Transportation Infrastructure Resiliency:

A Review of Practices in Denmark, the Netherlands, and Norway

The U.S. Context

Extreme weather events and changes in climate pose significant challenges to the U.S. highway transportation community. From heat waves and droughts to storm surges, these events can not only damage roads and bridges, they can 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, most 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 infrastructure. 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 connected to changes in climate and to manage the associated risk.

In order to help inform and advance similar efforts in the U.S., FHWA undertook a Global Benchmarking Program (GBP) study in 2015 to learn how transportation agencies in other countries are adapting their roadway infrastructure 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.

As part of the study, two FHWA representatives 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.

This brief summarizes the key policies and practices identified through the study and how FHWA is putting this knowledge to use for domestic benefit.

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—with little resistance or controversy—is a primary motivator regarding 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. This close collaboration has encouraged FHWA to increase its cooperation with other federal climate science agencies such as the US Geological Survey, the National Weather Service and the US Army Corps of Engineers.

U.S. Department of Transportation
Federal Highway Administration

Integrating climate projections into highway planning and design procedures

■ **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 used climate model projections to update future storm depths. The current 25-year storm in Denmark drops 58 mm of rain, but by 2050, the 25-year storm is projected to dump 65 mm. When building a road with a design life out 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 (e.g. 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, on newer projects, Norway has installed debris deflectors or screens to keep debris out of drainage systems and energy dissipaters in channels and culverts to reduce increased velocities (see figures 1 and 2).

Figure 1 (Above): Debris screen at culvert in Norway. Photo credit: FHWA

Figure 2 (Left): Energy dissipater with roughness elements in culvert in Norway. Photo credit: FHWA

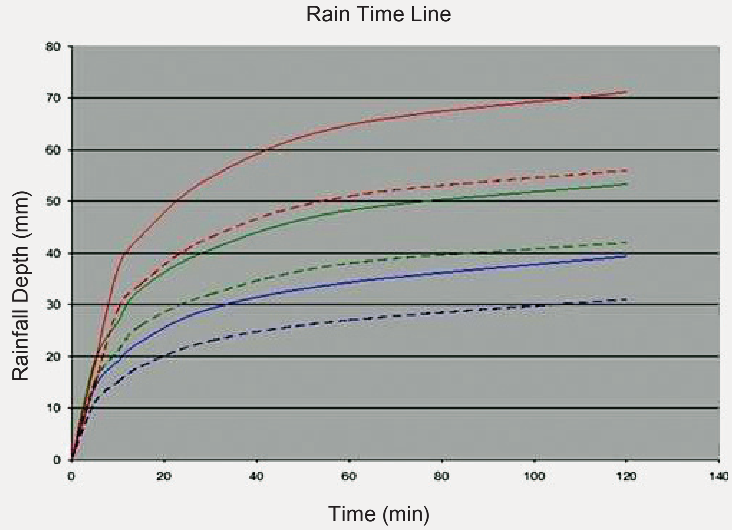

Figure 3: Rainfall depth-duration-frequency curves that the Netherlands uses to reflect climate trends. The future depths (solid lines) are projected to be 30 percent higher for the 10-, 50-, and 250-year frequency curves (blue, green, and red, respectively). Dashed lines represent current rainfall depths. Source: Buishand and Wijngaard, 2007.

■ **Applying climate factors.** Norway applies a climate factor to its design flows to reflect engineering judgement, the history of past flooding, and expected future precipitation increases. For installations with a life expectancy of 100 years, Norway multiplies flows by a factor of 1.3 for the 10-year flow, 1.4 for the 100-year flow, and 1.5 for the 200-year flow. Multiplying past conditions by a climate factor allows for a rough approximation of probable future conditions without undertaking a detailed climate model downscaling effort.

■ **Updating technical guidance.** The Norway Public Roads Agency 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 and 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 percent (see figure 3). This percentage is based on the Netherlands Meteorological Institute analysis of precipitation projections for 2050 under a warmer climate scenario.

Managing uncertainty

The countries visited are moving forward with risk reduction by managing uncertainties rather than allowing uncertainties to stymie action. While there is scientific consensus that the climate is changing, there is uncertainty regarding the exact magnitude and timing of changes. Sources of uncertainty include uncertainty regarding the level of greenhouse gas emissions humans will produce in the future, natural climate variability, and uncertainty in the computer models scientists use to model Earth's many complex physical processes.

■ **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, while two other scenarios reflect a future with higher levels of warming. Within each of these two categories, one scenario reflects greater change in air circulation patterns that influence overall humidity while the other reflects a lesser change. Furthermore, the 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.** Researchers in the Netherlands advocated choosing flexible strategies with timeframes that allow for changing course 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 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 countries visited use the high end of the range of national climate projections.

Emergency management tools

■ **XGEO.** The Norwegian government uses a suite of interactive tools, many on mobile phone platforms, to inform the travelling public of weather hazards and road conditions. These tools integrate data such as avalanche forecasts from climate science agencies, road closures from road agencies, and photos and reports from the general public. The applications use common maps and have layers of security governing public and professional access. They provide the public with warnings on which roads may be vulnerable to floods, avalanches, and landslides. Near real-time feedback from the traveling public can help officials react to road closure events and set up detours. Weather station data, stream gage data, and road condition information can be accessed from a single location at *http://xgeo.no*.

Multi-sectoral, large scale adaptation

Large scale storm surge barriers. The Netherlands uses large-scale storm surge barriers to protect highly urban areas. For example, opened in 1997, the Maeslant storm surge barrier consists of two interlocking gates designed to come together and fill with water, sink, and thereby block storm surge from entering the waterway that leads to the Rotterdam port. This barrier provides protection for one million people, as well as the Rotterdam port facilities. It obviates the need for many smaller site-specific resilience measures in the areas protected.

Figure 4: The Maeslant Storm Surge Barrier, one of the facilities of the Delta Works project in the Netherlands. Left photo shows normal operation with ship moving upstream with gates in open position. Right photo shows gates in closed position during high surge event.
Source: Deltawerken online media gallery at www.deltawerken.com/

Study Benefits

Knowledge gained through the GBP study is being used by FHWA to address U.S. infrastructure resilience challenges.

- FHWA is applying findings from the study in its update of the *FHWA Climate Adaptation Framework,* which guides transportation agencies in assessing the vulnerability of transportation assets and implementing strategies to reduce risks. All three countries visited use ROADAPT, the European equivalent of FHWA's *Framework*. FHWA is incorporating their insights and experience with using ROADAPT into FHWA's *Framework* update.

- Danish, Norwegian and Dutch approaches to choosing the more extreme 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 the technical guidance document, *Hydraulic Engineering Circular (HEC) 17: Highways in the River Environment.*

- Study findings are informing FHWA's work to develop procedures for addressing climate in project level scoping studies.

- FHWA Order 5520 establishes policy on preparedness and resilience to extreme events associated with changes in climate. 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.

- FHWA is broadly disseminating lessons learned from the GBP study through presentations and frequent interactions with State DOT and MPO partners.

- In addition to the valuable knowledge gained, the study allowed FHWA to establish valuable connections with counterparts in Denmark and Norway, which has resulted in ongoing information exchange and collaboration on this topic.

- The study also strengthened FHWA's collaboration with Dutch counterparts. Under a bilateral agreement, FHWA, Washington State DOT, and the Netherland's Rijkswaterstaat are testing European and U.S. climate change analytical tools on a major highway construction project in Washington State and in the Netherlands. This cooperation also includes exchanging information on techniques for incorporating climate change precipitation projections into hydrologic analysis and design of highways, bridges, and culverts.

Figure 5: New culvert in Norway designed to prevent road destruction.
Photo credit: FHWA

The Global Benchmarking Program

The Global Benchmarking Program (GBP) serves as a tool for accessing, evaluating, and implementing global innovations that can help FHWA respond to U.S. highway challenges. Instead of re-creating advances already developed by other countries, the program focuses on acquiring and adopting technologies and best practices already available and used abroad. This is accomplished through studies that connect FHWA technical experts, either directly or indirectly, with transportation advances around the world and with the people involved in applying them. The program also provides structured implementation support to facilitate the implementation and/or adaptation of promising findings in the U.S. context. Ultimately, the goal of the GBP is to help avoid duplicative research, reduce overall costs, and accelerate improvements to our transportation system.

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