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Transportation Systems Resilience

Preparation, Recovery, and Adaptation

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Transportation Systems Resilience

Preparation, Recovery, and Adaptation

Prepared by

Transportation Systems Resilience Section
Standing Committee on the Logistics of Disaster Response and Business Continuity
Standing Committee on Emergency Evacuations
Standing Committee on Critical Transportation Infrastructure Protection

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Preface

In 2015, the Transportation Research Board's Activities Council established the Transportation Systems Resilience Section, which includes three standing committees: Critical Transportation Infrastructure Protection, Logistics of Disaster Response and Business Continuity, and Emergency Evacuations. Over the past 3 years the Transportation Systems Resilience Section has embraced its mission and developed six goals to fulfill that mission.

The section's mission is to promote discussions among principals, disseminate research findings, and identify priority research topics in the area of transportation systems and services before, during, and after periods of increased stress, service disruptions, and human need in order to increase resilience and enhance communications among interested parties. The goals include promoting communication among transportation stakeholders; building understanding of the sources of risk and potential mitigation options; developing an integrated conceptual framework for increasing transportation resilience; identifying transportation requirements during emergencies from the community perspective; promoting research that will lead to new methodologies; and supporting the needs of end users by incorporation of system resilience and sustainability into their routine activities.

The need for enhanced dialogue is readily apparent as researchers and practitioners try to understand and promote resilience in our communities, regions and the nation. Together with the September/October 2017 print edition of *TR News,* the articles included in this E-Circular provide a snapshot of the many interested parties and research issues involved in understanding and implementing transportation systems resilience. It is hoped that this special edition will stimulate readers' interest in this topic and their participation in the ongoing efforts of the Transportation Systems Resilience Section.

—Thomas Wakeman
Chair, Transportation Systems Resilience Section

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Resilience in a Transportation System

A Whole System Approach

RYAN MARTINSON

This article explores the definition of resiliency and how this concept relates to transportation systems. It then provides ideas for how resilience could be included in transportation engineering practices.

USE OF THE WORD RESILIENCE IS ON THE RISE, BUT WHAT DOES IT MEAN?

A quick search in Google's Ngram Viewer (*1*) of the word "resilience" shows a marked increase in its use in the past 15 years (Figure 1). Yet, compared to the word "sustainable," it still is in the shadows (Figure 2).

FIGURE 1 Ngram of the word "resilience."

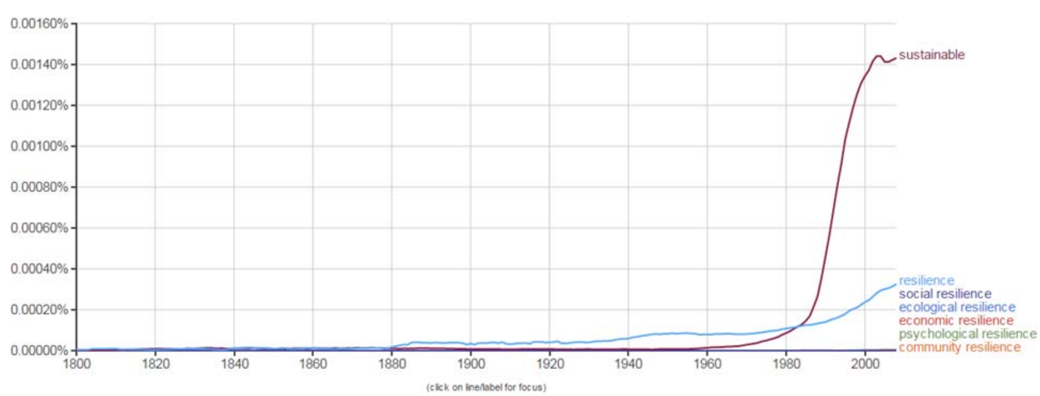

FIGURE 2 Ngram of the word "resilience" compared with "sustainable."

With the use of the word resilience growing and the idea of sustainability already included in the vocabulary of many agencies, it now may be the time to consider if the idea of resilience should be given the same attention.

First, the definition of a system is provided since both sustainability and resilience may be considered properties of a system. From this systems perspective, resiliency is defined and the outcomes of a resilient transportation system are explored.

TRANSPORTATION WHOLE-SYSTEM APPROACH

When you are dealing with a system and are acutely aware that everything is connected in some manner, the system's response to an economic interruption or physical interruption all relates to its resiliency. When we look at our cities, if we look hard enough, it is possible to identify single components that are at play. But, these components, or elements, are influenced by other components, which are themselves influenced by still other components.

Our cities are not factories that follow processes and flows; they are places where the built environment, technologies, and people all interact over a variety of time scales. These social–ecological systems are complex and adapt to influences over time, which means that understanding how individual elements function does not mean that the overall system can be understood or predicted. Given that we live in a complex world, one way that we can seek to understand our current situation is to view the system as a whole, acknowledging all the interconnected parts (*2*).

Some graphical models of the transportation system are shown below and demonstrate the interconnectedness of the various elements and the difficulty in isolating single variables (Figures 3 and 4).

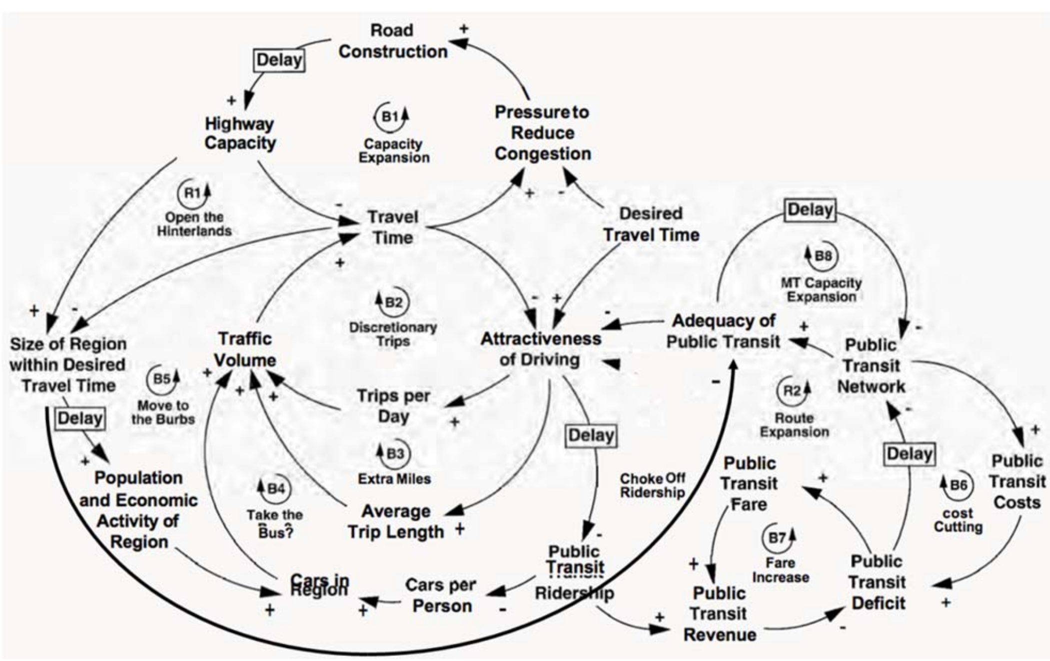

FIGURE 3 Example of automobile use system as presented by Sterman (*3*).

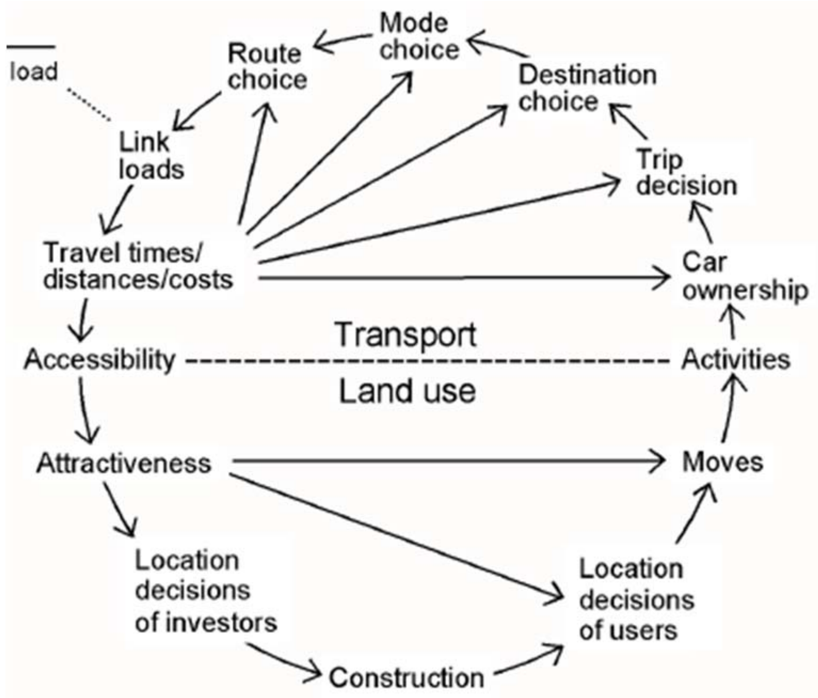

FIGURE 4 Land use and transportation system example (*2*).

As depicted in Figures 3 and 4, our urban areas and societies are comprised of multiple connections, some being completely engrained in the way we think and do things. In some cases, new services (e.g., Uber or Car2Go) emerge and surprise us with their effectiveness and uptake. Perhaps this is because we are so comfortable in seeing the world within our personal viewpoints and do not or cannot recognize these potential disruptions. A whole-systems viewpoint will not provide a crystal ball into the future enabling us to predict these types of disruptions, but instead provides a better framework to understand why these changes are effective and how we could frame our policies and practices to recognize these new contexts.

To better understand the whole-system approach, it is important to provide a more formal definition of what a system is:

> A system is an interconnected set of elements that is coherently organized in a way that achieves something. (*4*)

In this definition of a system it can be seen that the elements and the connections between them, the interactions, is present, but it is also important to note the presence of a purpose or goal of the system. This purpose will be important to remember when we discuss the idea of values that would be held if a resilient system is sought.

Another, definition to consider for the system that we live in is that of a Complex Adaptive System. Somewhat fittingly, there is no widely accepted definition for a Complex Adaptive System, but some have said it has the following characteristics (*5*):

- Sustained diversity and individuality of components;
- Localized interactions among those components; and

- An autonomous process that selects from among those components, based on the results of local interactions, a subset of replication or enhancement.

The definition for a system as presented in Meadows (*4*) and the definition of a Complex Adaptive System are very similar and may actually differ only in the style of the language used to describe each. Both acknowledge that systems have parts (e.g., elements or components), connections, and achieve something.

It is with the idea of social–ecological systems in our minds that we now explore sustainability and resilience as properties of complex systems.

RESILIENCY DEFINED

Resiliency is defined as how a system can react to tremors, shocks, or catastrophes (*6*). These impacts can be over a short duration or long durations. How well it can perform during these changes depends on how resilient the system is. Many times, the desire is for the system to just endure what has been going on, but sometimes the need is for the system to be able to change or adapt to what could potentially become a new normal.

Some definitions of resiliency that have been used include the following:

- The capacity of the system to function in spite of external drivers (both shocks and directed change). "The resilience of what to what" (*7*)?
- The capacity to sustain a shock, recover, and continue to function and, more generally, cope with change (*8*).
- The ability of a system to absorb disturbance and still retain its basic function and structure (*9*).
- Resilience is the ability of households, communities, and nations to absorb and recover from shocks, while positively adapting and transforming their structures and means for living in the face of long-term stresses, change, and uncertainty (*10*).

Underlying elements in all of these definitions are: systems and abilities to absorb and recover from shocks. One nuanced element of the definition is in relation to transforming abilities. Especially with climate change, social equity, and obesity epidemics becoming linked to our built environment and the transportation systems we currently have in many North American cities, change to our current systems is required, making the aspect of transformation very important to consider.

While it is important to know what a concept is, it is also important to understand what a concept is not. A leader in systems thinking, Meadows, was clear in defining what resilience is not in her book *Thinking in Systems: A Primer* (*4*):

> Resilience is not the same thing as stability, which we can define here as relative constancy over time. Resilient systems can be very unstable. Short-term oscillations, or periodic outbreaks, or long cycles of succession, climax, and collapse may in fact be the normal unstable condition, which resilience acts to restore!
>
> And conversely stable systems can be un-resilient. The distinction between stability and resilience is important, because stability is something you can see; it's the measurable variation in the condition of a system week-by-week or year-by-year.
>
> There are always limits to resilience.

> Resilience is something that may be very hard to see, unless you exceed it and the system breaks down. Because resilience is not obvious without a whole-system view, people sacrifice resilience for stability, or for productivity, or for some other more immediately recognizable system property.

Of particular interest to transportation professionals is that resiliency is based on a system or network and is difficult to summarize simply into equations, quantities, even observations. By not considering all the other factors at play, a single answer may be found, but it may not mean the entire system is going to benefit. In addition, the system is constantly changing, as it is responding to feedback from all directions, internally and externally. As stated in Martin-Breen and Anderies (*11*), "ecosystems do not evolve toward a single stable climax state, but undergo periodic cycles of change." By not considering the whole system, practitioners can take a singular perspective in the pursuit of a complex problem which result in counterintuitive outcomes.

A VALUE-BASED APPROACH TO DELIVER ON RESILIENCY

The focus on disaster preparedness has been of major interest to organizations and governments. With billions of dollars of damages associated with disaster relief (*12*), it is understandable that this is of concern. But what is clear is that a focus on resilience can be a more reaching topic than a single focus on one type of risk.

According to Walker and Salt in their book *Resilience Thinking—Sustaining Ecosystems and People in a Changing World* (*9*), a resilient world would value diversity, ecological variability, and modularity; acknowledge slow variables, tight feedbacks, social capital, and innovation; and overlap in governance and ecosystem services. These values represent a strong foundation that societies and municipalities can, and do, base themselves around.

Additionally, structuring resiliency planning around these values is an approach that other organizations cite as a way to move past positions, which can be at odds with others. This, then, allows them to operate from a shared goal. Figure 5 is from the International Association of Public Participation and describes the concept of moving away from positions and instead working from shared visions to resolve issues.

By planning for resiliency from key fundamental values, the actions needed to operationalize this type of thinking can be derived. Given the influence of whole system thinking in this area, these values alongside a stronger understanding of the system dynamics we are living within is necessary.

> Operationalizing resilience thinking is, in part, about getting people to cross a mental threshold into a systems mind space in which systems with multiple stable states and adaptive cycles make sense. Cross this particular threshold of understanding and the world takes on a different light.
>
> —B. Walker and D. Salt (*9*)

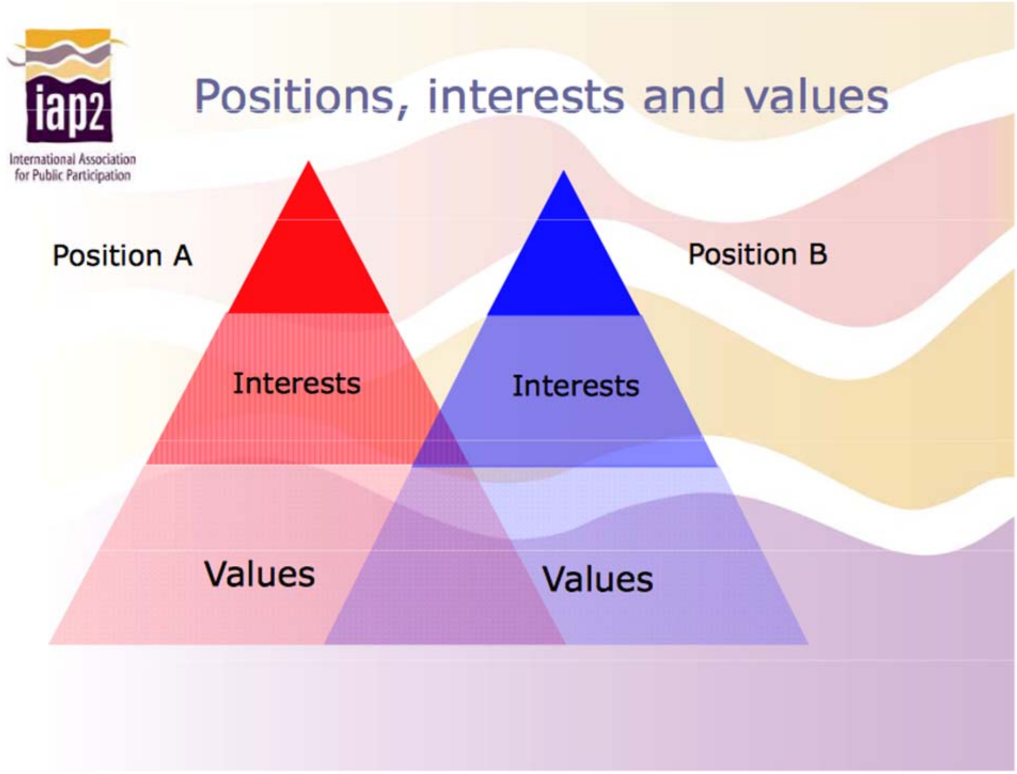

FIGURE 5 Description of positions, interests, and values. (Source: International Association of Public Participation.)

Table 1 provides a summary of the values a resilient system would hold as stated by Walker and Salt (*9*), together with the possible outcomes that this value could contribute to within a transportation system.

The values and examples shown in the table above are only some of the possibilities that would present themselves in a more resilient system. These values could be applied to various aspects of transportation systems and the governance structures that own and operate them, such as policy and regulatory bodies, planning processes and guiding documents, design of infrastructure, incorporation of technology, and operation and maintenance of the existing infrastructure.

HOW CAN YOU TELL IF YOU HAVE A RESILIENT SYSTEM?

In many cases, it is not possible to determine if the system you are within is resilient or sustainable. Often, you can only see if you are doing a good job in the heat of the moment, when you are most in need of it being there. This, then, makes endeavors towards planning a sustainable and resilient system sometimes difficult since we only know how well we did when it's at the point where we don't have any other options other than hope. Climate change could be a current issue that is a relevant example of this occurring.

TABLE 1 Summary of Resilient System Values

Resiliency Value	Supporting Statement	Possible Outcomes in Transportation System Under This Resiliency Value
Diversity	A resilient world would promote and sustain diversity in all forms (biological, landscape, social, and economic).	Meaningful engagement with stakeholders. Diversity in land uses within near proximity. Multimodal transportation planning. Diversified mobility choices for ridesharing. Equitable allocation of mobility investment.
Ecological variability	A resilient world would embrace and work with ecological variability (rather than attempting to control and reduce it).	Context-sensitive approaches, not one size fits all. Variety or reduction of policy and regulations based on desired outcomes and evidence based.
Modularity	A resilient world would consist of modular components.	Gridded networks for all transportation modes to allow for multiple options from origins to destinations.
Acknowledging slow variables	A resilient world would have a policy focus on "slow," controlling variables associated with thresholds.	Phasing out of surface parking over structured or hidden parking as redevelopment occurs. Land use changes or growth priorities within municipalities in the long term.
Tight feedbacks	A resilient world would possess tight feedbacks (but not too tight).	Piloting projects to test potential outcomes. Monitoring and evaluation programs feeding into new development and planning procedures (e.g., refining trip generation rates).
Social capital	A resilient world would promote trust, well-developed social networks, and leadership (adaptability).	Projects that not just build infrastructure, but contribute to communities strengthening their social bonds (e.g., Build a Better Block, Tactical Urbanism).
Innovation	A resilient world would place an emphasis on learning, experimentation, locally developed rules, and embracing change.	Local standards and national rules being accommodating for new evidenced-based designs or guidelines are published. Working with standards and guidance sources, as well as the legal system, to emphasize technical judgment and reasonability as key criteria in determining the appropriateness of transportation decisions rather than strict adherence to standards.
Overlap in governance	A resilient world would have institutions that include "redundancy" in their governance structures and a mix of common and private property with over-lapping access rights.	Stronger emphasis on participatory planning and community engagement. Regional partnerships and national associations being partners in governance of practitioners.
Ecosystem services	A resilient world would include all the unpriced ecosystem services in development proposals and assessments.	Life-cycle cost accounting or full cost accounting that aims to include more externalities associated with infrastructure.

As a result of this invisibility, measuring and monitoring programs have been developed and studied to provide metrics that would help indicate the health of a resilient system.

Often the phrase "what matters, gets measured" or "what is measured, gets managed" is used. System indicators have been suggested for resiliency, so as to provide something to manage and advance a more resilient system. These indicators are from guidelines published by the OECD for the analysis of a resilient system (Table 2) (*6*):

- System resilience indicators (outcome indicators) look at the resilience of the main components of the system over time, including how the overall well-being of people and the system is affected when shocks actually occur, for example, how political capital is affected by an actual earthquake, or how social capital is affected by new or escalating conflict. These indicators should be complemented by negative resilience indicators.
- Negative resilience indicators look at whether people are using strategies to boost resilience that may have negative impacts on other areas of the system, for example turning to crime to deal with unemployment; or negative impacts on certain vulnerable people, for example by reducing the number of meals eaten a day or taking children out of school.
- Process indicators ensure that the resilience roadmap is being used in policy making and programming.
- Output indicators show the results of implementing different parts of the resilience roadmap.
- Proxy impact indicators help show the results of resilience programming. These must be used with caution, but can be necessary when other more nuanced measures (such as system resilience indicators) are difficult to create, or difficult to communicate to a specific target audience.

Possible metrics that could be used to monitor the resiliency of a transportation system are shown in the table below.

The scope of the system that you are concerned with will determine the headings or parts of the system that are evaluated. Then, these various parts of the system and the associated well-being can be mapped (*6*). The monitoring of the various parts is necessary to determine how the system is performing over time.

TABLE 2 System Indicators

Indicator	Example of Indicator Being Used in a Transportation System
Outcome indicators	Health of the population Social capital of the area
Negative indicators	Equity in access to transportation infrastructure Equity in access to employment and learning opportunities
Process indicators	Regular reporting of progress and accountability to decision-makers Spending by mode of transportation Number of stakeholders and public engaged in project development
Output indicators	Diversity of transportation options in an area Transportation mode split by trip purpose Safety performance of the transportation system

Throughout this article definition of resiliency in relationship to a whole-system perspective was provided. Then values that would be present in a resilient system were provided and examples of those values being present in a transportation system were given. Finally, indicators of resiliency were suggested to provide guidance on the measurement of how resilient a system is. By applying this whole-system approach to the resiliency of a transportation system, perhaps many of our social, environmental, and economic issues can be overcome through purposeful design and policy development.

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Getting Ahead of the Weather with Advances in Forecasting

KATHERINE THOMAS
DAVID ALLEN
NANCY HUDDLESTON

Inclement weather has a daily impact on our lives. The impacts range from personal clothing decisions to preparing for extreme events that can potentially endanger lives and property. Two recent reports from the Board on Atmospheric Sciences and Climate explore the ability to project changing conditions in weather and climate. The first report assesses the science of evaluating the relative influence of human-caused climate change on individual extreme weather events. These extreme event attribution studies could lead to improved projections of the frequency and magnitude of extreme events. The second report explores how subseasonal-to-seasonal (S2S) weather forecasts—defined as those made 2 to 12 months in advance—might be improved. Such forecasts could inform decisions-makers in transportation and other sectors, enabling them to increase economic vitality, protect property and the environment, and potentially save lives.

ADVANCES IN ATTRIBUTION OF EXTREME WEATHER EVENTS

As the climate has warmed, a new pattern of more-frequent and greater-intensity weather events has begun to take hold across the globe. In 2015 alone, reports of a severe summer heat wave in India and Pakistan, a 1,000-year rainfall in South Carolina, widespread flooding in northern New England, among other events, have fueled interest in the role that climate change plays in driving extreme weather. In the wake of extreme weather events, communities have to decide whether to rebuild or relocate critical infrastructure. Such decisions could hinge upon whether the occurrence of an event is expected to become more likely or more severe and, if so, by how much.

Climate models can simulate some of these changes in extreme events, and some of the reasons for the changes are well understood. Warming increases the likelihood of extremely hot days and nights and favors increased atmospheric moisture that may result in more frequent heavy rain and snowfall. Warming also leads to evaporation that exacerbates droughts.

Even with evidence of these broad trends, scientists cautioned in the past that it was not possible to attribute any given individual weather event to climate change. However, the science of extreme event attribution has advanced rapidly in recent years, bringing new insights into the ways that human-caused climate change can influence the magnitude or frequency of some extreme weather events. The report Attribution of Extreme Weather Events in the Context of Climate Change, released in 2016, provides the first comprehensive assessment of these new insights.[1]

Attributing a weather event to climate change does not mean that storms or heat waves would not have occurred without humans. Weather events are the result of a variety of factors, both natural and human influenced. Extreme weather attribution is the science of determining the degree to which human-induced climate change influences the probability or intensity of a specific weather event. As capabilities improve, attribution studies could inform decisions regarding assessment and management of risk and guide the development of climate adaptation strategies.

SOME EVENTS ARE MORE ATTRIBUTABLE THAN OTHERS

While significant advances have been made, some events are more attributable than others. The report assesses the events for which there is greatest confidence in attributing to human-caused climate change according to three criteria: (1) the capability of models to simulate the event; (2) the quality and length of the observational record; and (3) an understanding of the physical mechanisms that produce extremes as a result of climate change (Table 1). The greatest confidence is in events that have a direct link to climate change, such as cold snaps and heat waves, while there is much less confidence for events such as tropical cyclones that are related to climate change in more complex and less well-understood ways.

TABLE 1 Current Scientific Confidence in Attribution Results Varies for Different Types of Extreme Events

● = high ◉ = medium ○ = low	Capabilities of Climate Models to Simulate Event Type	Quality/Length of the Observational Record	Understanding of Physical Mechanisms that Lead to Changes in Extremes as a Result of Climate Change
Extreme cold events	●	●	●
Extreme heat events	●	●	●
Drought	◉	◉	◉
Extreme rainfall	◉	◉	◉
Extreme snow	◉	○	◉
Tropical cyclones	○	○	◉
Extratropical cyclones	◉	○	○
Wildfire	○	◉	○
Severe convective systems	○	○	○

NOTE: Overall confidence in event attribution is strongest for extreme event types that are adequately simulated in climate models, have a long-term historical record of observations, and are linked to human-caused climate change through an understood and robustly simulated physical mechanism. The entries in this table, which are presented in approximate order of overall confidence, are based on the available literature and are the product of committee deliberation and judgement.

THE WAY ATTRIBUTION QUESTIONS ARE POSED INFLUENCES HOW THEY ARE ANSWERED

Statements about attribution are sensitive to the way the questions are posed and the context within which they are posed. The results hinge on how the extreme event is defined, the specific questions asked, the assumptions made when analyzing the event and the data, and the modeling and statistical tools used for the analysis. Unambiguous interpretation of an event attribution study is only possible when the assumptions and choices that were made in conducting the study are clearly stated, and uncertainties are carefully estimated.

A definitive answer to the commonly asked question of whether climate change caused a particular event to occur cannot usually be provided in a deterministic sense because natural variability almost always plays a role. Many conditions must align to set up a particular event. Event attribution studies generally estimate how the intensity or frequency of an event or type of events has been altered by climate change (or by another factor). Thus, the scientific community would be better able to address questions such as:

- Are events of this severity becoming more or less likely because of climate change?
- To what extent was the storm intensified or weakened, or its precipitation increased or decreased, because of climate change?

Because event attribution is a relatively young field of study, standards have not yet been established for presenting results. Event attribution could be improved by the development of transparent, community standards for attributing specific types of extreme events. Such standards could include an assessment of model quality in relation to the event type, or the use of multiple lines of evidence, and clear communication of sensitivities of the result to how event attribution questions are framed.

IMPROVING RESILIENCE THROUGH BETTER FORECASTING

The reliability of weather forecasts has advanced significantly in the 21st century through a combination of greatly improved atmospheric and oceanic observations and accelerating computer power. Computer-calculated forecasts of global and regional weather patterns are now as accurate at 72 h as they were at 36 h in the 1990s.

Governments, businesses, and individuals have increasingly come to utilize and rely upon short-term forecasts in order to plan the days ahead. Should a city pre-treat its roads to ensure a smooth commute? Should a school system cancel or delay classes in order to ensure the safety of its students and faculty? Will electric utilities need to adjust the amount of power they generate to meet air conditioning demands this week?

While short-term forecasts have become a critical part of decision making on a day-to-day basis, many planning and management processes are made weeks to months in advance. A frontier in forecasting involves extending the capability to skillfully predict environmental conditions and disruptive weather events to several weeks and months in advance. The growing ability to produce S2S forecasts—defined as those made 2 weeks to 12 months in advance—could better inform those decisions in a wide range of sectors, reducing society's vulnerability to weather, climate, and other environmental variability, both in the United States and globally.

A second report released in 2016—Next Generation Earth System Prediction—lays out a vision that that, within a decade, S2S forecasts will be as widely used as short-term forecasts are today.[2] Realizing that vision will require a concerted, coordinated research effort that emphasizes increasing the skill of forecasts; expanding the breadth of forecast models and variables; improving the prediction of extreme and disruptive events; and bringing researchers and decision-makers together to develop more actionable forecasts.

APPLICATIONS OF IMPROVED S2S FORECASTS

Improved S2S forecasts have many potential applications (Figure 1). Water managers would benefit from forecasts of drought or extreme rainfall. For the energy sector, improved understanding of heat waves and outbreaks of cold weather would help predict and plan for potential spikes in demand and the availability of renewable energy resources. Agriculture can benefit advance forecasts of variables that affect crops such as temperature, precipitation, and relative humidity.

The applications in transportation operations and planning are many. From shipping and navigation to highway, railroad, waterway, and airport maintenance, transportation practitioners require information on weather conditions. Improved information in the S2S range could increase efficiency and minimize disruptions (Table 2).

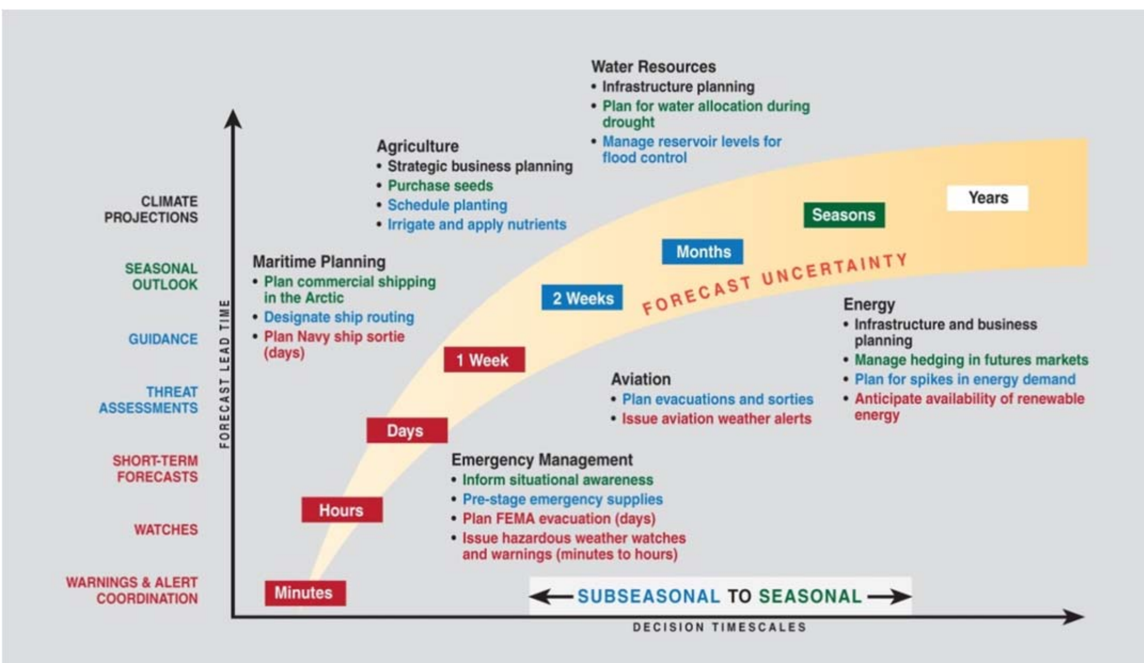

FIGURE 1 S2S forecasts (shown in blue and green) fill a gap between short-term weather forecasts (shown in red) and longer-term Earth system projections (shown in black). They inform critical decisions (also shown in blue and green) across many different areas.

TABLE 2 Example Decisions from the Transportation Sector That Can Be Informed by S2S and Longer Forecasts

Decision Process	Weeks–Months	Seasonal–Annual	Longer Term
Shipping and navigation	Disruptions to surface transportation systems; preparing evacuation routes for hurricanes (probability of flooding; periods of active tropical activity)	Timing of opening shipping lanes in the Arctic (sea ice; summer temperatures; streamflow on major waterways)	Susceptibility of ports to inundation; transit routes (sea-level rise; storm surge; ice-free Arctic)
Maintenance of highways, railroads, waterways, airports	Positioning equipment and assets, e.g., salt for roads, barges and railcars for transportation, deicing equipment and supplies for airports (probability of adverse weather, including snowfall or ice, heavy rainfall, drought)	Positioning equipment and assets for repairs of infrastructure and equipment; seasonal supplies of road salt, deicing supplies, fuel; (probability of favorable, adverse, or severe weather; number of freeze–thaw cycles; first and last frost; seasonal snowfall; ice storms)	Resizing of bridges and culverts to handle flood flows; selection of materials to handle extreme temperatures (projected number of days exceeding critical temperature thresholds; changes in maximum probable precipitation)
Maintenance	Positioning equipment and assets, e.g., salt for roads (probability of winter weather including snowfall or ice)	Planning for pothole repairs; seasonal supplies of road salt; possible repair of flooded roadways and bridges (probability of extreme rainfall; number of freeze–thaw cycles; first and last frost; seasonal snowfall; ice storms)	Resizing of bridges and culverts to handle flood flows; selection of materials to handle extreme temperatures (projected number of days exceeding critical temperature thresholds; changes in maximum probable precipitation)

Improved forecasts of the probability of flooding and periods of heightened tropical activity from weeks to months in advance would allow decision-makers to better anticipate disruptions to surface transportation or plan for hurricane evacuation routes. In addition, seasonal to annual forecasts of sea ice, summer temperatures, and streamflow on major waterways would improve forecasts of the timing of open waterways in the Arctic, allowing for safe passage.

Understanding of the probability of adverse weather, such as snow, ice, heavy rain, and drought weeks to months in advance would assist in developing improved plans for positioning equipment and other assets such as road salt, deicing equipment, and other supplies. Further, understanding the probability of favorable, adverse, or severe weather, the number of freeze–thaw cycles, first and last frost, and seasonal snowfall and ice storms on the seasonal to annual timescale would assist in positioning equipment and supplies for repairs of both infrastructure and equipment.

AN AMBITIOUS, BUT ACHIEVABLE RESEARCH AGENDA

Despite their large potential value, Earth system predictions on S2S timescales remain challenging for researchers, modelers, and forecasters. Many sources of predictability exist in the Earth system on S2S timescales, but representing these sources of predictability in Earth system models is challenging. Models must adequately capture the initial states of the atmosphere, ocean, land surface and cryosphere, as well as the interactions, or coupling, of these different components. Furthermore, the longer lead times associated with S2S predictions make the representation of uncertainty and the verification process more challenging and more computationally intensive than short-term weather prediction. Nonetheless, potential advances both in technology (satellites, computing, etc.) and in science (model parameterizations, data assimilation techniques, etc.) make advances in S2S forecasting feasible within the next decade.

Available S2S forecasts have already proven useful in several sectors including agriculture, energy, and water resource management. Overcoming a variety of remaining knowledge, resource and organizational challenges will help make these forecasts much more widely useful and beneficial to society.S2S forecasts currently fall in a gap that exists between short-term forecasts and a growing capability to predict longer-term climate. To date, S2S forecasting has not received the same focused attention as research and forecasting programs focused on weather or climate change timescales.

Achieving the report's goal for S2S forecasting in the next decade will require improvements in modeling, the Earth observing network, and in understanding of sources of S2S predictability processes in the atmosphere, ocean, or land that influence the Earth system in predictable ways. Additional factors that are critical to the realization of improved S2S forecasting include better understanding of and interactions with user communities, better support of infrastructure such as computing power, and a specialized workforce. The report identifies four research strategies, each with multiple recommendations for accelerating progress (Figure 2): engage users in the process of developing S2S forecast products in research plan development, the design process and continuing with iterative product prototyping and user feedback; increase S2S forecast skill; improve prediction of extreme and disruptive events and of the consequences of unanticipated forcing events; and include more components of the Earth System in S2S forecast models.

Perhaps even more critical than improving forecast products and access is building trust in the S2S forecast process. Scientists and operational forecasters who create the information are often disconnected from how that information is being applied, at least outside of agency operations. Broader use of S2S forecasts will be encouraged by creating systems and processes that bring together scientists with users of information to enable application of forecast information. The goal of this enhanced interaction would be to ensure that S2S predictions are tailored to the needs of the end user and that further research and product development efforts are applied to those areas that will provide the greatest value to decision makers.

Development of S2S predictions for disruptive events represents a significant opportunity. Currently, forecasts are generally limited to the probability of temperature and precipitation anomalies. New products that focus on the likelihood of extreme events in the S2S timeframe would provide significant increased value to a variety of different stakeholders, mitigating loss of life and damage to property.

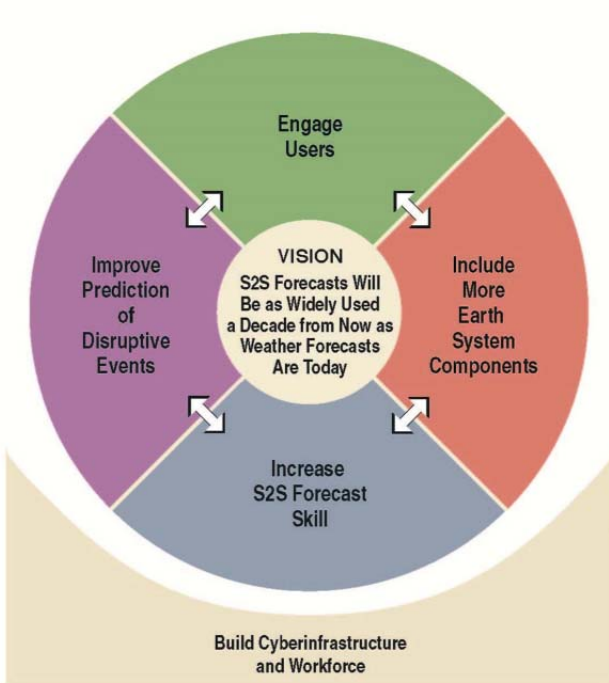

FIGURE 2 Relationship between the four research strategies and supporting activities outlined in the report for advancing S2S forecasting over the next decade, which all contribute to the overarching vision. (Note: The white arrows indicate that the four research strategies interact and are not mutually exclusive.)

GREATER RESILIENCE THROUGH INFORMED DECISIONS

Improving our ability to attribute extreme weather events to climate change may substantially inform our ability to plan and manage risk and in guiding climate adaptation strategies. Improved S2S forecasts will substantially improve our ability to plan in advance, making them as useful in 10 years as daily forecasts are today. These two National Academies' reports identify priorities for improving observations, modeling, and understanding – many of which would advance our abilities in both of these frontier areas. Advances in extreme weather attribution and S2S forecasting could inform planning, in transportation and beyond, in ways that reduce disruptions, increase efficiency, protect investments, and protect lives, increasing our resilience.

NOTES

1. https://www.nap.edu/catalog/21852/attribution-of-extreme-weather-events-in-the-context-of-climate-change.
2. https://www.nap.edu/catalog/21873/next-generation-earth-system-prediction-strategies-for-subseasonal-to-seasonal.

Benefits and Needs for an Integrated Approach to Cyber–Physical Security for Transportation

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Physical and cyber security mechanisms protect people and infrastructure assets for transportation from hazards, both natural and human-initiated. Both physical and cyber security mechanisms are diverse in size, function, deployment, and cost, and have proliferated. Since they are often colocated and functionally interdependent they need to be compatible. These physical and cyber mechanisms accomplish multiple security functions and reinforce one another for cost savings and conflict avoidance. First, connections between cyber and physical systems are presented in the context of interdependencies and resilience. Second, patterns and trends in cyber-attacks on transportation set the stage for typologies for both physical and cyber systems with illustrative cases. Third, social and economic effects and organizational arrangements are introduced to begin shaping solutions. Finally, conclusions are drawn as lessons learned.

CHARACTERISTICS OF CYBER–PHYSICAL SYSTEM COMBINATIONS

Interdependency and Resilience Principles Applicable to Cyber–Physical Systems

Interconnections and interdependencies among infrastructure sectors are well-recognized. Rinaldi, Peerenboom and Kelly (*1*) identified these concepts, and detailed typologies were identified by Petit et al. (*2*). Furthermore, resilience has become linked with infrastructure interdependencies (*3*). Resilience, traditionally defined as returning to a previous state, subsequently has signified withstanding adverse changes, and moving to a stronger state (adaptation) (*4*). Furthermore, the concept is multidisciplinary (*4*, *5*). Qualifications have been made, for example, the element of withstanding adverse changes has been interpreted as robustness (*6*), however, robustness has been considered an element of resilience (*7*). Resilience has been adapted with metrics for cyber systems (*6*), and integrates risk assessment and risk management (*8*).

Colocation and Cofunctionality of Cyber and Physical Security

Physical and cyber systems in transportation have become increasingly colocated and functionally dependent on one another. The U.S. Department of Transportation (DOT) (*9*) reported increases in information technology (IT) deployment in physical transportation support systems for 72 metropolitan areas.

IT and control systems and physical transportation components connect in many ways. Signals and switches that control transit train routing and track alignment involve control system connections (*10*). Computer-controlled highway systems include traffic lights, signage, automatic toll collection, and infrastructure such as pumping apparatus at gasoline stations. Road vehicles themselves are becoming increasingly connected to computers and electronic control systems, and braking systems and air bags are among those that, if disabled, could compromise safety (*11–14*). Automated vehicles could increase this risk if security is not considered in designs. While functional dependencies of physical and cyber systems in the transportation sector are beneficial, they may create vulnerabilities, since disabling a cyber system can disable the physical transportation system it is supporting and vice versa.

CYBER AND CYBER–PHYSICAL ATTACKS ON TRANSPORTATION SYSTEMS

Patterns and Trends in Selected Cyberattacks on Transportation Systems

Cyber-attacks directly against transportation control systems are small in number relative to other industry sectors, however in 2014 and 2015, according to Industrial Control Systems–Cyber Emergency Response Team (ICS-CERT), they escalated, and from 2012 to 2015 the number more than quadrupled (*15–18*). These only represent the ones reported to ICS-CERT, and other sectors with higher attack incidents—e.g., energy—indirectly affects transportation. Also, cyber-attacks can disrupt traditional IT systems, like tolling management and airline reservation systems

Need for Designing Cybersecurity into Physical Security Systems

Physical security systems—such as access control, intrusion detection, and video systems—are becoming increasingly reliant on networked digital technologies. Many are connected as part of the Internet of Things (IoT). Unlike older stand-alone security systems, these are potentially vulnerable to cyber-attacks, putting physical security systems at risk.

Many physical security system managers lack knowledge and skills in cybersecurity, and many (incorrectly) feel that their networks are separate and not at risk. Physical security systems are treated as industrial control systems in most organizations, not under the purview of IT professionals. Some physical security vendors have not included adequate cyber protections in their technologies (*19*).

Adversaries can use cyber-attacks to disrupt physical security systems in many ways. As illustrated by Krebs (*20*), cyber-attacks can block alarms from intrusion-detection systems, compromise access-control systems, and spoof video and inspection system images. As elements of the IoT, physical security systems can also be used as vectors for large-scale cyber-attacks. In 2016, IoT devices—such as video cameras and digital video recorders—were exploited by hackers to create a distributed denial-of-service attack which caused widespread disruption to Internet infrastructure services (*20*).

Physical security system technologies and designs must include cybersecurity protections similar to those used in other IT systems, and be monitored for intrusions as other IT networks are. Organizations need to treat physical security technologies as part of their IT networks, and ensure that cybersecurity is part of system design, management, and operations.

Examples of Attacks

Transportation systems face several types of physical and cyber-attacks, including attacks by terrorists, criminals, politically motivated groups, and disgruntled employees. Cyber- and physical attacks may be directed separately or combined as hybrid attacks.

Types of Intrusions on One System Followed by an Effect on the Other

1. Chicago Air Traffic Control Center Fire (*21–23*). On September 26, 2014, Federal Aviation Administration's (FAA) Air Route Traffic Control facility outside of Chicago was closed by a massive fire, shutting down over 91,000 mi^2 of airspace and disrupting thousands of flights. The fire, set by a disgruntled contractor, provides insight into the challenges to making systems resilient to both physical and cyber-attacks. The facility was protected by physical security systems, including electronic access-control systems and video surveillance, but the trusted attacker had access privileges. The air traffic control system and the FAA employees adapted quickly and minimized the disruption by using air traffic control centers in other locations.

   The Chicago attack illustrates the importance of coordinated programs for physical, cyber, and personnel security. It also highlights the need for system redundancy and preparation to ensure the adaptability of processes and personnel.
2. Polish Tram Hacking Attack. American Public Transportation Association (APTA) (*24*) identified the hacking of track switching points on a Polish tram in 2007 resulting in several derailments. This exemplified a cyber-attack disabling an unprotected physical transportation component.
3. San Francisco Municipal Transportation Authority (SFMTA) Ransomware Attack. Ransomware attacks computer systems and data, but critical cyber–physical systems can also be impacted.

   The SFMTA ransomware attack occurred on November 25, 2016 (*25*), encrypting SFMTA's information systems. To prevent malware from affecting their fare gates and ticket vending machines, SFMTA disconnected these systems from the network.

   This was an example of a cyber-attack affecting the physical operations of a transit system and creating disruption for users. The impact on physical control systems was minimized because SFMTA used a segmentation approach to separate operational control and communications systems from other IT systems. SFMTA had backed up its data, and received assistance quickly from the U.S. Department of Homeland Security (DHS), the Federal Bureau of Investigation, and their IT vendors. The attack shows the importance of integrating IT and control system response plans into an organization's overall incident response plans and keeping system documentation and response plans up to date (*26*).

Cyber and Physical Hybrid Attacks

Another type of attack is a joint or hybrid attack where both cyber and physical system attacks are coordinated over time.

1. Port of Antwerp Cyber–Physical Attack (*27*). From 2011 to 2013, drug smugglers reportedly hacked into the terminal management system that controlled container movements at

the Port of Antwerp (*28*). Smugglers used cyber-attacks to obtain security details for containers with illegal drugs hidden in legitimate cargo. They also physically broke into the terminal offices and installed monitors on computers to gain access to data on containers, which they then took control of. The drug smugglers' attack on the Port of Antwerp illustrates the need for a comprehensive cyber–physical systems approach to security (*28*).

2. The Bay Area Rapid Transit (BART) Hacking and Physical Protests (late summer and early fall 2011). According to accounts by Barnard (*29*), Elinson (*30*), Geng (*31*), and Zimmerman's summary (*14*), the attacks on the BART system involved both physical protests intended to disrupt rail transit service and cyber-attacks that reinforced one another. The attacks were conducted by different groups, but occurred in the same approximate time period, which exacerbated the impact (*30*, *31*). This was a joint attack on the basis of timing, and it highlights the need to be prepared for simultaneous physical and cyber-attacks.

SOCIAL AND ECONOMIC IMPLICATIONS OF THE BREACHES

Social and economic effects of cyber and physical security breaches can be widespread given cascading effects of these attacks. They have economic impact on industry and workers, disrupt supply chains, and impact social services. Cyber–physical security breaches impact recovery time, which is a key resilience factor.

If both physical and cyber assets are damaged the response to attacks may be compromised. Organizations may not have access to key information or other resources for effective response and recovery. In addition, the public may be unable to get information on the extent of the disruption, how they should respond, or what alternative services are available. Both cyber and physical attacks can adversely impact public confidence in the safety, security, and reliability of the system.

Many public and private-sector initiatives are focused on improving transportation resilience. The National Infrastructure Protection Plan (*32*) and its transportation sector-specific plan (*33*), and the National Institute of Standards and Technology (NIST) Cybersecurity Framework (*34*) provide guidance and standards. In addition, there are many professional organizations which are developing guidance and specifications on security and resilience for the various modes of transportation.

SOLUTIONS AND LESSONS LEARNED: NECESSITY FOR ACTION

Transportation system designs and operational procedure must be able to adapt to cyber and physical disruptions. Cyber, physical, and personnel security must all be addressed in a coordinated approach.

Challenges to Designing the Two Systems to Be Compatible and Resilient

Cyber and physical systems, and their respective security systems, are often managed independently, and traditional design configuration and asset management are often inadequate to address the two simultaneously. Based on the case studies in this paper four important challenges are:

- Redundancy and back-up systems are needed to mitigate impacts of disruptions. They should be part of continuity of operations plans, and require training, management, and close oversight.
- Cyber and physical systems, and their respective security system products, are specified and purchased independently from different sources. A systems approach to acquisitions should include security and resilience in system specifications. Where possible product designs should address both cyber and physical security.
- Many organizations lack enterprisewide resiliency plans addressing all risks simultaneously. All hazards resiliency plans can reduce the impact of interrelated risks and cascading impacts.
- Personnel must understand both cyber and physical risks and mitigation strategies. Some organizations are facing this challenge with workforce training programs, for example by NIST, DHS, ICS-CERT, and the Transportation Research Board Critical Transportation Infrastructure Protection Committee.

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Research for Resilient Road Infrastructure
A European Perspective

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Efficient and widely available transport infrastructure is one of the most important prerequisites for sustainable economic development to meet the demand for mobility. In this context, being able to manage traffic growth forecasts is of particular importance. In Germany, current forecasts indicate a 40% increase in rail and road transport in the country.

However, about 60% of bridges (as measured by bridge area) on the national German highway system that are suitable for freight transport were built before 1985. In other transport sectors as well, aging infrastructure is one of the key challenges for the availability and the resilience of European transport infrastructure.

Many bridges in the national German highway system are already at their load-bearing limit. Furthermore, required maintenance measures have not been adequately carried out in the past due to limited budgets, leading to overall bridge deterioration. Further challenges for owners and operators of transport infrastructure result from the effects of climate change, associated climate extremes, natural catastrophes, and possible criminal and terrorist threats.

To ensure that future infrastructure challenges can be successfully addressed, strategies and solutions must be developed and implemented in a timely manner to enable holistic and sustainable life-cycle management. The concepts of Resilience Management as well as Resilience Engineering are essential building blocks in this process. Resilience is the ability to survive in the face of a complex, uncertain, and ever-changing future. It is a way of thinking about both short-term cycles and long-term trends. Using this concept, owners and operators can reduce the risk of disruption in the face of shocks and stresses. Resilience requires cyclical, proactive, and holistic risk management practices.[1]

RESEARCH PROGRAMS

To address the challenges identified above, both the European Union and individual European states have initiated extensive research programs.

At the European level, the HORIZON 2020 program should be mentioned first and foremost.[2] This program has a budget of €77 billion for the years 2014–2020, making it the largest research program of the European Union to date. The focus of this program is scientific and technological excellence for increasing human knowledge, improving economic competitiveness, addressing social challenges, and removing innovation obstacles.

In HORIZON 2020, questions about sustainable and resilient transport infrastructure as well as civil security are discussed within the following topics (challenges): (1) Smart, Green, and Integrated Transport; (2) Climate Action, Environment, Resource Efficiency, and Raw Materials; and (3) Secure Societies—Protecting Freedom and Security of Europe and Its Citizens. The challenge of Smart, Green, and Integrated Transport addresses the competitiveness of the European transport. The aim is to create a European transport system that is resource-efficient, environmentally friendly, safe, and seamless for the benefit of all citizens, the economy, and society.

Climate Action, Environment, Resource Efficiency, and Raw Materials also concerns resilience and sustainability through reducing a global average temperature increase of 2°C. It also addresses resulting adaptations of society and ecosystems.

In HORIZON 2020, Secure Societies—Protecting Freedom and Security of Europe and Its Citizens addresses questions about the creation of a sustainable and resilient transport infrastructure. This challenge addresses research and development activities that contribute to the protection of the population, society, and the economy, as well as the infrastructures and services.

The main objectives of the Secure Societies challenge are as follows:

- Increasing the resilience of society against natural or manmade disasters through the development of new crisis management tools to protect critical infrastructures;
- Fighting against terrorism through the development of new forensic tools to protect against any threats;
- Improving maritime border security to ensure the safety of product chains and thus the security of the European Union; and
- Improving cyber security, from secure information processing and distribution to new security processes

In addition to European programs, individual member states have formulated national security research programs. In Germany, for example, the federal government's high-tech strategy has addressed the topic of civil security as one of the priority tasks of the future.[3] One focus of this program is the topic of Security of Infrastructures and Economy with the following subtopics:

- Critical infrastructure security;
- Security of tomorrow's infrastructure;
- Operational contingency management in disaster situations;
- Security of civil aviation–air cargo security;
- Maritime security;
- Protection against economic crime, product piracy, and industrial pioneering; and
- New security services.

Research topics that focus on a sustainable and resilient transportation infrastructure are discussed under the topic of Security of Critical Infrastructures. The following are possible research topics:

- Risk-based resilience strategies, which focus on an all-hazard approach to improve both the resilience and recovery capacity of individual critical infrastructures and also the overall system of connected infrastructure;
- Multi-infrastructure–spanning simulation and prediction models that help secure the robustness of critical infrastructures in the long term and facilitate the management of interdependencies;

- Technical solutions, as well as crisis management and emergency supply concepts, which enable the fastest possible restoration of damaged infrastructure or a temporary emergency supply of vital goods and services; and
- Technical solutions and measures that are integrated, mobile, or even autonomous to better protect critical infrastructure against the consequences of natural disasters, terrorist attacks, or new technical risks, including investigations into the effects of electromagnetic impulses or geomagnetic storms.

RESEARCH PROJECTS ON THE RESILIENCE OF TRANSPORT INFRASTRUCTURE

The HORIZON 2020 program has undertaken many research and development projects dealing with transport infrastructure resilience. Several relevant projects are briefly described below. An overall survey of all projects funded under HORIZON 2020 can be found on the website of the Community Research and Development Information Service (CORDIS).[4]

The project called RESOLUTE (Resilience Management Guidelines and Operationalization Applied to the Urban Transport Environment) is developing a European Directive on Resiliency Management based on a systematic analysis and assessment of the concepts of resilience management.[5] Particular attention is paid to the fact that resilience is not influenced only by the performance of individual components, but also by system interdependencies. The project's goal is to adapt and operationalize the concepts with regard to critical infrastructures of urban transport systems.

The project called EU-CIRCLE, which is a pan-European framework for critical infrastructure resilience to climate change, focuses on creating infrastructure networks that are resilient to natural hazards. [6] Here, the project also considers interdependencies of systems as well as cascading effects.

The INFRARISK project has already been funded under the EU Research Framework Program 7 (FRP7) and addresses:[7]

- Development of an approach to analyze extreme threats and possible cascading effects;
- Decision-support for owners and operators of critical infrastructures with regard to extreme events;
- Provision of software tools and training materials for owners and operators; and
- Demonstration of how to conduct stress tests for critical infrastructure.

The project—called Realizing European Resilience for Critical Infrastructure—deals with resiliency management of infrastructure networks.[8] For example, a decision-making and support platform to improve crisis and disaster management for critical infrastructure will consist of a European Resiliency Management Guide and various web-based applications.

Beyond the HORIZON 2020 program, other national and European security research projects have addressed important aspects of the resilience of transport networks and infrastructure. For this purpose, a few selected projects are highlighted below.

Germany has carried out a national research project that focused on protecting road transportation infrastructure. This project was called SKRIBT, which is a German acronym for

Protection of Critical Bridges and Tunnels in the Road System. From this program, Germany then developed SKRIBT^{Plus}, a procedure for the identification of critical structures in the road system. This procedure uses an all-hazard approach to investigate the effects and impacts of natural events and terrorist attacks.[9] It analyzed vulnerabilities and critical links at the road network level. Within the scope of a detailed object analysis, the project carried out many numerical investigations and simulations (Figure 1) as well as large tests of fires at bridges or in tunnels (Figure 2).

Among other things, SKRIBT–SKRIBT^{Plus} considered human behavior; it looked at the interaction of humans in crisis situations and emergency personnel who would be called upon as first responders. Through the use of a new 3-D multisensor laboratory, users' behavior was investigated directly to ensure utilization of the results in practice (Figure 3). Field experiments in actual tunnels validated the laboratory results. Finally, based on the results, a behavioral and an impact model was developed and integrated into the existing evacuation simulation model. The project represents a newly developed linkage of a behavior-based escape and evacuation

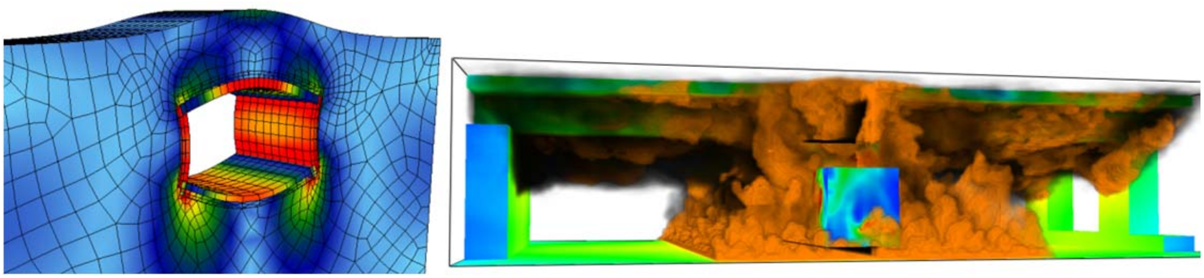

FIGURE 1 Numerical simulation of explosions (*left*) and liquid fires in tunnels (*right*). [Sources: Ruhr-University Bochum (*left*) and MFPA Leipzig GmbH (*right*).]

FIGURE 2 Laboratory results were confirmed using large-scale tests and numerical simulations were calibrated. (Source: BASt.)

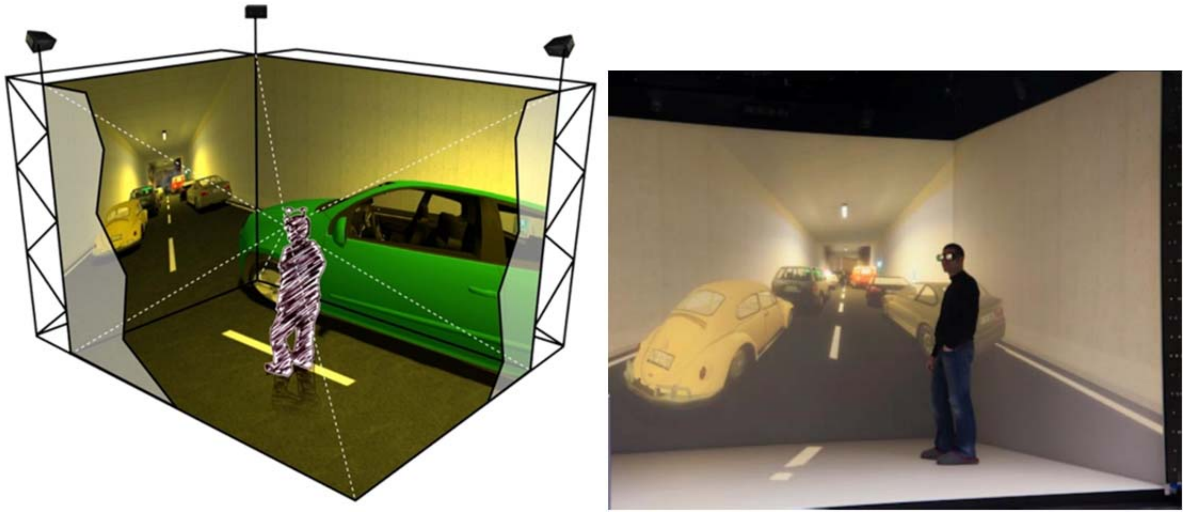

FIGURE 3 3-D Multisensor Laboratory (CAVE). (Source: University of Würzburg.)

simulation of tunnel users with CFD codes for determining the spread of substances (for example flue gas). A visualization of the simulation results is shown in Figure 4.

The SKRIBT–SKRIBT^{Plus} project also focused on developing an operational crisis management system for major damage events in the area of transport infrastructure (Figure 5). The project examined psychological aspects relevant to the fire brigade and the rescue services and integrated them into the psychosocial emergency care plans.

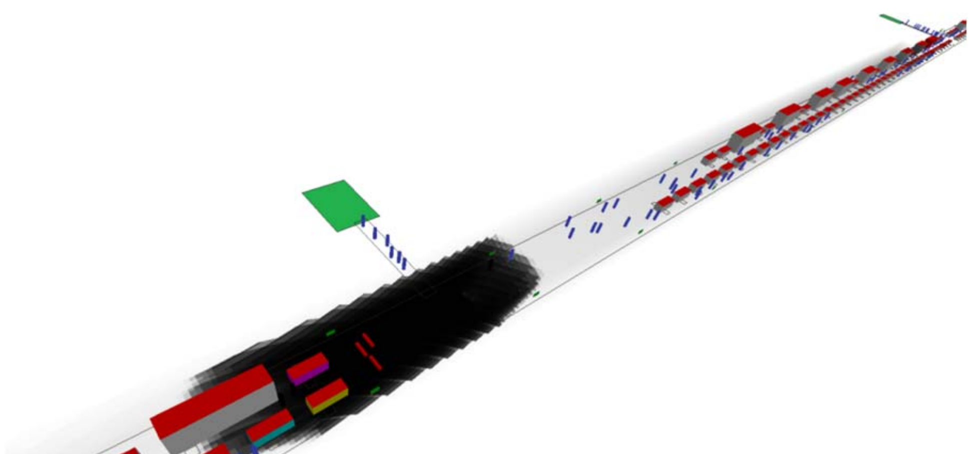

FIGURE 4 Escape and evacuation simulation for a tunnel within the scope of SKRIBT^{Plus}. (Source: PTV Group.)

FIGURE 5 Training in a tunnel. (Source: BASt.)

The RETISS project developed a real-time security management system to detect potentially hazardous events for control center operators.[10] The ESIMAS project (real-time safety management system for road tunnels) further developed this approach for additional detection technologies like video decoding, intelligent loop detection, and infrared detection of overheated vehicles and vehicle parts in moving traffic (Figure 6).[11] In addition, a complex safety–security management system has been developed to detect all possible risks for tunnels, users, and real-time traffic. The system includes a user interface that alerts control center operators at an early stage (Figure 7). Moreover, several projects are currently underway in the German information technology (IT) security research program on cyber security of traffic and tunnel control centers (Cyber-Safe Project).[12]

At the European level, SKRIBT results were transferred to the European project called "Security of Road Transport Networks," (SeRoN) and an independent methodology developed to evaluate critical structures and road corridors in Europe.[13] The focus was on regional and supra-regional effects on transport links and the resulting economic consequences. Within the framework of SeRoN, an innovative method can analyze and evaluate risk in road networks and the structures within them. In addition to identifying critical road infrastructure elements, the modular four-stage process also examines and assesses the efficacy and cost-effectiveness of measures to increase security for users and structures.

To make the results more useful for owners and operators of road infrastructure, the program called Prevention, Preparedness and Consequence Management of Terrorism and Other Security-Related Risks of the European Commission has initiated several projects.[14] For

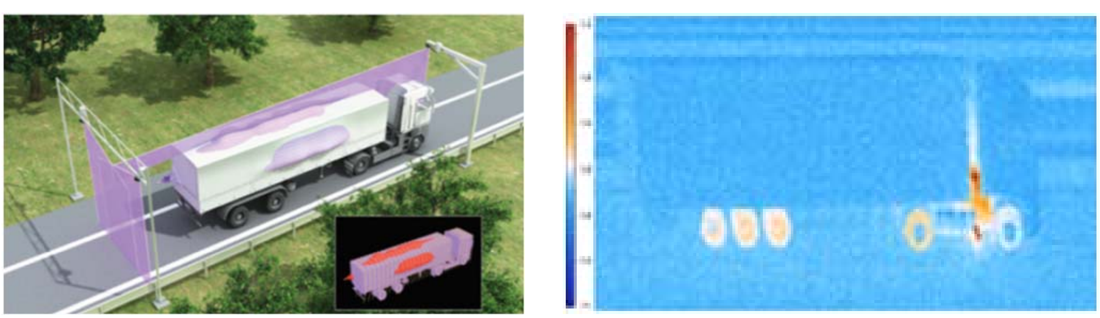

FIGURE 6 Hotspot detection by means of an infrared camera for the detection of overheated vehicle parts and silhouettes within ESIMAS. [Source: Sick (*left*); Strehle & Partner GmbH (*right*).]

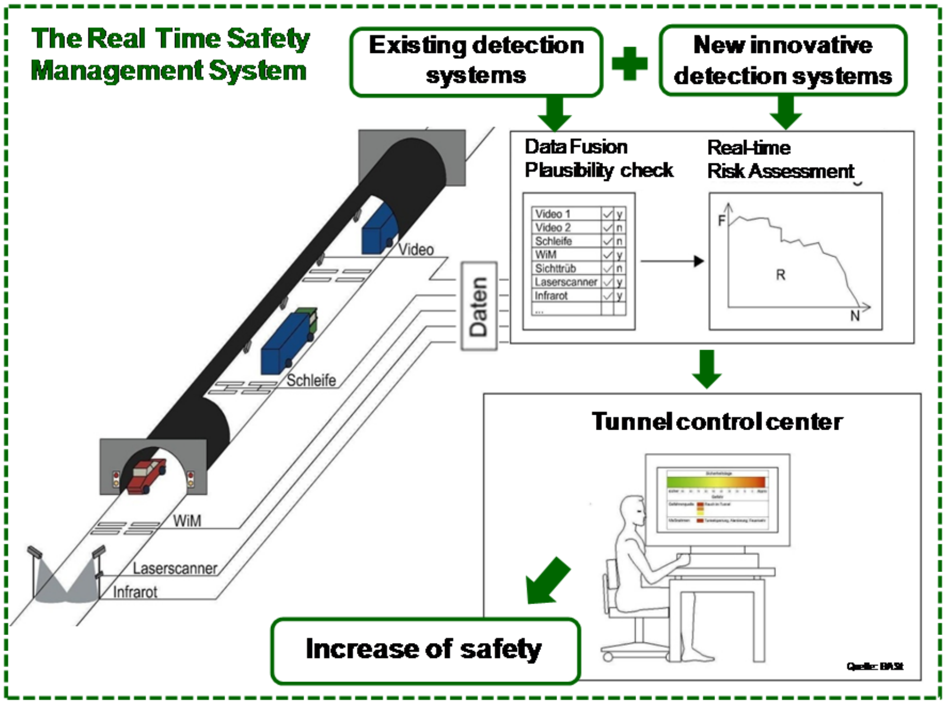

FIGURE 7 Schematic structure of the ESIMAS real-time security management system.

example, one project—called the Security Risk Management Processes for Critical Road Infrastructure—involved developing a security guide for European road infrastructure. The guide demonstrates a semiquantitative identification procedure for critical structures as well as a software-based selection of measures to improve the protection of these structures.[15] In the AllTraIn project (All-Hazard Guide for Transport Infrastructure), a hazard catalog for transport infrastructure is based on the results of the Security Risk Management Processes project; this catalog also takes rail transport, geo hazards (e.g., earthquake or volcanic activity), and extreme weather hazards into account.[16] The RAINEX project (Risk-Based Approach for the Protection of Land Transport Infrastructure Against Extreme Rainfall) includes tools to examine road and rail infrastructure structures for exposure and vulnerability to hazards caused by extreme rain events (e.g., river floods and debris flow).[17] The risk-based assessment using this methodology allows owners and operators to identify and compare critical structures and the relevant hazards.

NEW RESEARCH APPROACH FOR RESILIENCE OF INFRASTRUCTURES

The aim of the German federal government's transport policy is to use technical and scientific innovations to implement new and sustainable concepts in order to make its infrastructure sustainable and resilient. In 2016, the Federal Ministry of Transport and Digital Infrastructure (BMVI) initiated a new research network. This network is an amalgamation of BVMI departmental research agencies that aims to take advantage of synergies within different cross-cutting research activities. The main focus areas addressed within the research network are as:

- Resilience to foreseeable and unforeseeable events;

- Minimization of the impact of climate change and extreme weather events through targeted adaptation; and
- Reduction of environmental impacts through movement towards sustainable mobility.

This will be achieved both by research and development and by effective knowledge and technology transfer. This research and development will focus on the consequences of different foreseeable and unforeseeable impacts on the reliability of the transport infrastructure (road, rail, and waterways).

In the first cycle of 2016–2019 of the new research network, the four main topics of the various projects within the network are as follows:

- Development of procedures and procedural methods for collecting and evaluating bridge stock;
- Development of procedures for assessing the reliability of civil engineering structures;
- Analysis of forecasts and vulnerability; and
- Accelerating construction and upgrading measures under traffic.

One focus of the various projects will be on issues relating to the resilience of transport infrastructure. The aim is to develop and test procedures and models that quantify and forecast the availability and safety of the transport infrastructure during extraordinary events (such as extreme weather events), taking into account the transport network's functionality and possible mitigation measures. In addition to structural reliability, the project will consider aspects of operational (traffic) reliability, especially availability.

SUMMARY AND CONCLUSION

Ensuring a resilient road transport network requires a holistic approach that not only includes elements of vulnerability and criticality, but it also includes other aspects of resilience, such as response to event occurrence, restoration, and re-operation of the infrastructure. In addition to optimizing existing protective measures and systems, new technologies will continue to be applied. Beyond the research initiatives listed here, further urgent research is needed to investigate specific and novel threats, such as cybercrime. Moreover, transferring research results into the practice to improve infrastructure sustainability is a particular challenge. In particular, it requires the implementation of systems, guidelines, methodologies, and tools that facilitate practical application by road operators. The German Federal Ministry of Transport is also promoting new approaches for coordinated research.

ACKNOWLEDGMENTS

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NOTES

1. RESILENS: Realising European Resilience for Critical Infrastructure, European Research Project.
2. https://ec.europa.eu/programmes/horizon2020/.
3. http://www.sifo.de/.
4. http://cordis.europa.eu.
5. Http://Www.Resolute-Eu.Org.
6. http://www.eu-circle.eu/.
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10. http://www.skribt.org.
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Employee Qualifications

The Need to Train and Recruit Qualified Employees Who Can Assist During Adverse Events

Gina Hubbs

> Employee qualifications: the need to train and recruit qualified employees who can assist during adverse events. What those employees look like these days, how difficult they are to find and the challenges in transportation of finding not only qualified employees but the growing concerns of finding drivers/owner operators in the continued regulatory environment.
>
> —Gina Hubbs

The younger generations of employee prospects are coming out of college with a better understanding of the global supply chain and transportation industries. Even with the advanced educational knowledge there is more demand for focused and specialized training on the subject matter that person is responsible for, in order to have a successful partnering. Those courting employment are more particular with the companies they want to partner with; selecting those companies that allow them to have immediate input in helping to shape the area of their control, and they are interested in obtaining meaningful results. Understanding each other's expectations, which include the climate of work possibility and unpredictability of assignments, should allow for successful preparation in primary and adverse events.

While the employee outlook can be favorable for a corporation to be able to support a disaster response, the continued erosion within the transportation driving sector places those companies at adverse risk of being able to respond effectively. Today, the transportation industry is challenged to find the next generation of quality drivers. Many of the experienced, qualified drivers are currently at retirement age or have grown weary of the over-the-road jobs. Trucking companies are challenged not only with reducing the turnover rate, which occurs within trucking segments as well as companies; Universal ended 2016 with an average truck turnover rate of 65%, well below industry (owner–operator) average. Also of concern is the decline in the younger generations' interest in the trucking industry; in roughly the last 21 years the number of drivers in the 25- to 34-year-old-age group has been reduced by almost 50%. There are not enough drivers and owner operators entering the industry to compensate for those exiting.

The continued regulatory environment of complying with the ever-evolving changes in medical qualifications, electronic logging devices, and speed limiters are just a few regulatory matters that are making it more cumbersome to operate a Class 8 truck. Couple the regulatory concerns with an hourly wage that has decreased since 1985 and pair that with inflation and it results in an industry that is in need of sustainable reform. Qualified workers with options stray to other industries where the compensation package is more desirable and the quality of life is more favorable to young families. In a study done by the American Trucking Association (ATA), they found 90% of carriers were unable to find enough drivers who met the criteria put in place by the U.S. Department of Transportation. With the current driver shortage, finding truck drivers is a daily battle; at Universal there is on average more than 900 openings for drivers and owner–operators. With the current regulations and those on the horizon, it's going to become even harder to not only attract and retain, but to qualify those entering into the industry.

In order to combat these challenges, Universal has taken decisive steps that will assist in growing our fleet by recruiting and retaining owner operators and drivers. From an operating standpoint, our sales efforts have been focused on reducing the average length of haul by concentrating on growing regional traffic, which will increase home time for drivers and owner operators. We have instituted many recruiting initiative including a recruiting bonus, and upgrading our company truck fleet in order to capture potential drivers and owner–operators. Finally, retention has been an active and evolving endeavor that has paid off with decreases in the turnover rate: 68.9% in 2013; 61.3% in 2014; 60.1% in 2015; and 56% in 2016. Universal stands ready to make sizeable contributions in order to assist during natural disasters, by understanding the changing climate within the transportation industry while aligning our strategic objective to meet the challenges ahead.

TCRP A-41

Improving the Resilience of Transit Systems Threatened by Natural Disasters

DEBORAH MATHERLY
JON CARNEGIE

This concise "how to" guide, as developed for the Transportation Research Board's (TRB's) Transit Cooperative Research Program (TCRP), helps transit agencies working to improve resilience and get better outcomes in emergency planning, response, and recovery. More frequent extreme weather and a changing climate make resiliency a critical imperative for many public transit operators nationwide. Because transportation is essential for evacuation and other emergency response measures, the capacity of transit agencies to remain in or quickly return to operation when an emergency strikes is crucial for the entire community's readiness and resiliency.

Figure 1

The research included a comprehensive literature review: 17 case studies of U.S. and international transit agencies and two case studies on regional resilience efforts. Based on the research, the guide encourages incremental adoption of resiliency practices. Resilience is seen as most effective as an overarching practice or "lens" that touches all domains, comparable and complementary to asset management, safety, and sustainability in the way it can overcome silos between capital planning, operations, and maintenance; and systems planning and other domains, as illustrated in Figure 1. The emphasis is on measures needed to embed a resiliency culture into and across the major domains, consistent with lessons learned in implementing safety, sustainability, and asset management in transit industry culture.

Chapter 1 provides an introduction to the topic and its urgency, and how to use the Guide and Transit Resilience website.

Chapter 2, What is Transit System Resilience?, documents the four main pathways to resilience identified in the research:

1) Past disaster experience;
2) Leadership and organizational culture;
3) Sustainability and environmental programs; and
4) Asset management and state of good repair.

Chapter 3, Charting Your Agency's Own Path to Resilience, provides a four-step process towards adoption:

Step 1. Getting Started (agency context, opportunities and constraints, articulating resilience business case);

Step 2. Taking Stock (evaluating threats and impacts, risk assessment, resilience self-assessment);

Step 3. Move Forward (shared sense of need, vision and goals, strategies and action plans); and

Step 4. Monitor Progress (performance metrics, track data, evaluate progress).

Chapter 4, Dealing with Interdependencies: Your Agency as Part of a Resilient Community, addresses external stakeholders and interdependencies. This chapter is recommended as a parallel effort to Chapter 3, not sequential.

Step 4.1 reflects on "who depends on you?" as a building block for entering a regional dialog.

Step 4.2 asks the agency to "identify existing regional resilience efforts."

Step 4.3 provides guidance to "identify and address your agency's key external interdependencies and resilience priorities, working within the regional context as appropriate."

Chapter 5 profiles tools and resources, such as the case studies, that have been referred to throughout the Guide. All tools and resources reside on the project website, found at resilienttransit.org (will go active upon TRB publication and with TRB permission). The database of research findings and tools supports ongoing transit resilience efforts.

The study team also worked with APTA to establish a process for incorporating resiliency considerations into APTA guides and standards as they are updated. This approach is consistent with the layering and resilience lenses embodied in the Guide.

The Guide has been reviewed by the panel and is anticipated to be published web-only for greater accessibility and timeliness in late 2017.

For more information, please contact: Deborah Matherly, AICP, Env SP, Principal Investigator, Principal Planner, The Louis Berger Group, 202-303-2653, dmatherly@louisberger.com; or Jon Carnegie, AICP/PP, Co-Principal Investigator, Executive Director, Alan M. Voorhees Transportation Center, Rutgers, The State University of New Jersey; 848-932-2840, carnegie@ejb.rutgers.edu.

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