Considering the Uncertainty for Large Projects

By Lewis E. Link

Recently a $15 billion project, one of the largest and most sophisticated U.S. public infrastructure projects ever undertaken, was completed in New Orleans in response to the devastation caused by Hurricane Katrina in August 2005. The project was necessitated by the failure of a Hurricane Protection System (HPS) that could not withstand the test of time and a hurricane that created conditions not believed to be likely. This combination led to exposure of flaws in the design of some structural components. It also demonstrated that non-stationarity is real in a number of dimensions and that we cannot become complacent about past assumptions and/or guidance.

Large uncertainty in the data and guidance/standards were the basis of the initial HPS design criteria that resulted in the system that Hurricane Katrina so devastatingly exposed. The uncertainty started with the hazard, the likelihood of experiencing different levels of surge and wave conditions in and around New Orleans. That uncertainty continued with the structural designs and the expected performance of levees and floodwalls, including discrepancies in the as-built elevations of some key structures. And finally, the uncertainty concluded with the assumption that what was in place in and around New Orleans would perform as a system, including associated capabilities for pumping, evacuation, and emergency response. The result was over 1,500 fatalities and up to $200 billion in economic losses.

The hurricane hazard for pre-Katrina high-performance computing was rooted in the 1960-1970 body of knowledge. That meant using a design storm concept, being a single Standard Project Hurricane (SPH) thought to represent the most severe hurricane “reasonably likely” to occur in the area. In contrast, the Hurricane & Storm Damage Risk Reduction System (HSDRRS) design criteria was based on a joint probability analysis of a cadre of 152 hurricanes that represent the spectrum of storms deemed possible for the region over the life of the project (some considerably more severe than Hurricane Katrina). An additional complication was the statistics changed dramatically with time. In the 1965 time frame, a hurricane like Katrina (measured based on its intensity or central pressure deficit) would have been considered a 900-year storm. In the mid-1980s and with additional data and understanding, the National Weather Service criteria would have reduced that number to about a 300-year event. In 2006, based on even more data and knowledge, National Oceanic and Atmospheric Administration (NOAA) criteria would have estimated Katrina’s return period as roughly a 100-year storm. To cap it off, these estimates do not represent the return period for the surge that Katrina produced (estimated to be in the neighborhood of a 400-year period for some areas). Katrina created water elevation conditions considerably more severe than projected for the SPH, especially on the east side of New Orleans.

Katrina's surge and waves caused over 50 severe breaches of the floodwalls and levees surrounding New Orleans. Many of the levee breaches were measured in miles, not feet. The levee breaching was caused by massive overtopping and erosion. Floodwalls too failed by overtopping and erosion, but some failed before overtopping largely because the failure mode that occurred was not considered in the design process. Other than the traditional freeboard (the height above the high-water mark of a structure associated with water, such as a dam or levee), resilience to overtopping was not part of the design. This performance reflects a system designed and constructed using criteria that was erroneously considered adequate at the early stages of the HPS development but not modified or updated over time. When Katrina struck (40 years after authorization of the HPS), the system in place was considerably less capable than believed and not nearly equal to the task of mitigating this massive hurricane, an event far more severe than the early hazard represented. The HPS system criteria were not upgraded to deal with these changes nor were the physical structures. The risk in New Orleans rose with time from both changes in the hazard and in the vulnerable population and property.

Why was the HPS not updated? Largely because the HPS was constructed over decades rather than years, with piecemeal funding and use of a congressionally mandated cost-sharing concept between the federal and state entities involved. Needless to say, this was an overwhelming challenge to design and construct, and ultimately, an overwhelming challenge for the people and the city of New Orleans. When Hurricane Katrina made landfall on August 29, 2005, the HPS initially authorized in 1965 was not yet completed and what was completed was outdated.

The new HSDRRS was conceived and constructed by a much different process, with significantly more sophisticated criteria and construction. The HSDRRS, in contrast to the HPS, was fully funded, using modern and advanced criteria and knowledge within a short time frame (2008-2011). It also incorporated deliberate and quantitative consideration of the major sources of risk and uncertainty, including the hazard, the performance of system components, and system interdependencies with related capabilities, such as pumping and emergency operations. Also, it was recognized and communicated up front that the HSDRRS was not the end-all for protecting New Orleans.

While significantly reducing the risk (annual expected losses) for the area, significant residual risk remains that must be recognized and addressed. This has led to a number of regional initiatives by the federal and state governments to identify additional measures (structural and nonstructural) that would work in concert with the HSDRRS to further reduce risk. Given the experiences of the past, it is likely that this system too will be found to have unanticipated vulnerabilities as new knowledge emerges concerning hazards and system performance. What remains to be seen is if this system also will suffer from the lack of upgrades or improvements necessary to maintain a desired risk profile.

An approach to deal with the non-stationarity and uncertainty associated with large infrastructure projects is revealed in the strategy being taken by the Government of the Netherlands to deal with that country's extensive water management infrastructure in the face of changing climate, social, and economic conditions. The Netherlands recently completed a major study of its entire riverine and coastal infrastructure (Delta Model) to determine its sensitivity (in terms of risk) to a range of potential social and physical changes. The results have been used to formulate an adaptive strategy for dealing with change (and the large uncertainties involved). By identifying the relationships between the magnitude of social/physical change and the performance of infrastructure systems, the Netherlands has developed a strategic approach (Delta Program) to incrementally adapt its infrastructure systems as the levels and types of change become more certain.

By identifying now the types of infrastructure modifications or additions that the incremental system will be required to deal with in different change scenarios, the infrastructure can be evolved in a step-by-step, coordinated, and synchronized way that avoids rampant speculation about the degree of future changes, over- or under-design, and surprise. It also facilitates incorporation of new knowledge as it emerges, and provides for a more reasonable and credible resourcing stream that can be an adaptive long-term strategy in its own right.

About the author: Lewis E. Link is a research professor at the University of Maryland. He was inducted into the National Academy of Construction in 2014.