COLORADO Department of Transportation

U.S. Department of Transportation Federal Highway Administration

TRB TRANSPORTATION RESEARCH BOARD

Transportation Security Administration

American Association of State Highway and Transportation Officials AASHTO

RISE

2018 TRANSPORTATION RESILIENCE INNOVATIONS SUMMIT AND EXCHANGE

OCTOBER 9-10, 2018 | DENVER • COLORADO

ATTENDEE POSTERS COMPILATION

RISE

COLORADO Department of Transportation | Federal Highway Administration | TRB Transportation Research Board | Transportation Security Administration | AASHTO American Association of State Highway and Transportation Officials

RECOGNIZING SUCCESS IN RESILIENCE-RELATED WORK

The national Transportation Resilience Innovations and Summit Exchange (RISE) was held on October 8-10, 2018 in Denver, Colorado. The Summit attracted over 450 participants who attended sessions on a wide range of topics focused on how to make the transportation system more resilient. As part of the meeting, state departments of transportation (DOTs) were asked to prepare posters on aspects of their resilience program that they were most proud of. This document presents images of these posters. In its entirety, it represents a diverse set of activities across all types of DOTs that illustrate how agency actions can enhance the resilience of the transportation system.

The following 44 state DOTs and transportation agencies from other countries attended RISE

- 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

International Representatives

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






A Climate Engineering Assessment for Transportation Assets (CEA-TA)
Incorporating Probabilistic Analysis into Extreme Weather and Climate Change Design Engineering

Steven Olmsted, Arizona Department of Transportation; Alan O'Connor, Trinity College Dublin; Constantine Samaras, Carnegie Mellon University;
Beatriz Martinez-Pastor, Trinity College Dublin; Lauren Cook, Carnegie Mellon University

Abstract

Transportation infrastructure is a complex system of assets required to deliver a myriad of services and functions. As fiscal constraint for the development and rehabilitation of such structures remains, and endless retrofitting continues to be cost prohibitive, new and novel approaches to long term planning and project development, engineering design, and life cycle assessment are paramount. The management of these infrastructure systems has now evolved from a decentralized, project-based focus, to one that now encompasses enterprise wide endeavors – administration, technology adoption, planning, design, construction, operations and maintenance. In addition, the expansion of risk analysis for extreme weather management and climate change adaptation has complicated the long term delivery of these complex transportation systems. At the 2015 Transportation Research Board (TRB) Annual Meeting, Session 197: *Mainstreaming Climate Change and Extreme Weather Resilience into Transportation*, the Arizona Department of Transportation (ADOT) introduced the challenge ahead for public entities to coordinate a host of known and unknown extreme weather and climate change issues. That challenge – Continue considering the balance between predictable asset deterioration curves, the sudden and unpredictable nature of extreme weather events and long term climate trends, new models for risk assessment and life cycle cost analysis, and appropriate adaptation strategies. This multiple part challenge necessitated a new end-to-end engineering approach to incorporate such current and future risks. At the 2016 Annual Meeting ADOT submitted a paper representing the core of that new approach – a Resilience Program and an ADOT/United States Geological Survey Partnership. That paper was graciously recognized as a best paper by the TRB Special Task Force on Climate Change and Energy. In the spirit of continuing that forward progress – this paper presents the remaining parts needed to develop a new end-to-end engineering-based asset adaption process – a structured sequence to incorporate extreme weather and climate change adaptation into the design engineering process. The paper benefits from preeminent researchers in the two integral, and practice ready, remaining parts – probabilistic modeling for engineering design and infrastructure system design life cycle outcomes for extreme weather and climate change in a transportation engineering setting.

Arizona DOT Resilience Program

Transportation infrastructure is a complex system of assets required to deliver a myriad of services and functions. The expansion of risk development for extreme weather management and climate change adaptation has complicated the long term delivery of these complex transportation systems.

In order to develop an innovative approach, the first step was to create a system process that allowed for a shift from a deterministic preset design parameter and/or frequency basis, statistical risk of failure, and historic project and programs budgeting focus – i.e. extreme events not considered – to a probabilistic analysis approach that inputs additional data, vulnerabilities, and considerations not previously considered. In 2015 and 2016 ADOT focused on linking scientific evidence-driven data capture with the design engineering processes through the development of a partnership with the United States Geological Society (USGS). Extensive 2-D/3-D engineered modeling underway.

(CEA-TA) – A Structured Sequence

Identify TX W & CC project and program candidates - *Vulnerability Assessment*

2015 FHWA Pilot Project - The study examined baseline (historical) and potential future extreme weather conditions, focusing on temperature and precipitation variables. Two future analysis periods were selected: 2025 to 2055 (referred to subsequently as 2040, the median year), which reflects the time horizon of ongoing long-range planning efforts, and 2065 to 2095 (2080), roughly associated with the expected design lifespans of some critical infrastructure types, such as bridges. To provide a long term baseline against which to compare the projections, the team also examined temperature and precipitation observations from 1950 through 1999. The report was issued by FHWA in the Spring of 2016.

WHY IS MOVING TO A PROBABILISTIC APPROACH EVEN NEEDED?

This question could cover pages and pages. The short answer is easy. In addition to sustainable transportation attributes, there is growing consensus that if transportation systems are going to incorporate extreme weather and climate change, consideration must be developed that account for hydrometeorology/climatology, hydrology, hydraulics, and hydrodynamics. Since all these areas continue to adopt advanced mathematical modeling approaches, it is therefore logical that transportation systems and projects develop also incorporate these progressions.

Develop economic analysis process - *Justification*

An economic analysis for the CEA-TA process would consist of using a probabilistic approach to life cycle cost analysis. The life cycle cost of an infrastructure asset such as a roadway or bridge, is the total cost to an agency throughout the asset's useful life. This includes the planning, design, construction, maintenance and decommissioning phases of infrastructure delivery. State DOTs typically initially approach this process without considering risk and uncertainty that future conditions will be different from the past, and assume a uniform distribution of annual maintenance costs and major reinvestment intervals. Long-lived infrastructure must perform under future climate conditions and climate-influenced usage that deviates from the historical data now populating infrastructure economic analysis and asset management models. Climate change impacts, such as sea-level rise, storm surges, changes in precipitation, hotter temperatures, and others are potential vectors of infrastructure failure and should be taken into consideration in infrastructure economic analysis and asset management models.

Resilience Program
Economic Analysis Pilot
US 191 MP 436 to Chinle
PROJECT NO. 191 AP 436 H8676 01 C
FEDERAL AID NO. STP-191-E(234)T
Apache County
Holbrook District

Design probabilistic modeling approach to produce an array of results - *Quality Control*

Optimize operation and maintenance of an increasingly aging stock, which is subjected to evolving loads (e.g. both live loading and climate induced loading). In response to this challenge the past decade has seen increased interest by infrastructure owners and managers in the use of probabilistic methods for the assessment/management of their assets. Employed once a deterministic assessment has rendered a repair/rehabilitate/replace low scenario

Define limits of simulation runs that incorporates latest science/engineering

Climate models can provide insight into future conditions, projecting air temperature, precipitation, evapotranspiration, and other factors of interest to engineers, at various temporal and spatial resolutions. However, there is a considerable disparity in the outputs provided from climate models for impacts analyses and the inputs needed by engineers for planning and design. These discrepancies include mismatches in temporal and spatial scales, complicated data extraction and preparation requirements, sizeable model, data, and scenario uncertainties, and a lack of direction for the rigorous selection of models for use in different engineering applications.

Innovative change examples:

- Every Day Counts – 4 : Collaborative Hydraulics: Advancing to the Next Generation of Engineering (CHANGE)
- NCHRP 15-61 - Applying Climate Change Information to Hydrologic and Hydraulic Design of Transportation Infrastructure
- NOAA – Updating Intensification of Hourly Precipitation Extremes – Analysis & Research in Progress 2016
- LIDAR, UAS/UAV, 2-D water modeling, 3-D visualization and animation tools
- Translational organizations to provide rigorous standards for interpretation of climate data, development of a single, simplified user interface that accesses all downscaled data sources, and tools that automatically post-process data based on defined standards

Systematically record location and resilience efforts GIS/TAMP - *Risk Management*

ADOT has been systematically capturing data sets for extreme weather and climate change use through an extensive geographic information system (GIS) effort that will subsequently support ADOT's transportation asset management planning (TAMP). ADOT's studies showed concerns with the climate and extreme weather vulnerability of bridges, culverts, pavement, and roadside vegetation / stabilization. Legislation – focus in MAP-21 on performance based management and risk-based asset management plans; inclusion of "resilience" in FAST Act.

Develop life cycle models to monitor investment - *BCA/ROI*

Civil infrastructure systems are among the largest local, state and Federal investments, and these infrastructure systems are critical to U.S. economic, environmental and social outcomes. Yet longstanding underinvestment in infrastructure has resulted in the poor condition of much of U.S. infrastructure, with an estimated $3.6 trillion of re-investment needed by 2020. New methods for benefit cost analysis, return on investment studies, and major rehabilitation timeline analyses are needed that incorporate probabilistic approaches, and minimize regret by DOTs under a changing climate. The results of CEA-TA provides that method.

Acknowledgments

The completion of this project would not have possible without assistance from many stakeholders both within and outside ADOT that contributed to this effort. Specifically, the International Symposium - Transportation Resilience Adaptation to Climate Change and Extreme Weather Events, June 16-17, 2016 at the European Commission Brussels, Belgium that was the catalyst for the transatlantic partnering. The ADOT author wishes to acknowledge the efforts and support of ADOT State Engineer's Office and ADOT Environmental Planning.

COLORADO
Department of Transportation

Planning Ahead for a Strong TRANSPORTATION SYSTEM

Recognizing Success

1. I-70 Risk and Resilience Pilot Strengthens a Critical Corridor
2. Comprehensive Public Communications Strategy Deployed During Massive Flood Reconstruction
3. Calculated Economic Impact of Geohazard Events Statewide

Areas for Improvement

1. Measuring Resilience
2. Incorporating Resilience into Funding Decisions

COLORADO RESILIENCE: The ability of communities to rebound, positively adapt to, or thrive amidst changing conditions or challenges—including human-caused and natural disasters—and to maintain quality of life, healthy growth, durable systems, economic vitality, and conservation of resources for present and future generations.

codot.gov/programs/planning/cdot-resilience-program | Oana Ford | 303.512.4179 | oana.ford@state.co.us

RISE

Connecticut Department of Transportation

CRITERIA FOR MAKING DECISIONS TO MITIGATE OR ADAPT TO IMPACTS OF HAZARDS/THREATS

Recent CT legislation requires that projects in a coastal floodplain (with a drainage basin over 1 square mile) consider and use a freeboard of at least 2' above base flood plus any additional freeboard necessary to account for the most recent sea level change scenario for the state calculated and published by UConn's Marine Science Division.

RECOGNIZING SUCCESS IN RESILIENCE-RELATED WORK

Climate Change and Extreme Weather Vulnerability Project. CT DOT conducted a Climate Resilience Pilot Project, sponsored in part by FHWA, in 2014.

- A systems-level vulnerability assessment of bridge and culvert structures
- Focusing on inland flooding associated with extreme rainfall events
- Focused on structures in the northwest corner of the State
- In recent years extreme precipitation events have been more frequent and intense, resulting in damage to DOT's infrastructure in several locations
- Ultimately, 52 hydrologic and hydraulic evaluations were performed on 52 structures.
- The final Report contains valuable recommendations and lessons learned.

COMMUNICATING PROGRAMS / EXPECTATIONS

A DOT handbook for regional Councils of Government, the Unified Planning Work Program, emphasizes climate change and resiliency, and has a link to FHWA's sustainability webpage.

OPPORTUNITIES FOR IMPROVEMENT

Enhancement/development of cybersecurity strategic plan for DOT. In May 2018 CT issued a Cybersecurity Action Plan for state and local government and the private sector. It calls for each state agency to develop and/or update a cybersecurity strategic plan.

CONNECTICUT DEPARTMENT OF TRANSPORTATION 2800 BERLIN TURNPIKE, NEWINGTON, CT 06111 PHONE: 860-594-2000 | WWW.CT.GOV

Delaware Department of Transportation - *Resiliency for a Low Lying State*

Outstanding Accomplishments to Date:

- **Strategic Implementation Plan for Climate Change, Sustainability & Resilience for Transportation** (https://www.deldot.gov/Publications/reports/SIP/pdfs/SIP_FINAL_2017-07-28.pdf)
- **SR 9 Corridor Study of climate effects on vital infrastructure** *(ongoing)*
- **SR 1 Living Shoreline Project** *(ongoing)*

Opportunities for Improvement:

1. **Continued investigations on the sea level rise effects to the state and coordinating efforts amongst all stakeholders to accelerate the deployment of effective adaptation factors and programs through holistic risk and resilience strategic management.**
2. **Take a holistic approach and determine how the Department of Transportation can become a leader in the mitigation of greenhouse gas emissions within the transportation industry through effective programs such as alternative fuel vehicles.**

Silvana Croope, Ph.D., ENV SP, Planning *Brian Urbanek, P.E., Assistant Director, Maintenance & Operations*

Jim Pappas, P.E., Deputy Director, Transportation Solutions

FLORIDA DEPARTMENT OF TRANSPORTATION
TRANSPORTATION RESILIENCE

Four Things FDOT is Proud of for Enhancing System Resilience

- Emergency Pre-Event Contracts
- Emergency Shoulder Use for Evacuations
- Open Roads Policy between FDOT and FHP
- Bridge Unknown Foundation Disposition

FDOT Wants to Enhance System Resilience Through:

- Use of Composite Materials/Carbon Fiber (Corrosion Resistance)
- Emergency Generators for Rest Areas/Traffic Signals
- Florida's Fuel Distribution System

FDOT Definition of Resilience

FDOT builds resilience into transportation planning, design, operations, and maintenance to eliminate or minimize impacts caused by planned or unplanned disruptions to Florida's transportation systems.

Website: www.fdot.gov
POC: Brian A. Blanchard, P.E., Assistant Secretary for Engineering and Operations

FDOT

What DOT Resilience Looks Like in Georgia

What Makes Us Proud

Weather Response

Planning and preparation for personnel management and deployment, procurement and storage of materials and equipment, process oversight, collaboration between offices, districts and individuals and open collaboration with other state agencies and organizations all have led to dramatically improved response to extreme weather events

Emergency Traffic Control

Oversight of traffic patterns and management of signal phasing and timing technology have helped GDOT provide higher levels of traffic management to Georgia citizens, as evidenced during 2017's 42-day closure of I-85 in Atlanta due to a bridge fire and subsequent collapse of the span

Communications

Building GDOT's visibility as a responsive, proactive state agency and issuing useful and timely information to the public during times of crisis – such as inclement weather events or emergencies like the 42-day closure of I-85 in 2017 –has greatly aided our efforts to return to a state of normalcy and elevated GDOT's perception among key leaders and the public we serve

Planning with Resilience in Mind

Continual Assessment

Broadening GDOT staff's understanding of the potential for risk and threats to our existing infrastructure, and preparing to respond; an example is being at the ready to secure adequate temporary housing, at an equitable rate that adheres to state guidelines but provides the necessary shelter for team members working in extreme conditions, as well as acquiring the necessary products and resources to support our resiliency in emergency response scenarios in as timely a fashion as possible.

Consideration of New Infrastructure

Considering and planning to develop new needed infrastructure in geographic areas of Georgia which are known to have extreme weather events; such infrastructure can aid in evacuation as well as provide a quicker return for residents following these events.

How GDOT Defines Resilience

Resilience is not just about reacting and responding in times of crisis; it means building the organization so that our basic functionality supports the ability to return to a state of normalcy as expediently as possible. By considering and addressing our vulnerabilities and incorporating resilience into all of our processes – from planning, to project development and design, to operations, to asset management, we have become an agency that stands at the ready to deal with emergencies large and small.

WWW.DOT.GA.GOV

Bryan Haines bhaines@dot.ga.gov

#WORKINGFORYOU

GDOT Georgia Department of Transportation

Transportation Resilience

Hawai'i is rising to the challenge

Our Successes:

Working with subject matter experts to address sea level rise on coastal roads and facilities.

HDOT is updating our 2003 Statewide Highway Shoreline Protection Study with the University of Hawaii at Manoa to identify short-term and mid-term projects designed to keep our existing highways accessible while HDOT investigates long-term projects such as realignment.

Coordinated pre-emergency actions for tropical cyclone threats.

Planning out alternative emergency routes, preemptively closing routes with known concerns, and pre-storm clearing of culverts and drains.

Leveraging technology to maintain/restore access to lava impacted routes.

HDOT made use of ground penetrating radar and drones to determine if Chain of Craters Road (covered in 2016) could safely serve as an evacuation route. Heat resistant concrete panels were installed over fissures on Highway 130.

In the future HDOT will improve...

Funding for resilience/mitigation projects.

HDOT will engage with legislators to increase funding for potential realignment projects in areas expected to be impacted by sea level rise or rockfall hazards. *Example: Honoapiilani Highway in Olowalu, Maui.*

By building new facilities to meet anticipated challenges.

The new pier at the centerpiece of HDOT's Harbor Modernization Project, the Kapalama Container Terminal, will be built at 9.81 feet, or over two feet higher than the current average height of piers within Honolulu Harbor.

Resilience for HDOT means creating systems and relationships before a threat to ensure minimal disruption to the state's vital multi-modal lifelines.

http://hidot.hawaii.gov

Contact: George Abcede & Robin Shishido
DOTPAO@hawaii.gov

Idaho Transportation Department (ITD)

RESILIENCE

Quickly returning to normal operations after a major event alters the norm. Providing flexibility through prior planning, simulations/exercises, and increased situational awareness to ensure rapid deployment of resources, execution of funds and key data capture for reimbursement.

Three things ITD is proud of:

1 Winter Mobilization

a. Technology – increasing percentage of time roads are free of snow and ice
   - Techniques – storm tracking, debriefing storm performance, and yearly overall performance debriefing

b. Pathfinder – warning the travelling public ahead of the storm to inform on the best times to commute/travel

2 I-84 Winter Repair

a. Contractor support
b. Safety
c. Documentation for reimbursement from state's Emergency Relief Funds

3 Employee Safety

a. New safety vest
b. Work/Rest Cycle Management Fatigue Policy
c. Employee work zone safety – VSDO, SDO
d. Prevention based approach to safety incident and near miss management – Gotcha factor removed
e. Operator equipment training program with emphasis on safe operations

Two things ITD is looking to improve:

1 Information Technology

a. Training
b. Robust state and organizational cyber security team
c. Reliance on third-party vendors
d. Insurance procedures
e. Mechanism for sharing with other DOTs

2 Safety & Security of All Employees

a. Changing world
   - Outside threat
   - Inside threat
b. Local area changes
   - Fastest-growing state in nation
c. Changing to a safe and prepared culture

IDAHO TRANSPORTATION DEPARTMENT

YOUR *Safety*

YOUR *Mobility*

YOUR *Economic Opportunity*

itd.idaho.gov | POC: Neal Murphy, ITD Emergency Management Planner | Acknowledgements: ITD Office of Communica

Illinois Department of Transportation

Remember Abraham Lincoln?
You wouldn't have, if he had given up!

RESILIENCE: Knowing how to deal with limited resources; continue moving forward in-spite of setbacks, obstacles and barriers.


NEWS
AASHTO

Two States Earn Top Awards in National Transportation Competition

The I-55-Lake Shore Drive interchange was recognized for its creative use of a temporary bridge to accommodate inbound I-55 traffic to southbound Lake Shore Drive, saving the public countless hours of delays by avoiding extended closures and detours during the reconstruction.

The project, selected from a field of 79 nominations from 35 states, also was in the running for the People's Choice Award determined by online voting. The project received 10,622 votes, the third most in the contest.

IDOT performed a vulnerability assessment in 2017 to identify all the critical infrastructure that IDOT is responsible for within the State of Illinois. The assessment looked at threats and hazards and determined how to plan for future projects with built-in mitigation strategies.

TIM
TRAFFIC INCIDENT MANAGEMENT

The Traffic Incident Management Program is administered through IDOT in conjunction with many federal, state and local agencies and responders including the towing industry. The goal is to educate all first responders within the State of Illinois on best practices, policies, procedures and laws, all while ensuring their safety and the safety of the travelling public.

There is always room for improvement...

COMMUNICATIONS:

- ✓ Improve upon our inter-operability within IDOT as an agency and statewide
- ✓ Improve upon our communications with partner agencies
- ✓ Improve communications with all customers (internal and external)

Learn more: idot.illinois.gov
Point of Contact: Debbie Sassen

Illinois Department of Transportation

GETTING YOU THERE

SAFELY, EFFICIENTLY, AND CONVENIENTLY

IOWA DOT

RECOGNIZING SUCCESS IN RESILIENCE-RELATED WORK

3 THINGS **MY DOT IS PROUD OF**

- Multi-agency response planning exercises – Black Sky event, radiological events, animal disease outbreaks
- 2016 Iowa Crude by Rail/ Biofuels Transportation Study
- Historical assessment of transportation system repairs made in Iowa

OPPORTUNITIES

2 THINGS **MY DOT IS LOOKING TO IMPROVE**

- Develop a Resiliency Index to be used in the prioritization of projects
- Develop an across-the-board emergency response plan

DOT DEFINITION OF RESILIENCE

"The ability to prepare and plan for, absorb, recover from, or more successfully adapt to adverse events."

iowadot.gov **Scott Marler** scott.marler@iowadot.us

Kansas Department of Transportation

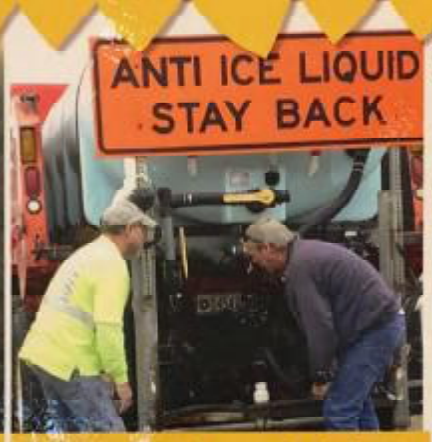
KEEPING KANSAS MOVING

Wildfire Response

KDOT's main objective when it comes to assisting firefighting efforts is to help with road control access.

Our crews are also able to haul water to assist firefighters in the field.

Once the fire has been extinguished, KDOT crews repair guardrails and sign posts along the highways in areas affected by wildfires.



Snow Fighter Training

In 2014, KDOT began a new training course to help keep Kansas moving during snow and ice season. In the past four years, more than 800 employees have had the opportunity to learn how to combat winter weather.

Plowing procedures, decision making, salt-brine production and spreader operations are part of the topics that are covered during training.

Tornado Response

After the initial tornado strikes, KDOT crews are self-responders and are often first on the scene to remove debris and clear roads. During past disasters, crews were on the scene within 30 minutes. KDOT crews help remove and push debris out of the way so first responders can assist victims. After a disaster declaration, KDOT offers further assistance to communities affected by tornadoes.

Goals: Communication Improvement

When preparing for weather emergencies or disasters, many crews are required and coordinating those responsibilities in various regions or even across the state is necessary to keep motorists moving.

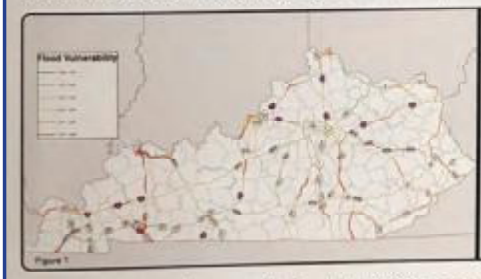
The use of DMS boards, social media, kandrive, radio and television are just some of the avenues KDOT uses to inform travelers of road and weather conditions.

Kentucky Transportation SYSTEM RESILIENCY

In 2018, the Kentucky Transportation Cabinet (KYTC) has already experienced flooding, landslides and rockfalls that have accounted for over 450 emergency repair events its roadways and bridges.

Recognizing Success In Resilience-Related Work

In 2017 KYTC and the Kentucky Transportation Center (KTC) completed a vulnerability assessment of the state's National Highway System (NHS) to flooding, landslides, sinkholes, and earthquakes.



Asset Type	KYTC Total	PGA* ≥ 60	PGA ≥ 30 and < 60	PGA ≥ 18 and < 30	100-yr flood-plain	Major Karst Potential	Mod. Karst Potential	High Landslide Potential	Mod. Landslide Potential
Total NHS Road Miles**	6,151	194	425	771	229	1,921	[illegible]	1,372	401
Interstate	2,064	31	169	241	49	762	398	290	58
Parkway	1,034	60	61	218	33	209	174	59	77
US Highway	1,932	101	128	395	97	694	136	613	181
KY Routes	1,076	2	76	17	49	227	141	409	86
Local Road	44	0	0	0	0	29	0	0	0
Bridges***	772	51	93	143	431	149	46	231	67
Culverts	292	12	21	21	166	86	40	75	27
Structures	1,409	56	109	178	26	462	186	205	86

Table 1 Kentucky NHS and Selected Vulnerability Measures

KYTC is currently one of six state DOTs completing a pilot project for FHWA to incorporate the effects from extreme weather and climate change into KYTC's Transportation Asset Management program.

KYTC has forged partnerships with other agencies to discuss on-going resiliency issues, strategies, and programs specific to the infrastructure impacts from flooding and natural hazards.

- **U.S. Army Corp of Engineers Silver Jacket Program**
- **U.S. Department of Homeland Security's Louisville Levee Regional Resiliency Assessment Program**

Future Resiliency Activities KYTC Is Working Toward Improving

Integrating natural hazard vulnerability assessment results into KYTC's Transportation Asset Management Plan (TAMP) and into the KYTC's project prioritization process (SHIFT). Formation of KYTC Resiliency Working Group and development of KYTC Resiliency Program website

CONTACTS:

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Ben Blandford, PhD, KTC Project Manager
(859) 257-7504 / Benjamin.Blandford@uky.edu

MORE INFORMATION:

Blandford, Schurman, Wallace. "Assessing Transportation Assets for Vulnerability to Extreme Weather and Other Natural Hazards." Transportation Research Record: Journal of the Transportation Research Board, 2018. DOI: 10.1177/0361198138793297.

Blandford, Schurman, Wallace. "Transportation System Vulnerability and Resilience to Extreme Weather Events and Other Natural Hazards – Final Results of Vulnerability Assessment of National Highway System for All KYTC Districts." University of Kentucky, 2018. DOI: 10.13023/KTC.RR.2018.08.

Blandford, Schurman, Wallace, McCormack. "Transportation System Vulnerability and Resilience to Extreme Weather Events and Other Natural Hazards: Report for Pilot Project – KYTC District 1." University of Kentucky, 2016. DOI: 10.13023/KTC.RR.2016.20

Louisiana: Growing in our Resilience

Louisiana is an extremely resilient state, and DOTD is equipped to face any challenges that come its way.

EMERGENCY RESPONSE

- Designation and communication of primary corridors to prioritize resources
- Innovative applications to protect areas from flooding and maintain system mobility
  - AquaDams and HESCO deployment

RESILIENCE INNOVATION

- Study and adapt processes for integrating resilience in daily planning and practice
  - Annual Innovations Showcase
  - Application of innovations
- Targeting resources
  - ITS

DOTD will continue to improve public perception.

INFRASTRUCTURE RESILIENCE

- Establishment of watershed council to deploy a statewide policy implementation across governmental jurisdictions
- Study to identify vulnerable coastal bridges and create Storm Surge and Wave Atlas
  - Establish 100-year design surge/wave data for coastal waters
  - Identify bridges vulnerable to this type of loading from the surge/wave data and bridge information
- Armor embankment slopes
  - Used for erosion control in coastal areas

DOTD
LOUISIANA DEPARTMENT OF TRANSPORTATION & DEVELOPMENT

www.dotd.la.gov
877-452-3683

Shawn Wilson, Ph.D., Secretary
Vince Latino, Assistant Secretary for Operations

RISE

Maine Department of Transportation

DEFINITION OF RESILIENCE

A resilient transportation system is one that maintains it's safety and functionality in both the wake of extreme events and during longer term anticipated changes in it's surrounding environment.

RECOGNIZING SUCCESS IN RESILIENCE-RELATED WORK

- Surrounding Resource and landscape features that may be governed by laws/ rules cisallowing impacts resulting from adaptation measures or surrounding community impacts.
- Timeframe for threat vs timeframe for asset replacement
- Pilot project with University of Southern Maine's Environmental Finance Center to enable municipalities to apply TRAPPD to local infrastructure
- Participation in forums focused on community resilience in collaboration with other agencies and nongovernmental organizations.

OPPORTUNITIES FOR IMPROVEMENT

- Asset specific identification of both real-time (ie: storm surge, slope failures) and incremental (SLR) threats.
- Expanding risk assessment to inland highways

MAINE DEPARTMENT OF TRANSPORTATION 24 CHILD ST., AUGUSTA, ME 04330 PHONE: 207-624-3000 | MAINEDOT.GOV

MARYLAND DEPARTMENT OF TRANSPORTATION

RISK AND CLIMATE RESILIENCY

What are we proud of?

1 Risk and Climate Resiliency

MDOT invests $3.7 million annually toward cyber-safety to protect transportation data from 8 million cyber-attacks per month, and has dedicated resources for a Risk and Climate Resiliency Program Manager who participates/supports several organizations including the Maryland Commission on Climate Change, Maryland Silver Jackets, and Coast Smart Council.

2 Pilot Studies

MDOT SHA has participated in two FHWA pilot studies.

MDOT SHA is currently conducting a pilot study for FHWA on Asset Management, Extreme Weather, and Proxy Indicators. Working with Pavement, Bridge, Planning, and Operations, several changes were identified to integrate climate vulnerability into asset management. Final report in November 2018.

Developed methodology to determine roadway and bridge vulnerability.

3 Vulnerability Viewer

Sea level change and coastal precipitation were modeled and mapped for 2015, 2050, and 2100 for the 10, 25, 50, 100, and 500-year return interval storms. This Arc GIS Online viewer is easily accessed on any device and can be utilized by the County and Local Governments for data on roadway vulnerability.

City of Crisfield Facebook Page, Tyler Land drone footage

What can we improve?

Cyber security is critical to operate and maintain DOT functions. While many systems are in place to protect MDOT data, threats continue to change and become more sophisticated. Security to protect transportation data must also continue to be updated, therefore MDOT will adapt by adding Integrated Dynamic Cyber Defense in 2019-2020.

To date, only the shoreline has been modeled for potential flood impacts. To better understand how an extreme precipitation event would affect the state, it is critical to consider riverine flooding as well. MDOT is currently developing riverine flood modeling and incorporating these models into planning, maintenance, and operations decision-making. Complete flood data provides better customer service and economic opportunity to support our economy.

massDOT
Massachusetts Department of Transportation

State Hazard Mitigation Climate Adaptation Plan (SHMCAP)

Massachusetts Definition of Resiliency

The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.

Three Things MassDOT has Done to Improve Resilience

1

MassDOT completed a 2015 pilot transportation infrastructure vulnerability analysis.

- The analysis incorporated sea level rise scenarios, and hydrodynamic-wave numerical model, called the Boston Harbor Flood Risk model, to quantify magnitude and extent of flooding.

2

2015 MassDOT Climate Change Summit.

- The Summit identified climate change-related threats to key assets and infrastructure including the Boston Metropolitan Highway System.
- 9 initiatives to enhance MassDOT's climate preparedness and mitigation efforts were identified for implementation.

3

MassDOT collaborated with multiple state agencies to create an integrated State Hazard Mitigation and Climate Adaptation Plan.

Two Things MassDOT will do as Part of the State Hazard Mitigation and Climate Adaptation Plan

1

MassDOT will collaborate with other state agencies to develop climate change design standards.

These new design standards will support best management and construction practices for new and improved agency structures, roads, parkways, parking lots, housing, and other facilities.

Estimated timeframe for completion: **3-5 years**

2

MassDOT will expand and improve the Boston Harbor Flood Risk Model to create the Massachusetts Coastal Zone Model.

Expansion of this model will create improved sea level rise and storm surge scenarios for the present, 2030, 2050, and 2070/2100. This model will consider future shoreline changes and create updated GIS mapping.

MassDOT will assess the storm surge vulnerability of the coastal transportation network and make data available to state agencies, coastal communities, and other stakeholders.

Estimated timeframe for completion: **greater than 5 years**

Each of these four elements are analyzed to determine infrastructure vulnerability

To access the Massachusetts Hazard Mitigation Climate Adaptation Plan, please visit: **https://resilientma.com**

MICHIGAN DEPARTMENT OF TRANSPORTATION

Making Progress in Resilience

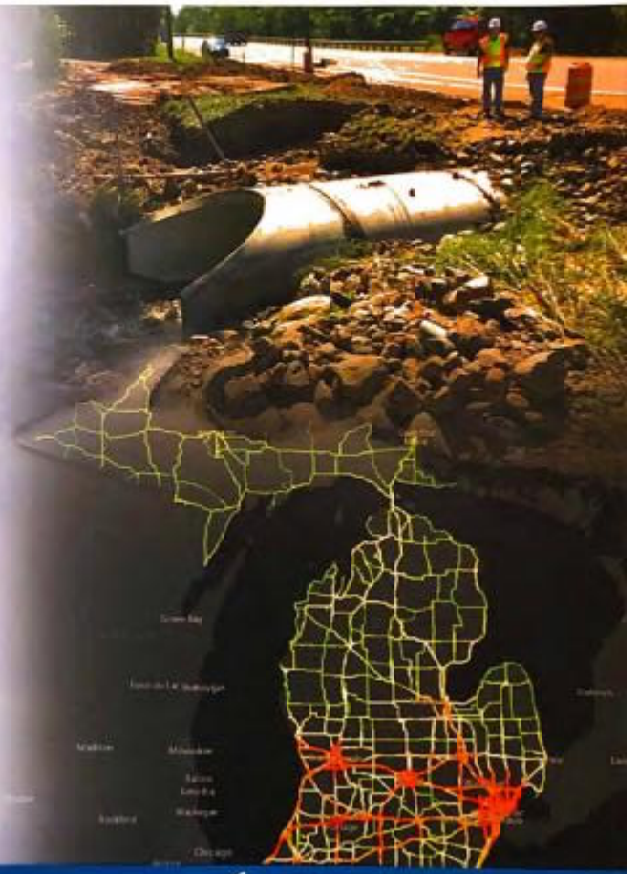
Three things MDOT is proud of

- Greater emphasis toward inventorying non-traditional assets, such as culverts and geo-technical assets.
- Reducing the "silos" around risk and resilience through close coordination between the Safety and Security Administration and the bureaus of Transportation Planning, Development, and Bridges and Structures.
- A commitment to incorporating elements of risk and resilience in the State Long-Range Plan and the Transportation Asset Management Plan.

Two things MDOT is looking to improve

- Further enhance the data available to MDOT to help identify and mitigate against risk and hazards.
- Continue to explore options to include risk and resilience in department business processes.

DOT Definition of Resilience: "We're working on it."



www.michigan.gov/mdot

MDOT
Michigan Department of Transportation

DEPARTMENT OF TRANSPORTATION

Recognizing Success in Resilience-Related Work, "3 Things My DOT is Proud Of"

Research

- "Flash Flood Vulnerability and Adaptation Assessment Pilot Project" (2014)
- Incorporate resilience into Transportation Asset Management and Bridge Replacement and Improvement Management systems (ongoing)

Collaboration

- MN - participate in state climate change, climate adaptation and air quality groups to collaborate with other state agencies to minimize impacts and increase resilience.
- National – participate on committees led by FHWA, AASHTO, and TRB to stay informed on transportation-related climate strategies.

Action

- Dedicate funding for MnDOT Flood Mitigation Program
- Partner with other agencies to develop flood and drought tolerant seed mixtures to use on roadsides and stormwater ponds

Flash flood damage along TH23 in Carlton County, MN, June 2018. Source: MPR

Climate Impact	Likelihood this will change in MN over next 20 years	Potential Negative Implications for the Transportation System
Heavy precipitation / flooding	Very High	• Damage to highway and rail infrastructure, airport runways • Flooded roads will slow operations and performance • Slope failures and erosion
Warmer winters	Very High	• More ice • Reduced pavement conditions and life cycles • Downed power lines with ice storms
New species ranges	High	• Changes in roadside vegetation mixes • Soil erosion • Increase in invasive species populations • Increased exposure of construction and maintenance crews to vector-borne diseases
Drought	Medium	• Reduced river navigability for barges • Roadside vegetation stress, reduces rainwater storages and increases soil erosion
High heat	Low	• Pavement and rail buckling • Vehicles overheating • Electrical system malfunctions • Limitations on construction hours
Wildfires	Unknown	• Road closures • Immediate and significant threat to human safety • Damage to roadside infrastructure

Tim Sexton, Chief Sustainability Officer http://www.dot.state.mn.us/sustainability/

Opportunities for Improvement "2 Things My DOT is Looking to Improve"

Connect research to practice

Engage more staff in resilience conversations

Resilience at MnDOT: *Design, construct, operate, and maintain infrastructure to be resilient to the changing climate*

Summary of the Report of the Interagency Climate Adaptation Team

May 2017

Adapting to Climate Change in Minnesota

Our climate is changing

Climate change is already occurring in Minnesota and its impacts are affecting our state's environment, economy, and communities.

Over the last several decades, the state has experienced substantial warming during winter and at night, with increased precipitation throughout the year, often from larger and more frequent heavy rainfall events.

In the years and decades ahead, winter warming and increased extreme rainfall will continue to be Minnesota's two leading symptoms of climate change.

How we're adapting

Minnesota is taking many steps to increase climate adaptation in our state, including a wide range of planning, assessment, and implementation efforts.

This report summarizes ongoing adaptation activities in eleven Minnesota state agencies, including the Departments of Agriculture, Commerce, Health, Military Affairs, Natural Resources, Homeland Security and Emergency Management, and Transportation, as well as the Environmental Quality Board, Pollution Control Agency, Board of Water and Soil Resources, and Metropolitan Council.

Planning For the Future

State agencies have developed five statewide climate adaptation indicators to help track Minnesota's progress in climate adaptation.

The Interagency Climate Adaptation Team has also identified six priority recommendations for needed action in climate adaptation by state government. These focus on: resilience to extreme precipitation, health of vulnerable populations, preserving ecosystems, strengthening agricultural water management, managing climate impacts on population centers, and better using climate data.

Download full report at www.pca.state.mn.us

MINNESOTA

VISION ZERO
zero deaths • zero serious injuries
MONTANA DEPARTMENT OF TRANSPORTATION

Montana RISEs to the Challenge

MONTANA DEPARTMENT OF TRANSPORTATION

Montana RISEs to the Challenge

Recognizing Success in Resilience-Related Work

"3 Things My DOT is Proud Of"

- *Our ability to quickly respond to infrastructure emergencies*
- *Our ability to apply lessons from emergencies to future resiliency efforts*
- *Our partnerships with local governments and contractors to that help our responses be more effective*

Opportunities for Improvement

"3 Things My DOT is Looking to Improve"

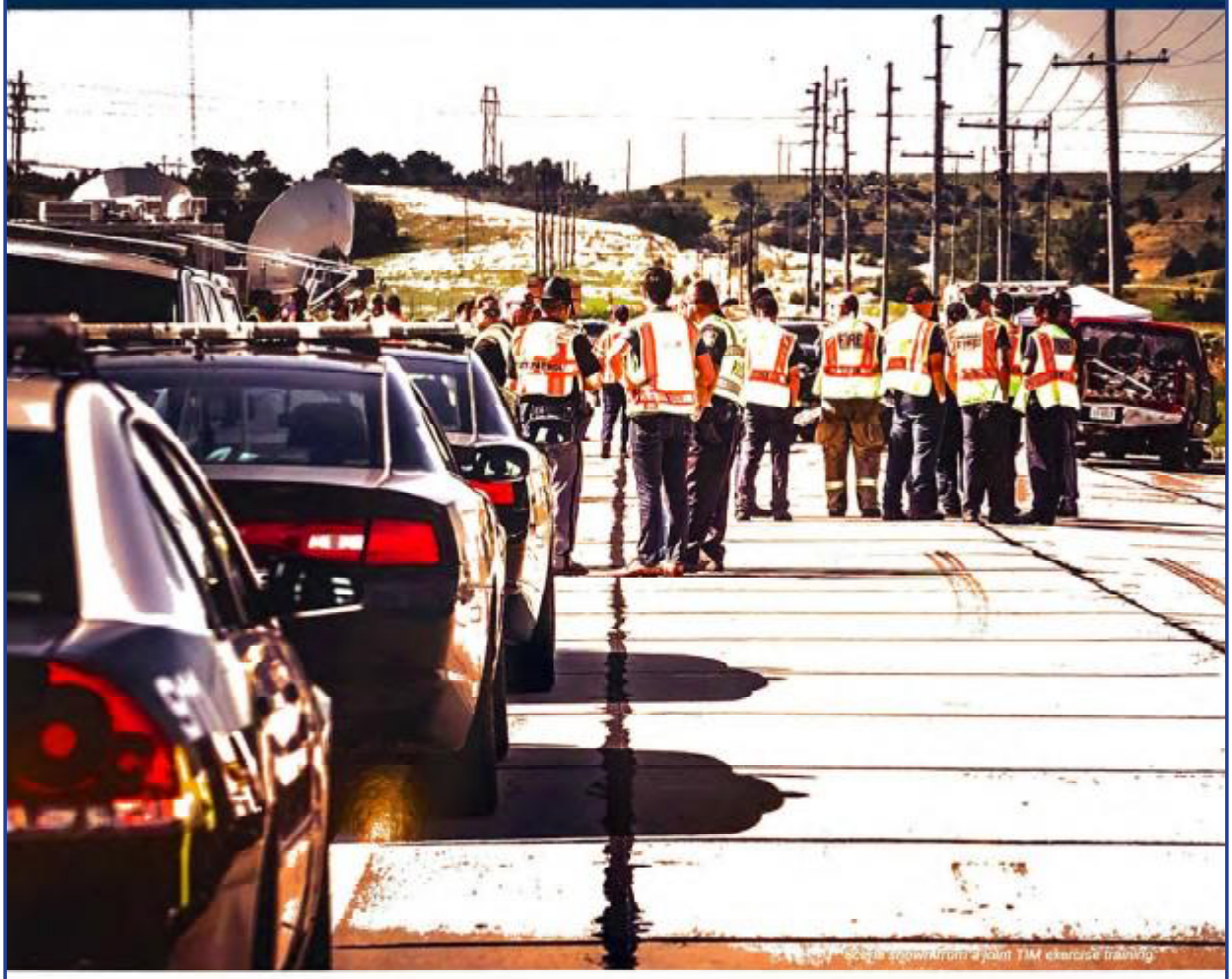
- *Overall Project Delivery*
- *Communication with the public and stakeholders*
- *Risk Based Investment Decision Making*

Resilience is the ability to anticipate, prepare, and adapt to changing conditions and to withstand, respond, and rapidly recover from natural or human caused disruptions.

https://www.mdt.mt.gov/ Contact email: lryan@mt.gov Phone (406) 444-6821

NDOT

"A Successful Merge: Meeting the Moment"



Scene shown from a joint TIM exercise training

Recognizing Success in Resilience-Related Work

"3 Things My DOT is Proud Of"

- NDOT is delivering the largest construction and maintenance program in our history – all with the fewest number of employees in our history.
- NDOT created our first Public Engagement Manual to guide our interactions with the public and stakeholders – ensuring a team approach to fulfilling infrastructure goals.
- NDOT manages our assets with a steady hand, mindful of taxpayer investment, to provide a safe and reliable transportation system – no matter the economic climate.

Opportunities for Improvement

"2 Things My DOT is Looking to Improve"

- NDOT looks to continually foster public-private partnerships to anticipate the ever-changing technology landscape.
- NDOT seeks to nurture innovation within our ranks so we can be a leader amongst our peers.

NDOT defines resilience as the ability to leverage the power of our partnerships, our people and our public to create opportunity in the midst of adversity.

NEBRASKA

Good Life. Great Journey.

DEPARTMENT OF TRANSPORTATION

dot.nebraska.gov

Jeni Campana jeni.campana@nebraska.gov

– "Always Prepared and Ready to Bounce Back"

Recognizing Success in Resilience-Related Work

"3 Things My DOT is Proud Of"

Conducts regular disaster training exercises for management and staff in collaboration with state and local agencies.

Maintains strong relationships with FHWA and FEMA.

Southern Nevada Freeway & Arterial System of Transportation (FAST) – Co-locate operations and emergency response of the RTC, Clark County, NDOT and the cities of Henderson, Las Vegas and North Las Vegas.

Opportunities for Improvement

"2 Things My DOT is Looking to Improve"

Provide more outreach to the public and utilize social media on what we are doing as an agency to prepare for disasters and how they can benefit from this.

Work closer with the Nevada National Guard on training and resource coordination in preparation of a large scale disaster.

DOT Definition of Resilience

"Prepare for the unexpected and be ready to think outside the box"

www.nevadadot.com –Thor Dyson Assistant Director Operations / Anita Bush Chief Maintenance and Asset Management Engineer

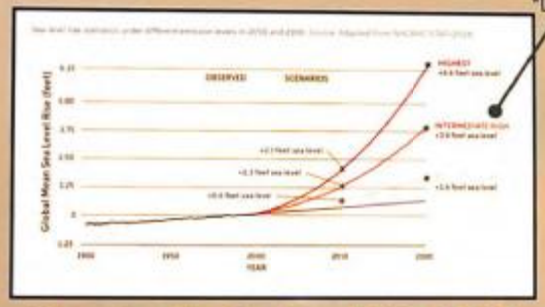
RESILIENCY

NEW HAMPSHIRE DEPARTMENT OF TRANSPORTATION

New Hampshire DOT Department of Transportation

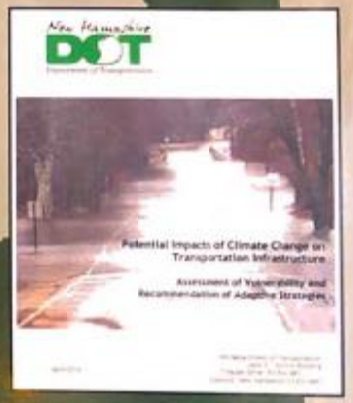
What Are We Doing in New Hampshire?

Recognizing Success in Resilience-Related Work



Planning for Sea Level Rise (SLR)

Networks



Strategies to Prepare

Opportunities for Improvement

- Prioritization process for projects affected by SLR and/or adaptation as part of Ten Year Plan planning process
- Enhance the incorporation of innovations and resiliency designs into transportation projects

www.nh.gov/dot/climate-change/index.htm • Public Information Office (603) 271-6495

North Dakota Department of Transportation

Resiliency - The North Dakota Way

Successes

1

Pothole Regions of North Dakota - Construction of grade raises built to the ultimate height

Before

After

2

Installation of living snow fences and snow fences near affected roadways

Without

With

3

WEB EOC - State Emergency Operations Center - *(Collaboration of statewide emergency events)*

EOC

Flood

Opportunities for Improvement

Planning

Work to improve design standards by designing roads with higher traffic capacity

Design

Mitigating the impact to the transportation system disruption

Resilience is NDDOT's plan to preserve and enhance our transportation assets.

NDResponse statewide emergency website:
ttp://www.ndresponse.gov/

NDDOT
North Dakota Department of Transportatio

OREGON

STATEWIDE RESILIENCE ASSESSMENT

Seismic and Extreme Weather

Oregon Department of Transportation's work in preparation for the **Cascadia Subduction Zone Earthquake** is highlighted by:

- Seismic Vulnerability Assessment of State Highway and Local Agency Bridges
- Oregon Resilience Plan, 2013
- Partnering with Oregon Public Broadcasting and News Outlets for Resilience Messaging

ODOT is striving to further improve its resilience plan by initiating:

- Statewide Seismic Triage Assessments
- Multi-Sector Asset Interdependence Planning

OREGON DOT
Seismic Resilience Definition:
"Oregon citizens will not only be protected from life-threatening physical harm, but because of risk reduction measures and pre-disaster planning, communities will recover more quickly and with less continuing vulnerability following a Cascadia subduction zone earthquake and tsunami."

https://www.oregon.gov/ODOT/Bridge/Pages/Seismic.aspx
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Oregon Department of Transportation

Road to Resilience

Overcoming past challenges & experiences with innovative solutions

TN TDOT Department of Transportation

SAFETY

Resilient in getting our employees and the users of the transportation facilities home

work with us

PROTECT THE QUEUE!

EDUCATION

Resilient in advancing career development for all employees

TDOT Reconnect

GTA

INNOVATION

Resilient in quickly and effectively maintaining our transportation system

MemFix4 240

IMPROVEAct

AREAS TO IMPROVE

- Keeping up with society's trends and technology's capobilities
- Innovating and improving design/construction techniques:
  - 3D modeling
  - Drones
  - Alternative Delivery

Building a Stronger Transportation Program in Times of Change

Tennessee Department of Transportation

"3 Things TDOT is Proud Of"

1) Assessing the Vulnerability of Tennessee Transportation Assets to Extreme Weather (2015 report)
2) Integration of Resilience into TDOT Programs and Practices
3) Response to Extreme Events

"2 Things TDOT is Looking to Improve"

- Phase 2 of TDOT's Extreme Weather Vulnerability Assessment (Assessment of Critical Transportation Assets)
- Complete Integration of Resilience into TDOT Programs and Practices

resilience - noun

\ ri-ˈzil-yən(t)s

Definition of resilience

1: an ability to recover from or adjust easily to misfortune or change

2: The Tennessee Department of Transportation (TDOT)

https://www.tn.gov/tdot.html

Paul Degges P.E.

TRUE TEXAS GRIT

Organizationally confident that you are ready, capable and properly equipped to respond, withstand and recover with true Texas GRIT, and safety as the number one priority.

Grit in Action – Points of Pride

Our rapid response, communication and innovation were all evident in our response to Hurricane Harvey in 2017.

Technology and Coordinated Communication

Drive Texas, our 24/7 up-to-the-minute information system on road closures and conditions available to drivers via Web, mobile and phone, was put to the test with more than 5 million visits to the website alone during the peak of Harvey and weeks after. Conditions are verified by TxDOT employees and contractors to provide accurate and timely travel condition information for all events.

Innovation and Rapid Deployment

During Harvey, TxDOT implemented two important innovations that helped address important challenges. Water-filled barriers that use food waters to help keep roadways open were quickly acquired and deployed. Base camps were built within days to provide critical staging areas for equipment and personnel, equivalent to a small city. We adapt and respond.

Massive Emergency Response

When Hurricane Harvey hit Texas on Aug. 25, we mobilized a massive response involving more than 5,000 employees. At the height of the storm, more than 580 state road segments were closed as TxDOT crew members and equipment addressed the disastrous impacts across 50 Texas counties. Our effort lasted almost another year as we removed more than 21 million cubic feet of debris, enough to fill 100,000 dump trucks.

Committed to Continuous Improvement

Safety Never Sleeps

Even one death on our system is unacceptable. We are committed to designing the safest system possible as a shared responsibility with Texas drivers. Our safety campaigns educate drivers in every corner of the state and our engineers work diligently to design a system that is more forgiving of driver error. Our internal focus on safety has made a difference, and we want to do the same on our system.

Valuing Our Employees

In addition to our focus on the resilience of our system, we strive to keep the resilience of our employees top of mind. We embrace a diverse work culture that attracts and retains the best talent, and we make the safety and wellbeing of our employees a key priority. This maximizes our ability to be ready, capable and equipped to respond, withstand and recover with true Texas grit.

Contact: Michael Lee, Director, Engineering and Safety Operations

UDOT Achievements in Risk-Based Asset Management
Keeping Utah Moving

Things We Do Well

1. Asset Management

To keep Utah moving, UDOT's strategic plan states three goals: 1) zero fatalities, 2) preserve infrastructure, and 3) mobility. UDOT's achievements in approaching these goals can be attributed to a robust asset management program as well as comprehensive performance metrics.

❶ UDOT has completed a natural hazard risk assessment for the I-15 corridor and is beginning a second Pilot for US 40. The intention of the second pilot is to augment the corridor planning process with added attention given to threats from natural hazards and resulting system resilience.

❷ In 2013, UDOT launched a first-of-its-kind data collection effort using ground based LiDAR to create a three-dimensional model of highway assets collected at highway speeds in a single data collection pass including the entire highway system in both directions, covering 3,184 centerline miles. UDOT knows the quantities of the assets to a degree of accuracy never achieved before through previous methods.

The following types of data were collected: roadway condition, ramps and collectors, median type and width, guardrails, shoulder type and width, lanes, bike lanes, intersections, bridges striping, rumble strips, sign faces and supports, surface areas and pavement width. This data is publicly available through UDOT's open data portal: https://data.udot.opendata.arcgis.com/ In addition, UDOT hosts a web map gallery (https://udot.maps.arcgis.com/home/index.html).

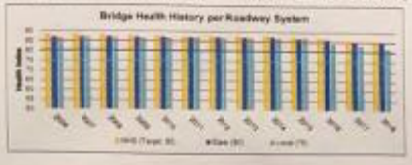
2. Performance Management

❶ The American Society of Civil Engineers 2017 report card for America's Infrastructure gave Utah a grade of B+ making Utah number ten in the nation in terms of infrastructure condition. In addition, U.S. News & World Report rated Utah number two in the nation for transportation. Criteria included bridge quality, commute time, public transit usage, and road quality.

❷ UDOT has identified the following performance measures to meet our strategic goals: Pavement Condition – UDOT uses distress surveys and modeling techniques to forecast pavement conditions. UDOT tracks ride quality for Interstates, High Volume, and Low Volume roads based on assumed annual funding. Bridge Condition – UDOT inspects all bridges in Utah on a 2-year cycle. UDOT tracks bridge condition, age distribution, and pavement and bridge expenditures.

2018 Highway score: 246 out of 400 points (ASCE 2015 Report: B+)
Deficient bridges: 2.9 percent (ASCE)
Average commute to work: 21.8 minutes (U.S. average: 25.1 minutes)

One-half of all structures are inspected annually and assigned a score according to the Bridge Health Index (BHI). The information is reported to FHWA in March each year and is included in UDOT's Federal Performance Reporting.



3. Risk Management

To preserve infrastructure, reduce fatalities and maintain mobility, UDOT also plans for the future – for additional capacity, safety enhancements, and for mitigating the potential consequences of natural hazards. UDOT has completed a Pilot risk and resilience study for the I-15 corridor and is beginning a second study for US 40. The I-15 corridor study, completed in November 2017, assessed I-15 for multiple threat asset pairs (see figure below). As shown, UDOT studied a range of physical threats and a range of highway assets. Each threat-asset pair was analyzed to determine the expected annual risk from each at the asset level, meaning for any individual asset along I-15 included in the study, expected annual monetary risk was assessed for both UDOT and the traveling public.

❶ The I-15 Pilot exercised the RAMCAP/ISO 7-step process for risk analysis: 1) Asset Characterization 2) Threat Characterization 3) Consequence Analysis 4) Vulnerability Analysis 5) Threat Analysis 6) Risk/Resilience Assessment 7) Risk/Resilience Management.

❷ GIS was used to overlay transportation assets with natural hazard threat layers. The map in the figure below shows the results of modeling the Magnitude 7 Salt Lake City earthquake scenario.

Next, the annual risk by threat type was estimated for all assets along I-15. The figure below notes that for I-15, the highest annual risk to UDOT is earthquakes followed closely by flooding.

❸ The largest annual risk to travelers on I-15 is earthquakes, followed by flooding. This annual monetary risk is associated with closures and detours that may increase travel time and vehicle operating costs.
❹ With this information, UDOT can begin to consider management strategies or capital investments that can reduce or buy-down annual risk from any particular threat at the asset level, for example, investing in mitigation to reduce flood risk to culverts.
❺ UDOT is currently reviewing business processes and decision making processes to determine where annual risk information could best inform investments. One management area seeking to incorporate risk analysis is Corridor Planning.

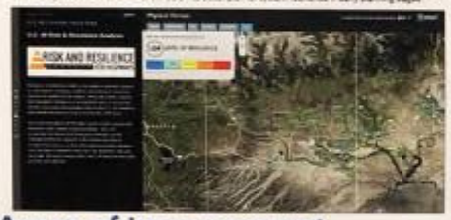
Integrating Risk and Resilience into Corridor Planning
FHWA Extreme Weather & Durability Grant

UDOT's definition of Resilience is similar to FHWA Order 5520:

Resilience is the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.

With funding from FHWA's Extreme Weather and Durability Grant Program, UDOT has begun work to incorporate risk and resilience information into its Corridor Planning Process. UDOT is moving towards determining metrics of risk and resilience and thresholds of expected performance to support decision making for corridors that not only includes safety, mobility, and operations, but also anticipated risk and resulting system resilience. In addition, the US 40 corridor will be analyzed for annual risk from physical threats and anticipated corridor resilience. This information will be incorporated into the US 40 corridor plan.

The figure below depicts a mock-up of potential system resilience from physical threats along the corridor. In this case, as with safety information, UDOT can better understand the current Level of Resilience from physical threats along the corridor. This type of information will allow UDOT to better plan for system resilience in early planning stages.



Areas of Improvement

❶ UDOT's investments in data collection to support their asset management program, has allowed our agency to mature our performance management program to provide better information to the public and decision makers. Building on information regarding asset location and condition, UDOT is beginning to build an understanding of annual risk from physical threats in our risk based asset management program as well as resulting system resilience.

❷ First, by standardizing metrics for reporting annual risk from applicable threats, UDOT will improve the ability of our staff to incorporate risk assessment and system resilience into decision making processes. Next, UDOT is seeking ways to incorporate annual risk and system resilience information into our management programs, such as Corridor Planning. Finally, UDOT is moving towards integration of asset risk and performance management systems and metrics to reflect the impact of each on the other.

❸ With a complete asset inventory, comprehensive performance measures and risk analysis pilot programs, UDOT is advancing forward to meet our strategic goals as well as the challenges of recent legislation to meet the needs of our growing population and key corridors that support national surface transportation movement of people and goods.

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FHWA EXTREME WEATHER AND DURABILITY PROJECT

UTAH RISK40

Improving Resilience to Floods

Highways, Bridges and Culverts

VERMONT
AGENCY OF TRANSPORTATION

Planning: *Completed the Transportation Resilience Planning Tool*

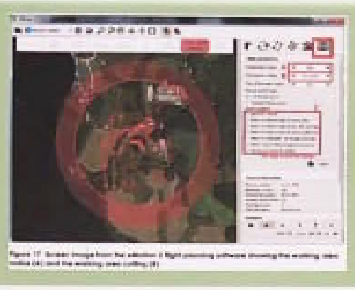
Programming: *Resilience in the project selection and prioritization process*

Design: *Updated the hydraulics manual to include a resilient design standard*

Operations: *Rivers & Roads Training*

Areas to Improve

- Develop Quick Response Unmanned Aerial System (UAS) Program
- Integrate Mitigation Project Planning and Funding into Agency Processes



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2018 TRANSPORTATION
RESILIENCE INNOVATIONS SUMMIT AND EXCHANGE
RISE

Creating a resilient multimodal transportation system
THE WSDOT WAY

Washington State Department of Transportation

OUR PRIMARY FOCUS AREAS:

1 Asset Management

We're working to identify, map and evaluate our assets and climate risks; this aids in understanding the threats to our system.

- **WSDOT's Climate Impact Vulnerability Assessment**
  This GIS map is the basis for our consideration of climate risk in planning and project design. We created an easily replicable method, tailored from FHWA's conceptual model for determining asset vulnerability.

- **Seismic Lifeline Route**
  WSDOT has been working to improve our seismic resiliency for over two decades. Recently, we have focused our efforts on a specific lifeline route to enable federal support and supplies to reach Federal Staging Areas across Western Washington.

- **State Ferries plan for 2040 incorporates resilience in its long-range planning for terminals and ferry operations**

2 Practical Solutions

Simply stated, WSDOT views Practical Solutions as the right investment, at the right time, in the right place, using the right approach.

- We're using nature-based solutions such as placing cobble instead of rip/rap along shorelines to mimic a natural beach. It absorbs wave energy while minimizing effects on adjacent shorelines.
- By using root balls along river banks, we create a more natural approach to erosion and scour, while providing habitat for fish.

3 Project Design and Program Operations

- **SR 99 Tunnel and SR 520 Floating Bridge** – We considered seismic risk, storms, sea level rise and other potential disruptions as part of the project design for these large, complex projects.
- **Integrated Vegetation Management** – Our roadside design and management strategy restores native vegetation and allows roadside plant communities to evolve and mature over time, resulting in lowest lifecycle maintenance costs and maximum highway operation, environmental, and social values.

WSDOT SEEKS TO IMPROVE IN THESE AREAS:

Better coordination among jurisdictions:

- How we identify and address network and system vulnerabilities with transportation partners and communities.
- How to meet the needs of vulnerable communities, and improve evacuation plans for transit-dependent, low income, elderly, people with disabilities – wherever they live.

Greater engagement of resilience planning throughout the agency:

- Ways we incorporate risk of natural hazards into life cycle cost accounting, and programming.

WSDOT'S DEFINITION OF RESILIENCE

The term "resilience" means the ability to prepare for, and adapt to, changing conditions and withstand and recover rapidly from disruptions.

Adopted from:
Presidential Policy Directive 21, Critical Infrastructure Security and Resilience, February 12, 2013.

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FOR MORE INFORMATION, GO TO:
www.wsdot.wa.gov/SustainableTransportation/adapting.htm

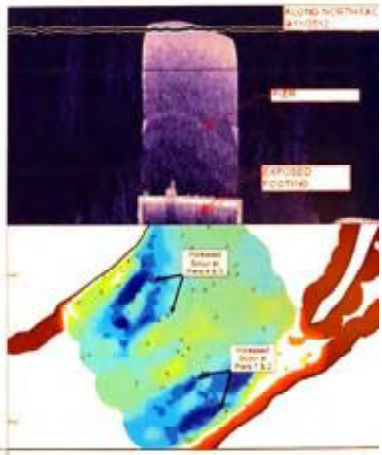
WisDOT Resiliency Practices

PARTNERSHIPS

- TIME Program
- FHWA Emergency Relief
- County Highway Departments
- WI Indigenous Tribes
- WI Dept of Natural Resources
- WisDOT Region Staff
- WI Emergency Management
- FEMA
- Consultants and Contractors

TECHNOLOGY

- Remote Monitoring
- In-field iPads and WiFi
- 511 Wisconsin: Traffic Management Center
- Bathometric and Sonar Surveys
- Drone Photography
- Social Media



STREAMLINED CONTRACTING

- On-Site Contractor Meetings
- Expedited Quotes and Selection
- Quick Mobilization
- County Highway Dept. Accounts

FUTURE IMPROVEMENTS

- Identify At-Risk Structures
- Improve Statewide Guidance
- Improve Monitoring and Technology
- Flood Plain Surveys
- Bridge Strengthening Program

wisconsindot.gov • For more information contact: rosanne.meer@dot.wi.gov

SOLVING TOMORROW'S PROBLEMS TODAY

Successes

Winter Weather – Connected Vehicles; variable speed limits; dynamic messaging; road weather information systems; winter research team; snow fence; commercial vehicle operators portal; and WYDOT authorized travel.

Land Slides/Rock Fall – in-house investigation capabilities; ATV drill rigs; inclinometer program; vibrating-wire piezometer groundwater monitoring; rockfall hazard rating team; statewide rockfall hazard rating inventory; EPS Geofoam lightweight fill applications; couple shear pile applications; and northwest states communication network.

Avalanche Control – Gasex; O'Bellx; snow supporting structures; Aviguard; two full-time avalanche technicians; NIXLE notification system; and Gov Delivery notification.

Opportunities

Winter Weather – Increased truck parking; commercial connectivity; freight movement; and alternate fuel vehicles electric and compressed natural gas.

Future technology implementation – autonomous applications; smart cities; cyber threats; integration of information; and legal challenges.

WYOMING TRANSPORTATION DEPARTMENT

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WATER MANAGEMENT FOR ROAD AUTHORITIES IN THE FACE OF CLIMATE CHANGE

Poster 10604

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ABSTRACT

European National Road Authorities (NRAs) have recognized for a long time that climate change will have a significant effect on their assets and operations. Especially, water management assets will be affected. The damage caused by floods and rain to infrastructure assets amounts to €600 million annually, making it by far the dominant weather impact already in the current climate, let alone in the future when it is expected that likelihood and intensity of intense rainfall will increase. Many challenges exist in addressing intense rainfall events into proper design and maintenance of water management systems. These challenges exist both in the field of climate science itself as well as in the translation of climate projections into proper design and maintenance of water management systems. This paper presents results of the WATCH project (WATer management in the face of climate CHange) that was commissioned under the CEDR 2015 call - Climate Change: From Desk to Road. It addresses climate change, socio economic evaluation and sustainable drainage systems.

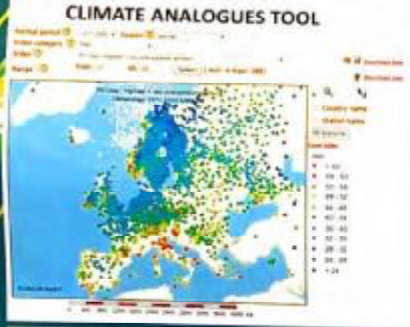
MANUAL

The manual aims at assessing current and future resilience of NRAs water management facilities, ensuring optimal design, maintenance planning and asset management. The approach considers two levels of analysis (high and detailed level) including risk assessment, socio-economic evaluation protocol and definition of measures and strategies.

On the high level, the analysis is performed for sub-groups of assets in order to identify the best adaptation strategy for those sub-groups (classification based on extrinsic site factors, infrastructure intrinsic factors, consequences and hazard level). The goal of this "screening" level is to prioritize the assets that should be further studied in the detailed level.

On the detailed level, an analysis is carried out for each type of assets following 4 main steps: asset inventory, hydrological calculations, hydraulic analysis of the asset and asset risk evaluation. The adaptation strategy from the high level is translated into design options, up to the individual asset. Design and maintenance choices are compared using a socio-economic evaluation for specific assets. The final socio-economic evaluation, aggregated at the project level, should then be compared to the initial economic evaluation to confirm the validity of the strategy selected at the high level.

CLIMATE ANALOGUES TOOL



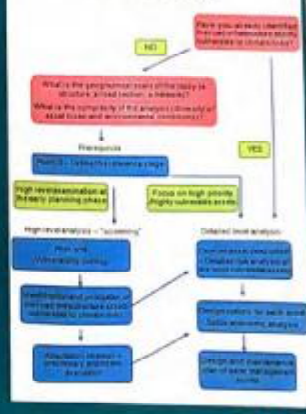
SUDS FEATURES

RESULTS

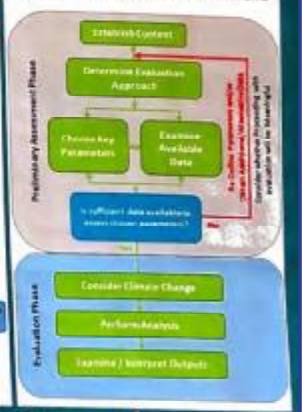
Results of the project are:

- Comprehensive **manual** on how to determine the **resilience** of drainage systems and the consequences for inspection and maintenance as well as for the design and assessment of alternatives. In this manual all below mentioned other outputs culminate.
- **Guidelines** to correctly interpret and apply relevant information extracted from **climate projections**, to be used in road drainage maintenance and design.
- **Climate analogues tool** for rainfall extremes in Europe.
- **Protocol for adapting Sustainable Drainage System** (SuDS) systems for climate change, with applications for roads across Europe.
- **Guidelines for a socio economic analysis** of adaptation and maintenance approaches for water management for optimized decision making properties of NRAs. Socio economic evaluations are seen as an essential, and often lacking, tool for implementation of climate change adaptation measures.

MANUAL STEPS



SOCIO ECONOMIC ANALYSIS



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Development of a Climate Adaptation Strategy for the InnovA58 Highway in the Netherlands

Poster 10313

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Kees van Muiswinkel, Rijkswaterstaat, the Netherlands
Wim Leendertse, Rijkswaterstaat and the University of Groningen, the Netherlands
Thomas Bles, Deltares, the Netherlands

ABSTRACT

Climate change induced extreme weather events may affect the functionality of (federal) highways and therefore pose a risk for safety and traffic flow. As the asset manager of the main road system in The Netherlands, **Rijkswaterstaat** has to ensure that road networks continue their operational functions, both now and in the future. Therefore **adaptation strategies** are needed to develop and maintain **climate resilient infrastructure, integrated in the environment**. To develop such a strategy, the **ROADAPT methodology** - developed in response to the 'CEDR call 2012: Road owners adapting to climate change' – and **Dynamic Adaptation Policy Pathways** were tested on a planned Dutch highway project, InnovA58. We conclude by stating that both methods are useful to assess vulnerability and potential measures for road infrastructure ,and to increase adaptive design. An area-oriented approach is needed, since climate resilience requires regionally tailored solutions.

CASE STUDY

- The InnovA58, highway, the Netherlands, is used as a test case. The project area experiences heavy downpours, which are increasing as the climate changes, resulting in localized flooding and need for enhanced storm water management. The project is currently in the planning phase, and construction is expected to begin in 2020;
- A process has been designed to assess risks, vulnerability and possible measures for the InnovA58 highway and the close environment (see table 1), using the ROADAPT methodology and Dynamic Adaptation Policy Pathways.

Process steps	Actions taken
Quick Scan	Two workshops: - To determine climate threats for the A58 infrastructure and surrounding environment - To determine key risks and potential measures
Vulnerability Assessment	GIS-methodology for mapping distinctive vulnerabilities in the road network
Socio-economic Impact Assessment	Two methods: - Cost Effectiveness Analysis - Cost Benefit Analysis
Adaptation Strategy	Dynamic Adaptation Policy Pathways to determine an adaptation strategy

Table 1: Research strategy InnovA58 case

RESULTS

The application of the ROADAPT and the Dynamic Adaptation Policy Pathways methodologies on the InnovA58 has led to output that resulted in an adaptation strategy for the highway. The output consists of:

- Risk matrices: in the Quick Scan workshops risks of current and future climate were identified and plotted on risk matrices;
- Selection of top risks: top risks were derived from the risk matrices and potential measures identified (see fig. 1);
- Vulnerability maps: the ROADAPT Vulnerability Assessment led to GIS maps, presenting the most vulnerable locations of the InnovA58 project (see fig. 2);
- Impact Assessment: the ROADAPT Socio-economic Impact Assessment was carried out to assess which measures are potentially viable;
- Adaptation Strategy: potentially viable measures have been plotted to establish an adaptation strategy for the InnovA58 (see table 2).

Figure 1: vulnerable locations for collapse of road embankments

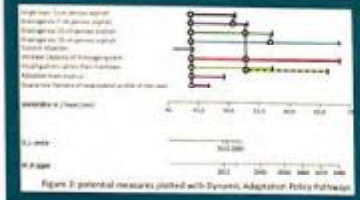

Figure 3: potential measures plotted with Dynamic Adaptation Policy Pathways

Key risks	Possible measures (non exhaustive list)
Flooding of infrastructure as a result of inundation	• Enlarge capacity of the existing bridges and/or culverts (wider/higher) • Elevating the road • Realizing upstream water retention • Increase maintenance
Flooding of infrastructure due to extreme precipitation	• Increase capacity of rainwater drainage system • Use gutters rather than gullies • Increase inclination of the road • Dimension/design intersections for extreme precipitation
Erosion of embankments	• Improving erosion protection
Loss of safety due to splash and spray	• Thicker asphalt for water drainage or vertical/vertical drains under the asphalt • Intensifying management and maintenance of verges and rainwater drainage • Adaptive lighting / notifications on the road
Flooding of streams and urban areas due to extreme precipitation	• Realizing water retention • Infiltration of pump water into aquifer • Preventing rainwater to drain into urban drainage systems

Table 2: Top risks for the InnovA58 and potential measures

CONCLUSION

- The ROADAPT method provides a clear tool for generating and assessing risks, consequences and possible measures;
- In addition, the Dynamic Adaptation Policy Pathways provide insight into which measures can be combined into an adaptation strategy;
- However, the methodologies are dependent on the input of local knowledge and the ROADAPT method is line-oriented, rather than area-oriented.
- Therefore, to be able to make an integral assessment of climate resilience of the road and its environment, a process that incorporates an area-oriented approach is absolutely needed. Such an area-oriented approach should be adaptive in itself, since future climate conditions and effectiveness of measures is uncertain.

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CEDR ROADAPT and FHWA Frameworks for Vulnerability Assessment in The Netherlands and Washington State - infrastructure climate resilience

Poster 10510

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Introduction and background

United States Federal Highway Administration (FHWA) and Rijkswaterstaat, the executive part of the Ministry of Infrastructure and Water Management in The Netherlands, work together on the topic of infrastructure climate resilience. Implementation of climate change resilience tools, developed in the United States and Europe, was tested on infrastructure projects in both countries, InnovA58 in The Netherlands and SR167 in Washington State.
Using these tools is anticipated to result in cost savings, as proactively planning for climate change is generally cheaper than waiting for infrastructure to be damaged.

Climate change adaptation frameworks for road infrastructure

ROADAPT : climate change adaptation framework for road infrastructure, sponsored by the Conference of European Directors of Roads (CEDR).

FHWA Climate Change and Extreme Weather Vulnerability Assessment Framework : Includes three main segments: 1. Define Scope; 2. Assess Vulnerability; 3. Integrate Results into Decision-making.
The Assess Vulnerability segment is compared with the ROADAPT Vulnerability Assessment tool, and contains three tools:

- Sensitivity Matrix to determine how assets like roads, bridges and railways may be negatively affected by extreme weather situations.
- CMIP Climate Data Processing Tool calculates local Temperature and Precipitation projections for transportation planners
- Vulnerability Assessment Scoring (VAST) Tool supports analysis and ranking of multiple assets.

InnovA58 project test area – The Netherlands

The InnovA58 project expands an existing highway in the southern part of the Netherlands from two lanes in each direction to three lanes in each direction. The project area experiences heavy downpours, which are increasing as the climate changes, resulting in localized flooding and need for enhanced stormwater management. The project is currently in the planning phase, and construction is expected to begin in 2020.

SR167 project test area – Washington State

The SR167 Project will complete a critical missing link to Interstate 5 near Tacoma, in Washington State. The project includes 10 km of new construction and five new interchanges. It traverses a floodplain of a minor tidal creek affected by sea level rise and is within the floodplain of a major river impacted by sea level rise, channel aggradation due to glacial retreat, and increased peak flows. The project area is experiencing increases in heavy downpours and continued urbanization that results in localized flooding. The project is currently in the design process. WSDOT expects to begin construction in 2019.

Results of comparison of frameworks

- The frameworks have similar approaches and result in comparable outcomes. Each framework has specific qualities and applicability.
- Results of methods are indicative; checking results based on expert judgment is of great importance.
- FHWA Sensitivity Matrix is useful to road managers with less experience in and knowledge of sensitivity to extreme weather and climate change of assets.
- FHWA VAST tool allows more manipulating of factors and weighting than the ROADAPT Vulnerability Assessment approach. This allows users of VAST to understand the sensitivity/robustness of results.
- ROADAPT framework lends itself to sharing information to the public / lay users. FHWA tools are spreadsheet-based and thus less accessible to a wide audience.

Conclusion

- These excellent frameworks can be used and customized by users to effectively identify extreme weather and climate change vulnerabilities, prioritize vulnerabilities, and develop adaption strategies.
- The main benefit of using the tools is that they help users determine the most vulnerable locations in an objective manner. This takes away any personal bias or over representation of well-known locations or assets.
- Testing frameworks in different countries and contexts is of great value.
- Comparison helps future users understand strengths and weaknesses of frameworks to be able to best apply them in projects.
- FHWA has used knowledge from testing in the FHWA Framework update. Rijkswaterstaat uses knowledge and experience for improved implementation of the ROADAPT framework, for benefit of other projects in Netherlands.

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Intra-Agency Skill Based Approach to Build a Resilient Work Force in State DOTs

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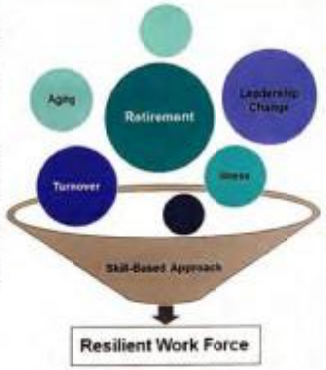
In an ever-changing environment, resilience is one of the most critical characteristics for an organization to survive and thrive. In the last two decades, studies were established to explore how organizations survive from the change of various external factors. However, some changing internal factors are also challenging the resilience of organizations.

The employee aging, retirement, and their physical and mental condition, associated with other internal issues, such as the lack of skill, succession strategy, raising the cost of agencies to maintain their organization continuity and development. Additionally, when leadership and management changes, their rich experiences and comprehensive understanding of the structure, precious resources, are lost. This usually leads to operational instability. Thus, developing a systematic method to retaining the skill-based resources for improving transportation agencies' resilience is important.



What is Intra-Agency Skill-Based Resilience

In different fields, resilience was defined through various perspectives. However, there were a few common definitions that most approaches included:

- The speed of recovering from disturbance;
- The magnitude of adversity that an entity can adapt;
- The ability to maintain its function;

As a critical aspect of organizational resilience, intra-agency skill-based resilience is defined as the ability of a government agency, such as a State Department of Transportation, to tolerate skill-related adversities and maintain its continuous operation, still producing a resilient transportation system.

Existing Management Strategy Review

Skill-based resilience is a new topic from a management perspective. There are few studies focused on this topic to review. Thus, reviewing other relevant topics in different fields is necessary. Some crucial elements in knowledge management, community of practice, change management, succession management, and employee resilience are examined.

Knowledge Management
- Storytelling – old but efficient way to capture and share knowledge.
- Expert system and knowledge mapping;

Community of Practice
- By developing a community of practice, an organization obtain the recognition of learning from and sharing knowledge with others.

Change Management
- Change management helps organizations to adapt the ever-changing environment by changing more spontaneously.

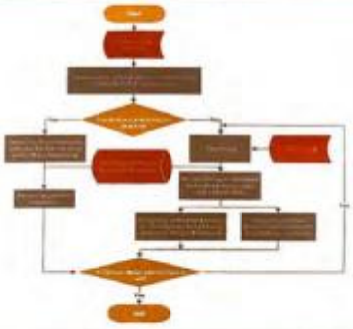
Succession Management
- Succession Management strategies can help multigenerational workplace to maintaining skills.

A Framework of Skill-based Resilience Strategy

This sample strategy has three major components – skill-based resilience culture, skill identification and location, and skill retention. The culture, as the bottom layer of this pyramid, is the most critical foundation part of this strategy. A good foundation gives this whole structure good stability. The second layer is skill identifying and locating. It depends upon the culture, which also support the skill retention layer to the top. The third layer moving up, is also the last layer before finally achieving the skill-based resilience: the retention layer. This layer relates to time and cost sensitivity to having a skill-based resilience strategy that works for an organization.

The intra-agency skill-based resilience has two dimensions that impacts the production of a resilient infrastructure system – agency's resilience and employee's resilience. An agency plans to achieve the skill-based resilience need to consider both systematic strategies and individual wishes. Researches unveiled the positive behavior, healthy workspace and employees' positive psychological capital are critical to support organizations facing significant changes. However, strategies coming from different levels can cause negative influences between agency and employees. Thus, it's necessary to discuss strategies from both perspectives to reach the equilibrium point.

The agency's dimension focuses on the organizational planning and management and its ultimate mission. The other dimension targets on potential influences on employees, which is driven by the agency's operational natures, as well as the need of employees. An example of agency's operational nature to be able to deliver the result of its mission is the use of performance assessment that can bring anxiety to employees in some cases. Thus, existing strategies will be examined for achieving skill-based intra-agency resilience.



This study explored the existing strategies developed for varied purposes. It served as an insight to develop a model for strategies of skill-based resilience through a systems thinking perspectives acknowledging real world interactions. Creating a workspace with skill-based resilience culture is considered the foundation of skill-based resilience. It's powerful to mitigate the resistance against maintaining operations when adversity occurs. The second more in-depth part of the model is the skill identification and location. Strategies or this part targets both hard and soft skills. Soft skills are usually hard to capture. However, through storytelling and personnel portraying, soft skills are possible to be identified. Skill retention is a well researched topic for which there are plenty of good strategies in the literature.

Focus of this work is on the resilience skill systemic approach, capturing ways a culture of resilience can become an integral part of the skill-based resilience personnel, and the transfer and continuity of this dimension supporting the agency's resilience dimension that enables the end result of the production of a resilient infrastructure system to come to fruition. With efficient skill transferring, the agency can maintain skills with less concerns on employee turnover, as well as improve the career adaptability of employees. Besides the model, some elements, such as employee resilience, are part of concern when developing strategies for achieving skill-based resilience. Critical infrastructure such as transportation need to continuously evolve in all resilience dimensions.

Delaware Resilient and Sustainable Communities League.
https://dnrec.alpha.delaware.gov/coastal-programs/planning-training/resilient-communities/sustainable-communities-league

RESILIENCE ASSESSMENT OF TRANSPORTATION TUNNELS

UNIVERSITY TRANSPORTATION CENTER
UNDERGROUND TRANSPORTATION

Sandeep Khetwal, Shiling Pei, Marte Gutierrez

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MINES

Motivation:

Tunnels are one of the most critical links in a transportation network and they greatly undermine network resilience when they lose functionality (either entirely or partially) due to disruptive events. However, most of the tunnel owners or managers typically analyzed these functionality loss events on a case-by-case basis. There is currently a lack of systematic data collected or analysis done to look into the overall trend for the occurrence and severity of such events. Some of the most critical questions of interest to tunnel owners are:

- In a given tunnel, what is the best and worst-case scenario function loss one can expect, when a certain hazardous condition occurs?
- Are there certain tunnel type, design, or management methods that are vulnerable to such functional interruption?
- Is there a statistically significant difference in the recovery time for the same event under different circumstances?

To answer this question, one needs a systematic collection of the tunnel function-loss data and based on the needs of resilience assessment, an "ideal" data collection framework to support resilience modeling.

Objective:

1. Developing ideal data collection framework in order to correlate tunnel functionality or performance with existing tunnel parameters.
2. Improvement of existing tunnel infrastructure, using a data-driven approach, by strategizing the distribution of funds for repair and upgrade.
3. Development of Probabilistic Model for tunnel function loss to complement the lack of available data.
4. The ultimate result of the previous objectives will be improvement in he design of tunnel, based on performance of existing underground transportation infrastructure.

Tunnel Functionality Losses: Some Major Incidents

Tunnel	Tunnel type	In service since	Date of event	Incident	Closure time	Cost* (million $)	Casualty (and injury)
Sasago tunnel, Japan	Uni-Directional	1977	12/2/2012	Ceiling collapse	68days	Not available	9 (2 injured)
Mont Blanc, France and Italy	Bi-directional	1965	3/24/1999	Vehicle fire	~3 years	451	39
Gotthard road tunnel, Switzerland	Bi-directional	1980	10/24/2001	Accident / fire	~2 months	14	11
Big-dig tunnel, I-90 connector tunnel, USA	Uni-Directional	2000	7/10/2006	Ceiling collapse	6 months	34	1
Tauern tunnel, Austria	Bi-directional	1975	5/29/1999	Fire	3 months	26	12 (49 injured)
Caldecott, USA	3 tubes	1964	4/7/1982	Collision / Fire	6 weeks	3	7 (2 injured)
Holland, USA	2 tubes, Uni-Directional	1927	5/13/1949	Goods falling / fire	3 days/ partially closed for 3 months	0.6	1 (86 injured)

Resilience:

Resilience is the measure of the ability of a system to resist an unusual disruption and to re-cover efficiently form the damage state induced by the disruption.

Resilience in Civil Infrastructure:

Resilience of the structure is its ability to function at a certain service level even after the occurrence of an extreme event and to recover to desired functionality as rapidly as possible.

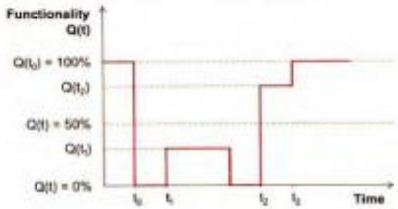
Resilience in Tunnel Infrastructure:

- Resilience study for transportation tunnels is in its nascent stage.
- There are a few resilience studies related to tunnels, mainly about specific hazards, like fire and lining.
- A general quantitative assessment of the tunnel based on functionality loss is not available.
- There is a lack of quantifiable data, determining improvement in tunnel's resilience, given a design or management change.

Tunnel Functionality:

- Simple metric – Defines state of tunnel operation, Ease of recording
- Functionality Q – Ratio of Traffic Capacity open to public to maximum traffic capacity
- Metric Considers – Tunnel lanes closure & Speed Limit

$$Q = \left(\frac{\#\ of\ open\ lanes}{Total\ \#\ of\ lanes}\right) \times \left(\frac{Reduced\ speed\ limit}{Normal\ speed\ limit}\right)$$



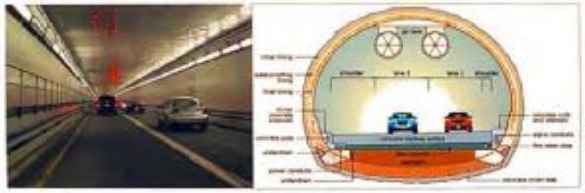
The graph shows typical function loss event in the tunnel versus time. The case considers, 1 Lane closure, in a unidirectional, 2 lane tunnel. The procedure is:

- Whole tunnel closed to set taper
- One lane opened with lower speed than maximum allowable.
- Task which caused closure performed. (Tasks like, washing of walls, inspections, replacements, etc.)
- Tunnel Closed again to remove taper
- Whole tunnel opened with lower than normal speed and then transitioned to normal speed

Transportation Tunnel: Complex Infrastructure

Tunnel Infrastructural Data (Information) division:

- Geotechnical – Geological profile, Support System, Drainage
- Structural – Geometry, Lining Type, E&M related structures
- Electro-Mechanical – Ventilation, Lighting, Power Supply, Cables, Control Rooms, etc.
- Safety – Cross Passages, Fire Suppression, Signs, Sensors and Alarms
- Interdependency of Systems

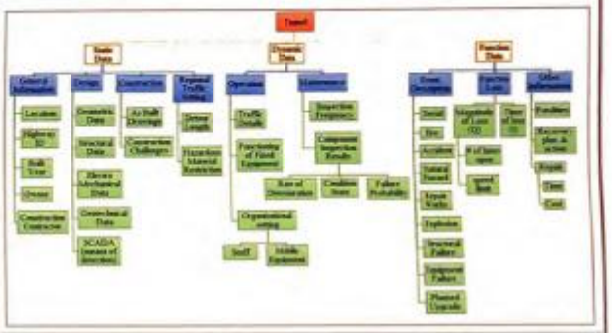


Typical Tunnel Image & Cross Section: (Left) Eisenhower Tunnel, (Right) Caldecott Tunnel's Fourth Bore

Data Collection Framework:

This study proposes to collect the tunnel data according to the framework shown below. The data can be broadly divided into Static, Dynamic and Function Data.

- Static – Tunnel data which does not generally change with time except when tunnel is upgraded
- Dynamic – Operation and Maintenance data, regularly updated
- Function Data – Performance data, in normal operation and with respect to an event. Resilience metric is derived from this data



Data collection framework to support tunnel resilience assessment

Concept & Future work:

- Performance prediction from model after upgrade and repair
- Calibration of model based on data

Acknowledgement:

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