Transportation Infrastructure Resiliency: A Review of Practices in Denmark, the Netherlands, and Norway

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To promote system resiliency and prevent road destruction, a new culvert in Norway was designed using design flows that reflect engineering judgment, lessons learned from past flooding, and anticipated future precipitation increases. All Photos: Federal Highway Administration.

Extreme weather events and changes in climate pose significant challenges to the highway transportation community in the United States. From heat waves and droughts to storm surges, these events can not only damage roads and bridges but also result in large repair costs and disrupted travel. State and local transportation agencies across the country have begun to assess the vulnerabilities that their roadway systems and operations face from these climate risks. While there are some notable examples of cities and states using climate science and technology to implement responses, many agencies are early in the process of understanding climate vulnerabilities and implications and developing adaptation and resilience strategies.

Learning from Abroad

Transportation agencies in other countries face similar and sometimes more urgent climate challenges to their transportation infrastructures. Some of these countries have made significant progress in developing strategies for reducing climate risks at the national level and have begun integrating climate projections into design criteria and specifications for transportation infrastructure projects. Some have also employed systematic methods to address some of the inherent uncertainties in predicting climate changes and to manage the associated risks.

To help inform and advance similar efforts in the United States, the Federal Highway Administration (FHWA) undertook a Global Benchmarking Program (GBP) study in 2015 to learn how transportation agencies in other countries are adapting their roadway infrastructures to severe weather events and changes in climate, and to identify innovative and best practices to help advance the development and implementation of resilience strategies in the United States.[1] This article, which is based on the GBP study, summarizes key policies and practices identified through the study and how FHWA is putting this knowledge to use for domestic benefit. Note that some practices may have been updated since the study's publication.

As part of the study, FHWA conducted technical field visits and discussions with officials from transportation agencies in Denmark, the Netherlands, and Norway. These countries were selected based on information gathered from a "virtual review," which used webinars to gather information from a broad range of countries and to identify where climate adaptation and resilience activities have been implemented and have yielded demonstrable results.

Policies

The GBP study observed two policies across all three countries that catalyzed progress in developing and implementing resilience strategies:

- **Clear national government support for infrastructure resilience:** Climate change is a primary motivator, with little resistance or controversy, for project-level decisions. Strong national government support for infrastructure resilience facilitates action by the transportation agencies. In addition, each of the three countries has climate resilience strategy documents that provide direction to government agencies.

- **Close collaboration between science and transportation agencies:** Climate scientists and transportation engineers and planners work jointly to develop, interpret, and apply climate projections to transportation design processes. In addition, meteorological and science agencies have mandates, resources, and funding to provide climate projections and interpretation to support transportation agencies and others.

Practices

In Denmark, the Netherlands, and Norway, practices for integrating climate projections into highway planning and design procedures include the following:

- **Incorporating future projections:** In Denmark, roads are often designed to accommodate a 25-year rainfall event. However, as a warmer atmosphere holds more water, heavy rainfall events are projected to become even heavier. The Danish Road Directorate uses climate model projections to update future storm depths. The current 25-year storm in Denmark drops 58 mm (2.3 in.) of rain, but by 2050, the 25-year storm is projected to dump 65 mm (2.6 in.) of rain. When building a road with a design life extending to 2050 or beyond, Denmark now considers the depth of the future 25-year storm, not just current conditions.
- **Using information on the direction of change:** There is generally much greater certainty regarding the direction of change than the exact magnitude and timing of change. Knowledge of the expected direction of change (for example, increasing or decreasing precipitation) is sufficient for some decisions. For instance, based on knowledge that debris and water flows are expected to increase as the climate changes, Norway has installed debris deflectors or screens on newer projects to keep debris out of drainage systems, and energy dissipaters in channels and culverts to reduce increased velocities.
- **Applying climate factors:** Norway has multiple alternative climate factors that are used by its climate science agencies (the Norwegian Water Resources and Energy Directorate [NVE] and the Norwegian Meteorological Institute [MET]) and the Norway Public Roads Agency (NPRA). In Norway, the expression "climate factor" conveys the relationship between the value of a parameter (for example, runoff or precipitation) today to the value of that parameter in the future under the influence of climate change. The NVE applies climate factors to watershed flows, and the MET applies them to precipitation. The NPRA recognizes these factors but does not necessarily use them in design. Currently, the NPRA applies a climate factor of 1.0 to 1.5 to its design flows to reflect engineering judgment, past flooding, and anticipated future precipitation increases. However, the factors may be revised as NPRA's highway design manual is updated. For now, the climate factor for installations that have a life expectancy of 100 years is 1.3 for a 10-year return period of precipitation, 1.4 for 100 years, and 1.5 for 200 years. The NPRA advises its regional offices on the best data to use, and recommends making calculations based on several combinations of input parameters, performing a rough estimate of costs, and choosing the most cost-effective solutions.
- **Updating technical guidance:** The NPRA added consideration of climate change to its manuals on project planning, design, operations, maintenance, and network management. For instance, the maintenance manual recommends implementing climate adaptation measures as part of scheduled maintenance. Norway also developed new guidelines for hazards exacerbated by climate change: rockslides, debris flows, slush avalanches, and snow avalanches. Finally, Norway is creating a drainage textbook incorporating new requirements on climate adaptation, erosion, pollution control, and traffic safety.
- **Adjusting rainfall depth-duration-frequency curves:** Rather than using climate factors, the Netherlands' transportation agency increases rainfall depth-duration-frequency curves by 30%. This percentage is based on the Royal Netherlands Meteorological Institute's analysis of precipitation projections for 2050 using a warmer climate scenario.

Managing Uncertainty

Denmark, the Netherlands, and Norway are moving forward with risk reduction by managing uncertainties rather than allowing uncertainties to stymie action. Although there is scientific consensus that the climate is changing, there is uncertainty regarding the exact magnitude and timing of changes. Areas of uncertainty include the level of greenhouse gas emissions humans will produce in the future, natural climate variability, and the computer models scientists use to model Earth's many complex physical processes. Uncertainty is managed in the following ways:

- **Scenario analysis:** The Royal Netherlands Meteorological Institute developed four climate change scenarios for use in the Netherlands. This allows agencies to account for uncertainty by considering the performance of agency policies under a broad range of plausible scenarios. Two scenarios reflect a future with moderate warming, whereas the other two scenarios reflect a future with higher levels of warming. Temperature and precipitation projections for each scenario are expressed not as single values, but as ranges reflecting natural variability and model variability.
- **Flexible adaptation pathways (or adaptive management):** Researchers in the Netherlands advocated choosing flexible strategies with time frames that allow for course

Because debris and water flows are expected to increase as the climate changes, Norway has installed debris deflectors or screens on newer projects (top) to keep debris out of drainage systems, and energy dissipaters in channels and culverts (bottom) to reduce velocities.

changes as new information emerges. The decision tree or pathway is mapped out over a timeline. Transfers from one adaptation strategy to another can be made at various points in time. As the climate changes, some adaptation strategies have a limited window of effectiveness, at which time they run into terminals or tipping points and new pathways must be followed. Each of the pathways can be rated qualitatively for cost effectiveness and possible unwanted side effects.

- **Conservative assumptions:** As a precautionary approach, the three countries use the high end of the range of national climate projections.

Study Benefits

FHWA has used knowledge gained through the GBP study in the following ways to address infrastructure resilience challenges in the United States:

- FHWA applied findings from the study to the update of its "Vulnerability Assessment and Adaptation Framework,"[2] which guides transportation agencies in assessing the vulnerability of transportation assets and implementing strategies to reduce risks. The framework update also incorporated all three countries' insights and experiences from using ROADAPT (roads for today, adapted for tomorrow) guidelines,[3] the European equivalent of FHWA's framework.
- Danish, Dutch, and Norwegian approaches to choosing the more extreme greenhouse gas emissions scenarios associated with future precipitation projections have influenced the FHWA narrative on scenario selection associated with more critical assets in a major update of its technical guidance document, Hydraulic Engineering Circular 17, "Highways in the River Environment."[4]
- Observing the close collaboration between science and transportation agencies has encouraged FHWA to increase its cooperation with federal agencies such as the U.S. Geological Survey, the National Weather Service, and the U.S. Army Corps of Engineers.
- Study findings guided FHWA's work to develop procedures for addressing climate change in project-level scoping studies.
- The study was an important step in gathering needed technical information for implementing FHWA Order 5520,[5] which establishes policies related to preparedness and resilience to extreme events associated with changes in climate.

Conclusion

FHWA's responsibilities include developing, prioritizing, implementing, and evaluating risk-based and cost-effective strategies to minimize risks and protect critical infrastructure using the best available science, technology, and information. The GBP study was an important step in gathering needed technical information for implementing this requirement.

For additional related information, see also FHWA's TechBrief on climate change adaptation for pavements[6] and its Transportation Engineering Approaches to Climate Resiliency (TEACR) Study.[7]

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