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Technology

Emerging Technologies Help State DOTs Meet the Growing Challenge of Extreme Weather

As extreme weather events continue to take their toll on transportation, state DOTs need every possible tool to reduce vulnerability and respond and recover when events occur. This article highlights a wide range of promising technologies to help agencies respond to extreme weather events, including damage assessment technologies to aid state DOTs in rapid recovery, flood prediction software, and technologies for communicating with the public. Transportation agencies will increasingly look to advances in technology to help meet extreme weather challenges.

Pursuing 'Resilient Road' Technologies

While transportation agencies across the globe have been facing impacts from more frequent and severe floods, winter storms, dust storms, and heat waves, European researchers have been advancing a range of "resilient road" technology goals to proactively meet the growing challenge of extreme weather for transportation.

According to the Forum of European Highway Research Laboratories (FEHRL), "The resilient road will adapt itself to the impacts of extreme weather conditions and climate change. The road will monitor flooding, snow, ice, wind and temperature change, and mitigate their impacts through integrated storm drainage, automatic heating and cooling, and will be linked to the integrated information system for travelers and operations."

Among others, technologies that FEHRL has identified for resilient roads include:

- Rapid and automated inspection and survey methods, as well as sustainable maintenance measures and techniques for pavement, sub-surface, structures and drainage.
- Automated and remote sensors for measuring environmental conditions and change.
- Interaction between vehicle/road/driver.

FEHRL's resilient road is embedded in a larger concept called Forever Open Road, which also emphasizes environmental sustainability and optimization of daily roadway operations.

FEHRL's vision of the resilient road offers a comprehensive approach, and while some elements seem far in the future, others are based on current technologies which are either already in use or are well along in research. These include research on low-cost "smart skin" sensors at the Georgia Institute of Technology and research on damage assessment through unmanned aerial vehicles at the University of Vermont.

Disaster Response and Recovery Innovations

FEHRL's resiliency roadmap emphasizes building in resiliency for the long term, but there also is a need for technologies that support immediate response to extreme weather events. In late August 2013, the White House Office of Science and Technology Policy and Federal Emergency Management Agency convened a day-long meeting with innovators from Google and other organizations, challenging them to create new tools and services for disaster recovery and response. The resulting list of innovations included several that could be valuable for transportation agencies in the aftermath of extreme weather events:

- a technical schema that tags all disaster-related information from social media and news sites - enabling municipalities and first responders to better understand all of the invaluable information generated during a disaster;
- a Disaster Relief Innovation Vendor Engine (DRIVE) which aggregates pre-approved vendors for disaster-related needs, including transportation, power, housing, and medical supplies, to make it as easy as possible to find scarce local resources; and
- aggregating crowd-sourced imagery taken and shared through social media sites to help identify where trees have fallen, electrical lines have been toppled, and streets have been obstructed.

Meeting participants committed to follow up on these innovations, taking responsibility for turning the ideas into actions. For the first item above, participants actually wrote code and created working prototypes.

Damage Assessment Technologies Based on 2011 Iowa Flooding

After extensive flooding in Iowa in 2011, FHWA and Iowa DOT sponsored research on damage assessment technologies, based on actual deployment of the technologies in the field. The goal was "to assist county and city engineers by deploying and using advanced technologies to rapidly assess the damage … and develop guidance for repair and mitigation strategies and solutions for use during future flood events in Iowa."

The resulting report by Iowa State University relied on in situ testing after the flood waters receded and several months later in order to evaluate recovery and performance, especially subsurface foundation layer characteristics over time.

The report, published in August 2013, documents nine different field assessment techniques and twenty different potential repair/mitigation solutions for paved/unpaved roads, culverts, and bridge abutments. The damage assessment techniques are as follows:

- Aerial and LiDAR imagery review. This is often the first step in damage assessment after an extreme weather event - reviewing aerial images of the affected area (which can be obtained from commercial satellite imagery or aircraft flyovers), together with Light Detection and Ranging (LiDAR) elevation data. Based on this review, state DOTs can better determine where and how to proceed with other damage assessment technologies.
- Visual inspection. As the name implies, visual inspection requires staff who can view a damaged area to determine the nature and extent of the damage. Visual inspection plays a basic and vital role in evaluating damage, which can then be captured with photos or videos, but it requires physical access to locations and is often only possible after floodwaters have receded.
- Dynamic plate load tests. These tests are used to rapidly determine ground stiffness/modulus, in both surface and subsurface layers, using devices such as light-weight deflectometers (LWD), falling weight deflectometers (FWD), and Clegg hammers.
- Penetration tests. These tests take two forms: push T-bar tests can be used to detect voids or weep holes near the surface, while dynamic cone penetrometer (DCP) tests can determine the "California bearing ratio" of gravel base and subgrade layers, generally up to a depth of about 1 meter.
- Roller-integrated compaction monitoring. This is a technology that records and displays measurements of compaction, using sensors integrated into compaction machines. According to the report, "This technology can be used on gravel/base/subgrade layers to detect areas of concern to apply appropriate stabilization to improve the conditions. The data obtained using this technology is geo-referenced and can be easily imported into ArcGIS for data archiving and visualization."
- Ground penetrating radar (GPR). GPR can be used after a flood to detect (a) voids or weep holes beneath paved or unpaved surfaces; (b) voids or erosion in bridge abutment backfill, and (c) depth to a water table. It operates by sending an energy pulse into the ground, then recording time and strength of the return of the reflected signal.
- Surface laser scanning. This technology is helpful for road breaches or backfill erosion behind bridge abutments, by rapidly calculating earthwork volumetrics through three-dimensional laser scanning, with capability for overlaying photos and contour lines and obtaining volumetric calculations in real time.
- Underwater sonar scanning. This can be used to assess damage near key bridge abutments and culverts, especially erosion behind backfill and debris blockage in culverts. Even before floodwaters have receded. It can provide two-dimensional and three-dimensional images underwater or in low-visibility areas.
- Pipe Crawler for Culvert pipe inspection. This technology involves attaching a robotic mobile crawler to underwater sonar scanning devices in order to conduct underwater inspections inside culverts.

The report provides a helpful flow chart which links the damages observed to assessment techniques and potential repair solutions.

Unmanned Aerial Vehicles and Satellite Imagery

U.S. DOT is sponsoring research on two promising new approaches to damage assessment at the University of Vermont (UVM), with the goal of aiding state DOTs in rapid assessment of damages and rapid emergency response and recovery. The objectives of the research are to:

- develop, calibrate and deploy a decision support system capable of identifying road and bridge damage from high-resolution commercial satellite images; and
- test lightweight Unmanned Aerial Vehicles (UAV) programmed to fly over damaged road segments, in order to better gauge the location and extent of damage in inaccessible areas, and particularly to estimate the amount and type of fill material required for repairs.

For the first objective, UVM notes that commercial remote sensing imagery is increasingly used by state DOTs and others in disaster response and recovery, but "…acquiring imagery is far easier than extracting actionable information from it." Moreover, according to UVM, satellite image files are very large and not easy to read, and "…traditional automated image analysis techniques are inadequate for identifying or characterizing road and bridge damage from high resolution imagery."

To meet these challenges, UVM intends to collaborate with the Vermont Agency of Transportation (VTrans) and other state DOTs to develop a web-based interface to share information from commercial remote sensing imagery.

For the second objective, unmanned aerial vehicles are particularly promising for state DOTs which have stretches of roadways that might be inaccessible after an extreme weather event. Photography from these vehicles can provide more detail (including 3-D images) compared to commercial satellite imagery and can be activated if timely commercial satellite imagery isn't available.

Fortunately, cost is not a major challenge, as an unmanned aerial vehicle system costs only about $26,000. In addition, current challenges in obtaining governmental permits (e.g., from the Federal Aviation Administration) are expected to diminish in the next year.

With these two damage assessment technologies, state DOTs like VTrans will be able to launch recovery efforts faster, with more complete information, as well as provide better information to affected households, businesses, and governments. VTrans and the Maine Department of Transportation are both involved in guiding the research, which is partially funded by the U.S. DOT. UVM welcomes ideas from other state DOTs on use of both of these new technologies, through contacting Jarlath O'Neil-Dunne, Faculty Research Associate and Director of the UVM Spatial Analysis Laboratory.

Gathering Road Weather Information

When asked about technologies for extreme weather events, Richard Shaw of New Jersey DOT emphasizes "The first thing I want is a good weather forecast - short and long range." But Shaw, NJDOT's Assistant Commissioner for Operations, recognizes that weather prediction will always be challenging. Shaw said he relies heavily on roadway weather information systems (RWIS).

RWISs are not a new technologies, but they are continually improving through better siting of roadside sensors, "connected vehicle" research, and integration of RWIS information into traffic operations centers.

The Clarus Initiative, which Shaw said NJDOT has found particularly helpful, was launched by US DOT as a research project in 1995. The goal of the initiative is to improve the accuracy and timeliness of road weather information for state DOTs and others. Clarus - which means "clear" in Latin - has enabled participating state DOTs to link to near-real-time weather information at precise locations in their own states and surrounding states, providing key information to respond to weather events.

According to U.S. DOT, "Thirty-eight state DOTs, five local agencies and four Canadian provinces have connected 2,437 Environmental Sensor Stations (ESS) to Clarus for a total of 54,251 individual sensors…"

While the contract to run Clarus as a research project ended in June 2013, the Federal Highway Administration is transitioning Clarus to the National Oceanic and Atmospheric Administration as an operational system that will continue to be available to state DOTs.

To cope with weather variability in Alaska, the Alaska Department of Transportation and Public Facilities (ADOT&PF) has been equipping maintenance vehicles with devices that gather location-specific data on roadway temperature and humidity, feeding the data into a weather modeling system which predicts likelihood of roadway icing. This enables ADOT&PF to mobilize snow and ice treatment more quickly and efficiently - which helps with both "normal" weather variations as well as climatic changes. According to Mike Coffey, ADOT&PF Director of Maintenance and Operations, "This kind of technology gives ADOT&PF the ability to be in two places at once. Employees can keep an eye on infrastructure during extreme cold temperatures, and we can learn how the cold impacts structures. This technology is giving us real-time information to make smart decisions, fast."

There are many other road weather technologies and management systems in development or recently deployed. They are relevant for both normal weather variations as well as extreme weather. More information is available on FHWA's road weather management website.

Flood Prediction Models

State DOTs also may benefit from improved computer models aimed at predicting floods.

The U.S. Army Corps of Engineers is developing more sophisticated flood prediction models, which could be implemented by state DOTs to help with asset management and emergency response. In particular, HEC-RTS (Real Time Simulation) is a multi-tiered flood prediction model that links to existing Corps Hydraulic Engineering Center software and can be coupled with NexRAD radar predictions to predict flooding as storms approach. It is a multi-tiered dynamic watershed and riverine flood modeling system. The model can also incorporate an economic impact component- HEC-FIA.

While it is still in its beta version, and while it is designed primarily with Corps water management functions in mind (e.g., controlling dams and reservoirs), Nick Wark of the Vermont Agency of Transportation believes it could be helpful to state DOTs, both in design of highway facilities and in emergency planning in the face of expected flood conditions. Wark notes that one challenge will be its extensive data requirements.

Justin Lennon, a water resources engineer for Parsons Brinckerhoff, also said it could be helpful to state DOTs, citing two particular applications:

- flood early warning system for roads with known inundation problems, where the risk of loss of life warrants the implementation of this type of predictive system along with measures for closing the flood risk areas, and
- bridge scour early warning system with similar concerns, but only applied to scour critical bridges as a technology-based means of monitoring the structure and enabling early closure if critical/high flow conditions are predicted.

Extreme Weather Communications

Extreme weather events require effective, timely communications with the public, about road closures, detours, evacuations, and hazardous conditions. While most state DOTs rely heavily on 511 systems and traffic information websites, social media are growing in importance for extreme weather communications.

Jarrod Ravencraft of Mississippi DOT (MDOT) and Kelli Reyna of Texas DOT (TxDOT) particularly emphasized that their departments have come to use social media heavily, stressing that the public expects and demands it. The public wants mobile communications available to them wherever they are.

Ravencraft noted that in Mississippi the demand for social media communications isn't coming just from people in their 20's or college-educated citizens, but rather from a wide swath of the public.

Both Ravencraft and Reyna pointed out, however, that new forms of social media are emerging constantly and advised against jumping on each new format. Instead, they said, do a careful evaluation, and determine whether a new format has staying power and whether "your public" really needs and wants it. MDOT has found Twitter more powerful than Facebook and found that Linked-In is especially useful for information sharing with corporate entities during weather events.

TxDOT has found social media to be very helpful in staging evacuations, especially after Hurricane Ike. In addition, TxDOT uses social media to transmit video and photographs to the public, so they can see for themselves the road conditions and will be more likely to follow TxDOT advice and directions. TxDOT road crews capture extreme weather and road conditions on video or in photographs, and transmit them immediately to TxDOT Public Affairs staff, who then make them available through social media, the TxDOT website, and to news media.

While social media are growing in importance, Ravencraft said MDOT's traffic website is still "the hub" of their communications with the public. This very powerful site includes camera shots, tools for travelers to select routes for real-time notifications, and a key source of information for freight shippers and carriers.

Effective, reliable communications among state DOT staff and coordinating agencies also are critical during extreme weather events.

Richard Shaw, with New Jersey DOT, had first-hand experience during "superstorm" Sandy in 2012. He described inter- and intra-agency communications as "pretty well under control," drawing on cell phones, satellite phones, and an 800 Megahertz radio system that was designed to be interoperable across agencies.

Jarrod Ravencraft similarly described MDOT's extreme weather communications within and across agencies, noting "Cell phones are the biggest piece of the puzzle and will continue to advance. And satellite communications are available as our back up."

NCHRP Report 753, A Pre-Event Recovery Planning Guide for Transportation, includes the following helpful checklists for using communications technology during extreme weather events and other disasters:

Pre-Event Actions

- Identify and provide communications equipment required for recovery operations.
- Collect communications equipment instructions.
- Compile radio frequency lists, including on-scene emergency frequency for local/regional agencies.
- Develop internal and external communications procedures, including establishing message transmission protocols and procedures to establish mobile communication recovery centers.
- Plan exercises to practice implementing communications protocols and to identify gaps in communications procedures.

Considerations

- Include multiple types of equipment such as handheld satellite systems and hand-held radio systems operable as "point-to-point" as well as repeaters.
- Include replacement batteries for issued mobile radios.
- Provide mobile communications radios for assisting agency command personnel in the event that these personnel are not equipped with radios using the same frequency.
- Include local, state, and national channels. Collect channel and frequency being used.

- Define clear and streamlined communications protocols among responders, engineers, contractors and all other impacted stakeholders including the media. Ensure that information can be passed quickly and, importantly, horizontally.
- Update information lists and procedures based on experience with the exercises.

Other Technologies

There are many other technologies which can help state DOTs respond to extreme weather vents as well as the more gradual impacts of a changing climate. Indeed, virtually all transportation technologies can be called upon to meet this challenge.

Beyond the technologies covered above, roadway and structural sensors are being developed and deployed to detect potential failure due to weather-related and other stresses. In addition, the extensive array of traffic operations technologies are crucial during and after extreme weather events to reduce loss of life, speed evacuations, and optimize traffic flow during and after emergencies.

Even seemingly mundane technologies such as generators play an important role in extreme weather events and warrant technological advances (or at least specialization) for extreme weather situations.

All these technologies are constantly evolving, both in the research stage and in effective deployment. They are valuable tools for dealing with extreme weather, especially in combination with vulnerability assessments, risk assessments, and asset management.

Resource Links

Additional information on technologies for responding to extreme weather may be found at the following links:

- AASHTO Transportation and Climate Change Resource Center: Adaptation Topic
- AASHTO 2013 Extreme Weather Events Symposium
- FHWA Road Weather Management website
- FHWA Climate Change Website
- FEHRL's Forever Open Roads resiliency technologies
- NCHRP Report 753, A Pre-Event Recovery Planning Guide for Transportation
- Western Iowa Missouri River Flooding-Geo-Infrastructure Damage Assessment, Repair, and Mitigation Strategies