, encompassing five focus areas: 1) defining leadership roles and responsibilities; 2) ensuring informed implementation with the agency; 3) taking action; 4) defining and measuring success; and 5) institutionalizing adaptive management. Examples of how this roadmap was implemented were described earlier in the corridor planning efforts by CDOT.

CDOT made the distinction between natural and manmade sources of disruption. “Natural resiliency” is concerned with losing assets to unexpected natural events – floods, fires, utility failures, etc. “Operational resiliency” is related to losing functionality to known trends such as land use changes, increased travel demand, and so on.

CDOT is now incorporating resiliency into all aspects of the project life cycle. Pilot studies for doing so in early project stages were conducted utilizing planning and environmental processes for corridor planning. Data were collected and analyzed to assess risks to the operations of the corridor. Priority improvements were recommended, and efforts were made to communicate to local agencies and developers the potential risks of unplanned growth.

A risk tool was developed based on the definition of risk (R) being R = T x V x C, where T = Threat, V = Vulnerability and C = Consequence. Using this tool, CDOT showed community leaders the impact on levels of service (LOS) of proposed land use development plans. In short, CDOT tied the corridor’s Access Control Plan (ACP) to land use development and thus to operational risks of unplanned growth.

International Examples

Several international examples of adaptation/resilience frameworks were discussed in this track:

The Netherlands: Kees van Muiswinkel from the Dutch Ministry of Infrastructure and Water Management presented the Dutch approach to resilient infrastructure systems. As he noted, much of The Netherlands is reclaimed land from the Middle Ages. Sixty percent of the land is below sea level so crisis management is a critical aspect of government agency responsibilities, including evacuation plans. The Ministry has also been working on communication plans to convey to the public the risks associated with unexpected flooding. The national government goal is for the country to be flood resilient by 2050 and have policy and strategic actions in place by 2020.

Developing resilient transportation systems is increasingly challenging due to the uncertain nature of future environmental conditions and a greater dependency on telecom and power systems. Aging infrastructure also exacerbates the challenge. This has led to efforts at better estimating the costs and benefits of adaptation measures and the costs of maintenance. Noted efforts include:

- New tunnel design standards have been recommended.
- Recommendations have been made on how climate change can be considered in different steps of agency decision making, from changing procurement requirements for maintenance (presently, contractors are not required to clean out water discharge facilities) to analyzing the relationship between extreme weather and congestion (from the year 2000 to 2018 there have been noticeable congestion effects as a function of weather).
- Protection standards have adopted the perspective of protecting people not solely infrastructure. Protection standards are to protect against a 1 in 100,000 probability event, especially for levee protection.
- Climate change adaptation factors have been recommended as part of the determination of environmental benefits.
- Adaptation resilience has been recommended as an integral part of the agency mission and that it can be considered cost effective to address potential concerns now rather than wait.

Thomas Bles from Deltares, Inc. discussed a Dutch study that is assessing the stresses to highway assets caused by climate and weather events, including instability of embankments, wildfires, falling trees, aquaplaning risk during intense rainfall events, and fluvial and pluvial flooding (due to rain). The study

builds upon existing adaptation frameworks for considering climate change information on associated risks. The study led to maps of vulnerability to future threats. The goal of the national study is to prioritize by 2020 climate change risks and have an adaptation strategy to ensure a climate-robust road network by 2050. A further goal is to raise public awareness of climate change risks to the road network.

Mr. Bles also discussed a more quantitative approach that looked at different event return periods and associated impacts (direct impacts were costs to the operator using damage functions; indirect impacts were the risks to society). Metrics included road intensity, economic importance, network redundancy as indicated by detour times, and additional travel time when road is closed. The climate change scenarios considered were worst case and moderate scenarios for the 2050 horizon for 10-, 50-, and 250-year return events. Risk matrices were developed comparing risk levels. Identifying measures to balance between cost and benefits, effective solutions and adaptive construction, and the flexibility to switch from one measure to another are currently being developed.

Mike Woning of Deltares, Inc. discussed two projects for the World Bank, one in Paraguay and the other in Albania. The study in Paraguay was intended to develop a resilience methodology for evaluating impacts in an area having little historical climate data. A semi-quantitative approach was developed based on expert judgment. Expert information scored the threats by likelihood and impacts. Next, the increase of likelihood due to climate change was assessed, leading to a determination of where potential adaptation treatments should be considered. High priority threats were selected for the risk assessment. It was observed that inadequate maintenance exacerbated future damage estimates.

The project in Albania used a landslide susceptibility map to overlay asset information to determine road damage due to potential landslides. The economic impact of road closure was determined comparing the annual economic losses and repair costs to current costs of protecting the road today. Flooding and the capacity of culverts to handle future flows were also examined.

Rob Kafalenos from the FHWA discussed the bilaterial agreement between the FHWA and the Dutch Ministry (Rijkswaterstaat) and compared a FHWA pilot study in Washington State and a Dutch project (InnovA58) that looked at inland flooding. He noted both studies and tools found similar results. Both studies were concerned with heavy precipitation impacts and buildings in high groundwater table with low elevations. It was stressed in the presentation that vetting analysis results with stakeholders is important to ensure they make sense.

Risk-based project design: Several examples of risk-based design were discussed in this track. Brian Beucler of the FHWA discussed the U.S. experience with hydraulic engineering and the traditional use of return period events (a proxy for level of risk) in design practice. He made that point that the use of return periods for design varies among the states, with different road functional classifications, terrain, and other factors. Given what is expected in the future, risk levels will change over time. This will happen not solely because of changing climate, but potentially because of change in functional class of a road (and thus subject to different design criteria), change in water basin characteristics, road widenings, ties (lawful and otherwise) into the drainage system, change in water flow paths, and others. Given that the concern for engineers is the water flow at the point of a culvert or bridge, there are many changes that water could experience from the point it drops as rain to the time it possibly arrives at a culvert. Mr. Beucler noted that there are thus all sorts of possible changes to the inputs of drainage design that might or might not cause a change in the design characteristics in the future. He concluded his presentation by stating that an agency does not have to adapt everything at once; one can do what is possible now, monitor conditions, and modify when better information becomes available. This of course assumes one knows what the acceptable risks are over time.

Roger Kilgore from Kilgore Consulting & Management described some new tools he is preparing as part of an NCHRP project. He pointed to the fact that most hydraulic guidance already includes uncertainty. For example, the much-used intensity-duration-frequency (i-d-f) curves have confidence limits attached to the underlying data, which indicate the high and low values in the database used to develop the recommended curve. Therefore, he argued that before one changes the underlying values by simply looking at forecasted precipitation in future years (with the associated uncertainty associated with these forecasts), one could use the confidence limit values already in the databases (perhaps with scenario analysis) to determine the most appropriate input values.

Mr. Kilgore presented additional information on the uncertainties associated with climate change forecasts that fell into three major areas – scientific uncertainties and in the models used to forecast future emissions, uncertainties in the underlying emissions scenarios, and uncertainty in the natural phenomena being examined. One could use climate models to forecast future values of intensity (i), but in many cases the new value of intensity is within the confidence limit from the original i-d-f values. The NCHRP research is recommending a climate change index value that indicates what engineers should use for the value of intensity. If the index is small, then one could use the historical values within the confidence limits. For larger values, one needs to carefully look at forecasted values from climate models. Similar to Mr. Beucler, Mr. Kilgore recommended where feasible to stage implementation of a project design over time so that additional design capability can be applied when more is known about the environmental conditions.

Sarah Hammitt from the Port Authority of New York & New Jersey described the Port's resilience program, which has been in place for many years and has already resulted in adaptation projects and adaptive designs. The Port has taken the position that it is now "designing for a future climate." The Port has adopted climate resilient design guidelines that provide a "clear, science-based methodology to incorporate risk into the design of facilities and infrastructure." Four stressors have received attention, primarily sea level rise (SLR) and storm surge, and increasingly extreme heat and extreme precipitation. The approach to SLR is to adjust the base flood elevation by an amount that reflects an increase in future water levels. The guidelines, for example, look at the existing 100-year floodplain and the anticipated 100-year flood plain to determine the difference, The Port anticipates that both the 100-year and 500-year flood plain will move farther inland from the source in the future.

This approach represents a change from the historical analysis approach. For example, the Port did an analysis of the Port Elizabeth terminal facilities with today's base flood elevation and with a 20" increase in SLR for the year 2080. With the traditional analysis approach, no additional flood protection was needed; with the adjusted value, much of the terminal complex needed to be protected from encroaching water.

Several projects have already been constructed with new flood and storm surge protection. A new transit station entrance was designed with floodwalls, glass protection, deployable flood barriers, and other strategies to protect the entire station from water. Replacement power stations at JFK Airport were found to be in the expected future flood plain so steps were taken to protect these important airport assets. The approach at the Port is now to elevate what can be elevated and to protect that which cannot be elevated. Next steps include a more robust geographic information system (GIS) that maps risks and identifies gaps in the Port's water encroachment protection strategy; additional design criteria for incorporation into consultant solicitations; and enhanced relationships with other agencies facing similar problems.

Susanne DesRoches from the Office of the Mayor, City of New York discussed the evolution of New York City's resilience and sustainability efforts. The City's approach was to establish a clear policy in terms of fostering more adaptive designs, and then let engineers figure out how to implement. One of the key issues facing residents is the expected increase in the number of days over 90 degrees. By 2050, this number is expected to increase threefold. Already over 100 people die each year in New York City due to heat exhaustion, many from the most vulnerable populations. Many cascading effects could also occur in such an environment, for example, from heat-related power outages. City policy is now that no new city facility can contribute to the heat island effect.

With respect to flooding (both coastal and heavy rain event) and storm surge, the City's approach is similar to the Port's --- adding an incremental elevation to the base flood to account for future conditions. A hydrologic study is being done now to identify high risk areas by the year 2050. With this data, and presumably new guidelines, all City projects will be working off of the same foundation (note: this is not yet applied to private developments). The City has developed a cost/benefit framework that can be used to assess the relative value of different investments. The variables in the framework include: initial construction cost, operations and maintenance costs, environmental impact costs, quality of life benefits, constructability, reliability and durability, and reduction in risk.

Heather Paddock from the Colorado DOT discussed some of the project initiatives that CDOT undertook in response to the 2013 floods. With 187 repair projects, 486 miles of road closed of which 120 miles were severely damaged, and 200 bridges/culverts needing repair, the task facing CDOT was formidable. Given a gubernatorial mandate that the roads had be open in 60 days, there was not much time to rebuild with better designs. However, some projects were eligible for Emergency Relief funds from FHWA, primarily projects that were "severely damaged." The options available to CDOT were to "replace in kind," "replace to standards," or do a "betterment," which required a benefit/cost assessment that showed in a quantifiable way the benefits of investing dollars in doing the betterment. CDOT instituted a pilot project to develop a benefit/cost approach using historical damage costs from previous floods. The damage from 2013, which was caused by 100-year storm amounts and 500-year flood surges, provided useful data on the costs to repair. CDOT also used FEMA-based approaches that allowed the consideration of a range of benefits and costs. The CDOT methodology differentiated benefits and costs by road classification, critical routes/defense classification, level of risk, social and environmental effects, and economic impacts.

Ms. Paddock emphasized the importance of the social impact variable. Some communities in Colorado were completely cut off from road access following the storms. And yet some of these roads did not qualify for ER funds. In addition, the total amount of ER funding for the country is about $100 million per year, and CDOT's estimate for Colorado's needs alone was over $700 million. In the end, CDOT was able to obtain $35 million in ER funds.

In looking at the redesign challenge, CDOT adopted an approach that prioritized community access, impact on emergency response access, and access to supplies (which in many cases could be provided via routes other than those damaged). Assuming CDOT wanted to bring all repair projects up to 100-year flood design standards, the estimated cost was $500 million --- clearly unrealistic. Therefore, CDOT adopted a different approach. The assumption of bringing roads up to standards was abandoned and an approach was adopted of providing the bare minimum to guarantee community accessibility. This was defined as having a 15' surface available for trucks. In some cases, where alternate routes were available, failure of the road was considered acceptable. Even with this approach, the estimated cost for repair was $280 million.

Other project design approaches included working with River Commissions to figure out how to "let the river be the river." In other words, allow the river to flood as it will, and design the road around this outcome. In some cases, this meant moving the road away from an embankment and in other cases it meant excavating the road down to bedrock (because experience showed that floods would remove material down to the bedrock in some places…thus the road base at least would survive).

Organizational Capacity: Methods to assess organizational capacity to apply resilience concepts were discussed in sessions on capability maturity frameworks (CMFs) and all-hazard approaches to resilience planning. Ben Hawkinson from the FHWA discussed a study entitled "Framework for Assessing the Resiliency of the National Highway System" that used several indicators of resilience including, organizational/system performance, asset criticality, asset vulnerability and risk, system robustness, time to return to operating status, work force development and preparedness, to name a few. The report is not yet available (as of 2018) but when it is published it will provide useful information on the resilience of the National Highway System.

Two presentations were made on the use of CMFs in DOT self-assessment tools. Mike Meyer from WSP USA, Inc. discussed the development of a resilience self-assessment tool as part of the NCHRP 20-117 project. The tool, available in mid-2019, is based on the idea that there are a number of steps a transportation agency could take to improve its resilience-oriented efforts. Three levels of "maturity" have been identified for each of these steps with the tool then describing what actions could be taken to reach a higher capability level.

Paul Pisano of FHWA discussed CMF tools FHWA has developed on road weather, planned special events, traffic signal systems, traffic management, work zone management, and traffic incident management. From an operations perspective, it is not just extreme weather events that can affect system performance, but in addition other events that could affect the safety and efficiency of the travelling public. These tools include checklists of agency actions that can increase resilience of targeted transportation agency operations. The intent of the checklist is to determine what transportation officials can do to address identified needs.

Asset Management - An important focus in this track, as well as discussed in other tracks, was how resilience could be incorporated into asset management. Asset management was considered by many as an excellent platform for including resilience into investment decisions. This is especially true given the focus on life cycle costs. Federal law requires that a risk-based asset management plan be developed and used by state DOTs. Within Transportation Asset Management Plans (TAMPs), the requirements for risk management and life cycle planning provide opportunities for resilience to be considered. For example, the acceleration of asset deterioration rates could be captured in asset management tools to better plan for future conditions given changing environmental conditions.

Several studies and demonstration pilots have been undertaken over the past several years. Robert Kafalenos reported that FHWA is sponsoring pilots on how to incorporate extreme weather and changing environmental conditions into asset management (DOTs in Arizona, Kentucky, Maryland, Massachusetts, New Jersey and Texas). Some TAMPs that included such concerns have already been completed. An example is in Rhode Island where overlays of sea level rise, storm surge, and nuisance flooding have been used to highlight extremely vulnerable assets. He noted that the general process of incorporating resilience into asset management includes: 1) identify risks; 2) describe how the risks are currently manifested on the state's transportation system and how they might change in the future; 3) identify climate stressors in asset life cycle planning by considering which asset types are affected by

different stressors; and 4) consider whole life costs by asset grouping and how these should be addressed.

Steven Olmstead of the Arizona DOT (ADOT) observed that ADOT views asset management as one of the most important decision processes within the DOT where resilience risks can be considered systematically. ADOT has developed a formal risk methodology focusing on bridges, culverts, pavements, roadside vegetation, and slope/soil stabilization for different stressors (flooding, intense precipitation, drought, dust storms, wildfires, rockfall, slope failures, and measured long-term environmental trends). ADOT's most recent TAMP presents a risk register that considers agency and program risks. ADOT's executive leadership identified 25 overall risks, including six direct climate- and extreme weather-related hazards and six more that could indirectly affect asset conditions. ADOT is also developing a system-wide GIS resilience database that incorporates life cycle methodologies by asset class.

Mr. Olmstead speculated that one possible outcome of this approach toward asset management might be certified risk-based asset plans the lead to lower borrowing rates on financial bonds. Another likely outcome will be more emphasis on adaptive engineering methodologies (that is, bringing risk modeling into engineering).

Elkins Green from New Jersey DOT (NJDOT) noted that NJDOT is in the early stages of systematically considering climate risks in its asset management program. DOT officials have realized for some time that the transportation system is vulnerable to disruptions from both natural and man-made causes. Superstorm Sandy was one of the more dramatic examples of this vulnerability. With respect to weather-related hazards, NJDOT is mainly looking at sea level rise, storm surge, precipitation, and nuisance coastal flooding, but is also looking at vulnerabilities to extreme heat, icing, and inland flooding. NJDOT's risk register includes around 30 risks, with terrorism as the highest risk and extreme weather events ranked third. The DOT is also looking at developing a GIS "resiliency management system" to be incorporated into NJDOT's current processes.

William Johnson and Ty Ortiz from the Colorado DOT (CDOT) reported on one of the key hazards facing Colorado's highway network---repetitive landslides. The DOT has developed a geohazard management plan that outlines rockfall/landslide responses given different types of incidents. This was part of an overall effort by CDOT to provide more focus on transportation system resilience. With respect to CDOT's overall resilience efforts, the agency has learned many lessons that might be of interest to other states:

- With large-scale wildfires in recent years, CDOT has found that debris flow associated with post fire storms have been getting worse.
- For each hazard type, measure the impacts on the transportation system in terms of safety, mobility, and maintenance/system preservation.
- It is useful to have a monetary value associated with risk. Risk is measured by cost where delays and mobility impacts are the result of hazard-related disruptions as well as the actual costs of response (e.g., removing rocks on the road or cleaning culverts).
- Traveler safety should be an important consideration in resilience efforts; for example, drivers entering incident areas can themselves become injured or killed. CDOT calculates an annualized

safety cost associated with resilience projects, which is the likelihood of the event occurring x safety consequence in dollars (taking into account fatality and injury values of a statistical life).

- Safety concerns also occur when an incident leads to detours, which in Colorado usually means non-interstate highways that themselves have safety risks.
- Maintenance and preservation costs should be tracked and include all the costs associated with the efforts (e.g., maintenance + repairs + cleanup from debris flows following heavy rains). These types of costs lead to such questions as does it make sense, for example, to resize culverts in the normal reconstruction process? The key to getting decision maker attention is to recommend low-cost, high-yield mitigation strategies.
- CDOT is looking at optimizing the overall benefits of different types of mitigation strategies. For example, instead of necessarily leading to a recommendation of increasing culvert size, a more cost-effective strategy might be to place debris catchers at the culvert entrance.
- Some other observations:
  - CDOT uses an all-hazard approach to emergency response. The focus is on the continuity of operations, communication standard practices, vulnerability and self-assessments, and forming effective partnerships with local agencies.
  - Don't let a crisis go to waste. When a crisis occurs, do a post mortem to determine what worked and did not work. Use the event as a catalyst for change.
  - Organizational inertia can be the death knell of any effort to be more resilient-oriented (organization at rest stays in rest, one in motion stays in motion). Keep things moving; refine and improve.
  - It is important to have executive approval and sponsorship to increase attention on risk and resilience attention but it is also important to identify those people that will take ownership of the implementation of the different activities.
  - What gets measured gets done (such as through performance measures) -- 1) safety, mobility, maintenance can lead to multiple performance metrics to measure risk and prioritize investments; 2) risk-specific performance measures need to be developed based on existing and obtained data, and information that has not been part of a DOT's information resources (e.g., social vulnerability index); and 3) it is important to measure how people using the road system are affected by investment decisions.
  - Research-based guidance, analysis frameworks, and lessons learned from peers are critical resources to an agency's resilience efforts. CDOT benefited from Vermont's experience with the remnants of Hurricane Irene. For example, VTrans established an incident response command center and adopted a common lexicon for all of those involved in emergency response. CDOT did so as well --- learning from Vermont's experience.

Track on Recognizing Infrastructure Dependencies and Fostering Partnerships …. included sessions on:

- All-Hazards and Operations Approach to Disruptions
- Interdependent Infrastructures (e.g., Electrical grid and Transportation)
- Multi-sector Partnerships

- Workshop on Community Resilience Approaches and Considerations
- Application of Technology to Enhance Asset (Tunnel) Resilience
- Fostering Researcher/Practitioner Partnerships

This series of sessions focused on the importance of partnerships in developing effective resilience strategies, especially in light of the interconnected nature of the transportation system with other systems. The opening plenary session emphasized the following points.

- Successful collaboration, especially at the regional levels or higher, often cross political lines. James F. Murley, Chief Resiliency Officer, Miami-Dade County, FL noted that the Southeast Florida Regional Climate Change Compact shows that support across the political spectrum is empowering. This support enables technical staff to develop tools and pursue important data that provide information to inform decisions.
- Three key climate change-related challenges in the Miami-Dade region include:
    - Extreme weather and sea level rise are already noticeable in the region. As noted by Murley, "There is nothing unusual about coastal storms --- we live in the tropics, but we worry about the intensity and timing of the storms due to climate change…These conditions are changing from historical trends."
    - Vulnerability – The southern part of Florida has many low-lying areas with large and dense population clusters located near the coast. Key economic drivers (such as the tourist industry) are weather-dependent. The area has been prone to serious weather events in the past.
    - Water management – Low-lying coastal communities rest on porous substrates, and there has been a long-standing concern about saltwater intrusion in drinking supplies.
- In recognition of the regional climate change-related problems, Palm Beach, Broward, Miami Dade, and Monroe Counties have been working together for over 10 years. Efforts have been made to collaborate on policy development, creation of regional databases and tools, and the adoption of a Regional Climate Action Plan.
- The evolution of serious policy attention to the challenges of climate change impacts in south Florida could not have occurred without the willingness of a diverse set of agencies and organizations working together for a climate-safe future of the region.

C. Forbes Tompkin, Officer, The Pew Charitable Trusts identified four major resilience concerns that are part of its Flood Prepared Communities resilience policy all of which depend on effective partnerships --- flood insurance, nature-based solutions, pre-disaster mitigation planning, and infrastructure adaptive design. Some interesting facts:

- Thirty percent of the value of flood insurance payouts go to one percent of the total flooded areas that are repeatedly flooded.
- The payouts have surpassed in $30 billion in debt (although Congress forgave $16 billion of debt in 2017).
- Losses from flooding are increasing over time. In the 1980s, the amount was around $46.5 billion; from 2010 to 2017 it was $405 billion.

  - The federal government has spent $300 billion in disaster recovery but only hundreds of millions of dollars on pre-disaster design and other preparations.
  - FEMA estimates that 40 to 50 percent of small businesses never reopen after a disaster; for those small businesses that were closed more than five days after a disaster, approximately 90 percent are no longer in the area after one year, either closed or moved to another location.
  - After Hurricane Harvey, 30 hospitals throughout southeast Texas closed temporarily and a medical center closed permanently.
- Although there is a perception that climate change impacts are a coastal issue, eight of the top 10 most serious floods have occurred inland.
- Key to success in developing successful resilience efforts is a whole-of-community collaboration effort. Securing funding for resilience efforts entails regional approaches, state and local leadership, public/private partnerships, philanthropic contributions, and the participation of a range of other participants.

Network Interdependencies: A topic that is increasingly important to resilience and one that clearly depends on collaborative efforts is the interdependence of critical infrastructures. Fred Petit of Argonne National Laboratory noted that transportation infrastructure is highly interdependent with other sectors such as energy systems and telecommunications systems. He stated that those interested in transportation resilience are really dealing with a "system of systems." Such interdependencies create risk multipliers because they expand the set of vulnerabilities, which in turn expand the set of resilience requirements, and so on. This can be conceptualized as a set of dependencies and assets, each having management, control, and operational systems. They are connected via logical, cyber, physical, and geographic relationships and dependencies. To protect the various connected systems, back-up systems are created, which in turn, create new dependencies.

The logical, cyber, physical, and geographic dependencies are related to human decision making. One possible way to look at these dependencies is to use a top-down and bottom-up approach to examining regional interdependencies. This leads to considering cascading failures, which fundamentally requires a systems approach, especially for lifeline assessments.

Research: Another area for collaboration and partnerships is between transportation agencies and the research community. Many state DOT officials, for example, mentioned that the state university is working on different projects aimed at improving the agency's approach toward system resilience (for example, Arizona DOT and Hawaii DOT).

Session moderators were asked to identify potential research topics that were discussed in their session---these suggestions are provided later in the report. However, the session on research collaboration did address challenges and opportunities associated with research/practitioner interaction. The following was one of the interesting questions asked of the panelists.

What are the most significant impediments to seamless transition between research and practical applications?

University researcher --- taking time to understand problems and communicating objectives; building rapport and relationships with DOT staff.

University researcher --- getting out and meeting counterparts in academic environments to conduct "problem finding;" do not underestimate the lead time required to cultivate practitioner partnerships; when developing collaborative partnerships within a DOT environment, ask yourself "are the individuals with whom you are engaging the right people to get executive buy-in and the necessary funding?"

State DOT practitioner --- communication is critical; flexibility in working with researchers is needed; evaluating objectives and methods to ensure you are getting the results you need/want.

Research contract manager --- problems can be identified up front; when selecting the research team, it is important to understand how the research can transition into practice; overcoming obstacles is about communication.

University researcher --- contract negotiations can be challenging; consideration of intellectual property rights and publication credit are often an issue; manage expectations in securing contracts; clearly define the scope of the project. Additional key considerations include, 1) be clear and succinct about product deliverables, and 2) carefully review principle investigator credentials and his/her capability to manage project demands/needs.

> Communities become more vulnerable in the long term when their economic base, that is, the business community, is hit by a disaster
>
> -- Brook Nelson, Chamber of Commerce Foundation

Track on Making the Case for Resilience…. included sessions on:

- Social and Economic Considerations and the Value of Transportation in Risk Determination
- How to Define Benefits of Resilience Actions
- Disruptions Due to Man-made and Natural Causes: Lessons Learned from National Efforts
- Benefit Cost Assessments for Infrastructure Resilience: Tools and Approaches
- Communications and Outreach Strategies
- Securing the Supply Chain/Freight Flows

Brooks Nelson, Director for Global Resilience, U.S. Chamber of Commerce Foundation and Hyun-A Park, President, Spy Pond Partners, LLC spoke in the plenary session preceding the sessions. Mr. Nelson noted that many private firms, especially big companies, are looking at resilience as well. System resilience to companies means transportation systems that provide mobility and accessibility to employees, customers, and supply chain participants. Major disasters can also have a serious impact on business success. He noted statistics that indicated 25% of small businesses do not survive more than two years after a disaster or move from the community. Only one in six small businesses have business continuity plans. The Chamber in concert with the UPS Foundation has developed a tool “Resilience in a Box” that is designed to provide businesses with a self-assessment tool to determine how they can become more

resilient. This is particularly important given that businesses are not usually at the top of the priority list for support after a major disaster. It is important that both government and business groups work together to enhance community resilience.

Hyun-A Park talked about the importance of asset management plans and processes as a strong foundation for incorporating resilience into agency decision making. Looking at some of the initial risk-based transportation asset management plans (TAMPs) required by the federal government, there does not seem to be much commonality with how states are defining risks. Although it was evident that financial risk was considered by most as being most important (that is, not having enough funding to carry out the agency's mission). The TAMP is also supposed to show the mitigation plan that the DOT will be adopting to consider the identified risks. More will be known as the TAMPs are delivered to the federal government (June, 2019). Ms. Park concluded that the interface between resilience and asset management leads to better decision making, providing better information that can only strengthen management capabilities.

Definition of benefits: Several of the sessions in this track focused on how resilience benefits and costs can be defined and communicated. Applying benefit/cost principals and methodologies were viewed by many as the best way of justifying adaptation and resilience projects in today's world of scarce resources. Laurel McGinley, PMP presented benefit/cost frameworks for a screening level analysis and for a more detailed climate resilience level. Her recommended analysis assumes that the level of damages associated with an event of a given magnitude will remain the same and assumes as well that the return period for an event will decrease (i.e., become more frequent) due to climate change impacts. Three return periods are considered: the largest return period with no damages under current conditions (Design Flow); a return period with moderate structural damages, riprap displacement and scour, and/or roadway flooding and traffic interruption; and the largest return period considered major failures including possible bridge structural failure, road embankment erosion, loss of roadway function for weeks to months. Associated flood flows and corresponding damages are identified with each return period. Annualized damages are then estimated and multiplied by the present value interest factor for the selected discount rate and project useful life to get total damages under current climate conditions. McGinley made the following observations concerning the use of benefit/cost analysis:

- Factors to consider:
  - Cost – inexpensive projects might not warrant an analysis; expensive, complex projects might need a fairly detailed analysis.
  - Project useful life – benefit/cost analysis is especially appropriate for longer-life projects.
  - Risk – Projects with high risks could benefit from such an analysis.
- Select appropriate adaptation strategies to address the risk identified.
- Account for full life cycle costs of implementing the adaptation strategy.
- Determine if only financial benefits from adaptation will be considered, or also environmental and social impacts.
- Use throughout the planning and decision-making processes to determine when and where to invest in transportation resilience.

The session on community resilience broadened the discussion to include a range of benefits and costs that could occur at the community level. Transportation system disruptions can have numerous economic, social, and environmental "ripple effects" to beyond just the transportation system. As

Using Technology to Enhance Tunnel Resilience

This session summarized the key points from the tunnel field trip that occurred on the first day of the Summit. As context, Steve Harleson from CDOT said that on average there is one fire per year in the tunnels, which handle approximately 12 million cars per year. Any use of water to put out fires must collect the left-over water so that it does not pollute the water supply for the Denver metropolitan area. Because the tunnels have been declared an historic site, there are limitations to what CDOT can do to change the physical nature of the facility.

A water deluge system was selected was based on, simplicity in operation, ease of installation, costs, water supply quality from a nearby creek, degree of meeting the performance specifications, applicability for a variety of fire conditions, satisfying Buy America regulations, and nonproprietary. Lessons learned included:

- Performance-based specifications and procurement were successful, but CDOT spent more than was needed to test the system rather than rely on information already provided through research.
- Linear heat detectors are slower than visual inspection given that operators are on duty 24/7.
- Buying non-proprietary equipment makes repairs easier; local contractors can work on the system.
- Boiler and circulation systems keep hot water in pipes, rather than using heat tape. This keeps the pipes from freezing, far more effective, cheaper and off-the-shelf availability.

Presentations from Australia, New Zealand, Maryland, and the FHWA showed the importance of thinking through the approaches and technologies that can be used to protect assets and the users of the facilities.

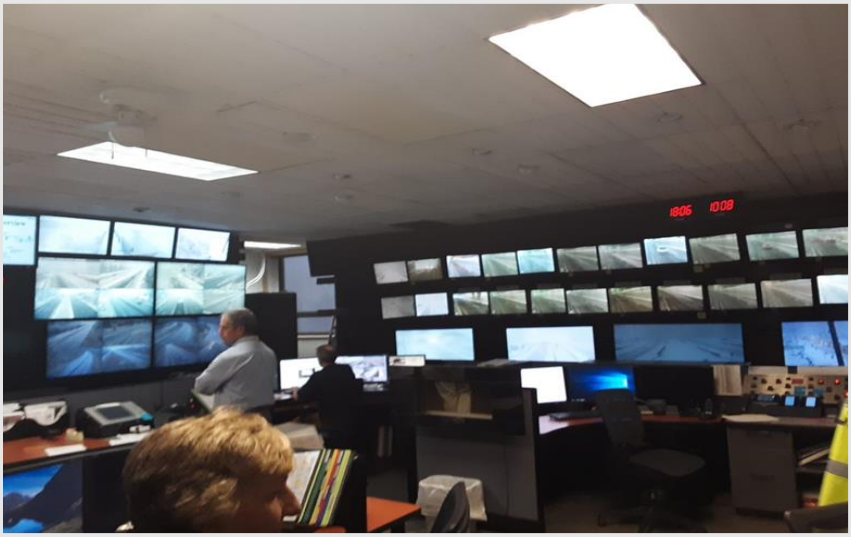

Figure 4: Control Center for the Eisenhower/Johnson Memorial Tunnels

noted, transportation resilience and community resilience rely on one another. Cassie Bhat from ICF International provided an example relating to inland ports in Memphis, TN. If freight is shifted to trucks from barges due to low water levels on major rivers or due to lock closures, highway pavement could face increased degradation, air quality impacts might be more severe, economic activity at the ports would be severely constrained affecting labor, and over the long term if the port is not able to be resilient to external "shocks," companies looking to site new facilities may choose to go elsewhere. In keeping with the theme of other sessions, she concluded that it is critical to include a wide range of stakeholders when considering the potential impacts in transportation resilience planning. In this example, this might include:

- Port stakeholders: Private and public sector port tenants, port users, nearby industries shippers, carriers, and port workers.
- Community stakeholders, residents and homeowners surrounding port, faith and community-based organizations, academic and research organizations, national non-government organizations (NGOs) and affiliated organizations.
- Local government stakeholders (local government staff, regional planning staff, stage agency representatives.
- Lead organizations (port and local governments)

Such an effort would consider a wide portfolio of resilience strategies, including public and private infrastructure options, mitigation of environment/human health and economic impacts, long-term economic strategies, emergency planning response and recovery, and effective communications inside and outside the region.

Adam Whelchel of The Nature Conservancy presented a tool called the Community Resilience Building Workshop Guide Toolkit. The tool has been used in 225 communities but never in a state DOT workshop. The tool allows the user to examine many different dimensions of community resilience. It is a community-driven process, with active participation of key stakeholders, able to examine range of resilience challenges, and can be applied in urban/rural and public/private contexts. The approach focuses on three key questions: 1) what are current and future hazards? 2) what are our strengths and vulnerabilities? and 3) what can we do about them? It addresses hazards comprehensively and links potential solutions to community objectives.

As noted by Mr. Whelchel, the process is about people – it is data- and science-light. It is about identifying community-derived inputs that are obtained in community workshops. Selecting the participants in the workshop is key – this should include people who make decisions, people who influence decisions, and people who are not included in the planning process but have a stake in the outcome.

Supply chains: Given the importance of freight movement to the economic health and quality of life of every community, making supply chains more resilient can provide significant benefits. The scale of supply chains, from local "last mile" operations to global trade patterns, suggests that such benefits can occur at many different levels. Importantly, the scale also requires the involvement of many different actors, some in the private sector and others in the public sector.

Ed Fritz from the Wyoming DOT discussed resilience for supply chains and how the benefits and costs of disruptions can have far-reaching impacts. The process used in the DOT is to first identify critical freight facilities (e.g., roads, airports, railroads, pipelines, intermodal facilities, ports, and origin and destination facilities), then think about the larger consequences of Wyoming-based disruptions (e.g., to logistics

providers in New York City for freight that travels through Wyoming). Wyoming DOT has identified risks on critical freight facilities relating to different types of hazards such as bridge strikes, road closures, and weather disruptions. Types of resilience strategies considered by Wyoming DOT included:

Before the event

- Harden the system
- Identify and prepare redundant facilities
- Create operation plans in preparation for an event occurring

During event

- Implement a redundant facility strategy
- Execute operation plan

After event

- Assess how system resilience could be enhanced
- Revise operational redundancy
- Harden the system

Anne Strauss-Wieder from the North Jersey Transportation Planning Authority (NJTPA) discussed supply chain disruptions and the importance of business continuity practices. She identified many ways that supply chains are made resilient, where lessons could be applied to how communities and transportation agencies consider resilience.

Business continuity is defined as keeping the supply chain moving through a disruptive event. There are three types of flows that are important--physical flows (truck, rail, crane lifts, etc.,); communication and information flows (how to connect with customers and suppliers); and regulatory considerations. There is also a spectrum of disruptions types …. from planned disruptions (e.g., road or lock closures) to disruptions giving no notice (e.g., earthquakes). There are different logistics and freight responses to the different types of disruptions. With advance notice, freight providers can move to disperse resources and implement contingency plans (e.g., with a 24-hour notice that Superstorm Sandy was going to hit the New York metropolitan area…trains and ships dispersed to safer locations). One of the important lessons from Superstorm Sandy was the vulnerability of port operations to utility disruptions and the priority in recovery. Millions of people were without power, which was the top priority of the utility companies …. port power recovery did not receive the same priority.

Superstorm Sandy also illustrated the importance of collaboration and communication. Since 9/11, the key emergency response agencies in the New York region knew who to call – even with some cell towers without power, one knew that contacts would be made soon. Within a week, through collaborative efforts of federal agencies, freight providers, customers, port officials and labor, the Port of New York and New Jersey was back in operation.

The success in dealing with such large-scale disruptions led to the creation of the Council of Port Performance, which focuses on supply chain resilience and monitors port performance. It also looks at different strategies for dealing with emergency situations, such as diverting containers to other ports and/or moving containers by barge/rail to reach destinations. The Council works with competing firms

to re-route trains, thus building an independent basis for recommending resilience strategies. The message was that unanticipated impacts can sometimes lead to long-term positive outcomes.

Tom Wall from Argonne National Laboratory observed that there is an increased emphasis on engaging the private sector when public agencies face emergency situations. He noted that the federal government approach of replacing that which is destroyed or damaged is not the best model for supply chain recovery. For example, grocery/food retail sector supply chain studies found that to replace a broken supply chain is essentially impossible after a disaster. A more adaptive strategy is to supplement and augment chains already existing in that region. FEMA has recognized this and emergency managers and agencies are now trying to understand the structure, operations, and vulnerabilities of supply chains operating in their regions and creating relationships among public and private organizations. What do emergency management agencies have to offer this process? They can integrate a broader understanding of disruptions into response plans to better support accelerated supply chain recovery. What does the private sector get out of this? As noted by another speaker in the Summit, "the worst day to meet your partner is during a disaster." Early collaboration is key to successful response and recovery.

Argonne is developing a tool called the Grassroots Infrastructure Dependency Model (GRID-M). The tool will model retail locations and simulated disruptions within a region. Dependencies on such things as where does the power come from? Is there backup power? Is there fuel on hand? Where does fuel come from? will be part of the analysis. The tool is intended to start building dependency into pre-planning, near-time situational awareness by providing an understanding of what facilities will likely be operational during a disruption.

FEMA is also working on guidance on best practices for the management of emergency response supply chains.

A good example of how collaboration occurs outside of the public sector was provided by Gary Tucker from Xcel Energy, Inc. Mr. Tucker discussed an often-overlooked aspect (by resilience planners) of recovery---mutual aid arrangements among utility companies. Located in Minneapolis, Xcel Energy is not often directly affected by major disasters such as hurricanes. However, they are able to support the east coast when emergencies happen. Mutual assistance programs serve as the institutional means of providing the personnel and equipment necessary to restore power (some municipalities have separate agencies but work together during an event). There are seven regional mutual assistance groups (RMAGs) in the U.S. When major disruptions occur with multiple states affected, RMAGs send out requests for assistance. In some cases, up to 35,000 utility workers might be pulled from across the Nation to restore power. After Hurricane Florence, for example, 20,000 workers were needed.

In addition to personnel, fleet availability is often a major concern. After Superstorm Sandy, RMAGs looked at ways to restore power faster and created regional fleet groups. It was estimated that such multi-state groupings could restore power in most cases in 24 hours. Fleet movement coordination occurs over a website with all resources coordinated, road restrictions identified, tools needed, etc. listed. However, not all issues were addressed, e.g., weigh station issues for utility trucks affected fleet travel to the areas in need. Waivers can be issued for bypassing required inspections for "emergencies;" however, such waivers are often not issued. For example, in response to Hurricane Maria in Puerto Rico, the utility fleet traveling from Minnesota to barges in Louisiana to assist Puerto Rico were slowed down significantly due to truck weighing requirements, until they finally reached Louisiana where there were waivers. In West Virginia, the police met the fleet at the borders and escorted the fleet through the state. Xcel's estimate is that a one-hour delay en route can lead to 24-

hour delay in getting power running again. The movement of utility fleets and personnel in cases of emergencies is an area where more collaboration and coordination can be fruitful.

Communication: Many Summit participants emphasized the importance of effective communications for not only coordinating responses to disruptions, but also for "make the case" for resilience. Russell McMurry from the Georgia DOT, for example, described GDOT's multifaceted communications strategy for responding to incidents while at the same time conveying to the public how important it is to invest in a resilient transportation system. The 2018 interstate bridge deck fire is a good example of how GDOT's communications strategy was instrumental in reducing the impact of what could have been an even larger system disruption than it turned out to be. When a bridge deck on I-85 in central Atlanta caught fire, closing the interstate in both directions and destroying both decks such that many months of road closure were anticipated, GDOT implemented its communications strategy for dealing with major disruptions. The strategy consisted of the following:

1. Within hours, information was being broadcast via many different media concerning what happened and GDOT's expectations for recovery. Importantly, the key message was for the users of the system to have patience and to seek alternative means of getting to and from their destinations if I-85 was on their normal travel path. An incident-specific communication plan was prepared within 36 hours after the event.

2. Daily/weekly updates were provided to all the media so that the latest information could be broadcast to the largest number of people as possible. Given the magnitude of the incident, the media was very interested in knowing the latest information on the recovery. In fact, many of the key T.V. stations in the region complimented GDOT repeatedly on the expeditious manner in replacing the bridge.

3. In times of emergency, GDOT's communications team is embedded in the Emergency Management Center so that real-time updates can be provided. They immediately relayed information to all media outlets of what was going on. All incident-related communications went through the Center to assure consistency of messaging.

4. The 511 system was used to provide updated travel information; such information was available on the 511 system within the first hour of the fire. A press release was issued within 4 hours to discuss what GDOT knew and what to expect tomorrow.

5. Transit partners were invited to discuss transit options, as well as other groups representing ridesharing, telecommuting, flextime, etc. This was critical in conveying to those no longer able to use the road that options existed. Having detour routes identified very quickly was also an important aspect of the strategy. Given the many different groups that were involved in the communications plan, one should not wait for an emergency for collaborative partnerships to be formed.

6. After the cause of the fire was discovered (homeless people starting a fire under the bridge deck), the reaction of the press was to focus on fixing the blame for the disaster. GDOT's goal was to convey information on how to survive many weeks if not months of disruption. Efforts were made to focus press attention on the recovery efforts. A press conference was held where a panel of transportation experts focused on what happened structurally to the bridge and what steps were now being taken to recover. Access was provided to the site for all the media interested in viewing the damage. GDOT officials were always available to answer questions. This was a key element of the strategy …. keep the media focused on what will be coming next.

There is no such thing as communicating too much. Much of what GDOT did established a great deal of credibility with the media.

7. Given national, state, and local interest in the incident and recovery, communication "hand-offs" were often made to those wanting to be seen as part of the recover (e.g., mayor, governor, cabinet secretaries, and the like).
8. GDOT's philosophy on the incident was to view the disruption and the agency response as opportunities to show concern, competence and sensitivity to community needs. Some actions taken in this regard included:
    - Politicians were provided opportunities to visit the site.
    - Social media and an incident website were used extensively.
    - Business community impacts were a concern from the very beginning; many meetings were held with businesses to get buy-in into alterative travel strategies (e.g., ridesharing).
    - Freeway variable message signage was used throughout the recovery to provide updates.
    - GDOT worked with Waze and Google to divert detour traffic away from neighborhoods.
    - Videos of the incident and recovery were made available throughout so that the public could see what was happening.

Other speakers in the communications session discussed the strong need for effective internal communications to assure successful response and the importance of making sure the agency's own employees are safe after the incident. Caltrans, for example, has established phone numbers that employees are to call after a major incident to report they are okay and to receive information on what they should be doing as part of the response.

Questions asked at this session provided additional insights into strategies for communicating key aspects of major incidents.

How does one gauge public reaction to the general concept of system resilience? Does one base a communications strategy by hazard/threat? It is important to "personalize" the incident in terms of what the disruption means to the average person. For extreme weather-related disruptions, most people expect everything to return to normal within three days. It is thus necessary to continue messaging about future hazards from extreme weather events. The message for a natural disaster is not "if" it happens, but "when" it happens again. One of the challenges with this strategy is combating the natural tendency for many to gravitate to social media to get the "truth."

How does one message resiliency when there is pushback from a community or it is clear the message is not getting through? Resiliency should be portrayed in combination with other societal goals …. public health, safety, economic development, and the like.

What lessons have you learned when an agency is planning lengthy road shutdowns? The key terms that should guide your strategy include: public education, extensive prior communications, emphasis on the improvements that are going to occur, and explaining how road users can minimize the impact on their travel. At the very least, although the public might not like the disruption, they should understand why the planned disruption is necessary.

What do you do when things do not go as planned? -- Address it directly! Provide information on why; get ahead of the messaging; tell the truth

How does one message climate change in an environment where it could be politically challenging? If necessary, do not use the term "climate change" but instead uses information and statistics from past events to show the threat. Also, discuss desired outcomes in public hearings before presenting solutions.

Are webcams useful tools for disseminating information? Yes, people love time lapse portrayals of recovery efforts as well as monitoring progress. Drone videos are good for disruptions along lengthy corridors.

Are simulations of potential outcomes useful for public information dissemination? Yes, simulations and renderings work well in explaining what is going to happen and how travelers can navigate paths through the disruption site during the recovery.

Cybersecurity

Several sessions in all four tracks touched on the challenge of providing cybersecurity to increasingly vulnerable transportation information systems. As noted by Pete Rahn from MdDOT, cybersecurity is an issue that all state DOTs need to be concerned about. There have been several high-profile cyberattacks against transportation agencies and companies. Perhaps the most notable was the 2017 cyberattack against Maersk (as reported in *Wired* magazine). One compromised computer was the pathway to companies and databases throughout the world. Cell phones/laptops/phones/terminal gate operations/ship communications were all down, affecting customers, truckers, and vessels. Containers could not be processed for 10 days. Because a Maersk facility in Ghana had experienced a power outage, one laptop computer was left operational across the entire company. In the end, Maersk had to buy 45,000 new laptops and 2,500 software applications. The total cost to the company was between $250 million and $300 million.

Ryan Rice from CDOT reported on a 2018 cyberattack against CDOT. The major cyberattack affected all of CDOT's business operations. In the aftermath, concerns ranged from internal management systems to human resource systems needed to pay CDOT employees. Because CDOT's Intelligent Transportation Systems (ITS) were independent of the core information technology (IT) system, it was not hit. The attack, however, did help CDOT identify vulnerabilities in these systems. The cyberattack led to a major initiative within CDOT to identify cyber vulnerabilities and begin developing solutions. CDOT worked with the Colorado National Guard and the Department of Homeland Security (DHS) Cyber Hunt teams to assess and identify vulnerabilities in CDOT. It was recognized that DOTs have to be willing to aggressively seek out where improvements can be made – this is not a "once and done" process. It is a continuous improvement process. Network monitoring is essential – networks will be attacked, therefore it is essential to detect the attacks and respond.

Rick Tiene from Mission Secure, Inc. reinforced that message of how vulnerable transportation agencies are to cyberattacks. Attackers' goal is to gain control of Level 1 devices such as an unprotected traffic signal cabinet. There are vulnerabilities at all levels, for example, one attack occurred through the HVAC system because the system vendor had remote access to make improvements, adjustments, etc. In this case, the vendor's remote access was not secure, so that was the route into the organization's data system. Hackers do not necessarily have a plan. If they find a barrier in one place, they will look for another way in.

For transportation agencies, there are major vulnerabilities in the field, e.g., traffic signal boxes are not protected because vendors do not build that into the system. Further, a lot of the field technology is old and has been upgraded to become "smart." The boxes are now vulnerable.

Mr. Tiene recommended agencies assess and repair, assess and repair again, assess and repair again. It is a continuous improvement process. You do not have to be "best in class;" you just have to be better than your neighbors – hackers are just like burglars, if your house is more secure than your neighbor's, they will most likely move on. As each state gets more secure, the overall system becomes more secure.

Bob Bosco, Director of Security and Communications Technology for HDR, Inc. noted the following systems that are of particular concern:

Transportation Industrial Control Systems

- Highway
- Intelligent Traffic Systems

Dedicated Short Range Communication

- Maritime
- Ports Crain Control Systems

Vessel Traffic Centers

- Aviation
- Air Traffic Control
- Air Ground Network
- Engine Health and Usage Monitoring

Surface Transportation

- Positive Train Control
- Signaling and Switching

Pipeline

- Flow
- Pressure
- Temperature
- Odorant Control

He also noted that the approach adopted today for cybersecurity is called providing cybersecurity in depth. The means blocking access to resources and services (e.g., firewalls); detecting malicious activity (e.g., cyber intrusion detection/scans); mitigating possible attacks; fixing core problems (e.g., conducting post incident response assessments); and adopting security policies (e.g., preventive/responsive measures).

David Weitzel from the National Institute of Standards and Technology (NIST) presented NIST's framework for conducting cybersecurity assessments. The approach includes very detailed and comprehensive examinations of all the possible vulnerabilities in an agency (see Figure 5). Mike Dinning (Volpe National Transportation Center, Retired) discussed other tools that are available to transportation agencies, including a lot of research by TRB's Cooperative Research Programs. The Cyber Security Evaluation Tool (CSET) from DHS assists organizations in protecting their key cyber assets. It was developed under the direction of the DHS Industrial Control System Cyber Emergency Response Team (ICS-CERT) by cybersecurity experts and with assistance from NIST. This tool provides users with a systematic and repeatable approach for assessing the security posture of their cyber systems and networks. It includes both high-level and detailed questions related to all industrial control and IT

systems. It was applied in the cyber vulnerability assessment undertaken for the transit agency in Atlanta.

Doug Couto from the Center for Digital Government recommended that the agency's IT community needs to be not only brought into the conversation regarding cybersecurity but directed to develop a "defense in depth." He also noted that the application of digital technologies into "smart" cities increases their vulnerability. As digital cities get more connected, there are more points of entry. There will be an increase in the risk of cyber disruptions as more services and jurisdictions continue toward a fully automated smart city.

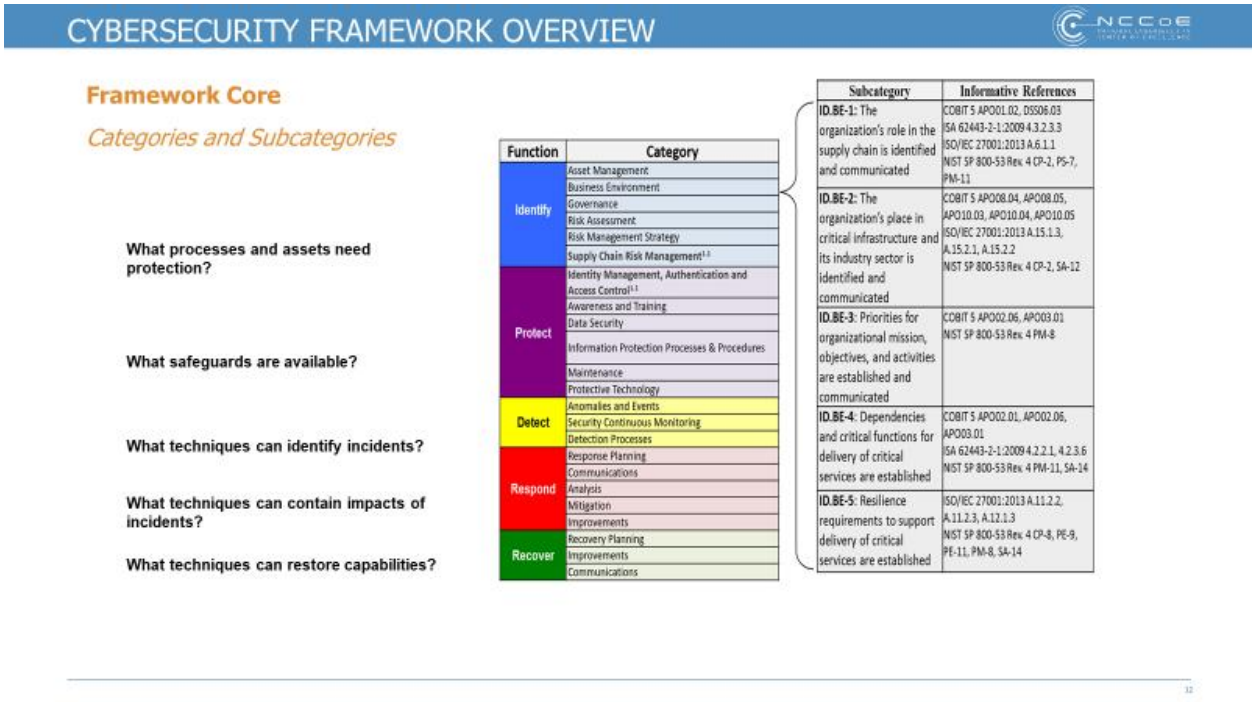

Figure 5: NIST's Cybersecurity Assessment Framework Categories

Research Topics

Session participants were asked to identify potential research topics that would be beneficial to enhancing transportation agency efforts at system resilience. In many cases, there was very little time for such an effort, but for those sessions that did so, the following were suggested topics. Note that they are not presented in any order of priority.

There is a need for:

1. Changing mindsets – what steps can be taken to support scientists or engineers become more conscious about integrating social issues into their work (the "why" and "how" are social issues going to be addressed by planners, etc.)? The distinction might be a focus on process (social science) vs. outcome (technical). Research needs to help broaden viewpoints to more holistically inform transportation resilience.

2. Best practices – how was community resilience effectively built up within the transportation organization and why was it effective? How did they organize the effort?
3. Methodologies and simulations that capture network interdependencies, cascading impacts, and failure points, with sufficient granular detail to enable targeted adaptation strategy development.
4. Investment models for adaptation strategy implementation: Are financial and technical resources being pooled to address shared risks?
5. Guidance/research on tools that can be used to justify betterments as part of the Federal ER programs.
6. Examination of best practices in communicating to different population groups and stakeholders during and after disruptions.
7. How to best include user costs and benefits into project selection processes?
8. How to best include social impacts into project selection? How to best use social impact indices for this purpose?
9. Organizational strategies for incorporating resilience concepts throughout the agency. What can we learn from each other?
10. How to best quantify risk and uncertainty into planning and decision making?
11. Continual collection of data on damage to assets for different types of threats and hazards so that over time we have developed a comprehensive database on damage curves. Especially important would be monitoring the effectiveness of mitigation strategies already put in place when incidents occur. Did the mitigation strategy work?
12. What changes in design standards and protocols are necessary to implement a more adaptive design process?
13. What are the best approaches for adopting a phased implementation strategy so that projects can be made more adaptive when more information is known about environmental conditions.
14. How can advances in technology be helpful in fostering a more resilient agency and transportation system?
15. How can resilience be best included in performance measures?
16. What are some the best ways of "making the case" for system resilience?
17. What can we learn from other countries on best practices? What can we learn from other sectors (e.g., utilities)?

Final Session

The final session summarized the key points from the Summit tracks. Key observations included:

Paula Hammond (WSP)

- Agency leadership in fostering a resilience-oriented agency culture is critical.

- More state DOTs are starting to consider risk and system resilience. This has occurred in a variety of ways---understanding enterprise risk, using a systems approach, and using asset management as platform for doing so.
- It is very important to consider system resilience at the planning level; this is where future risks and vulnerabilities would be logically considered in a systematic way.
- A serious concern expressed by agency CEOs was how to fund resilience projects and/or resilience-oriented project add-ons.
- State DOT officials noted the importance of partnerships with a range of agencies and organizations …. emergency responders, utility companies, health departments, Tribal Nations, key system users (e.g., freight carriers), media, local government, and many more.
- For large-scale disruptions, there is often a need to coordinate with other states. This might have to do with the logistics of bringing in relief supplies and personnel for recovery, or because detour routes extend into other states.

Cris Liban (Los Angeles County Metropolitan Transportation Commission)

- The focus of many efforts has been on planning----not much implementation. It is time to get proactive!
- Many resilience strategies and actions come from state and local government. Funding does not have to be a constraint if leaders are creative. Resilience champions can come from all levels of government and from many other groups as well.
- Network cascading effects and telecommunications are critical concerns at the local level where much of the interconnection of infrastructure systems occurs. Addressing such concerns often requires the participation of many agencies and companies that are not often involved in transportation decisions. Effective risk mitigation, however, will depend on such participation.
- The success of preparing for a very different future than what trends would suggest means many of us need to question the approaches and tools we use today. Engineering, in particular, needs to be more adaptive when designing a project in an area that is likely to be vulnerable to more intense environmental conditions.
- Disadvantaged populations should be part of the process in identifying resilience strategies for their communities. For example, evacuation plans need to consider the fact that many households do not have access to an automobile.

Debra Nelson (New York Metropolitan Transportation Commission)

- Coordination and inclusiveness in the process for identifying potential threats and hazards, and strategies for dealing with them, are critical for success. This means interaction with key decision makers, those who influence transportation policy, and those from sectors outside of transportation but whose own infrastructure influences transportation system performance.
- Many believe we need to be talking about a “system of systems” that recognizes the interdependencies among relevant infrastructure and services. This might entail shared responsibilities.

- Decisions should be supported with credible analysis that acknowledges uncertainties in projections and assumptions. However, decisions should not be paralyzed because data is not available or expected impacts are not known with great certainty.
- From an agency perspective, creating a more resilient culture does not necessarily depend on a "big win." Many small victories can add up to a significant change in an agency's approach toward system resilience. Be bold!

After the summary presentations, the audience was asked to identify key words or terms that surfaced from the discussions during the Summit and that best represent key characteristics of effective resilience efforts. The key question was, "what can we do to provide a more resilience-oriented agency environment (where 'we' is the collective 'we')? A word cloud was then developed based on this input. Figure 6 shows the resulting word cloud. The key words and phrases reflect much of what was discussed during the Summit. The importance of communications, the need for resilience champions, thinking and understanding what future potential disruptions might mean to transportation and local communities, and the importance of incorporating resilience concepts into decision-making processes are all key elements to successful resilience efforts.

Figure 6; Resilience Word Cloud from Summit Participants