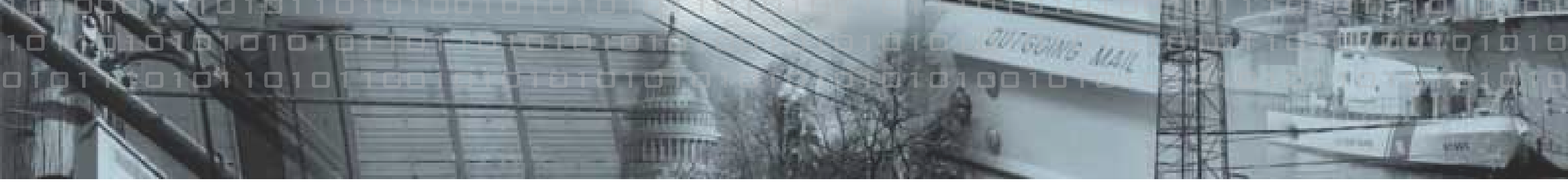

THE CIP REPORT

CENTER FOR INFRASTRUCTURE PROTECTION
AND
HOMELAND SECURITY

September 2013
Aging Infrastructure

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VOLUME 12 NUMBER 3

GEORGE MASON UNIVERSITY
School of Law
CENTER for INFRASTRUCTURE PROTECTION and HOMELAND SECURITY

This month's issue of *The CIP Report* focuses on Aging Infrastructure. Infrastructure disrepair, degradation, and obsolescence threaten interests throughout all sixteen critical infrastructure sectors. Our authors tackle the complicated challenges in resource prioritization, stakeholder cooperation, and risk assessment in surmounting the problem of Aging Infrastructure.

First, Richard Little, AICP, of Rensselaer Polytechnic Institute explains that in order to avoid the "tipping point" of rapid and irreversible infrastructure failure, stakeholders must invest in routine inspection, maintenance, and repair before aging causes a measurable decline in infrastructure performance. Next, Black & Veatch offer risk-based budget optimization as the key asset management practice to achieve the right balance between performance, cost, and risk. Then, Dr. Dan McNichol addresses the demand for immediate investment in the nation's failing critical infrastructure in order to thwart disaster and the accompanying human and fiscal costs. Jassandra Nanini, J.D. of CIP/HS follows with a discussion of the Fukushima nuclear disaster and need to fundamentally rethink nuclear energy resilience to include aging concerns and all-hazards risk assessment in the very design of nuclear facilities.

We would like to take this opportunity to thank this month's contributors. We truly appreciate your valuable insight.

We hope you enjoy this issue of *The CIP Report* and find it useful and informative. Thank you for your support and feedback.

Mick Kicklighter
Director, CIP/HS
George Mason University, School of Law

Enjoying the Golden Years: Coping with the Challenges of Aging Infrastructure[1]

by Richard G. Little, AICP
Visiting Research Scholar, Department of Industrial and Systems Engineering, Rensselaer Polytechnic Institute*

Whenever a major piece of infrastructure fails, usually with loss of life and high economic costs, the question is always raised whether excessive age and poor condition were to blame. Physical condition certainly played a role in some spectacular infrastructure failures in the United States, such as the New Orleans levees in 2005, the I-35 highway bridge collapse in Minneapolis in 2007, and the San Bruno, California natural gas pipeline explosion in 2010. Not surprisingly, in the aftermath of such incidents, calls for increased expenditures to "restore the infrastructure" hail from the media, public interest groups, and some politicians. However, is it really as simple as that?

At their most basic level, civil infrastructure systems facilitate the functioning of modern society and contribute to the overall quality of life and well-being. Earthquakes, extreme winds, floods, snow and ice, volcanic activity, landslides, tsunamis, wildfires, terrorism, and sabotage are active hazards that can damage infrastructure systems, interrupt the services they deliver, and endanger people and property. Interdependencies between systems further compound the problem. However, aging materials, inadequate maintenance, and excessively prolonged service lives are passive threats to infrastructure that are more insidious but can be equally disruptive. Additionally, when excessive age or inadequate maintenance weakens infrastructure systems, they become more vulnerable to otherwise survivable events.

Of course, infrastructure can do more than fall down or blow up. Systems that fail to keep up with changing technological demands also can become a drag on economic activity and present safety hazards. For example, long delays in moving the U.S. air traffic control system from twentieth century ground-based radar to twenty-first century satellite-based GPS has hindered efficiency gains in air travel that could increase safety and save travelers and shippers time and money. Most existing track and railbed in the United States is not capable of safely handling high-speed passenger trains, limiting the deployment potential of a technology that could measurably ease congestion and reduce travel times in select corridors. Similarly, many railway tunnels built in the nineteenth century, long before the advent of container freight, cannot accommodate today's double-stacked cargo containers, reducing the freight capacity of some east and gulf coast ports. These are random examples of physically sound but technically obsolete infrastructure components and systems that arguably pose as much risk to the national well-being as crumbling concrete and corroded steel.

Putting aside the politics of mankind's contribution to the phenomenon, climate change also poses a threat to older infrastructure. Sea levels are rising globally, placing coastal areas at greater risk of storm surge and flooding as a result. Many vital systems locations, such as the New York City subway, were decided years ago without a thought to this eventuality, but Superstorm Sandy changed all that. How such legacy systems are adapted to reduce their vulnerability to future, unknown conditions will be a major challenge to the infrastructure community. Whether infrastructures are

(Continued on Page 3)

[1] This article was adapted from "Managing the Risk of Aging of Public infrastructures" presented at the International Risk Governance Council (IRGC) expert workshop on Public Sector Governance of Emerging Risks, September 17-18, 2012 in Lausanne, Switzerland.

(Continued from Page 2)

hardened to resist the threat or relocated to avoid it, the cost of doing either will be substantial.

Further complicating the equation, infrastructure age, in and of itself, does not always appear to be the primary driver of infrastructure failure—it is neither necessary nor sufficient for failure to occur. For example, the United States experienced three significant bridge collapses in the 1980s—the I-95 Mianus River Bridge in Connecticut (Figure 1), the I-87 Schoharie Creek Bridge in New York, and the U.S. 51 Hatchie River Bridge in Tennessee. Two of the bridges had been in place for less than 30 years and the Hatchie River Bridge was 54 years old. By contrast, the Brooklyn Bridge (1883) (Figure 2), George Washington Bridge (1931), and Golden Gate Bridge (1937) are still in service today. A far more significant risk factor in these cases is the role that the lack of adequate and timely maintenance and repair (M&R) played in their demise.[2] This is a key point that can lead to an improved understanding of the risk of infrastructure failure and better-informed policies, guidelines, and regulations to reduce that risk.

Despite our obvious dependence on the services that infrastructure provides, the public is skeptical of

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Figure 1. The Mianus River Bridge Following Collapse of the Northbound Span in 1983

Figure 2. The Brooklyn Bridge, 130 Years Old

[2] NTSB (National Transportation Safety Board). 1984. *Collapse of a Suspended Span of Route 95 Highway Bridge over the Mianus River, Greenwich, Connecticut,* (HAR-84/03), National Transportation Safety Board, Washington, D.C.; NTSB. 1988. *Collapse of New York Thruway (I-90) Bridge, Schoharie Creek, near Amsterdam, New York*, (HAR-88/02) National Transportation Safety Board, Washington, D.C.; NTSB. 1990. *Collapse of the Northbound U.S. Route 51 Bridge Spans over the Hatchie River near Covington, Tennessee*, (HAR-90/01), National Transportation Safety Board, Washington, D.C.

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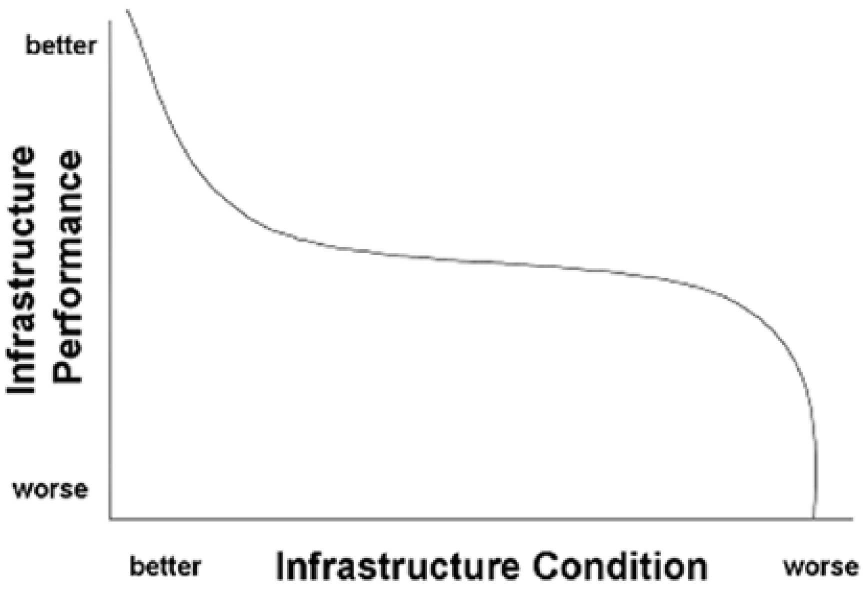

Figure 3. Infrastructure Condition Affects Its Performance Mostly at the Extremes

constant calls for increased investment (that they will ultimately pay for) to maintain existing systems and build new ones to replace the old. Unfortunately, the warning signs of infrastructure in distress are subtle and making a case that the general public can readily grasp is challenging. Mapping infrastructure performance to age and/or condition is by no means a straightforward exercise.

When systems are new and physical condition is good, performance will be high; conversely, when the condition of infrastructure is very bad, either as a result of age, neglect, or both, performance will suffer. However, as shown in Figure 3, there is a considerable range over which condition deteriorates without noticeably affecting performance. This long period of gradual performance decline can lead decision-makers and the public to believe that investment in routine inspection, maintenance, and repair is an unnecessary expense that can be deferred without penalty. Unfortunately, this fosters a "tipping point" environment for failure. Although the time leading to infrastructure failure may be quite long, once failure begins, it proceeds rapidly and irreversibly. In other words, once the levee breaks or the bridge is falling, it is too late to schedule needed repairs.

But how much is enough? The search for an "optimal" M&R investment strategy has been something of a Holy Grail to the infrastructure community and rightly so. Each year, tens of

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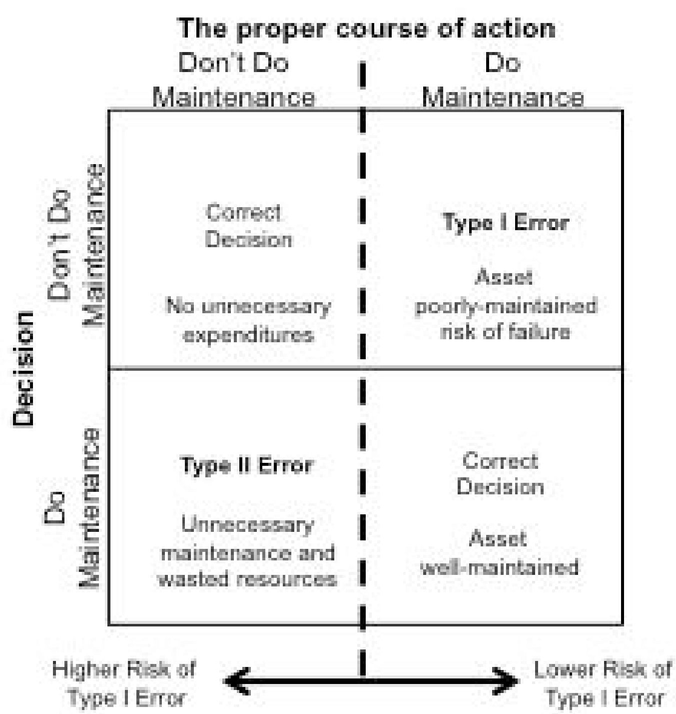

Figure 4. Asset Management Strategies Must Balance Risk and Cost

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billions of dollars are spent in an effort to maintain satisfactory performance levels for these systems. Public agencies and private corporations alike grapple with the question of how much they should spend to maintain their infrastructure assets and at the same time, wonder if they are spending too much. The goal, as shown in Figure 4, is to avoid spending more than necessary while avoiding the excessive frugality that could bring on calamity.

Changing public perception on an issue whose effects emerge slowly is rarely quick and seldom easy. Despite fifty years of an aggressive campaign to raise awareness about the health risks of smoking, people continue to engage in this harmful behavior. By comparison, the September 11th terrorist attacks raised awareness immediately and led to a "teachable moment" wherein political action was possible (Figure 5).

Similar teachable moments have not taken root with infrastructure, possibly because that with few notable exceptions such as the flooding of New Orleans in 2005, past infrastructure failures have not caused great bodily harm or loss of life. For example, although certainly spectacular, the San Bruno pipeline explosion resulted in only 8 deaths; 13 people died in the collapse of the I-35 bridge in Minneapolis, and there were no reported deaths resulting from an epidemic of water main blowouts in Los Angeles in 2009. At the same time, the amount of money necessary to "rebuild our infrastructure" is very large. The American Society of Civil Engineers estimates a rolling five-year need in the United States in excess of $2 trillion or about $1300 annually on a per capita basis. This compares with per capita expenditures of about $3400, $3000, and $2900 for health care, education, and defense, respectively. In a time of budget sequesters and threatened government shutdowns, it will be difficult to muster the political will to generate this level of funding.

Regardless of what is done

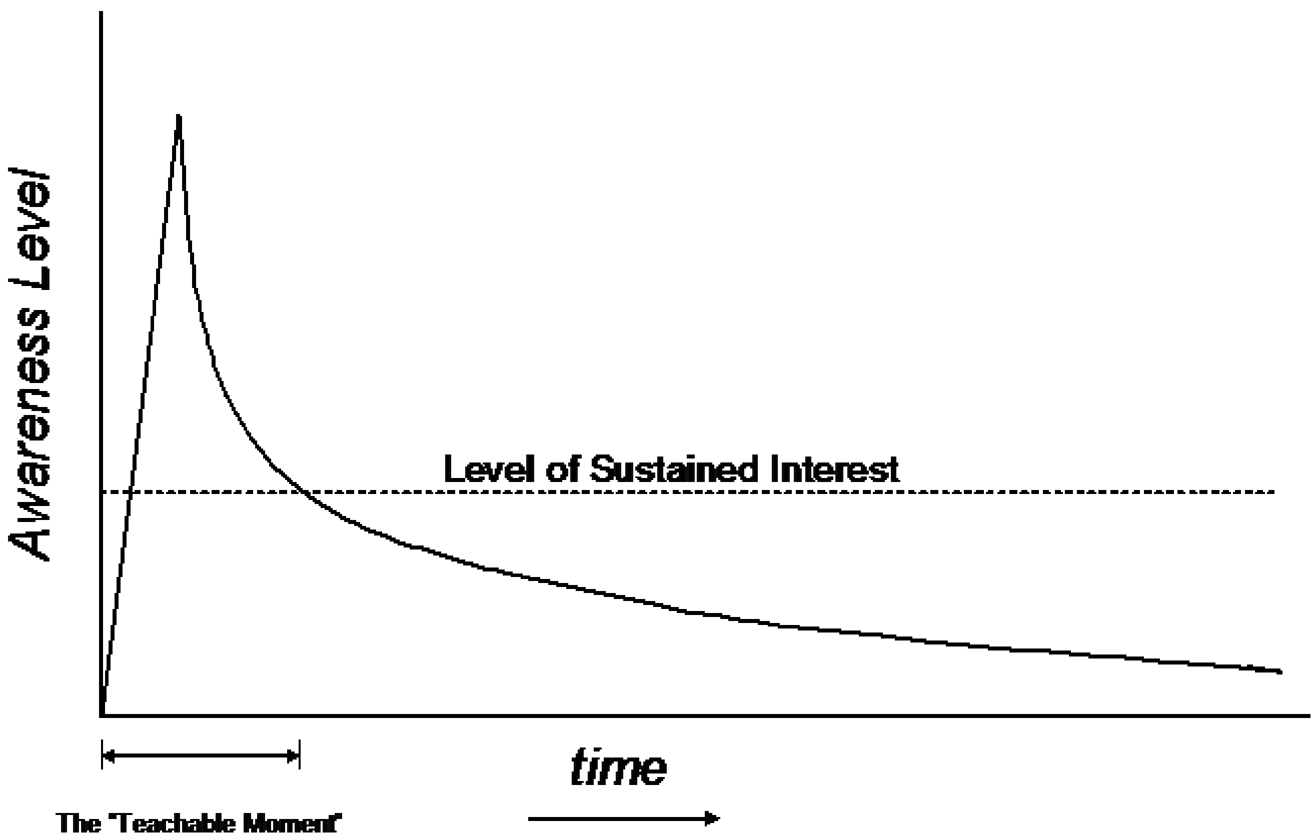

Figure 5. "Teachable Moments" Following an Event Can Drive Political Action

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(including the option of doing nothing) to address the risk of infrastructure failure today, it will have implications for the future. Funds expended for infrastructure renewal to reduce the risk of failure will not be available for other current priorities (the opportunity cost burden). Funds spent today "so that our grandchildren will not have to bear the cost of our shortsightedness" must overcome the effects of discounting over time. Depending on the discount rate chosen, the present economic value of future benefits decreases rapidly with time and it is quite rational (if not necessarily moral) to assign little or no value to the future. This incompatibility of timescales is a fundamental driver in our widespread disinvestment in infrastructure.

Despite these obstacles, we can begin to draw up a list of actions that could form the basis for how an environment more conducive to overall risk reduction could be fostered.

• Make risk management an enterprise goal for governments and infrastructure agencies. The adoption of foundational documents such as ISO 31000[4] would provide a basis for sustained action.

• Adopt and promulgate infrastructure risk reduction as core values through all levels of the responsible organization. For years, the Dupont Corporation has held safety on an equal footing as profitability and no one in the corporate chain is exempt. Cultures can change.

• Develop broad stakeholder support for risk reduction and collective action through meetings and dialogue at all governmental levels. The benefits of risk management activities must be understood if they are to be supported by the public and their elected officials.

• Hold management accountable for organizational risk performance; good performance should be rewarded and poor performance corrected.

• Develop the necessary funding sources and financing strategies for better asset management and risk reduction. Water boards in the Netherlands fund flood defense mostly with locally generated taxes and fees. Local solutions are possible.

• Continue to expand our understanding of how infrastructure age and condition affects its performance and risk of failure. Technological advances offer many opportunities to improve asset management and reduce risk.

Although there are many lessons to be learned from around the world, all politics are local. What is possible in a small country like the Netherlands that faces a well-recognized and existential threat from the sea is quite different from what can occur in the much larger and broadly diverse United States. A strong government in Singapore can compel national actions to a degree unthinkable here. However, despite the challenges, we can adopt and apply good risk management practices and blunt the threat to national well-being posed by aging and obsolescent infrastructure systems. ❖

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[4] http://www.iso.org/iso/home/standards/iso31000.htm.

Risk Based Asset Investment Approaches to Improve System Resilience

by Mike Elenbaas, Martin Jones, Arlin Mire, and Will Williams
Black & Veatch*

Executive Summary

The need to invest in and address the growing risk of aging infrastructure and an aging workforce has put increased financial and performance pressures on U.S. utilities. For many, the response has been to adopt asset management practices to achieve the right balance between performance, cost, and risk. Risk-based budget optimization, already used extensively in the United Kingdom and Australia to target and prioritize investment, is key to this response.

Recent legislation, such as Senate Bill 560 recently passed in Indiana, highlights both the problem and the solution that risk-based planning provides. Frameworks for the implementation and governance of good practice asset lifecycle management must be adopted so that any investment plan developed now is continually improved and refined over time. The release of ISO 55000 later this year will provide an opportunity for the rapid uptake of leading practices by utilities in multiple sectors.

Aging Infrastructure and Aging Workforce are Strategic Issues for Utilities

Recent research[1] reiterates a number of key post-recession issues facing utilities. The need to manage risks related to aging infrastructure and the need to capture key knowledge, processes, and procedures while managing an aging workforce have become top concerns. Utilities are also faced with the lack of regulatory appetite to raise rates, lack of available capital, and the need to further reduce capital and operating costs.

As a result, the utility industry is shifting its emphasis away from identifying new build opportunities and toward optimizing the operations and maintenance practices of its existing asset base. Utilities are starting to adopt asset management practices as part of their strategic planning as a means of delivering levels of service to their customers while achieving the best balance of performance, cost, and risk.

Utility commissions and legislatures across the United States are also recognizing that funding is needed to make well-targeted investments in aging infrastructure. Recent legislation, such as Senate Bill 560 in Indiana, provides mechanisms for utilities to develop sound, long-term investment plans that improve system reliability and customer experience while stimulating the regional economy.

Successful Business Cases for Dealing with Aging Infrastructure

Assembling a successful business case in a world where aging infrastructure is a significant and ever increasing problem requires more than just the conventional elements, such as problem statements or simple benefit-cost analysis. Utilities are being required to put together comprehensive business cases that include a sound assessment of the investment need, the investment priorities, and the type of investment. A core foundation for the business case should address the trade-off between performance, cost, and risk. Although business cases have historically addressed some or all of these issues, a comprehensive analysis of all three within an interconnected framework should be conducted to appropriately consider their interrelationships. Conducting the analysis requires a clear understanding of the relationship between performance requirements now and in the future, lifecycle costs of ownership, and failure risk. Clearly, each utility has specific performance targets and risk tolerance. Figure 1 visualizes this

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[1] Black & Veatch, 2013 *Strategic Directions in the U.S. Electric Industry and 2013 Strategic Directions in the U.S. Water Industry* (2013).

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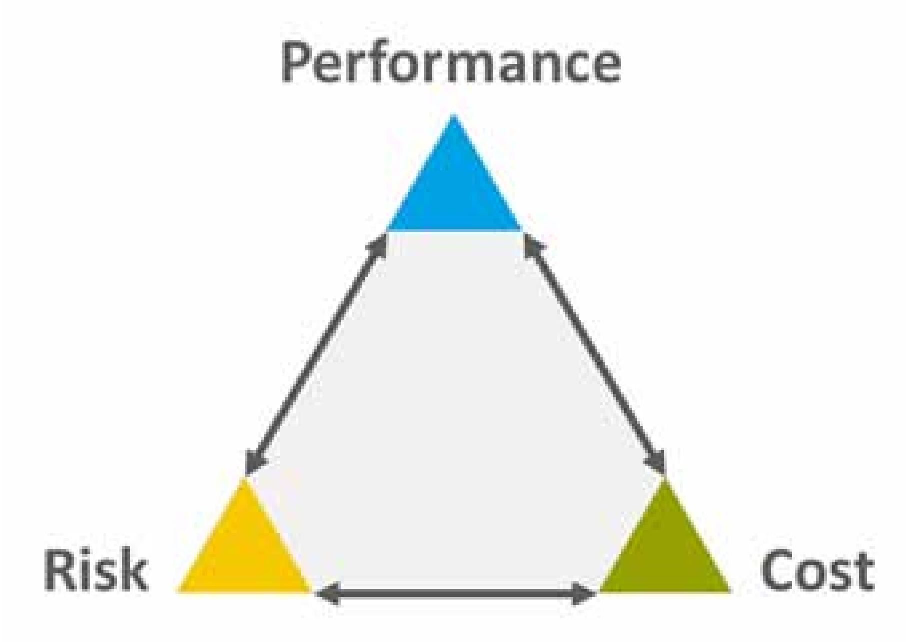

Figure 1: Trade-off between performance, risk, and cost

concept of balancing the tradeoffs.

Risk Management

Risk can be defined as the "effect of uncertainty on objectives."[2] It is typically represented as the combination of the probability and consequence of an event occurring. The international standard, ISO 31000:2009, Risk management – Principles and guidelines, is an international standard for the implementation of risk management principles. Figure 2 shows the ISO 31000:2009 risk management process.

A risk assessment identifies risks through activities, such as condition monitoring, inspections, and network analysis. Risk analysis determines the likelihood and consequence of an event occurring, and typically involves the use of a risk matrix (Figure 3, p.10). Risk evaluation compares the level of risk identified with the organization's risk tolerance to determine the need to reduce or eliminate the risk.

Following the risk analysis, risk treatments or mitigations are developed. Different mitigation solutions should be assessed, such as capital projects or changes in the magnitude, targeting, and type of operation and maintenance activities. Figure 3 shows how the reduction in risk for different mitigation solutions can be assessed, and, when combined with cost, can

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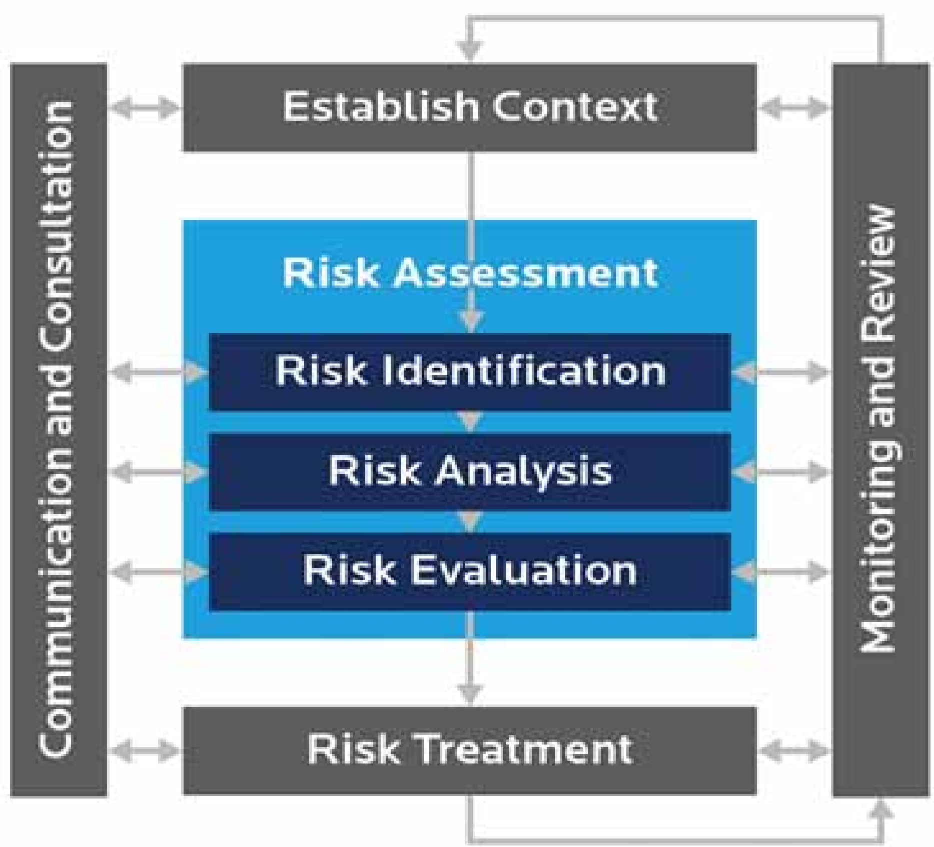

Figure 2: Risk Management Process

[2] ISO Guide 73:2009—*Risk management – Vocabulary* (2013).

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be used to assess the cost/benefit of each solution.

Risks change over time. Continual monitoring and review of risks and the effectiveness of risk treatments is a key part of the overall risk management process, as is communicating those risks and consulting with stakeholders. The risk management process described above is used by many organizations for their risk frameworks, and forms the basis for risk- based planning in asset-intensive industries, such as utilities.

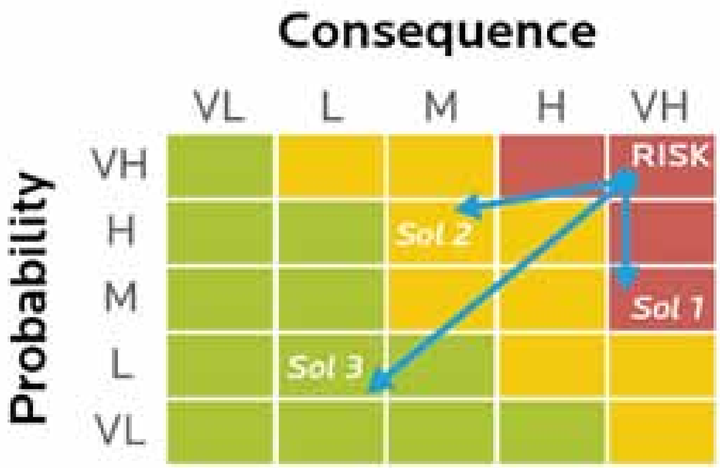

Figure 3: Example of risk reduction for different risk

Example of Risk-Based Replacement Planning

More and more utilities are turning toward a risk-based approach to long-term infrastructure investment planning. A risk-based replacement analysis provides a robust basis for investment planning as it considers the criticality of assets and likelihood of their failure, which enables investment to be targeted at the highest risk assets.

A medium-sized Midwestern electric utility recently applied risk-based replacement planning as part of its long-term capital plan to replace its transmission and distribution infrastructure. The analysis developed consequence factors, including loss of generation, loss of connected load, safety issues, transmission system planning violations, and environmental impacts. Each asset received a criticality score or every applicable factor in the event of that asset's failure. Likelihood of failure for a particular asset was based upon its current performance/load, age, failure rates of similar assets, and vintages and technical obsolescence. In addition, deterioration curves were used to develop the likelihood of failure of different asset classes.

After consequence and probability of failure for each asset in the system was scored, a risk score was calculated using a risk matrix, similar to the matrix shown in Figure 3. The assets were categorized and plotted on the risk matrix to identify which asset groups carried the most risk and, therefore, deserved the most attention for investment planning. This provided a consistent framework for quantifying risk in the system and helped the utility balance the risk inherent in its aging electric system with performance and cost objectives. The utility could then make capital prioritization and allocation decisions that considered overall system risk and develop a balanced and optimized long-term capital plan.

Similar risk-based approaches are being deployed in the water and gas utility industries to target performance improvement and risk management at the least life-cycle cost. In short, risk-based approaches are enabling utilities to effectively target the rehabilitation or replacement of the right assets in the right way at the right time.

Asset Management Frameworks

To ensure that utilities realize sustainable benefits from the adoption of risk-based planning approaches, it is essential that the right processes and systems are in place, and the appropriate data is available to support decision-making. An asset management framework helps an organization establish these processes and systems to support asset life cycle management. Risk management is at the heart of the framework.

The U.K.'s Institute of Asset

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Management developed Publicly Available Specification 55 (PAS 55) to provide guidance on good practice asset management. Updated in 2008 with inputs from more than 50 different organizations across 15 industry sections and 10 countries, PAS 55 is the only asset management standard that has been adopted worldwide. Continual improvement is an important concept of PAS 55 is, and it is designed around the widely utilized Plan, Do, Check, Act framework. Applying good practice asset management approaches will ensure that any investment plan developed now is continually improved and refined over time.

ISO 55000, an international standard for asset management based on PAS 55, is currently in development with support from approximately 22 countries, including the United States. It incorporates the risk management approaches defined in ISO 31000. Asset management strategic planning is one of its key concepts. ISO 55000 will provide an opportunity for the rapid uptake of leading asset management practices by utilities in multiple sectors. It is scheduled for publication in late 2013.

Conclusions

Utilities are relying more on asset management as part of their strategic planning efforts to help achieve the best balance of performance, cost, and risk. Applying risk-based investment prioritization to developing long-term asset rehabilitation and replacement programs results in improved business cases to justify expenditure. It also improves targeting of investment on critical assets, resulting in a more efficient capital program, better returns on investment, shareholder confidence, and higher levels of customer satisfaction.❖

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Rust = Risk

by Dan McNichol, Ph.D.*

"America's infrastructure is as old, rusty and energy defunct as my 1949 lead-sled," is the message I'm driving—literally driving. On Labor Day, 2013, I set out on a circumnavigational journey around America in my original Detroit classic car. As an author, journalist, and advocate I'm dedicating the next six months, and 15,000 miles on my odometer, to the re-building of America. I believe that we need to build smarter, safer infrastructure faster than the maddening slow pace we the citizens currently accept. Central to the tour's theme is the significance of robust structures to our homeland's security.

The empirical data I'm primarily drawing on belongs to the American Society of Civil Engineers (ASCE). They are the guardians of our built systems. As the oldest body of our country's engineering practices, they're duty bound to communicate the depth of the infrastructure crisis we're in the midst of. Smartly, they've simplified the message, over decades of delivery, by assigning an academic letter grade to the cumulative state of our structures: D+. That's right, a failing grade by any standard, our infrastructure as a whole has a GPA that no parent wants to see their child score in a subject, let alone in totality.

Putting more than gas in the tank of my 1949 Hudson, which I've named Mrs. Martin in honor of the matriarch that was her only owner prior to my purchase on eBay, is Case Construction Equipment. The Racine, Wisconsin based firm has partnered with me and understands not only the challenges facing our infrastructure today, but also the importance to our nation's economy and wellbeing that can be fostered through smart infrastructure development. Around the country we're hosting forums to dive deep into the problem. Together we are asking town folk, business people, and governmental leaders to own their infrastructure, to step towards the crisis by demanding robust systems and replacing aging structures that are becoming hazards to pubic safety, if they are not already, for the wellbeing of our communities.

Right Now—Everywhere

If the decrepit state of our infrastructure is addressed immediately, we have just enough time to save countless lives and trillions of dollars—ambitious, but possible. This crisis's urgency has two faces. One face is practicality—the longer structures such as

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bridges, dams, levees, subways, water systems, and even schools are left to the forces of decay, the wildly more expensive the costs become. The second face is disaster. Natural and manmade disasters seem limitless. Hurricanes, tsunamis, and earthquakes are growing in intensity while the trigger of political instability is more likely going to be pulled by a small group of radicals with little to lose as opposed to Cold War superpowers with everything to gain by keeping the peace.

Lifelines are the travel routes search and rescue teams take to the heart of a disaster. Depending on location and the destruction endured, airports, roadways, and bridges allow first responders to act quickly when minutes matter most. In San Francisco Bay, the $7 billion rebuild of the San Francisco-Oakland Bay Bridge was undertaken after the 1989 Loma Prieta Earthquake proved that the pre-World War II bridge, designed and built with pre-World War I type steel, created a risk to the general population in the aftermath of an earthquake. The 75-year-old structure's dangerously decrepit portions were put to rest the day I began my journey, Labor Day 2013. That's good news—except that the rebuilding effort took 24 years.

When Hurricane Sandy, a Super Storm the size of the state of Texas, surged up the mouth of the Hudson River we witnessed how vulnerable our "toughest" city is. Dozens of lives and billions of dollars could have been saved had highway tunnel entrances been built with higher storm surge walls. If rudimentary steps had been taken to protect electrical systems, both subterranean systems and above ground lines, the crisis would have been minimized and recovery time reduced. This is not a matter of connivance—it's a matter of life.

Be Real—Sound the Alarm

I like Ike. I believe Dwight D. Eisenhower was one of our great presidents. My mother tells anyone who'll listen that the book I wrote about the undertaking, *The Roads That Built America: The Incredible Story of the US Interstate System*, is my life's work. Ike's mantra was the middle, believing that modesty was government's responsibility, wasteful spending its demise. In 1956, in keeping with this philosophy, he launched the most ambitious public works project in world history: The Dwight D. Eisenhower System of Interstate and Defense Highways. Counter-intuitively, he knew spending billions modernizing our transportation system and building safer structures would save hundreds of lives every day, not to mention reduce carnage at large.The economy would surge with efficiencies brought on by modernizing. In 1955 he wrote in his personal journals the most he ever did, about nuclear strikes he feared would kill millions of Americans. Eisenhower—the man, the general, the President—was certain millions more would be saved because resilient structures would allow rescue and rebuilding to begin immediately.

Susan Eisenhower, the President's granddaughter, and I shared a stage at an infrastructure conference several years ago. She told us at the conference that the Interstate System was her grandfather's favorite domestic achievement.

A little digging into film archives produces interviews with the President saying so himself. Ike dedicated his life to serving God and Country. As our Supreme Allied Commander during the Second World War, and as the nation's Commander in Chief, he believed it was necessary to build robust systems that strengthened the economy in peace—the same systems he was certain would protect the nation against catastrophe.

Ike believed the Citizen Soldier was the best solider. The legendary general citizens protecting their homeland fought the hardest. It's time to revisit our own dedication to country to reevaluate what's important to the United States of America. I'm certain Ike would say it's time to begin rebuilding our infrastructure in order to strengthen our nation by saving lives, building better, by taking ownership. ❖

**Dan McNichol is a best selling author writing about America's infrastructure. Reach Dan at: info@danmcnichol.com.*

Lessons from the "Island of Good Luck": Innovating Nuclear Power and Aging Infrastructure Resilience After Fukushima

by Jassandra K. Nanini, J.D.

The advent of nuclear fission as a uniquely powerful source of energy production has revolutionized the international energy industry with promises of increased sustainability and price predictability for energy resources around the globe. While disputes regarding the efficiency, environmental impact, and safety of nuclear power abound, the fact remains that over 430 nuclear power plants exist throughout 31 countries and supply over 13% of the world's electricity.[1] The United States alone houses 65 plants with 104 reactors, which have generated about 20% of U.S. electricity each year since 1990.[2] Whether or not nuclear power fulfills the promise of sustainable, clean, and low-cost energy, existing plants and those in development pose a profound challenge to critical infrastructure security and resilience in the global energy sector.

Nuclear reactors require extensive cooling systems to prevent the immense energy produced from melting the reactor itself and releasing radioactive materials. Efforts to address the aging nature of nuclear infrastructure generally focus on assessments of equipment and structures that serve reactor safety functions and pay special attention to materials that may suffer age-related degradation and failure. A focus on the infrastructure tends to limit assessments of safety weaknesses that are related to installation design or configuration, leaving the accuracy of safety assessments devoid of contextual, all-hazards considerations.[3]

For over two decades, the U.S.S.R.'s 1986 Chernobyl disaster stood as the most catastrophic nuclear accident in history—the only occurrence rated by the International Nuclear and Radiological Event Scale (INES) at the maximum level of 7, being characterized a "Major Accident." Health-related fatality estimates range from under 10,000 to over 40,000,[4] and the total clean-up and resettlement cost estimates exceeded $235 billion.[5] Investigations attributed the cause of the accident to insufficient operator training coupled with flaws in reactor design, as well as a lack of appreciation for the magnitude of the risk.

Since the 2011 Fukushima[6] Daiichi disaster, Chernobyl no longer stands as history's solitary example of the immense danger posed by catastrophic failures in nuclear reactors. With the estimated total economic cost ranging from $250-$500 billion,[7] complicated further by the recent Typhoon Man-Yi,[8] the Fukushima

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[1] "Nuclear Power in the World Today," *World Nuclear Association*, last updated April 2012, accessed September 10, 2013, http://www.world-nuclear.org/info/Current-and-Future-Generation/Nuclear-Power-in-the-World-Today/#.UieOXRukq0c.

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[6] "Fukushima" can be translated from Japanese as "The Island of Good Luck."

[7] Steven Starr, "Costs and Consequences of the Fukushima Daiichi Disaster," *Environmental Health Policy Institute*, accessed September 13, 2013, http://www.psr.org/environment-and-health/environmental-health-policy-institute/responses/costs-and-consequences-of-fukushima.html.

[8] David J. Unger, "Typhoon Man-yi complicates Fukushima nuclear cleanup," *Christian Science Monitor*, September 16, 2013, http://www.csmonitor.com/Environment/Energy-Voices/2013/0916/Typhoon-Man-yi-complicates-Fukushima-nuclear-cleanup-video.

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disaster has earned the only other INES level 7 rating ever assigned. It is noteworthy that within two months of the Fukushima event, Japan had lost 65% of its nuclear generating capacity resulting from the damage and other nuclear facility shutdowns required for inspection.[9] While lower radiation levels coupled with rapid evacuation and effective on-site treatment for radiation exposure have resulted in no deaths being attributed to Fukushima at this point, it may be many years before any health effects manifest.

Unlike Chernobyl and other nuclear disasters to date, the Fukushima incident was initiated by external forces—a 9.0 magnitude earthquake and the resulting tsunami. Tsunamis are a regular occurrence in Japan, sometimes with devastating effects. Accordingly, all modern nuclear facilities in Japan were built with a design basis implementing earthquake, tsunami, and flood protection based on available meteorological and threat data.

Some posit that the earthquake at the root of the Fukushima disaster was unpredictably powerful, creating a superstorm tsunami that overran objectively adequate protections. Others argue that the disaster was wholly preventable, and possibly foreseeable, asserting that Japanese administrators relied on flawed risk assessments and failed to follow intenational best practices.

Critical observations of preventative measures include claims that Japanese nuclear regulatory guidelines did not specify the extent of tsunami protection required at Fukushima, nor did they explain any steps the administrating body, the Tokyo Electric Power Company, should implement to protect the plant from a tsunami. Additionally, it appears that Japan's Nuclear and Industrial Safety Agency failed to review Fukushima's compliance with tsunami safety standards and update those standards in light of emerging evidence of vulnerability and evolving international best practices.[10] The coastal location of the Fukushima plant provided easily-accessible seawater for reactor cooling, but also exposed the location to the core of tsunami power—the very substance that provided safety became the architect of Fukushima's demise. Despite its seaside location, the plant was not designed to withstand a tsunami even half the size of the March 2011 culprit. In the years prior to the Fukushima disaster, international discussions regarding external threats to nuclear facilities abounded, and "well-understood and straightforward engineering measures" existed to prevent the catastrophe.[11]

A single-minded focus on extending nuclear facility lifetimes created a tunnel vision regarding nuclear power safety. This lead to an ad-hoc, reactive approach to aging infrastructure that was based on detecting areas for concern and replacement, rather than a proactive, forward-looking effort that incorporates aging infrastructure considerations into the very development of the infrastructure itself.

Aging infrastructure concerns involve more than physical deterioration, but extend to infrastructure obsolescence in the face of dynamic risk environments. Rather than assessing the state of a facility as infrastructure ages with the limited purpose of determining lifetime extension, nuclear engineers should consider

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[9] "Nuclear Power in Japan," *World Nuclear Association*, last updated August 5, 2013, http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Japan/#.Ujm9NWTXg0M.
[10] Acton and Hibbs, "Why Fukushima Was Preventable," 15-16.
[11] Ibid., 17.

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aging at the outset, and include all-hazards risk assessments at the same time, folding both concepts into facility design, construction, and maintenance plans. This increases the safety margin to protect against events that would render precautions based on current risk assessment obsoslete when the risk environment later changes. Such a long-range view from the outset is especially appropriate for nuclear facilities considering the immense capital invested in their development, as well as the difficulty in creating accurate eathquake risk projections.[12]

This approach, and discussion of the advantages, disadvantages, and costs, is already happening in the nuclear energy field, with experts around the globe contributing and developing international best practices. Among those addressing this precise problem is CIP/HS Advisory Board Member Dr. Kunmo Chung, who is helping lead the discussion in East Asia. The recent opening of George Mason University's campus in Songdo, South Korea and the partnership with the Energy Systems Research Center of Ajou University in South Korea will facilitate international dialogue and cooperation on such issues. In addition, the newly-established Virginia Nuclear Education Consortium will provide fertile ground to leverage these efforts with education and research.

Considering the extensive use of nuclear power both within the United States and throughout the world, coupled with the immense risk and costs posed by nuclear disaster, innovative perspectives on age in nuclear facilities are in order. Not only must sustainability be built into design, but the interest in extending facility lifetimes cannot exist in a vacuum—policymakers and industry experts must give attention to an all-hazards risk assessment at every phase of design, development, and maintenance.

Harnessing, in the short-term, one of the most powerful forces yet discovered by man has exercised some of the best technical minds around the globe. Maintaining control over nuclear fuels and the reactors that provide a basis for us to generate this valuable source of energy in the long-term while acknowledging that all infrastrucutre ages, and that which is in contact with the greatest forces of nature often ages fastest, will continue to tax our engineers and risk managers. Their success will ensure our safety and help to guide the design, maintenance and ultimate decommissioning of reactors that meet the lofty expectations attached to nuclear power.

If government and industry fail to address these aging infrastructure and all-hazards concerns, they resort to passive nuclear sustainability that relies largely on luck that a major earthquake or superstorm does not strike unexpectedly. Fukushima, "The Island of Good Luck," did not live up to its name, with demonstratively catastrophic results. ❖

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[12] Becky Ham, "Are Mega Earthquakes on the Rise?" *Inside Science News Service*, April 8, 2011, http://www.livescience.com/13632-mega-earthquakes-increasing-japan-indonesia.html. Severe earthquake incidences in the last 100 years appear to follow no consistent trend, making projections not only difficult, but possibly dangerously misleading.

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