Summer 2018

INFRASTRUCTURE

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The Future Design of Sustainable Infrastructure
Michael D. Lepech

The Promise of Smart and Resilient Cities
Reginald DesRoches and John E. Taylor

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Editors' Note

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Michael Lepech is an associate professor of civil and environmental engineering and senior fellow at the Woods Institute for the Environment at Stanford University.

A Vision for the Future of America's Infrastructure

In today's political climate, there are few issues that generate broad agreement. One that does is the importance of long-term investment in core national infrastructure systems—roads, bridges, seaports, airports, railroads, water systems, power systems, and telecommunication networks. Thoughtful, deliberate preparation is needed as the challenges of tomorrow remain highly uncertain but without doubt will require a collaborative national effort to solve. The articles in this issue, by academic and industry experts, focus on what's needed to prepare US infrastructure systems for the coming decades.

Infrastructure Investment: Benefits and Gaps

The economic benefits of national infrastructure investment have been extensively studied (e.g., Aschauer 1989; Gramlich 1994; Munnell 1990a,b). The specific returns on public investment in infrastructure systems are debated among economists but, according to a recent Congressional Research Service report, there is evidence that the capacity-building nature of infrastructure investment is associated with higher aggregate demand, lower unemployment, and increased productivity and gross domestic product in the long run (Stupak 2018).

Infrastructure investment must also be viewed as a core component of sustainable development. Because such investment occurs in multidecadal cycles, it is necessary to establish a trajectory toward comprehensive sustainability *now*.

Today's investments in surface transportation will result in less time spent on congested roadways and more discretionary time for motorists (ASCE 2017). Today's investments in renewable energy production will lower the carbon emissions of the nation's electricity supply (Hertwich 2015). And today's investments in electric automobiles will enable centralized emission controls during power generation rather than decentralized emission controls at the tailpipe (Hawkins et al. 2013). These are just a few examples of how infrastructure investment can directly deliver social, environmental, and economic benefits and enable achievement of long-term sustainable development goals.

Yet there remain large funding shortages in infrastructure investment: a gap of nearly $1.5 trillion is predicted through 2025 (ASCE 2017). This breaks down into estimated shortfalls for the following types of infrastructure: $1.1 trillion for surface transportation, $105 billion for water and wastewater, $177 billion for electricity, $42 million for airports, and $15 billion for waterways and seaports (ASCE 2017). The sources of these investments are not clear.

Yet circumstances are not as dire as they may seem. As noted by others, "there is plenty of money, especially in the private sector. There is currently an oversupply of private capital. In particular, there is also an unprecedented appetite for infrastructure assets from the private investment community—in part because the asset class has performed consistently well in recent years" (Kim 2016, p. 3). Infrastructure is increasingly seen as an up-and-coming fixed-income asset that provides attractive risk-adjusted returns and cash flows for investors (Kim 2016).

Why, then, does the funding gap still exist? Unfortunately, many core infrastructure projects are unattractive to financing because of a number of challenges:

- lack of clear revenue sources over the decades-long lifecycle of infrastructure

- lack of reliable models for long-term economic cost, social benefit, and environmental impact predictions (e.g., maintenance, replacement, operation)
- lack of robust decision-making tools and frameworks that incorporate real-world performance data and can consider innovative new technologies
- institutional barriers that prohibit sharing of information, experiences, and funding sources
- significant governance challenges in the management of projects that involve both public and private entities.

The difficulties range from the fundamental (e.g., the need to develop new technologies that reduce the environmental footprint of core infrastructure systems) to the practical (e.g., the need to break down institutional barriers that separate funding sources). They also span numerous academic disciplines and fields of practice, increasing the difficulty for focused researchers to address them and siloed practitioners to solve them. As one illustration, important questions of equity in infrastructure access, tax burdens, and benefits must be thoughtfully considered by policymakers, economists, user groups, and many other stakeholders in order to inform responsible and effective regulatory oversight of private investment in core infrastructure systems.

The Way Ahead

Interdisciplinary thinking and collaboration are needed to address these complex challenges that involve not only engineering but also business, management science, industrial ecology, environmental studies, sociology, and public administration, among potentially many others. The collective ability of academia, government, and industry to effectively reach across traditional working boundaries and address these challenges will be a major factor in the capacity to address the looming infrastructure crisis.

Much of the infrastructure investment in the coming decades will undoubtedly be to support "smart" systems that integrate purpose-built sensor networks (e.g., traffic loops, structure-mounted accelerometers, thermocouples) and native sensor networks (e.g., smartphone geolocation, IoT technologies, infrastructure travel cards, ridesharing data), while leveraging new artificial intelligence and machine learning technologies to make better sense of massive streams of data.

Smart infrastructure systems will enable innovative business models, advanced performance tracking and prediction, and robust decision-making support. Core infrastructure systems that will benefit include bridges, roads, seaport and airport facilities, buildings, social infrastructure (schools, health care, civic facilities), water/wastewater treatment and supply, solid waste/environmental management, IT/telecommunications, and power/energy utilities. When deployed at national scale, these smart infrastructure systems will constitute an unparalleled competitive advantage for US businesses and industries for decades to come, comparable to the country's investments in the railroad network in the late 19th century and in the highway network in the mid-20th century.

Smart infrastructure systems will also enhance risk diversification through data-driven portfolio management and asset allocation in the public and private infrastructure finance sectors. To more effectively bridge these two sectors, smart infrastructure systems will enable fundamentally sound methods to manage and diversify financial risks by assessing lifecycle cost volatility for a portfolio of infrastructure systems juxtaposed against revenue and overall fiscal volatility. This is one example of the tight integration made possible by coordination of infrastructure design, performance, financing, and governance.

To facilitate collaborative, interdisciplinary discussion, the articles in this issue present the insights of academics and practitioners into the challenges and opportunities associated with core US infrastructure systems:

- sustainable infrastructure – Michael Lepech
- smart and resilient cities – Reginald DesRoches and John Taylor
- water and sewer – Theodore Hromadka II and Prasada Rao
- bridges – Andrzej Nowak and Olga Iatsko
- electric power – Theodore Marston
- container terminal infrastructure and technology – Omar Jaradat
- infrastructure for automated vehicles – Ryan Harrington, Carmine Senatore, John Scanlon, and Ryan Yee

Given the great challenges associated with the US infrastructure systems, time is of the essence. We invite readers to consider these articles as a launching point for the design, construction, operation, and management of infrastructure systems that are economically sound, environmentally responsible, and socially equitable.

Conclusion

Bold national leadership and action are needed to plan, finance, build, operate, and maintain infrastructure systems that will be robust, resilient, and sustainable in light of rapidly changing economic, social, and environmental conditions. The nation's infrastructure systems must be adapted for a changing climate, accelerated technological advancement, increased urbanization, and changing work patterns. Engineers, planners, policymakers, owners, operators, users, and other stakeholders must work together to address the national infrastructure crisis for today and for generations to come. We envision this collection of contributions as an early statement of that resolve.

Acknowledgments

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New probabilistic, performance-based limit state design approaches for sustainability can prompt innovative solutions that meet sustainability goals in ways that are safe and economical.

The Future Design of Sustainable Infrastructure

Michael D. Lepech

Michael Lepech is an associate professor of civil and environmental engineering and senior fellow at the Woods Institute for the Environment at Stanford University.

As a critical set of systems, infrastructure forms much of the foundation for quality of life and enables national development and progress. However, it also consumes vast material resources and energy (Matos 2017). Thus, it is essential that it be designed using long-term design approaches that consider social, environmental, and economic impacts over many years of use.

What Is "Sustainable" Infrastructure?

Over the past decade the designers, builders, operators, and owners of infrastructure systems in the United States have been pushed by many stakeholders to adopt greater measures of sustainability in all facets of infrastructure projects. This push has resulted in the creation of sustainability-focused tools for the infrastructure sector that can be classified as (1) knowledge-based methods (e.g., European Commission 2013; Ross and Coleman 2008), (2) rating schema (e.g., BREEAM 2012; Greenroads International 2017a; USGBC 2018), or (3) performance-based tools (e.g., Kendall et al. 2008; Ramaswami et al. 2008; Reger et al. 2014; Zhang et al. 2010).

Together these tools have brought sustainability issues to the forefront of infrastructure and building design, construction, and operations practice in the United States. For example, the US Green Building Council (USGBC 2018) has certified more than 92,000 Leadership in Energy and Environment Design (LEED) projects, and the more recently introduced Greenroads

(2017b) rating scheme has already certified over 100 state and municipal roadway projects.

But sustainability is now often defined by the criteria used to recognize it (e.g., limited construction material transportation distance or the purchase of renewable energy for construction site use; Ehrenfeld 2007). There is no formal definition based on the perpetuation of natural, social, or economic systems (i.e., sustainability). Rather, prima facie definitions are rooted in practicality and are a result of the problematic ex post facto nature of sustainability. As such, today's criteria-based definitions can be judged as "sustainable" only from far in the future with little evidence of causality.

Moreover, while attempting to strike a balance between the built environment, the natural environment, and societal considerations, current sustainability-focused guidelines and points-based approaches are limited in their ability to support rational decision making and tradeoffs and fail to consider the large uncertainties associated with long-lasting infrastructure systems. This article presents a more practical approach for the sustainability-focused design of infrastructure.

Limit State Design for Sustainability

Limit state design is a hallmark of modern civil engineering theory and practice (e.g., ACI 2014; AISC 2001), yet it has not been applied to sustainability assessment and design of infrastructure systems or built environments.

The master builders of Renaissance cathedrals, who had relied on knowledge-based heuristics to inform their craft, transitioned to mechanics-based design theories that enabled more reliable, efficient, and well-understood structures. These theories then yielded to today's limit state design approaches that look to safely and economically balance uncertain structural loads and capacities according to accepted professional levels of safety.

A Code-Based Framework

Performance-based approaches that achieve these goals without the constraints of prescriptive design codes will likely grow more common, as is already the case in earthquake engineering (e.g., Moehle and Deierlein 2004). Analogously, today's sustainability-focused guidelines and points-based rating systems, which are well-informed heuristics, must yield to science-based assessment and design methods that balance loads and capacities in ways that are safer, more economical, more reliable, and better understood.

A code-based framework has been proposed that pushes sustainability-focused design toward this limit state approach. The 2010 fib Model Code (fib 2013, sections 3.4 and 7.10) proposes a design method that consists of two essential features: (1) a stochastic life-cycle assessment and service life prediction model for measuring the impacts of infrastructure construction, operations, and maintenance activities; and (2) sustainability-focused limit states that guide design. The latter are to be considered alongside today's accepted ultimate limit states (ULS), which protect against collapse and preserve life, and serviceability limit states (SLS), which ensure proper functionality.

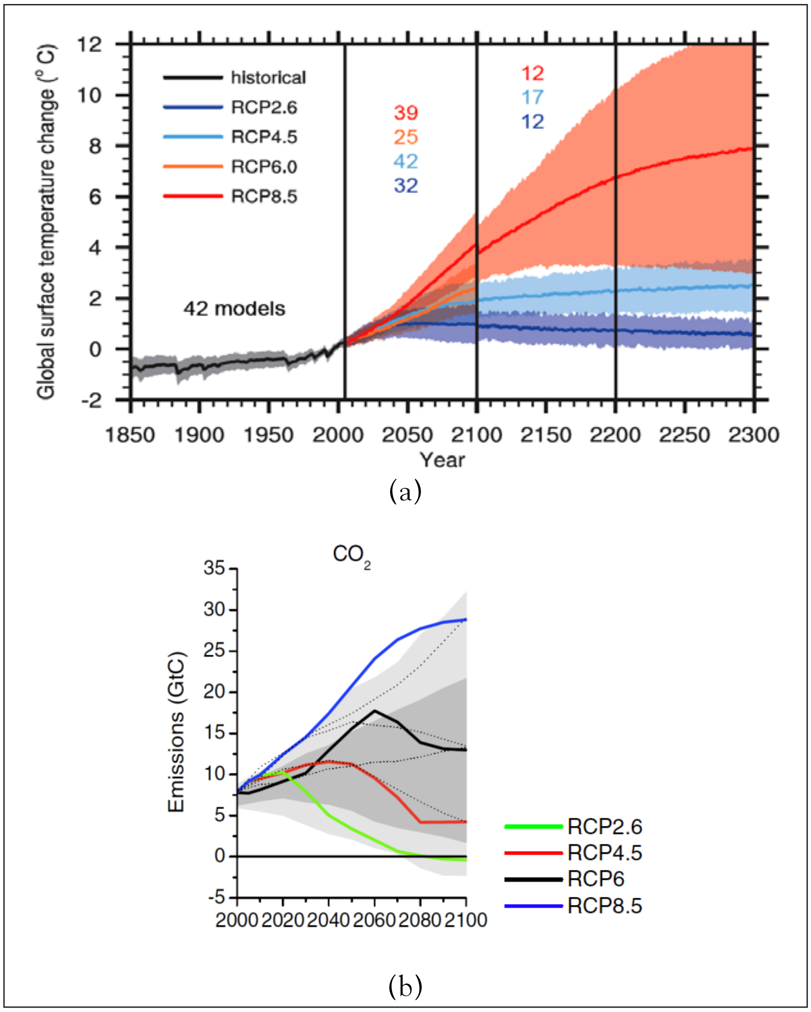
> *There is no formal definition of sustainability based on the perpetuation of natural, social, or economic systems.*

Recognizing the unique nature and environment of every project, the 2010 Model Code does not prescribe sustainability design criteria and limit states for designers. Where can these criteria and limit states be found?

Learning from Natural Ecosystems

Environmental sustainability limit states for infrastructure design and management are emerging from the study of natural ecosystem services. Natural ecosystems are the foundation of life on this planet: They provide grains, biomass, water, and genetic resources. They regulate the climate, pests, floods, and air and water quality. They support photosynthesis, pollination, and biogeochemical cycles. And they are of cultural, spiritual, and even aesthetic value (Bakshi et al. 2015). Natural ecosystem services include uptake of carbon monoxide, sulfur oxides, nitrogen oxides, and volatile organic compounds. Natural ecosystems are a planetary-scale life support system (Balmford et al. 2002; Costanza et al. 1997).

Until recent decades, engineers did not pay much attention to the dependence and quantitative impacts of engineering activities on natural and social eco-



(a)

(b)

FIGURE 1 (a) Estimated global surface temperature rise associated with a range of CO_2-equivalent (CO_2e) emission pathways (1850–2300), and (b) associated global CO_2e emission pathways (2000–2100). GtC = gigatonne of carbon; RCP = representative concentration pathway. Source: IPCC (2014).

systems. But viewing the engineered environment as loads on natural ecosystems, and looking to understand nature's ability to carry those loads, can shed light on a path toward limit state design for sustainability.

The balance between built infrastructure and natural ecosystem services exists at multiple spatial and temporal scales and for a variety of natural ecosystem services (Bakshi et al. 2015). For instance, the load on a natural ecosystem may be determined by specific emissions and resource use related to an infrastructure project design (e.g., lifecycle CO_2-equivalent [CO_2e] emissions, lifecycle water consumption). Capacity may be estimated from knowledge of relevant ecosystems at the selected ecological scale, such as the supply of carbon sequestration as a fraction of the mass of CO_2-equivalents sequestered globally by plants, trees, and oceans. At a smaller scale, the supply of water by natural ecosystems depends on features in the watershed such as rivers, the rate of groundwater replenishment, rainfall, and the degree of surface imperviousness.

For information about the capacity of natural ecosystems at multiple scales, various models and databases are becoming available (e.g., US Forest Service 2018). Models of natural wetlands, for example, can quantify their removal of water pollutants and other ecosystem services (Flight et al. 2012).

By viewing natural ecosystem services as a crucial, but limited, resource that sustains life, the definition of environmental sustainability limit states becomes a question of balancing load versus capacity, with an acceptable level of safety that accounts for the inherent uncertainty in the system.

An Illustration: Designing to Address Climate Change

The United Nations Intergovernmental Panel on Climate Change (IPCC) has proposed reduction targets for global CO_2e emissions (IPCC 2014). These targets are based on a global surface temperature rise of approximately 2.5°C, avoiding the greatest consequences of climate change and preventing irreparable damage to the biosphere.

The evolution of global surface temperature up to year 2300 for a range of global CO_2e emission scenarios is shown in figure 1(a), and figure 1(b) shows global CO_2e emission pathways through year 2100 (IPCC 2014). The scenario of greatest interest here is representative concentration pathway (RCP) 4.5, which corresponds to a global surface temperature rise of approximately 2.5°C.

Based on figure 1(b), to limit stabilized global surface temperatures to a rise of approximately 2.5°C (RCP 4.5), a 30–60 percent reduction in *annual* CO_2e emissions is needed by year 2050 (with year 2000 as the baseline). This reduction represents a sustainability limit state based on the natural atmospheric ecosystem's carrying capacity to take in and sequester (e.g., via plants, trees, oceans) global CO_2e emissions.

Building from the 2010 fib Model Code's sustainability-focused design approach, a proposed probabilistic design approach consists of two types of stochastic models: (1) service life prediction and (2) lifecycle assessment (LCA) of infrastructure construction, operation, maintenance, and end-of-life activities (Lepech et al. 2014). To combine the two models, future maintenance, repair, and rehabilitation activities and their impacts are described by probability functions. The resulting framework generates a distribution of cumulative sustainability impacts throughout the lifecycle of an infrastructure system, from the beginning of construction to the time of functional obsolescence (end of life), shown schematically in figure 2(a). This framework designs for sustainability through the reduction of impacts over time to meet current or future sustainability goals (i.e., 30–60 percent reduction in annual CO_2e emissions by year 2050 versus the year 2000 baseline proposed by the IPCC).

The comparison of two infrastructure design scenarios (status quo versus a sustainable alternative) is shown in figure 2(b). Based on this, the level of impact reduction associated with a sustainability-focused infrastructure design (lower trendline) versus the status quo (upper trendline) can be calculated at any time in the future with a given level of confidence. Figure 2(b) also shows the probability of failing to meet a sustainability-focused goal by implementing the sustainability-focused alternative, $P_f(t)$, over the lifecycle.

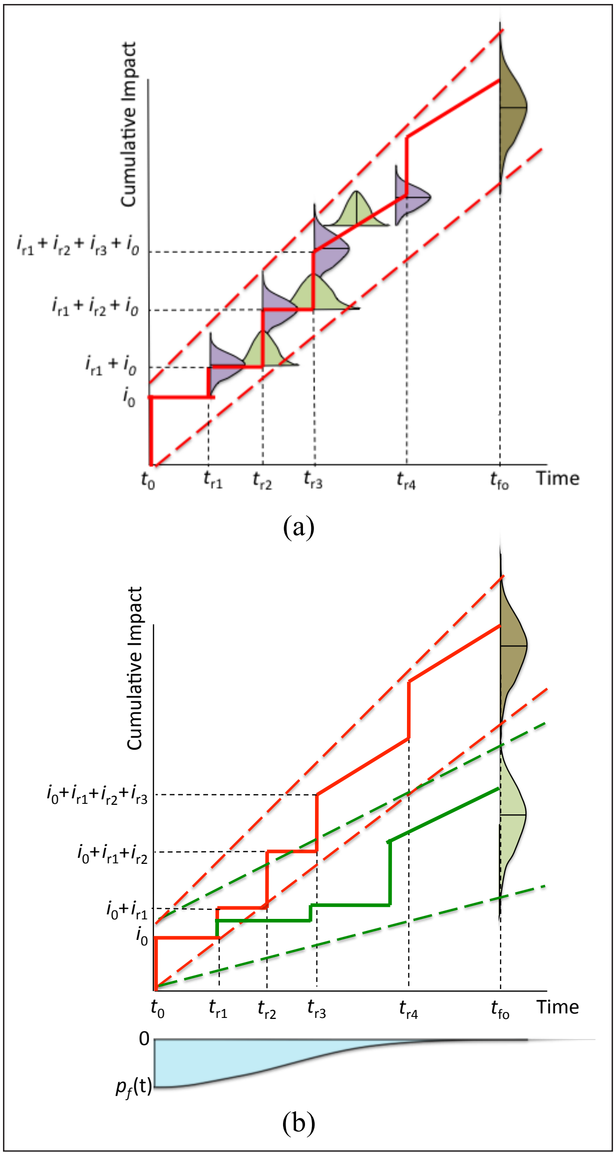


FIGURE 2 Probabilistic distributions of cumulative environmental sustainability impacts for (a) an infrastructure system designed to meet a sustainability limit state from time of construction (t_0), throughout a set of repairs at times (t_{rn}), to the time of functional obsolescence (t_{fo}); and (b) status quo infrastructure design (upper distribution on the right) and "sustainable" infrastructure design (lower distribution). Failure probability of not meeting reduction targets (P_f) is shown as a function of time. Reprinted with permission from Lepech et al. (2014).

Challenges of Limit State Design for Sustainability

Without doubt, a comprehensive, performance-based approach to sustainability-focused design will be difficult to implement. Significant challenges quickly come to mind; for example,

- Can infrastructure sustainability reasonably be reduced to a set of ecosystem carrying capacities?
- How should designers account for infrastructure designs that enhance natural ecosystems (i.e., a negative load on natural ecosystems)?
- How can ecosystems that have not been studied extensively by groups like the IPCC be considered?
- Should all sustainability-focused limit states be considered equally important?
- How would this approach be introduced or adopted in code-based design?
- What are allowable probabilities of failure for missing sustainability-focused limit states 5, 10, or 50 years in the future?

These (and other) challenges are significant, but it is appropriate to bear in mind that the transition from the Renaissance master builders to today's performance-based design of earthquake-resistant structures took centuries. And that dramatic shift required the collaboration of many academic disciplines, such as architecture, engineering, mechanics, and statistics, with contributions from economics (economic loss modeling and costing) and public policy (building codes). The transition to limit state design for sustainability will require substantially more collaboration among academics, practitioners, and policymakers, and will draw from the diverse fields of biology, chemistry, and sociology for the proper establishment of ecosystem carry capacities and social norms. On a positive note, the rate at which collaborative thinking and research have moved from theory to practice has accelerated greatly since the construction of Europe's great cathedrals.

One definition of environmental sustainability limit states balances load versus capacity.

To incentivize the transition to limit state–based design for sustainability there are measures for "socially responsible financing" (Kim 2016), including Green Bonds and Social Impact Bonds (e.g., Pigeon et al. 2012; Reed 2014). Through such bonds, investors can fund the construction of major infrastructure or other projects in return for the promise of reduced environmental impacts or positive social impacts (in addition to financial repayment). The bonds are financial instruments that weigh the potential positive impacts associated with an infrastructure project against other options, including the option to simply do nothing. They must also weigh the risk of not delivering on promised impacts. Such financing instruments are well matched to limit state design for sustainability, which supports rational decision making and tradeoffs and explicitly considers the large uncertainties associated with long-lasting infrastructure investments.

Opportunities

An important outcome of a shift to limit state design for sustainability is the potential to drive sustainability-related innovations in infrastructure planning, design, construction, operation, and maintenance. Innovations in construction materials (e.g., Billington et al. 2014), vehicle propulsion technologies (e.g., Hawkins et al. 2013), or entirely new transportation modes (e.g., SpaceX 2013) will accelerate in the coming decades, and many will reduce environmental impacts, increase access and equity, and reduce the cost of infrastructure systems and services. While guidelines and ratings-based design approaches may struggle to incorporate the sustainability benefits of relentless innovation in infrastructure systems, the fundamental load-versus-capacity nature of performance-based approaches is highly adaptable.

An example of such innovation for surface transportation infrastructure is the Hyperloop (figure 3). Although still in the early stages of technology development and proof of concept, this transformative innovation would have significant environmental, social, and economic costs and benefits that are complex, interrelated—and highly uncertain. These impacts include significant capital expenditures to build this entirely new form of transportation system (estimated at $6–7 billion to build a line from Los Angeles to San Francisco), significant savings in travel time over traditional surface transportation (the estimated Hyperloop travel time from Los Angeles to San Francisco is 35 minutes versus a minimum of 5½ hours by car and over 10 hours by conventional rail), the potential to power the entire system using renewable energy generation and storage (solar power arrays deployed along the route combined with a bank of lithium-ion batteries), and acquisition and site disruption of new right of way (SpaceX 2013).

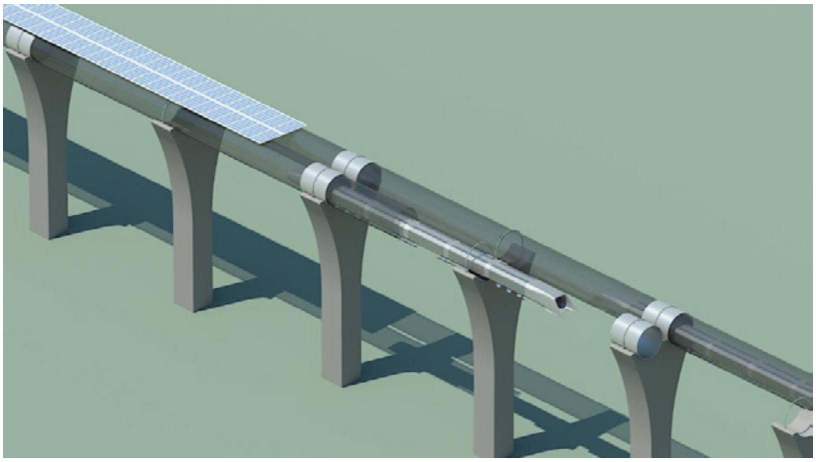
Existing sustainability-focused design approaches would struggle to accommodate the highly uncertain and complex nature of these costs and benefits, and might therefore become a barrier to innovative infrastructure projects that do not achieve a minimum sustainability rating. Limit state sustainability design approaches are well suited to consider (1) a variety of environmental and/or social sustainability limit states that would apply over the roughly 345-mile (570 km) route and (2) the unknown environmental, social, and economic performance of such a system decades into the future.

Conclusion

As reported in numerous academic studies, news events, and anecdotal stories about the condition of existing infrastructure systems, the time is now to think long term about ways to design infrastructure to meet social, environmental, and economic goals. Improved consideration of economic, social, and environmental impacts in the design of infrastructure and the built environment will be the legacy of guidelines and ratings-based design approaches that are being developed and applied today.

New limit state design for sustainability can reinvigorate designers by opening up a range of innovative solutions that meet sustainability goals in ways that are safe and economical. They reject prima facie definitions of sustainability and encourage designers, engineers, owners, managers, and financiers to collaborate with yet other partners—for example, in the natural sciences, social sciences, and humanities—to design systems that deliver socially, environmentally, and economically sustainable benefits.

(a)



(b)

FIGURE 3 (a) Hyperloop passenger transport capsule conceptual design rendering and (b) Hyperloop capsule in tube cutaway with attached solar arrays. Reprinted with permission from (a) Arabia, Inc. (2017) and (b) SpaceX (2013).

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Smart technologies and systems can improve disaster monitoring and threat assessment to strengthen cities' ability to predict and prepare for disaster impacts.

The Promise of Smart and Resilient Cities

Reginald DesRoches

John Taylor

Reginald DesRoches and John E. Taylor

The need to equip cities with smart infrastructure systems that make them more sustainable, more prosperous, more resilient, and more equitable is a critical challenge of this generation. Rapid and often unplanned urbanization, the impacts of climate change, and aging infrastructure combine to increase the frequency and severity of impacts from natural disasters such as hurricanes, landslides, and floods.

According to the United Nations, approximately 55 percent of the world's population lives in cities, and this number is expected to increase to 60 percent by 2030 and 85 percent by 2100 (Gu et al. 2015). Cities need to find new and creative solutions to survive, adapt, and thrive. Smart technologies can enhance urban disaster resilience by significantly improving preparedness and the capacity to quickly recover from the impacts of natural hazards.

The Need for Resilience in Cities

More than half of the world's cities with a population of over 300,000 are at high risk of exposure to at least one natural disaster (Gu et al. 2015).

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Most losses associated with natural disasters occur near known hazards such as floodplains, hurricane-prone areas, and earthquake fault zones, but the impacts are felt disproportionately by cities. The 2010 Haiti earthquake (figure 1), which occurred in the densely populated city of Port-au-Prince, resulted in an estimated 230,000 deaths (DesRoches et al. 2011). In the United States, New Orleans, New York, and Houston were hard hit by Hurricanes Katrina (2005), Sandy (2012), and Harvey (2017).

The very features that make cities desirable places to live—population concentration, physical infrastructure, and, often, location near water—also put them at high risk of significant impacts from natural hazards. And these risks are increasing, because of urban growth and complexity as well as uncertainty associated with climate change.

The concept of resilience has been explored in numerous fields, from medicine and psychology to materials science and economics. In this paper we use the following definition: "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" (NRC 2012, p. 16).

The impacts of numerous recent natural disasters show that inadequate infrastructure systems make it increasingly difficult for cities to respond to severe weather events. In the face of these and other natural events, cities across the country recognize the importance of replacing aging water, power, telecommunication, and transportation systems with smarter, more effective and efficient systems.

Urban Systems: Physical, Environmental, Social

Cities are centers of population with interacting and interdependent physical, environmental, and social systems. Physical systems include extensive infrastructure networks for water, storm water, and sewage; roadways, bridges, tunnels, and other elements of transportation; electricity, gas, and other types of power generation; wireless, Wi-Fi, and wireline communications; and the commercial, residential, and industrial built environment. This short list of urban physical systems indicates the complexity with which they must interact, interdepend, and integrate to provide necessary services.

Environmental systems include ground-level, botanical systems such as forests, wetlands, mangroves, and farms; the water systems of streams, rivers, lakes, and oceans; animal systems such as insects, mammals, fish, birds, and other creatures; and climate—air temperature, humidity, pollutants, pollen count, and the like. These different systems are directly linked to a city's resilience and their preservation is an important component of urban resilience strategies.

Finally, cities are social systems. Their citizens live, work, commute, and seek leisure using the physical infrastructure systems, and they depend on the natural systems for food, fresh water, and clean air. Cities cannot thrive without the people in them, and people cannot thrive without well-functioning, resilient physical systems and healthy, abundant environmental systems.

FIGURE 1 (left) The Haitian National Palace after the 2010 earthquake, which killed over 230,000 people and is considered one of the deadliest natural disasters in the Western Hemisphere. Photo by Reginald DesRoches. (right) Homes near Addicks Reservoir, west of Houston, after Hurricane Harvey, the costliest natural disaster in the United States in 2017. Photo by Philip Bedient used with permission.

System Interconnectivity

Until recently human systems and their interactions with physical and environmental systems lacked interconnectivity. Now, driven by the demands of rapid urbanization, increasing broadband connectivity/availability, and the reduced cost of sensors, many cities are investing in smart technologies and systems that establish interconnectivity within and between social, physical, and environmental systems.

Interconnectivity enables new forms of interaction between humans and urban physical systems, such as digital delivery of services, real-time feedback on traffic and transportation system performance, and smart homes that can use machine learning techniques to adapt to occupant needs. It is also making it possible to introduce sensor infrastructure in natural systems to develop a real-time understanding of important changes in environmental systems.

Strengthening the robustness of smart technologies and systems, and optimizing interactions within and across social, physical, and environmental systems, will make cities more efficient, more sustainable, more equitable, and, ultimately, more resilient. Investment in and deployment of sensor-connected technologies and systems to create smart cities can benefit all four phases of disaster management: mitigation, preparedness, response, and recovery.

Smart Cities and the Resilience Imperative

There is no formal standardized definition of a smart city, but it involves deploying technologies and systems to interconnect citizens and improve services with the goal of enhancing urban system efficiency.

A report by the International Telecommunication Union (2014, p. 4) defines a smart city as “an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects.” And a report by the UN Commission on Science and Technology for Development (2016) sets out principles for the design and development of smart cities, spanning buildings, mobility, energy, water, waste management, health, and digital layers.

Notably absent from these definitions is the impact of smart systems and technologies on urban resilience. Most cities are characterized by sprawl, rapid urbanization, poorly planned and managed development, inadequate and fragile infrastructure, and degraded ecosystems, all of which contribute to low resilience and poor capability to cope in disasters. Unfortunately, data suggest that disasters may be increasing in frequency and severity, and their impacts are taking a devastating toll on many cities.

Because a well-functioning city depends on the integration, interdependent functioning, and interactive capabilities of complicated infrastructure systems and services, strengthening their functioning will increase resilience and improve disaster management. Timely emergency communications, for example, are critical, but current systems fall short in terms of crisis detection, alerts, and assistance (NASEM 2017).

Developing Smart Resilience

Smart technologies and systems can be used to create a smart “digital twin” city for monitoring, assessment, prediction, and, ultimately, adaptation across systems (Mohammadi and Taylor 2017) to improve disaster resilience.

Creation of a smart “digital twin” city enables monitoring, assessment, prediction, and adaptation across systems.

The rapid expansion of existing cities and the creation of entirely new cities (e.g., Masdar in the United Arab Emirates [www.masdar.ae] and Xiongan in China; Phillips 2017) offer the opportunity to make cities disaster resilient by design. Urban planning can substantially improve communities’ preparedness and capacity to recover by using sensors in physical and environmental systems to diagnose, predict, and adapt. In addition, smart growth strategies such as flexible land use policies, targeted public investment, and community engagement in decision making can help communities recover more quickly from a disaster, rebuild according to a shared community vision, and be better prepared for a future event.

For cities and urban regions, the concept of resilience moves away from traditional risk assessment, which generally looks at specific hazards, to encompass a range of possible disruptive events. The focus is on enhancing system performance in the face of multiple hazards rather than preventing or mitigating losses due to a specific event. Resilience planning requires a systems-level approach, based on the notion that cities are "systems of systems," that combines a city's physical aspects with considerations of human behavior in the context of economic, physical, and social disruption.

> *Resilience planning requires a systems-level approach, based on the notion that cities are "systems of systems."*

The Multidisciplinary Center for Earthquake Engineering Research developed a framework that defines resilient systems and communities as having the following interconnected properties (Bruneau et al. 2003):

- *Robustness:* The ability to withstand a given level of stress or demand without degradation or loss of function
- *Redundancy:* The extent to which elements and components of a system are substitutable to satisfy functional requirements in the event of a disruption
- *Resourcefulness:* Allocation of the appropriate budget and capacity to establish priorities and mobilize resources after an extreme event
- *Rapidity:* The ability to meet priorities and achieve goals in a timely manner in order to limit losses.

Smart Robustness

In the context of resilience, robustness reflects the ability of physical, social, and environmental systems to withstand significant degradation from disasters. Physical infrastructure systems that are designed to modern code, are retrofitted, or use advanced materials and design concepts, including sensors and "green" methods, tend to be more robust.

Advances in sensor technologies and wireless communications have led to the development and application of monitoring systems to assess the real-time condition of infrastructure, from buried pipelines to dams, bridges, and power and telecommunication systems (Lynch and Loh 2006). Such monitoring systems are useful for tracking the behavior of structures during forced vibration or natural exciting (e.g., wind, live loading). They can also provide information to help cities (1) determine whether changes are needed in the material and/or geometric properties of a structural system, including changes to the system connectivity, and (2), more broadly, make both real-time decisions about infrastructure safety and long-term investment decisions. Sensor-connected infrastructure systems are critical in identifying potential vulnerabilities before catastrophic failure and enhancing infrastructure robustness.

Robustness also requires the security of financial and other transactions. Blockchain is a new smart technology that increases the reliability and transparency of transactions. It can ensure the security of transactions both during and after disasters, when restoring normal daily life—including the ability to make routine purchases and pay bills—is critical to a well-functioning city.

The robustness of an urban environmental system can be improved by passive solutions such as "green" water retention in coastal cities (e.g., Buffalo Bayou Park in Houston). These can be coupled with active smart solutions that integrate sensors to monitor the performance and danger levels of hurricanes and floods, such as the rain gauge sensors in the Houston area bayous that were pivotal in providing flood warning during and after Hurricane Harvey, whose impacts could have been even worse.[1]

Smart Redundancy

Redundancy refers to the extent to which alternatives can fulfill the functions of disrupted systems. For physical systems, alternative transportation routes or backup electricity can provide system redundancy.

Electricity is necessary for many of a city's essential physical system services, such as water, power, communications, and public transportation. These functions are particularly critical in the minutes, days, and weeks after a natural disaster.

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[1] A county flood warning system is posted online through the interactive mapping tools of the Harris County Flood Control District (https://www.hcfcd.org/interactive-mapping-tools/harris-county-flood-warning-system/).

Electrical power networks have become large and highly complex technical systems, geographically distributed, and with varying degrees of connectivity, often requiring constant real-time operation to manage supply and varying demand. Natural disasters can cause damage to a wide geographic area of an electricity system, leading to outages that can last several weeks. For example, over 8 million people along the East Coast were without power after Superstorm Sandy, and many homes and businesses did not return to normal operations for weeks. The cascading effects of power outages on critical systems have been shown to exacerbate the impacts of natural disasters (González et al. 2017; Wu and Dueñas-Osorio 2013).

Smart grid technologies can improve the resilience of cities by shortening the length of power outages and thus significantly reducing the scale and severity of disaster impacts. For example, microgrids can automatically detach from the greater grid and continue to deliver power to affected customers. This also enables utilities to deploy resources to damaged areas of the grid to make repairs and restore service. Smart grid technologies thus provide redundancy and reconfigurability.

Cities also are investing in green infrastructure for redundant systems. For example, alternatives to large storm water drainage projects, such as water retention parks, meet environmental needs while providing a place for storm water to collect during severe flooding. Atlanta's Historic Fourth Ward Park (www.h4wpc.org/) was completed in 2011 at a cost of $15 million less than the traditional storm water tunnel system. Designed to capture storm water runoff in an area of the city historically plagued by flooding, it "increases the sewer capacity, reduces the burden on aging city infrastructure, and minimizes downstream flooding and property damage."[2] It is credited with averting substantial flooding in Atlanta during Hurricane Irma when 3½" of rain fell over a short period of time—the park captured storm water from a 350-acre area of the city (Sears 2017).

For the urban social system, redundancy can be enabled through smartphone sharing applications, such as Lyft or Uber for ride sharing, Waze or Google Maps for traffic routing, and Airbnb for accommodations. Traffic routing applications crowd-sense information from users about roadway obstructions and delays and can provide realistic estimates of travel times. In times of significant traffic perturbations, such as evacuations, these applications identify lesser-known and less-trafficked alternatives. Ride and accommodation sharing applications post information about open seats in a vehicle and rooms in a home. When Hurricane Irma struck in September 2017, Airbnb launched a disaster response program in Florida that enabled providers to offer free rooms to displaced citizens, and Uber capped fares in South Florida, offering hundreds of thousands of dollars in free rides to communities in need (Griswold 2017).

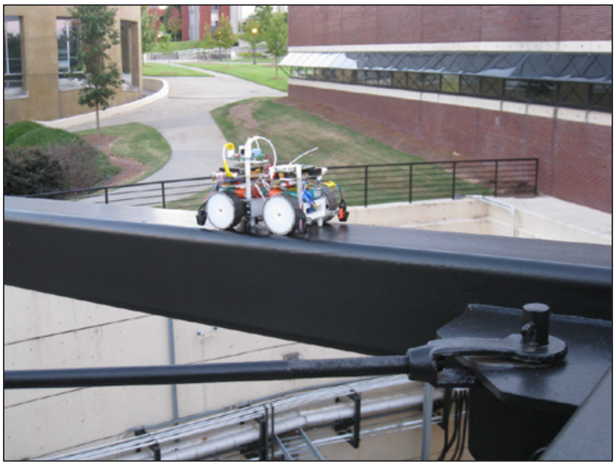

FIGURE 2 A smart mobile sensor used to assess the integrity of a bridge. Photo by Yang Wang used with permission.

Smart Resourcefulness

Resourcefulness reflects the availability of supplies, repair crews, and other resources to restore functionality to damaged systems. The 2010 Haiti earthquake and Hurricane Irma (2017) in Puerto Rico are clear examples of how lack of resources, supplies, and personnel can severely hamper the ability to recover from a disaster (DesRoches et al. 2011).

Advances in robotics, cyberphysical systems, and artificial intelligence support resourcefulness through the development of mobile sensors that can be used after a disaster to determine the safety of buildings, bridges, and other infrastructure. A network of such sensors can autonomously or semiautonomously move sensors around a structure to assess it at various locations (Zhu et al. 2010). Small crawling or flying robots (figure 2) have shown great promise for infrastructure inspection, particularly on remote sections of a bridge (Wang et al. 2017).

Smart resourcefulness has recently emerged in the social system during natural disasters, leading to fundamental changes in postdisaster response. During and

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[2] The park's features are described at https://beltline.org/parks/historic-fourth-ward-park/.

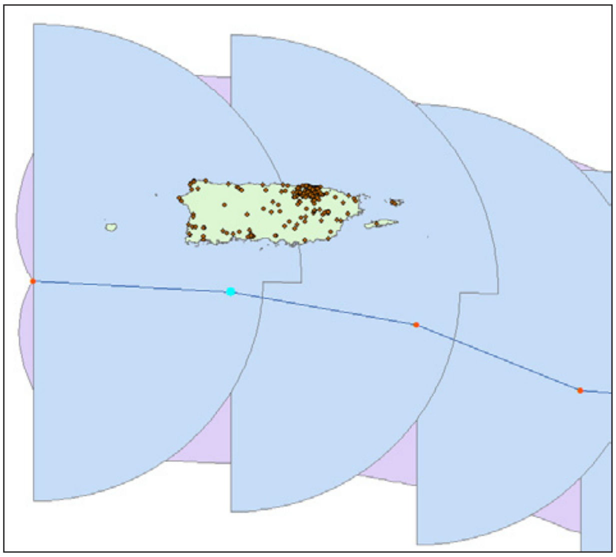

FIGURE 3 Image of 622 geotagged microblog postings in Puerto Rico during Tropical Storm Erica on August 28, 2015, with clustered postings in San Juan on the northeastern coast. The blue line south of the island is the storm's centerline, and the blue and red dots denote the tracking area using GIS data from the National Hurricane Center.

immediately after Hurricane Harvey, emergency lines in Houston were jammed and citizens in need of help were not able to reach emergency responders. Some users turned to geotagged social media microblogs on platforms such as Twitter to indicate the nature of their emergency and their location. Figure 3 illustrates geotagged social media postings during Tropical Storm Erica in August 2015 in Puerto Rico. This information provides first responders with an alternate channel to locate citizens in crisis. Other applications and methods are under development to use social media postings to assist first responders (e.g., Wang and Taylor 2015, 2018a).

Cities do not typically have the land space to support the scale of farming required to meet residents' daily food consumption needs, but a number of cities are including urban farming approaches in their smart resilience plans. The vulnerability of cities to sudden food shortages after a natural disaster was exposed in New York after Superstorm Sandy, when the city experienced persistent power outages, lack of fuel, and closed tunnels, all of which challenged food supplies (Mahanta 2013). High-tech urban farming companies can automate many aspects of the growing and harvesting process, and they can grow fruits and vegetables in vertical stacks indoors with no soil and as much as 95 percent less water compared to traditional farming (Marks 2014). In addition to the sustainability aspect of locally harvested food, if food supply lines are disrupted the availability of food nearby may be critical to survival.

Smart Rapidity

Rapidity concerns the ability to quickly restore system functions.

Crowd-sensing applications are accelerating the ability to assess natural disasters through physical, social, and environmental systems (Conrado et al. 2016). The US Geological Survey maintains a "Did You Feel It" website[3] that allows citizens to indicate the degree to which they feel an earthquake, and the data have been shown to correlate with actual earthquake-induced ground motion (Atkinson and Wald 2007). Applications are being extended to recognize sentiment of social media microblog postings, with a significant spatiotemporal correlation between the sentiment level of urban residents and earthquake intensity (Wang and Taylor 2018b). Such applications provide first responders with near real-time information about emergent crises to more rapidly deploy emergency services to areas of need in a city.

Social media data are also being used to enable rapid assessments of danger over large areas in physical urban infrastructure, serving as a new and critical resource for rapid attention and recovery in natural disasters (Kryvasheyeu et al. 2016).

Conclusions

The integration of smart technologies and systems with a city's physical, environmental, and social systems can enhance efficiency, sustainability, and disaster resilience by improving robustness, redundancy, resourcefulness, and rapidity. Emergency response and hazard mitigation officials also need to be involved in smart city planning efforts.

Smart technologies and systems can improve disaster monitoring and risk assessment, thereby strengthening cities' ability to predict and prepare for disaster impacts. They can also enhance the ability to respond to citizen concerns, monitor infrastructure and environments in crisis, and address associated safety issues. Finally, they can support the uninterrupted use or rapid restoration of critical services.

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[3] https://earthquake.usgs.gov/data/dyfi/

The promise of smart and resilient cities will be fulfilled only when cities broaden their strategic plans to incorporate smart technology and system implementation in order to increase the robustness, redundancy, resourcefulness, and rapidity of their disaster planning, response, and recovery.

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Radar data can be used for risk assessment and planning for sustainability in land development and infrastructure needs.

Use of Radar Data to Assess Water Infrastructure Resiliency and Sustainability

Theodore Hromadka

Prasada Rao

Theodore V. Hromadka II and Prasada Rao

An efficient and resilient water infrastructure is required for a healthy economy and social well-being. Any breakdown in this critical infrastructure can have serious short- to long-term cascading effects, as evidenced by recent catastrophic flooding in areas around the country. To ensure resilient and sustainable infrastructure, various engineering and scientific aspects need coordinated attention and solution.

Research and accurate data assessment are necessary to enable application of the best tools and knowledge to solve problems related to both current and future infrastructure conditions. Otherwise, today's engineering fixes may fail to address tomorrow's impacts.

Radar is an essential tool in the collection of meteorological data, which are used not only to provide weather forecasts but also to inform the planning and design of water infrastructure appropriate to both daily and storm-induced needs. Data collection and synthesis research programs are critical to the effective evaluation of risk and thus to the sustainability of hydrologic systems.

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FIGURE 1 Flooding due to high precipitation near Port Vincent, Louisiana, August 2016. Source: earthobservatory.nasa.gov.

Background

Global warming is associated with anticipated negative impacts on the boundary conditions assumed in the original engineering and design of various utilities and systems such as those for water delivery, sanitary sewer, flood control, and water quality enhancement, among others.

These impacts include the occurrence at ports and waterways of rising tide levels during storms and related hydraulic phenomena such as a sudden rise and fall of water levels (e.g., storm surges). In addition, many cities use combined sewer systems, in which sanitary sewage and storm runoff are designed to occasionally share piping system elements. Under many global warming scenarios of possible elevated water levels, these combined sewer systems may be negatively impacted by elevated outlet hydraulic conditions that may reduce overall discharge and cause overflows.

To address these and other impacts, planning and design need to anticipate where the target concerns will be so that the engineering design arrives positioned to handle future demands—much like running to where the soccer ball will be rather than running after it. Effective preparation requires accurate data and analysis, and radar is a principal tool in the acquisition of such data for water management.

Water-related engineering and planning technical fields of great importance include water distribution, sanitary sewer systems, flood control, water quality enhancement, and others involved in infrastructure resiliency. Water-related concerns in these areas are being transformed by changes in population, development, habitat, facility use, and the environment, among other stresses. Figure 1 illustrates an environmental stress, as populated US coastal and other low-lying areas have been subject to more frequent severe flooding in the past 25 years (USGCRP 2014).

This paper reviews a case study that is relevant to growing communities and their water infrastructure management: flood control in the severe storm environment of arid regions such as the southwestern United States. We estimated storm size (i.e., aerial extent) for the arid watersheds of California's San Bernardino County (SBC), the largest land-area county in the United States (Hromadka et al. 2018). We analyzed 18 years of rain gauge data and Doppler radar data to develop storm size characteristics as they relate to precipitation quantities of high intensity and associated rare return frequencies. This effort was carried out under the direction of the County of San Bernardino as part of its water resources planning and risk analysis efforts.

Doppler: The Radar of Choice for Meteorology

Radar technology helps meteorologists provide timely and useful rainfall and other forecasts. Ever since radar was first used in the Second World War to detect aircraft, its application for predicting weather phenomena (in particular, precipitation) has been fast maturing, with advances in both the equipment used at radar stations and the data processing software that analyzes the scanned radar data and processes them to yield precipitation estimates.

Weather Surveillance Radar (WSR-88D) is the technical name for the 159 high-resolution S-band Doppler weather radars (installed during 1990–96), part of the Next Generation Radar (NEXRAD) network operated by the National Weather Service (NWS; figure 2). The

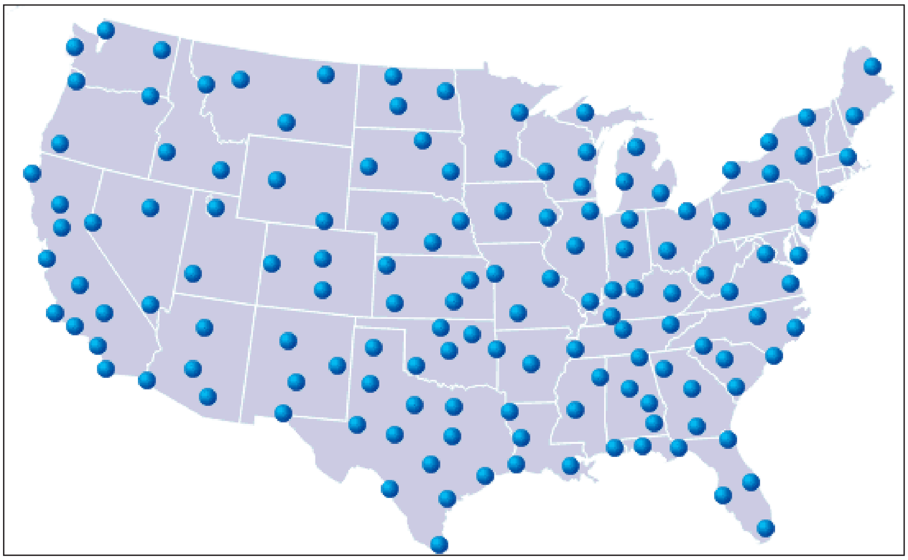

FIGURE 2 Locations of WSR-88D sites in the contiguous United States. Source: radar.weather.gov.

WSR-88D operates by sending and receiving microwave pulses in the 2–4 GHz range, known as the S band. Because the WSR-88D can estimate precipitation at high spatial and temporal resolution, it has great potential for hydrometeorological assessment and use in meteorological and hydrological modeling (Austin 1987; Fulton et al. 1998; Serafin 1996; Smith et al. 1996).

Advances in understanding of the science behind precipitation events led to the upgrading in 2011–12 of the WSR-88D to dual polarization, allowing for enhancements in data quality and addressing some reported limitations (Bringi and Chandrasekar 2001; Collier 2016; Vaccarono et al. 2016). Whereas the originally designed WSR-88D transmits and receives radio waves along a single horizontal polarization, dual polarization radars transmit and receive signals across both horizontal and vertical polarizations. The availability of reflected power and phase details along two directions enables the calculation of additional parameters that can be used to improve precipitation estimates, including better differentiation between heavy rain, hail, snow, and sleet.

Errors in Radar-Estimated Precipitation Values

Studies show, however, that, although Doppler radar has contributed significantly to the understanding and assessment of storm precipitation and related weather phenomena, radar precipitation estimates are subject to various errors and challenges.

Villarini and Krajewski (2010) provided a detailed examination of some errors in radar-estimated precipitation values, and before that Hunter (1996) presented an in-depth discussion of various precipitation estimation errors and potential remedies. Krajewski and colleagues (2010, p. 92) quantified some of the uncertainties in radar precipitation estimates and concluded that, although radar estimates improved over the last two decades, "comprehensive characterization of uncertainty of radar-rainfall estimation has not been achieved."

Berne and Krajewski (2013) discussed some of the challenges for the use of weather radar in hydrology (i.e., in validation studies, precipitation forecasting, mountainous precipitation, error propagation in hydrological models). They noted that the use of weather radar for precipitation measurements in mountainous regions has major limitations—such as interference due to ground clutter, beam shielding, and large vertical variability—that strongly affect the accuracy of estimates.

Thus radar data and outcomes still require careful interpretation and assessment to achieve a desired level of accuracy. In particular, in many areas of engineering and planning Doppler radar remains the primary measurement tool for the assessment of precipitation quantities, so it is important to examine and understand the uncertainty involved in its use.

Doppler Radar Assessment Update for Arid Regions of San Bernardino County

A case study of Doppler data for arid SBC areas sought to determine correlations between the Doppler aerial coverage and precipitation gauge data corresponding to selected storm events. The area is approximately 20,000 square miles and monitored by 77 precipitation gauges with hourly (or shorter-duration) data (excluding daily gauges). Based on the data from these 77 gauges, 156 storm dates with return frequencies estimated (using NWS data) at more than 10 years were identified between 1997 and 2015.

In addition to the arid region of SBC, radar sites in Yuma (KYUX), Edwards (KEYX), Santa Ana (KSOX), Las Vegas (KESX), and San Diego (KNKX) were analyzed for storm events. Once the storms of interest were identified, the relevant NEXRAD data were downloaded from the National Oceanic and Atmospheric Administration (NOAA) website (www.ncdc.noaa.gov/nexradinv/) and used in the creation of a Doppler animation for the 156 storm events. From these animations, 3-hour, 2-hour, 1-hour, 30-minute, and 15-minute peak rainfall durations were identified and, based on the intensities of each peak duration interval, the 11 most significant storms were selected for further analysis.

The Doppler data were used to calculate average rainfall quantity (precipitation depth) for each target peak duration, and the resulting values enabled computation of an average normalized estimated precipitation depth for each interval. The aerial extent versus estimated average precipitation depth for a given interval was plotted (figure 3), together with the published depth area reduction factor (DARF) curves for the county. The DARF takes into account the size of the watershed: a smaller one may have a relatively uniform rainfall over its entire area than a larger watershed. The larger the watershed, the smaller the DARF.

The similarity between the DARF curves and the graphs developed from the radar data suggests that continued monitoring is necessary for all the relevant water recourses variables as well as hydrometeorology variables, particularly as changes occur with new understanding of the variables.

Conclusions

The planet's hydrometeorological responses are continually changing as urbanization spreads and global temperatures rise. Data show evidence of extremely severe and rare precipitation events associated with floods and the failure of engineered systems such as flood control channels, dams, and others.

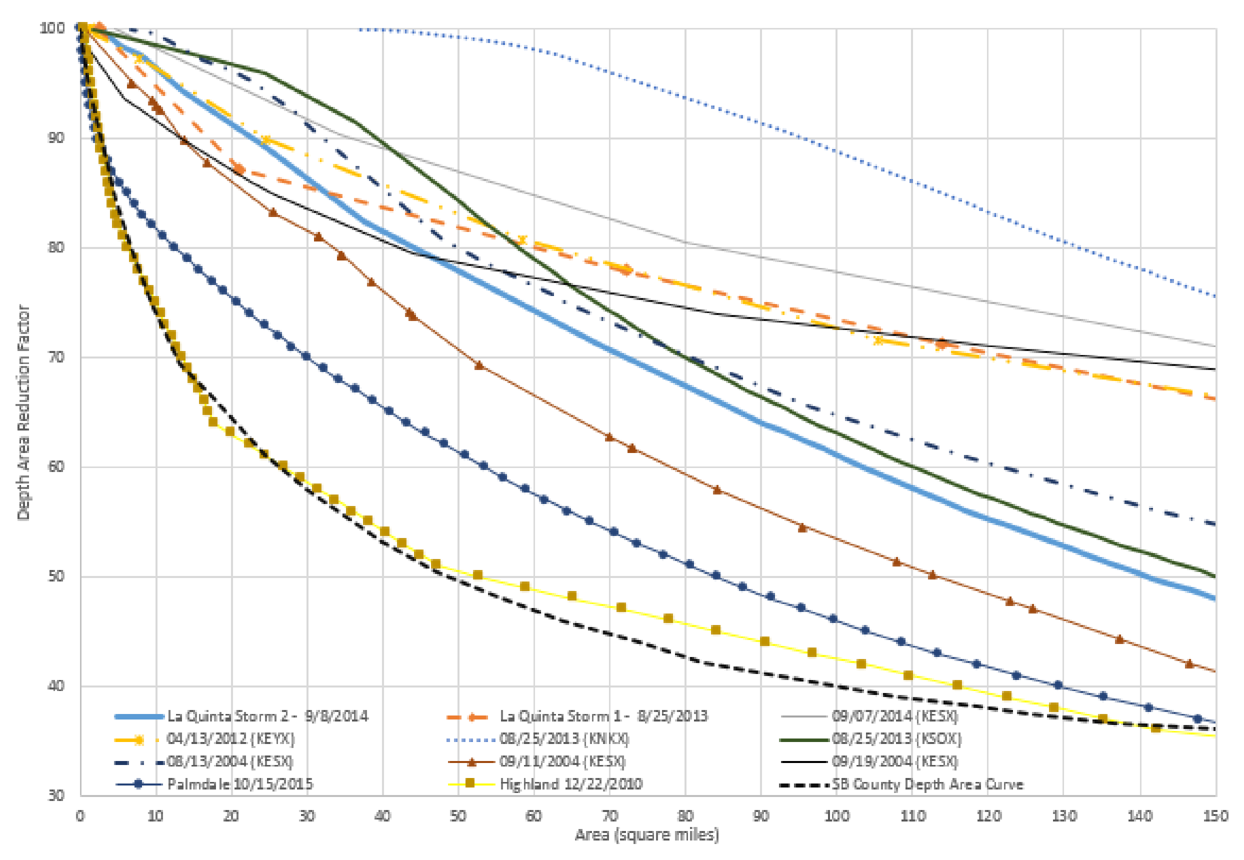

FIGURE 3 Comparison of depth area reduction factor (DARF) curves and Doppler radar (KESX, KEYX, KNKX, KSOX) synthesized graphs for selected storms in San Bernardino County (CA) and adjacent regions, 2004–15. KESX = Las Vegas; KEYX = Edwards Air Force Base; KNKX = San Diego; KSOX = Santa Ana. Reprinted with permission from Hromadka et al. (2018).

Analysis of storms that occurred in 1997–2015 in the County of San Bernardino, based on data from precipitation gauges and Doppler radar, has resulted in valuable information that can be used for a variety of investigations in engineering and planning. Important applications include predictions of risk assessment and sustainability for land development and infrastructure needs in these and other increasingly populated arid regions.

Given the possibility of major impacts from overarching conditions such as anticipated global warming effects, this ongoing data collection program and analysis provide crucial information for infrastructure designers and planners about an important aspect of storm risk analysis, particularly the DARF used in estimating storm size for analysis of storm events and their impacts.

Effective and reliable infrastructure performance and risk reduction require continuous relevant data collection, synthesis, and statistical assessment to evaluate risk with respect to performance goals and sustainability. These methods are only as effective as the data obtained, although advanced statistical and computational methods can also enhance accuracy in the assessment and understanding of hydrometeorological patterns and trends.

Although the focal point of our analysis is the characteristics of storms in arid areas, other hydrometeorological factors—such as weather patterns, watershed characteristics, and hydrological preconditions—need to be carefully measured, monitored, and evaluated to determine trends and patterns. Information about these trends and characteristics is necessary for urban infrastructure planners to make knowledgeable decisions about the vulnerability of regions to anticipated changing conditions. Those decisions can then be incorporated in assessments of risk and sustainability and used to guide planning and decisions about infrastructure maintenance and upgrades.

Note from the Funding Agency

This research was an academic exercise to understand the relationship between radar data and rainfall rates and must not be used for design considerations. The County of San Bernardino Flood Control District, which provided partial funding for this study, has embarked on an aggressive program to install more rain gauges in the arid regions of the county, and these will provide more localized rainfall data for future research.

Acknowledgments

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New materials, technologies, design techniques, monitoring equipment and procedures, and sensors can and should be used to make bridges safer.

Are Our Bridges Safe?

Andrzej Nowak

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Transportation, including the road network, is a very important part of the national economy, providing necessary connections between people, business, and industries. The US Interstate Highway System was initiated by President Eisenhower in the 1950s to benefit commercial and military transportation. Its nearly 50,000 miles were largely completed in 35 years and are now part of over 4 million miles of roads across the country (FHWA 2015). Bridges increase the efficiency of the road network operation and are a vital component of the nation's transportation system and economy. Loss of a major bridge can have national impacts.

Background

Half of the country's bridges are owned and administered by the states, the other half by counties and cities; very few are privately or federally owned. State-owned bridges are generally in better shape and regularly inspected (at least once every two years); counties and cities often lack sufficient funds for inspections, maintenance, and repairs.

Although the percentage of bridges that are in poor condition decreases from year to year, this is mostly because of an increase in the number of newly

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built structures rather than improved maintenance. The percentages of structurally deficient bridges around the country range from 1.6 percent (Texas and Nevada) to 23.3 percent (Rhode Island) (FHWA 2017). The variation is due to differences in state policies regarding the inspection, maintenance, and repair of bridges.

The National Bridge Inventory (NBI[1]) was created to support the use of data about the country's 614,387 bridges on public roads, 25 percent (145,104) of which are part of the National Highway System (NHS). With data collected in accordance with the National Bridge Inspection Standards[2] and submitted annually to the Federal Highway Administration (FHWA), the NBI includes basic information about every bridge—its dimensions (span length, roadway width), material, structural type, location, maintenance plan, repair history, and traffic.

The availability of bridge failure data, however, is rather limited. A bridge fails when it cannot perform its function, for example because of excessive vibrations or deflection, cracking of concrete, fatigue cracking of steel, or, in drastic cases, collapse of components or the whole structure. A 25-year review of data found that bridge failures occur with an annual frequency of approximately 1 per 5,000, but, because of incomplete or incorrect information about bridge failures reported by state DOTs, the actual failure rate is significantly higher (Cook et al. 2015).

About half of collapsed bridges were structurally deficient as a result of age, excessive loads, extreme weather, inadequate maintenance, and other aspects. Continuous corrosion and fatigue can lead to loss of the load carrying capacity and a major collapse.

The estimated total cost of US bridge repairs is $123 billion (ASCE 2017). To avoid the high costs of replacement or repair, bridge evaluation must be done at regular intervals and accurately assess load carrying capacity based on predicted loads and expected changes in capacity (deterioration).

What Are the Problems with Bridges?

Existing bridges are subject to aging, deterioration, corrosion, cracking, delamination, material fatigue, and chemical degradation. These may occur naturally over time or as a result of conditions such as traffic and weather events. Failures due to overload or deterioration are strongly age related.

The average age of US bridges is 43 years, and many were designed before 1970 for a service life of 50 years. Those bridges are thus nearing the end of their design life.

About 10 percent of all bridges have one or more deteriorated structural components (ASCE 2017). For example, an inspection of the Benjamin Franklin Bridge between Philadelphia and Camden, New Jersey, built in 1926, revealed that over 10 percent of the wires in the main suspension cables are corroded and broken (Weidlinger Associates 2000). Structural deterioration of materials and components accounts for 9 percent of bridge failures.

Bridges built before 1970 are nearing the end of their design life.

Growth in the volume and weight of truck traffic during recent decades is seriously affecting the long-term performance of bridges and increasing the need for maintenance. Bridge damage or failure is often due to extreme truck loading or collisions involving oversized and/or overweight vehicles. Many bridges were designed for loads that were specified years ago, and their design loads are now too small for the current traffic. In addition, with larger trucks on the roads, many bridges do not provide adequate clearance in width and/or height. Vehicle (or vessel) collision accounts for 7 percent of bridge failures.

About 60,000 bridges (10 percent) are posted for a weight or speed limit. Violation of the weight limit may lead to substantial damage or even collapse. But 80 percent of bridges with a posted weight limit are on local roads where truck loads are not properly monitored (if at all). Overweight vehicles account for 12 percent of bridge failures.

According to NBI data, about 60 percent of US bridges are made of concrete, 30 percent are made of steel, about 3 percent of wood, and the rest from other materials (masonry, aluminum iron, etc.). Steel beam/girder bridges are more prone to collapse than other types. The causes are mostly extraordinary or extreme events that produce stress levels significantly exceeding the capacity of the bridge, especially hydraulic disasters such as a flood or scour (erosion of the soil base under

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[1] https://www.fhwa.dot.gov/bridge/nbi.cfm

[2] https://www.fhwa.dot.gov/bridge/nbis.cfm

the foundations of piers or abutments), which account for over 50 percent of such events.

What Is the Role of Design Codes?

The main stakeholders in any construction are the owners/investors and the users/occupants. The former are interested in keeping costs down and maximizing profits; the latter are interested in having a safe and functional structure. The owner/investor hires the designer and contractor, so they represent the owner/investor's side. There may be a conflict of interest between keeping costs down and ensuring safety and functionality. The role of design codes is to balance these two conflicting interests.

> *Excessive shear can occur without warning, and an overloaded compression member can buckle without warning.*

AASHTO design codes (AASHTO 2017) for bridges specify the loads to be considered by the designer. The loads have to be conservative to provide a safety margin by using load factors. The codes also articulate procedures for selecting the type of structure and materials that will be sufficient to resist expected loads, again with a conservative safety factor. The determination of safety factors has evolved from one based on intuition to an advanced reliability-based code calibration (Nowak and Iatsko 2017).

According to AASHTO (2017), a bridge's expected performance life is 75 years (Kulicki et al. 2007). The expectation can be expressed in terms of the probability of failure that is acceptable to society: if the probability is too high then the bridge may require expensive repairs or replacements, while a very low probability of failure can be prohibitively expensive to achieve. Therefore, the development of a design code depends on the answers to the following three fundamental questions:

- How is bridge safety measured?
- How is the level of required safety determined?
- How is safety implemented?

How Is Bridge Safety Measured?

A bridge's safety margin is the difference between load and resistance. Failure occurs when the load exceeds a bridge's load carrying capacity or resistance.

But the loads acting on a bridge usually cannot be accurately predicted; they are random in nature. And the ability of the structure to resist loads depends on mechanical properties of materials (steel, concrete), connections, and dimensions that also cannot be predicted with certainty and are random in nature. Because load and resistance are random variables, the safety margin is also a random variable. The probability of failure, P_f, is the probability of load exceeding resistance. Safety, or reliability, is defined as $1 - P_f$.

A structure can be in one of two states: safe performance or failure. The borderline between these two states is called a limit state and a mathematical formulation of the limit state is called a limit state function. Calculation of P_f requires knowledge of the limit state function and statistical parameters of load and resistance. However, it is convenient to measure safety in terms of the reliability index, β, defined as the ratio of the mean value and standard deviation of the safety margin. There are several methods—from simple formulas to Monte Carlo simulations—for calculating β, taking into account the type of distribution function, nonlinearity of the limit state function, and correlation between variances (Nowak and Collins 2013).

How Is the Level of Required Safety Determined?

Safety is a commodity and depends to a certain extent on the availability of resources. Target reliability levels depend on the location of a structure, its components, and costs associated with safety measures. Selection of the target reliability index depends mostly on two factors: the consequences of failure and the cost of safety.

Determining the Reliability Index

The consequences of exceeding a limit state can vary significantly. For example, the single passage of a heavy vehicle that results in a deflection larger than the limit may not create an immediate problem—but for a steel beam it can cause a permanent deformation or even collapse. Beams in flexure when overloaded typically show some signs of distress, such as cracking and large deflection, so the structure can be closed and/or evacuated before a collapse. However, excessive shear can occur without warning, as a brittle fracture. Similarly, an overloaded compression member can buckle without warning.

The target reliability indices (β_T) in bridge design codes are different for beams and columns, depending on the expected failure scenario. The β_T for the deflection limit state can be as low as 0 (which corresponds to 50 percent probability of failure) if the consequences of exceeding it are negligible.

In the AASHTO (2017) code, for a ductile mode of failure, such as loss of flexural load carrying capacity for steel and concrete beams, the β_T is 3.5 and corresponds to a probability of failure of 0.02 percent. For a brittle mode of failure, such as shear capacity of concrete beams or buckling failure of columns, the β_T is 4.0 and corresponds to a probability of failure of 0.003 percent. With prestressed concrete, cracking caused by a very heavy truck can be a problem if it occurs too often; a single passage is generally not a concern and therefore a β_T of 1.0 is sufficient and corresponds to a failure probability of 15 percent.

Calculating the Costs of Safety

The other factor to be considered when determining the target reliability is the cost of safety, which is a function of expected additional expenses or savings resulting from changes in the safety margin. How much can be saved by reducing the safety margin? How much does it cost to increase safety? If safety is cheap, a higher target reliability index can easily be justified; if the cost to increase safety is too high, a lower β_T may be tolerated.

For example, the β_T will be very different for newly designed bridge girders and for existing structures. The cost of increasing the safety margin for a structure that is still on the computer is relatively low: selecting a larger steel beam from a catalogue may increase the total cost by a negligible amount. In contrast, increasing the load carrying capacity of an existing bridge can be very expensive as it may involve closing the structure to traffic, bringing in equipment, extensive labor, and so on. The β_T for newly designed bridge girders is 3.5 and for existing girders 2.5, corresponding to 0.02 percent and 0.62 percent probability of failure, respectively.

How Is Safety Implemented?

The safety margin is implemented through the design code, which specifies load values, and factors that support safety, as well as the required load carrying capacity (or resistance) and resistance factors. Design code provisions are based on available statistical parameters of load and resistance. The selection criterion for load and resistance factors is the requirement that the reliability index be not less than the target value.

The code assumes that the quality of workmanship is either good or average. However, a review of engineering practice shows that most failures are due to human error (other causes are extreme events such as fires, floods, hurricanes, tornadoes, earthquakes, collisions). Surveys of structural failures (e.g., Nowak 1986) indicate that half of the errors are in the design and the other half in the construction. The errors are associated with lack of understanding, miscommunication, neglected or inappropriate maintenance, and wrong construction procedures.

A major challenge for bridges is growth in vehicle volume and weight. Over 20 percent of trucks significantly exceed legal load limits.

In addition to efforts to reduce human error, safety can be enhanced through the development of new materials that are durable, long-lasting, and economical; new technologies that allow for faster construction and minimal traffic obstruction; and new design procedures using advanced analytical tools. New sensor technology should be applied for diagnostics and monitoring of structural performance, with warning systems for signs of distress. And bridge traffic loads can be better controlled by a new generation of weigh-in-motion devices that are accurate and reliable.

What Is the Future for Bridges?

Bridges can serve for over 75 years if they are properly built and maintained. New materials, technologies, design techniques, analytical methods, monitoring equipment and procedures, and sensors can and should be used to make bridges safer throughout their performance life. They must be complemented by efforts to ensure quality in design, construction, maintenance, and operation.

One of the major challenges is growth in vehicle size and weight. Recent traffic measurements indicate that over 20 percent of trucks significantly exceed legal load limits. Repeated passage of heavy vehicles can cause the fatigue of structural materials, resulting in more frequent repair/replacement—or collapse. Effective law enforcement and weigh-in-motion monitoring can prevent illegally overloaded vehicles from damaging roads and bridges.

For construction, there are significant new developments in materials, especially composites, but they require more research to assess long-term performance. New technologies allow for significant reduction in the time required for construction: structural components are built in the plant, delivered to the site, and put in place in a short time (e.g., overnight). However, time pressure can result in a higher probability of errors, resulting in tragic failures.

The threat of terrorist attacks points to the need to safeguard national infrastructure facilities. A better approach is needed for risk assessment of highway bridges, involving identification and sensitivity analysis of various failure modes and scenarios associated with terrorist acts. Structures should be assessed for vulnerability to terrorist attack, with recommended prevention procedures and damage control measures.

Conclusion

In general, US bridges are safe, but their continued safety depends on rigorous quality control and adherence to design codes and guides at all stages:

- planning and design—careful review, especially of new procedures;
- construction—examination of materials and technologies, on-site inspections;
- service—regular inspections and the performance of required maintenance;
- operation—effective enforcement of laws and control of traffic loads to prevent illegally overloaded vehicles from damaging roads and bridges; and,
- as needed, repairs, rehabilitations, and replacements.

Acknowledgments

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The reliability of the US electric power system is increasingly vulnerable to the effects of climate change, use of renewable energy sources, and cyberattacks.

The US Electric Power System Infrastructure and Its Vulnerabilities

Theodore U. Marston

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The US power infrastructure is one of the largest and most critical infrastructures in the world. The country's financial well-being, public health, and national security depend on it to be a reliable source of electricity to industries, commercial entities, residential facilities, government, and military organizations.

Considering the complexity and age of most of the equipment in the US power infrastructure, the lifetime reliability is extraordinary—and it has improved in the last ten years (NERC 2017). Future system reliability may be challenged, however, by the effects of climate change, increasing supplies of renewable energy, and potential cyberattacks.

Background

The electric power system has three principal components: generation, high-voltage transmission (moving the electricity efficiently from the point of generation to load centers), and distribution (supplying the electricity to customers) (figure 1).

The owners and operators of the US electrical system are numerous: more than 3,100 providers sell over 3.7 million gigawatt hours (GWh) of electricity worth over $375 billion to almost 150 million customers in the United States (APPA 2018). And they are diverse, with very different ownership structures, financing options, rate structures, and regulation (table 1).

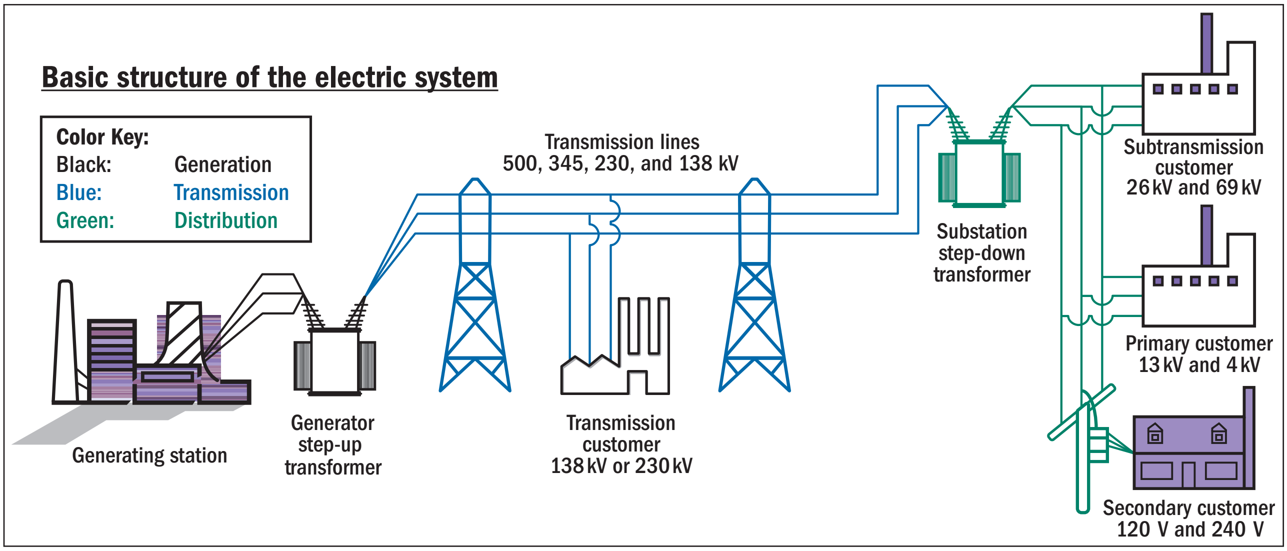

FIGURE 1 Schematic of the US electric power system (the high-voltage transmission system), from generation to transmission to distribution. Adapted from US-Canada Power System Outage Task Force (2004).

TABLE 1 Summary of US utility characteristics

Type of utility	Management	Financing	Revenue	Regulation	Infrastructure
Investor owned	Corporate with shareholders	Bonds and debt	Rates set to recover costs and reasonable return to investors	Rates set by state public utility/ service commissions	Own generation, transmission, and distribution systems
Publicly owned	Local entities and public officials	Tax-free bonds	Nonprofit, rates set to recover costs and secure investment for new facilities	Rates set by utility governing board or city council with public input	Primarily distribution, but can own generation
Cooperative	Board elected from members	Loans, grants, and private financing from members	Nonprofit, set to recover costs, margin for replacement	Rates set by board	Typically distribution with some generation and transmission

There are three primary types of utility owner/operators: investor-owned (IOU), publicly owned (California Energy Commission 2016), and cooperative (https://www.electric.coop). Unlike countries with a nationalized electricity supply system, the US system requires support from ratepayers, shareholders, and taxpayers to fund upgrades and improvements.

The overarching challenge for the US power system is how to maintain or replace the aging infrastructure, given the diverse set of owners/operators and financing mechanisms. In contrast to the high-tech sector, where the turnover of technologies is measured in months and characterized by high agility and potentially high profit margins, the electricity system is characterized by a capital stock turnover rate measured in decades, low agility, and small, regulated profit margins. The successful nexus of these very different sectors requires close cooperation.

Power Generation

The complex power system must operate on a "just in time" basis because there is no efficient means to store electricity at a commercial scale. There are over 8,000 generating units connected to the US electricity supply system.[1] In 2017 fossil fuels generated about 63 percent of the electricity, nuclear 20 percent, and renewables the remaining 18 percent (EIA 2017; table 2).

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[1] Information from the US Energy Information Administration (https://www.eia.gov/tools/faqs/faq.php?id=65&t=3).

TABLE 2 Use and capacity of US generation technologies, 2016. Data from EIA (2017).

Generation technology	% of generation	% of rated capacity	Asset use[a]
Natural gas	33.8	41	0.82
Coal	30.4	25	1.22
Nuclear	19.7	9	2.19
Renewables (total)	14.9	21	0.71
- Hydropower	6.5	10	0.65
- Wind	5.6	11 (all nonhydro renewables combined)	0.76 (all nonhydro renewables combined)
- Biomass	1.5	Included in the number above	Included in the number above
- Solar	0.9	Included in the number above	Included in the number above
- Geothermal	0.4	Included in the number above	Included in the number above
Other fossil fuel (oil, petroleum coke, and other industrial gases)	1.2	4	0.30

[a] ratio of generation realized to generation capacity

The oldest generators are mostly hydropower and date from the 1940s or before. Most coal-fired plants date from the 1970s and '80s, and nuclear plants were built between the late 1960s and 1980s. The most recent growth is in natural gas and renewable plants since 2000.

Since 2010 a number of electric generating plants have retired, predominantly coal- and gas-fired boilers as well as some nuclear plants. Almost 50 gigawatts (GW) of coal capacity were retired through 2017, and 13 more are scheduled in 2018. Approximately 22 GW of natural gas–fired boiler/steam turbine capacity was retired in the same period. The retirements are offset by the addition of natural gas–fired combined cycle and renewable facilities (EIA 2011; NREL 2017).

The states have the means and the authority to mandate cleaner generation, and there is a concerted effort by most to reduce reliance on fossil fuels: 37 have adopted either renewable portfolio standard (RPS) laws or voluntary RPS targets to increase the level of renewable electricity generation (NCSL 2017); the standards and goals range from 2 percent (South Carolina by 2021) to 100 percent (Hawaii by 2040). Recently, New York and Illinois included nuclear-generated electricity in their goals to reduce carbon emissions (NEI 2018); other states, including Wisconsin and New Jersey, are considering similar legislation. The state-level RPS efforts are successful, as shown in figure 2.

High-Voltage Transmission System

Components of the System

The US electricity supply system has more than 600,000 circuit miles of alternating current (AC) transmission lines, of which 240,000 operate at high voltages (i.e., >230 kilovolts, kV).[2] This extensive structure is necessary to move the electricity from the bulk generators to the load centers and to provide the redundancy and diversity required to ensure reliable electric power for all customers.

This high-voltage transmission system (HVTS) comprises towers and conductors and a large number of transformers, circuit breakers, switches, and control systems. Much of the latter equipment is in 70,000 or so substations (DOE 2015) at the generating source, along the HVTS (to maintain voltage and flow), at the load centers, or in the distribution systems (discussed below).

In addition to the AC lines, there are about 1,800 miles of direct current (DC) lines in the HVTS rated at 400–600 kV. The DC lines permit interaction among the four North American power grid interconnections: Eastern, Western, Quebec, and the Electric Reliability Council of Texas (figure 3).

How the System Works

The flow of electricity in the supply system requires an array of substations. High-voltage substations connect and stabilize the high-voltage transmission systems. The

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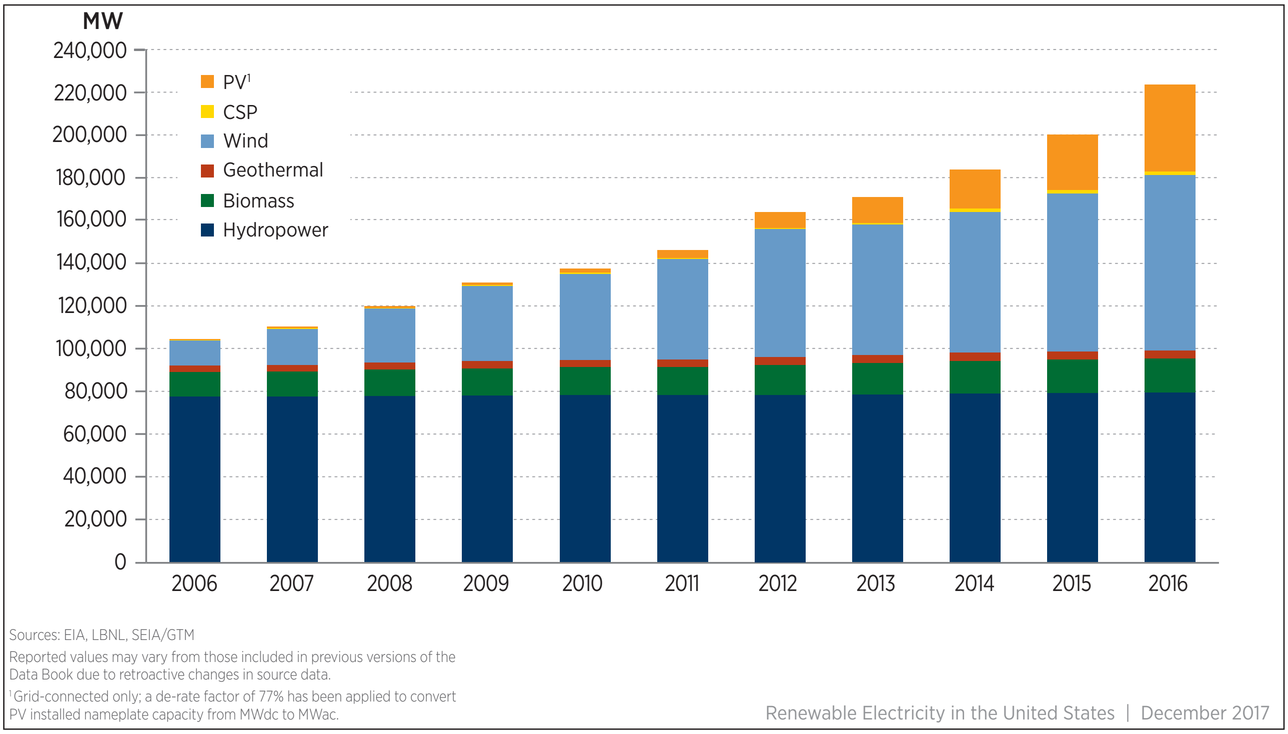
[2] Information from Edison Electric Institute (www.eei.org/issuesandpolicy/transmission/Pages/default.aspx).



Sources: EIA, LBNL, SEIA/GTM

Reported values may vary from those included in previous versions of the Data Book due to retroactive changes in source data.

[1] Grid-connected only; a de-rate factor of 77% has been applied to convert PV installed nameplate capacity from MWdc to MWac.

FIGURE 2 US renewable electricity nameplate capacity by source, 2006–16. CSP = concentrating solar power; MW = megawatts; PV = photovoltaics. Source: DOE (2017).

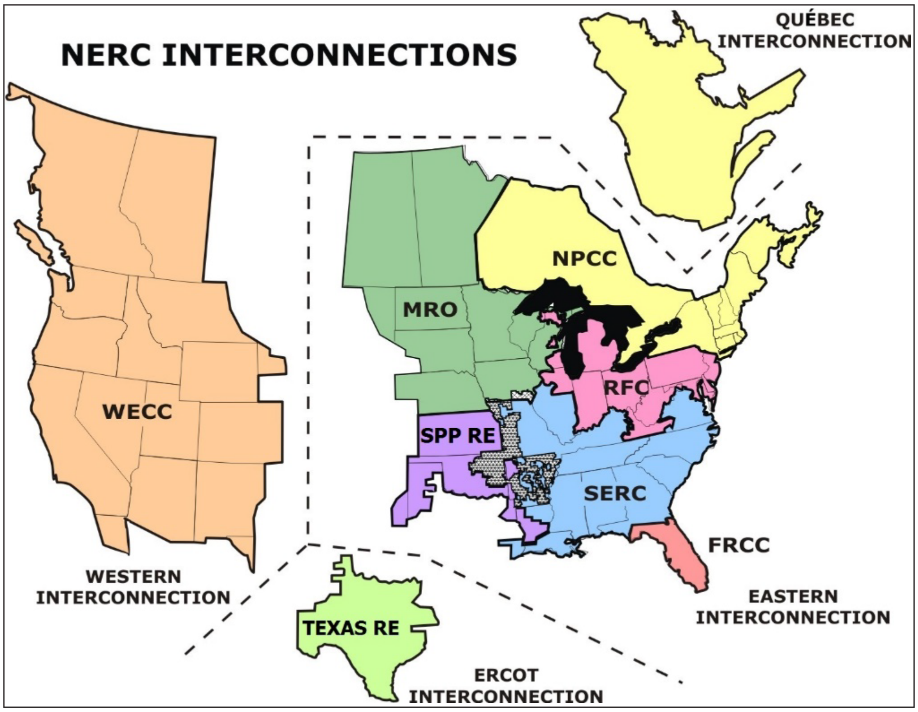


FIGURE 3 US-Canada electricity system regional interconnections. The cross-hatched area between the SPP RE and SERC denotes overlap between the interconnects. ERCOT = Electric Reliability Council of Texas; FRCC = Florida Reliability Coordinating Council; MRO = Midwest Reliability Organization; NERC = North American Electric Reliability Corporation; NPCC = Northeast Power Coordinating Council; RE = Reliability Entity; RFC = ReliabilityFirst Corporation; SERC = Southeast Electric Reliability Council; SPP = Southwest Power Pool; WECC = Western Electricity Coordinating Council. This image is the property of NERC, available at https://www.nerc.com/AboutNERC/keyplayers/PublishingImages/NERC_Interconnections_Color_072512.jpg. It may not be reproduced in whole or part without prior express written permission from NERC.

electricity is generated at less than 34 kV, but the HVTS operates at a much higher voltage to minimize transmission line losses, so a step-up substation is required. To connect with the load centers, step-down substations then reduce the voltage to less than 69 kV and feed into distribution substations, which transmit electricity to the consumer. A few converter substations convert the high-voltage AC to high-voltage DC for the regional interconnections.

The high-voltage transformers, particularly those of 345 kV and above, are critical to the proper functioning of the electric system. In the US HVTS there are about 2,100 transformers rated at 345 kV and above (DOE 2015). Such transformers are very expensive ($2–$7.5 million each), large (up to 56' wide × 40' long × 45' high), and heavy (up to 410 tons); have very long lead times for procurement (typically 24 months); and are traditionally custom designed for each application for maximum efficiency. Generally, there are few, if any, spare transformers with ratings above 345 kV in utilities' storage yards. Like most of the US electricity supply system, most of these large transformers are near end-of-life design conditions (DOE 2012).

The operation and planning of the HVTS in the United States have evolved in most areas from control by traditional, vertically integrated utilities to either regional transmission operators (RTOs) or independent system operators (ISOs); all three types are subject to the rules of the Federal Energy Regulatory Commission (FERC 2018). An ISO operates the high-voltage electricity grid, administers the region's wholesale electricity market, and provides reliability planning for the region's electricity system. RTOs have a similar role, but have more authority and responsibility for coordinating, controlling, and monitoring the operation of their region's transmission system.[3] There are still US regions where vertically integrated utilities exist; for example, in the West and the Southeast they still control about 40 percent of US electricity.

Changes in the HVTS

There are at least two drivers of major changes in the HVTS: technology and the changing landscape of generation to more renewables. The technological driver is the introduction of a smart grid, which uses electronic devices to replace the electromechanical devices originally incorporated in the HVTS in the 1950s. New technology includes advanced controls that improve system reliability, robustness, and capacity without the need to add transmission lines (an arduous and expensive process). These changes can increase the carrying capacity of the system by 30 percent or more (NETL 2010).

New technology includes advanced controls that improve system reliability, robustness, and capacity without adding transmission lines.

The addition of renewables (e.g., wind, solar) in the generation mix places stress on the HVTS because of their inherent intermittency. The grid must remain balanced with tight voltage and frequency limits, and the more nondispatchable (intermittent) generation feeding the system, the more difficult the system control and the more reserve generation required to meet demand.

Accelerating the transition to fully deployed smart grid technology will enhance control of the HVTS as power flow demands increase between regions. But, as discussed below, there is a tradeoff between smart control systems, which require the increased use of internet-connected devices, and the potential for cyberattack (NIST 2014).

Distribution System

The last segment of the electricity supply system is the distribution system (DS), which takes the electricity off the HVTS using step-down transformers and distributes it to the consumer, such as a residence or a commercial or industrial facility. This segment accounts for about 35 percent of the overall system costs; US investment in the distribution system since 2000 totals over $400 billion (EEI 2017). It is also the most complicated—most outages result from problems in the distribution system.

There are neither standards for DS reliability (Warwick et al. 2016) nor federal agency oversight of the system (as provided by FERC for the HVTS). State regulators for the IOUs and the managing boards for the public utilities have regulatory responsibility for distri-

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[3] ISO/RTO Council, www.isorto.org/about/role

bution; DS operation, maintenance, and planning are the responsibility of the local utility.

Traditionally, the DS is located aboveground. There are over 5.5 million miles of distribution lines in the United States and over 180 million power poles (Warwick et al. 2016). The undergrounding of electricity distribution began in major cities in the late 19th century and then spread to some suburban regions of large cities. Putting the DS underground has many advantages, such as improved aesthetics and greater resistance to wind, fire, and ice damage. But there are disadvantages as well, such as greater flooding risk, higher costs, and more disruptive maintenance (Sharma 2017).

The "reintroduction" of electric vehicles[4] in the United States may affect the distribution system of the future (Bullis 2013). Currently, less than 1 percent of electricity is used for transportation (EIA 2018), but with the development of modern electric cars and incentives to deploy them, the demand for electricity (especially in the evening) may increase substantially. There is plenty of generation and transmission capacity to meet this demand, but the increased charging requirements may challenge the distribution system, depending on when and where vehicle batteries are charged (Bullis 2013).

The increased charging requirements of electric vehicles may challenge the distribution system.

Microgrids are distributed generation and storage resources in the DS that can be cooperatively managed to form separate, "islanded" small grids in the event of a disturbance on the larger integrated grid (Warwick et al. 2016). The management of distributed generation and microgrids requires a high degree of automation. In particular, photovoltaic systems and electric vehicles connected to the DS require the ability to manage bidirectional power flow on a real-time basis. But while DS automation will improve the reliability and resilience of the system, it will also increase the number of entry points for potential cyberattacks (NIST 2014).

To improve DS reliability and resilience, utilities are implementing a suite of measures, including distribution automation, real-time fault analysis, and outage management systems. In addition, real-time pricing of electricity will contribute to the levelling of peak electricity demand, reducing the need for additional generation. But substantial investment—as much as $5 trillion—is required to transition to full automation (Rhodes 2017).

Major Vulnerabilities

The US electricity supply system, while very reliable, faces many events that challenge its reliability. These can be divided into natural or environmental threats (table 3) and human-related threats (table 4) (Preston et al. 2017).

Historically, natural events, especially severe weather, are the greatest contributor to loss of system reliability (McLinn 2010). The most recent DOE Office of Electricity annual report on electric disturbances shows that, in 2017, 149 events in the United States met their reporting criteria (DOE 2018), and the cumulative number of customers affected was almost 5.2 million. Severe weather accounted for 51 percent of the events, but affected 92.4 percent of the customers. Physical attacks and vandalism represented about 23 percent of the events but affected only about 0.5 percent of customers.

Electric System Resilience, Risk Assessment, and Management

Resilience is different from reliability, which is the ability of the system to deliver electricity to the customer in the quantity and quality demanded (Clark-Ginsberg 2016). The National Infrastructure Advisory Council defines four dimensions of resilience (Berkeley and Wallace 2010):

- *Robustness:* the ability to absorb shocks and continue operating
- *Resourcefulness:* the ability to manage a crisis during its evolution
- *Rapid recovery:* the ability to return service as quickly as possible
- *Adaptability:* the ability to improve system resilience based on lessons learned from past incidents or near misses.

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[4] Before the practical application of the electric starter in 1912, one third of all automobiles in the United States were electric powered.

TABLE 3 Natural or environmental challenges to the US electric system

Event type	Ability to forecast	Projections and considerations
Hurricanes/extreme winds	Excellent near-term forecasts, long-term forecasts still uncertain and generalized	Most likely will increase because of climate change. Distribution systems can be made more robust.
Tornadoes	Excellent very short term forecasts, uncertain long-term forecasts	Most likely will increase because of climate change.
Drought	Good short-term forecasts, reasonable long-term forecasts	Will increase in the US West and Southwest. Can impact generation and transmission capabilities. Effective water management is critical.
Winter storms/ice/snow	Very good short-term forecasts, uncertain long-term forecasts	Will increase because of climate change. Limits generation by impeding fuel access or delivery.
Extreme heat/heat waves	Very good short-term forecasts, uncertain long-term forecasts	Likely to increase in dry areas with climate change. Effective water management is critical.
Wildfire	Difficult to forecast in both the short and long term	Scale will increase in areas of drought. Care must be taken to minimize the likelihood of the electric system initiating wildfires.
Flooding/sea level rise	Excellent short-term forecasts for flooding; uncertain long-term forecasts for sea level rise	Sea level will rise as a result of climate change. Impacts on generation and distribution infrastructure. Managed by accommodation.
Earthquake	Poor short- and long-term forecasts	May increase as a result of local activities such as fracking. Managed by design improvements and increased diversity and/or redundancy of electricity delivery systems.
Geomagnetic storms	Very good short-term forecasts, uncertain long-term forecasts	No reason for increase. Improvements to mitigate impacts are available, but expensive.
Wildlife and vegetation	Wildlife forecasts are random, vegetation impacts predictable	No reason for increase other than regions with increased precipitation. Impacts managed with effective vegetation management programs.

TABLE 4 Human-related challenges to the US electric system

Event type	Ability to forecast	Projections
Physical attack	Very difficult to predict	No basis for change. System can be modified to be more resistant to physical attacks.
Cyberattack	Difficult to predict	Increased frequency. Owners/operators can take steps to mitigate cyberthreats, but requires constant attention.
Electromagnetic sabotage	Difficult to predict	Potential for increase. Effective mitigation as for geomagnetic storms.
Equipment failure	Historical experience applies, but exacerbated as systems age	Increasing age requires effective management or replacement.

The vulnerabilities of the US electricity system translate into risks to the reliable supply of electricity to the customer. Table 5 shows high and moderate risks for the various system components: generation, transmission, substations, and distribution above- and belowground (Preston et al. 2016).

The risks can be managed with future grid designs that maximize flexibility of grid operation. Management measures include hardening of the components to increase resistance to winds, winter storms, and flooding; and system modernization with improved sensors, automated controls, information management, and analytic tools (DOE 2017b). Proper preparation for such events reduces the risks, including effective equipment lifecycle management programs, vegetation management, and warehousing of critical equipment. Increased cybersecurity measures are appropriate to deal with increasing cyberattack threats; such measures are

TABLE 5 High and moderate risk for the various electric system components

Electric system component	High risk	Moderate risk
Generation	Large earthquakes[a]	Intense hurricane Extensive drought Extreme heat Moderate wildfires Sea level rise and major floods Strong geomagnetic storms Major equipment failures
Transmission	High-category hurricanes Major winter storms	Low-category hurricanes Minor winter storms Floods (100-year) Major wildfires Large earthquakes
Substations	Large earthquakes Strong geomagnetic storms Cyberattacks	Hurricanes (all) Minor winter storms Extreme heat Floods (100-year) Major wildfires Moderate earthquakes
Distribution (aboveground)	Hurricanes (all) Minor winter storms	Floods (100-year) Major winter storms Major wildfires Earthquakes (all) Cyberattacks
Distribution (belowground)	Large earthquakes	High-category hurricanes Floods (all) Earthquakes (small) Cyberattacks

[a] >7 on the Richter scale

discussed thoroughly in *Cyber Threat and Vulnerability Analysis of the US Electricity Sector* (Glenn et al. 2016).

Conclusions

- The reliable and resilient operation of the electric system is critical for the health and safety of the public and the health of the US economy and security.
- The capital stock turnover for the electric system is slow, measured in decades, whereas the technologies needed to strengthen the system advance in months, creating potential challenges for long-term planning.
- The entire electric system is in the "late-in-life" stage, but still maintains a very high level of reliability.
- Trillions of dollars of investment are required to rebuild the infrastructure of the US electric system.
- Climate change poses a significant threat to the reliability and resilience of the electric system by increasing the frequency and severity of weather-related threats.
- The use of "smart" devices in the electric system improves its reliability and resilience, but also increases its vulnerability to cyberattacks.

Next Steps

- Full deployment of the smart grid concept for the HVTS and the diverse distribution systems across the country must become a top priority. Sufficient funds need to be allocated at the federal, state, and local levels to maintain the reliability and resilience of the US electric system in light of increased stresses from the effects of climate change and growing deployment of renewable generation and electric vehicles. In addition to government support, the ratepayers and stakeholders of US utilities must contribute to this transition through cost recovery mechanisms, such as rate increases, appropriate to the type of utility involved.
- The automation of the US electric system is necessary, but appropriate care must be exercised to mini-

mize the potential effects of cyberattacks from all sources.

- Greater funding and increased focus for the research, development, and deployment of practical electric storage devices at the utility scale are required.

Acknowledgment

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Research, investment, and information sharing are needed to ensure critical upgrades in US container terminal capacity and infrastructure.

Trends in Container Terminal Infrastructure and Technology

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Omar A. Jaradat

Container ports are the center of the cargo distribution transportation hub and the most significant contributor to the US economy. Port cargo activity contributes roughly $4.8 trillion to the economy yearly (26 percent of US GDP), over 23 million jobs, and over $320 billion annually in federal, state, and local tax revenues (AAPA 2017a).

An ocean carrier's greatest asset is its ship and a port owner's greatest asset is its infrastructure. These assets use technology because of its ability to enhance productivity, data analysis, and integration. How these assets are managed and interact is crucial to provide seamless movement of cargo through the supply chain to consumers. Trends and changes in one part of the chain have a cascading effect on the rest of the chain. The ability to understand and forecast these changes helps stabilize and reduce risk in the process.

There is a growing gap between infrastructure development and technology. Ongoing growth in ship size requires an integrated approach to infrastructure development and technology to ensure technology advancement, infrastructure resiliency, terminal operations, and sustainability at future container terminals.

As port planners, engineers, and scientists look forward, the continued growth in the use of containerized cargo, ever-increasing ship size, and need to modernize container terminals at US ports require a review of the evolu-

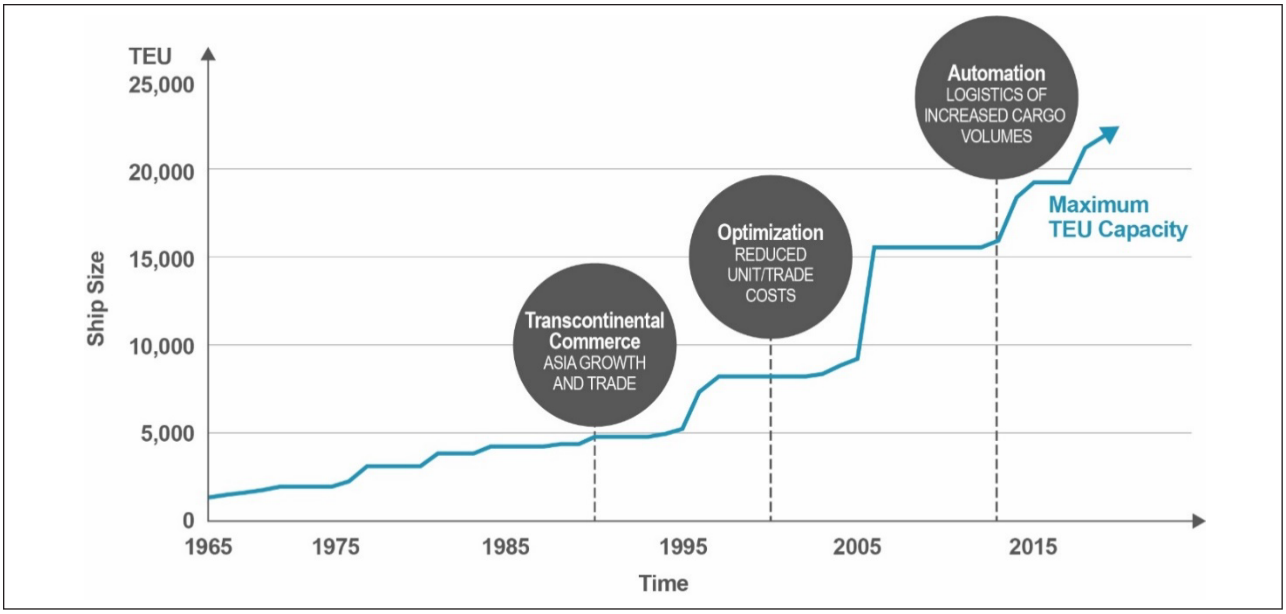

FIGURE 1 Evolution of container terminals since 1965. TEU = twenty-foot equivalent units. Based on data in International Transport Forum (2015).

tion of container terminals, current and future trends, and needed investments. This article provides insight into future infrastructure development and technology needs based on these factors and suggests steps to maintain resilient port systems.

Evolution of Container Ships and Terminals

The use of modern ports as hubs for transportation, shipping, and logistics was transformed in 1956 when Malcom McLean first lifted entire truck trailers onto and off ships. Soon after, containers became the standard method of shipment worldwide. Today, containerized ships carry 90 percent of global cargo (Alfred 2012).

Over the past 20 years, increasing container ship size has been a key market driver. Port planners and engineers cannot predict the upper limit for future ship size based on past trends, it can only be extrapolated.

There are three main triggers for recent significant increases in containerized cargo at US ports: (1) expanded growth of Pacific trade in the 1990s; (2) optimization of port systems, tools, and technology in the 2000s; and (3) greater use of terminal automation (spurred by cargo volume). Figure 1 shows the evolution of container terminals to accommodate increases in containerized cargo capacity since the 1960s.

Throughout the 1990s, increased cargo trade volume with Asia spurred the growth of not only terminal infrastructure but also ship requirements at berth. The physical dimensions and features of terminals were sized for larger future classes of ships, from 6,000 to 8,000 twenty-foot equivalent units (TEU).[1] Terminal features included larger container yards (of 150–250 acres), larger cranes to handle bigger ships, and dedicated on-dock rail to allow for direct loading to transcontinental double-stack container trains.

In the early 2000s the commissioning and completion of new "mega" terminals at the Port of Los Angeles (Pier 400) and Port of Long Beach (Pier T) facilitated the expansion of US-Asia trade and spurred other US ports to construct similar facilities. These mega terminals enabled shippers to enhance efficiency and system reliability through improved wharf and building design, faster information technology (with fiber optics), truck gate process automation, and terminal planning tools. By 2010 these terminals, in some cases exceeding 350 acres, housed even larger cranes, on-dock rail, deeper shipping channels, and more robust berths to handle the newest class of cargo ships, the 9,000–10,000 TEU.

Conventional wisdom originally held that no ship owner would build vessels larger than what could pass through the third set of locks planned for construction

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[1] The TEU is an inexact unit of cargo capacity based on the volume of a 20-foot-long container for transport on ships, trains, and trucks.

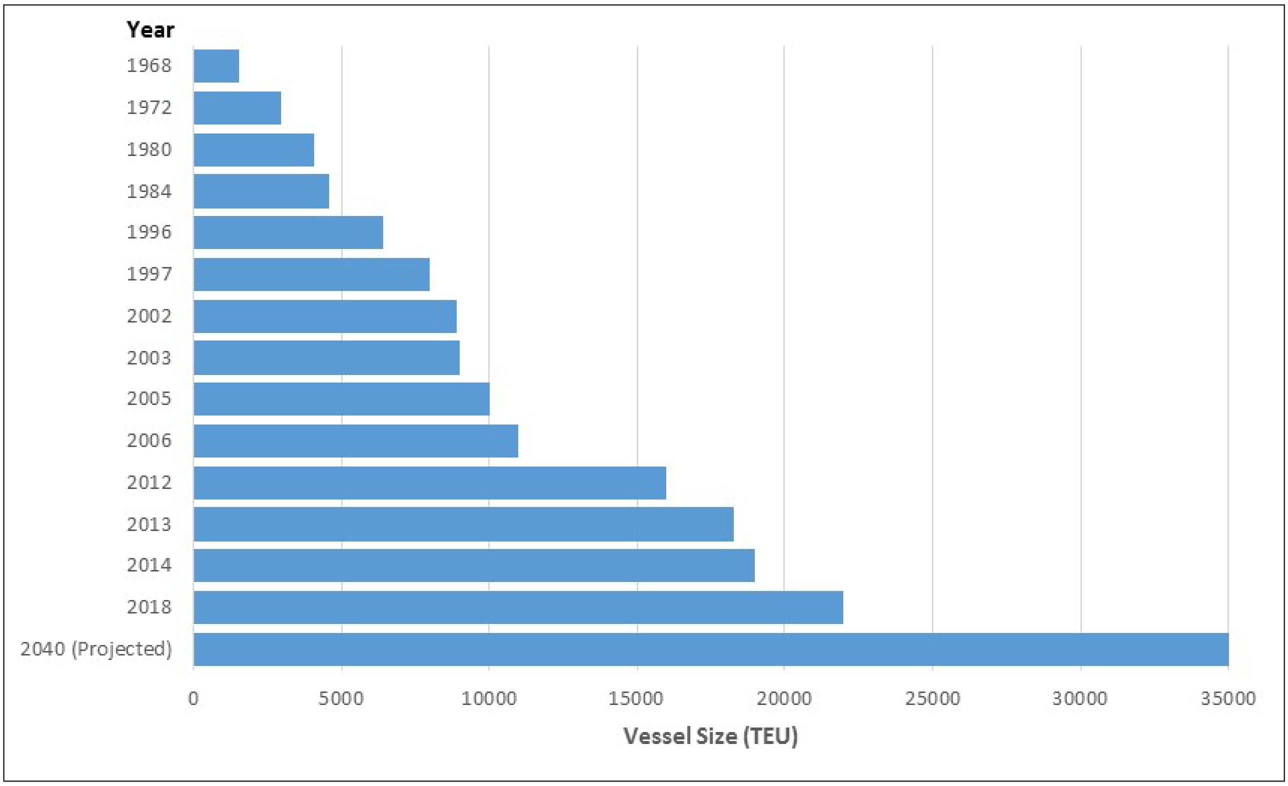

FIGURE 2 Container ship size growth, actual and projected, 1968–2040. Modified from Allianz Global Corporate & Specialty (2015).

through the Panamanian Isthmus. The maximum ship size that can pass through the Panama Canal is 13,000 TEU, called the Neopanamax. However, to further reduce unit cost for each container and to offset higher fuel costs, ship builders started to deliver even larger vessels, from about 15,000 to more than 20,000 TEU. These were mainly deployed between Asia and Europe, but started calling at US ports in 2015.

Worldwide, increases in cargo volume and the need for reliable handling facilities have led to the development of a new wave of automated terminals. In the past decade such terminals have been or are being implemented in Europe, North America, Australia, and China; semiautomated terminals are also coming online (Ying 2018).

Forecasts for the Next 20 Years

Since 1968 container-carrying capacity has increased by approximately 1,200 percent, and by 2040 ports and container terminals will be able to handle the world's largest ships, which, by extrapolating ship growth over the last 20 years, could reach 30,000 TEU or more (figure 2). (Another prediction theorizes that 50,000 TEU ships could be built and launched by 2060; Bebbington 2017.)

Malchow (2017) forecasts container ship size to grow to 30,000 TEU as a practical limit: such a ship, the Malaccamax,[2] would require the scaling and optimization of cranes, berths, channels, container yards, gates, and a rail system to handle peak volumes. These facilities would need to be open 24 hours a day, 365 days a year and be fully automated, robotic, and electrified to provide rapid storage and retrieval, allowing owners and logistics providers immediate access to each container. Electric autonomous or semiautonomous ships, trucks, and trains would be needed to accommodate the volume of cargo. Facilities, terminal operating systems, utilities, and infrastructure would need to be resilient and redundant to avoid disruptions from natural hazards or man-made failures.

Advances in container shipping technology include the introduction of the "Tesla of canals," the first all-electric, emission-free barge, developed by Dutch man-

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[2] The name derives from the largest size of ship capable of passing through the 25-meter-deep Strait of Malacca between Sumatra and the Malay Peninsula.

ufacturer Port Liner. Five of these barges, scheduled to be deployed in August 2018, will be fitted with batteries ("power boxes") that provide up to 15 hours of power. The 52-meter-long, 6.7-meter-wide barge does not require engine rooms, has up to 8 percent more cargo space, and can carry 2 dozen 20-foot containers with a total weight of up to 425 tonnes. Port Liner has plans to produce larger, 100-meter-long barges capable of carrying 270 containers and powered by four power boxes for 35 hours of autonomous driving (Lambert 2018).

The Port Liner innovations illustrate the electrification of this industry, which has been highly dependent on the internal combustion engine. Emerging technologies are forcing other rapid changes.

Contrasting Development Trajectories

Technology

Advanced technology solutions are being integrated along the supply chain from waterside port operations to yard logistics and the distribution chain of truck, rail, and air transport. Understanding the technology development lifecycle helps to determine what technologies will be useful to the future container terminal.

Technology generally advances exponentially and follows a recognizable trajectory. The Gartner Hype Cycle for Emerging Technologies (Panetta 2017) provides a graphic representation of this trajectory for the maturity and adoption of technology innovations. Depending on the technology type and its application, the cycle, which consists of the following stages, can range from 2 years to 10 years or more.

- *Technology trigger:* This stage comprises emerging technology products with unproven commercial viability, such as artificial general intelligence, smart robots, volumetric displays, and the smart workspace.
- *Peak of inflated expectations:* In this category are prototypes and product success stories, such as virtual assistants, machine learning, autonomous vehicles, and blockchain.
- *Trough of disillusionment:* Momentum wanes as experiments and implementations don't find consistent support or market acceptance; technology stalls or fails, as with software-defined security and augmented reality.
- *Slope of enlightenment:* Benefits to the industry become more widely understood and accepted; second- and third-generation products emerge, as with virtual reality products.
- *Plateau of productivity:* Adoption takes off; provider viability is clear; applicability and relevance pay off, as with overnight shipping.

Terminal planning must consider future technology and its impacts on infrastructure development and redevelopment.

Infrastructure

Infrastructure developments advance at a linear rate and require longer evolution time than technology. The typical cycle to plan and develop a container terminal is 5–10 years, with 25–30 years of use and another 20 years of repurposing for further return on investment (figure 3). This equates to a potential 30-year gap between a terminal construction planning cycle using current technology and the cycle for container terminal infrastructure development and use. During the lifecycle of most existing container terminals, there has been enormous change in ship size and tremendous advances in technology. To bridge this gap, it is crucial to have careful planning that considers future technology and its impacts on infrastructure development and redevelopment.

Bridging the Gap

A more integrated approach to technology, engineering, and infrastructure development should be included in rigorous upfront planning and decision making. Current trends indicate that key characteristics of the future container terminal may include technology advancement, infrastructure resiliency, multigeneration terminal operations, and sustainability.

Technology advancement

- A conveyance system in open seas or near the coastline; ultralarge (50,000 TEU) ships may not even dock at a port.
- Wharves designed to accommodate "mega" ships (25,000–35,000 TEU).
- Large, automated cranes that onload and offload simultaneously.

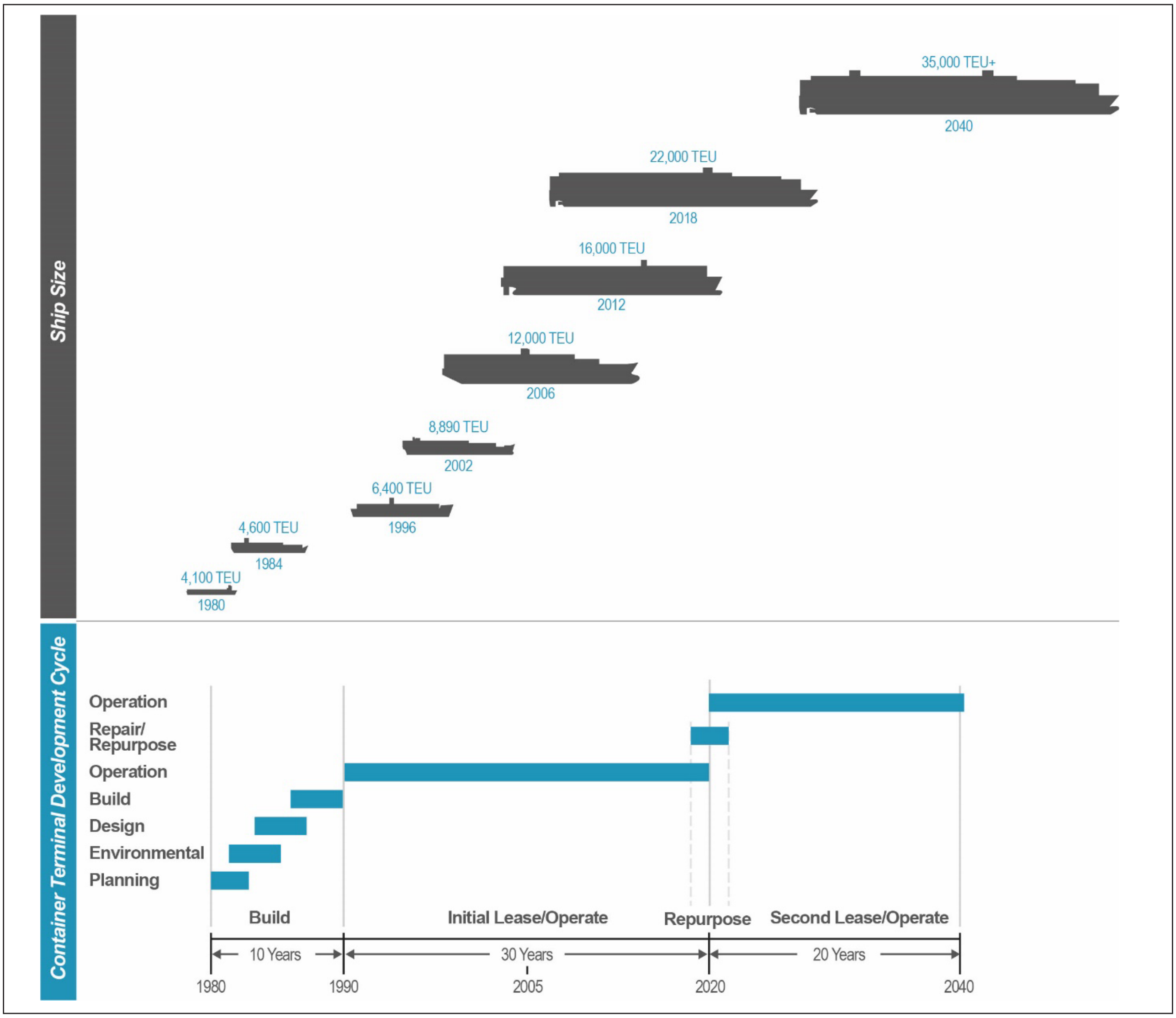

FIGURE 3 Container terminal development cycle.

- Automated or semiautomated electrified tractors, trains, trucks, and ships.

Infrastructure resiliency

- Infrastructure designed to survive and operate with all-hazard protection in the event of storms, typhoons, floods, tsunamis, fire, and earthquakes.
- Sensors or other technology to provide advance warning of natural disasters.

Multigeneration terminal operation

- Smart artificial intelligence controls that fully integrate all port operations.
- On-demand cargo pickup using technology like that for on-demand car services.
- Reuse and repurposing of terminals to minimize the use of new resources.

Sustainability

- Green technology throughout the supply chain to minimize environmental and community impacts.
- Reduced community impacts through holistic, integrated planning of logistics chain with stakeholders.

Challenges and Opportunities for Ports

More than 50 years of containerization have resulted in continuous building of most of the unused and unbuilt US port lands. As ships increase in size and trade lanes become more heavily trafficked, US ports will experience intense pressure to modernize old facilities or risk losing market share to competitors. Canadian and Mexican ports, which can service inland US destinations via rail, are already taking market share from some US ports. Other market forces on ports include consolidation among port authorities, operators, and shipping carriers.

As carriers get larger, ships will need to increase in size and landside automation will need to compliment this increase in order to improve efficiencies. The largest ships are likely to bypass smaller, underfunded port facilities, forcing them to reorient to niche or specialized trades to avoid decline. There will be exceptions, as in the airport industry, where medium and smaller facilities can thrive where they have a cost, geographic, or special value-added proposition. Additionally, ports are responding to increased safety, environmental, and social requirements.

Investments in research are required to more clearly identify challenges and provide solutions to better define the future terminal and supporting infrastructure needs. Table 1 presents a noncomprehensive list of strategic research areas for consideration and prioritization of investments in efficiencies and development initiatives for container terminals.

What Is Next?

There is a recognized need for additional investments in port infrastructure by the American Society of Civil Engineers, which assigned the US port system a grade of C+ (mediocre, requires attention) in its 2017 Infrastructure Report Card (ASCE 2017).

In addition to being economically essential to US competitiveness, the port industry is vital to national security. In fact, it is one of 16 critical infrastructure protection sectors identified by the Department of Homeland Security. DHS defines these sectors as those “whose assets, systems, and networks (whether physical or virtual) are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, [and/or] national public health or safety.”[3] Given their importance to the US economy, ports are a growing market sector clearly worth strategic investments and protection.

Policy goals related to port funding generally concern efficiency improvements to increase productivity, secure and stable financing, and support for regional and terminal-specific development initiatives.

Also at the national level, it is important for researchers, practitioners, and government and agency representatives to come together to discuss objectives and define an approach to consider the strategic research areas shown in table 1. Such a forum could be organized by leading national agencies and initiated with federal funding for the collection of data on trends, gap analysis studies, and research on emerging technologies.

> *The port industry is one of 16 critical infrastructure protection sectors identified by the DHS.*

At the local level, it is important that port experts publish a port-by-port infrastructure and technology development plan, reach out to and link port infrastructure and technology experts, create needs assessments, and conduct bench and pilot testing of promising emerging technologies.

Based on past and current trends, the impacts of ship size on infrastructure development and technology can be predicted. A panel of experts in ports, technology, and funding can help develop a container terminal planning and investment toolkit, following the process outlined in the Port Planning and Investment Toolkit for infrastructure upgrades (AAPA 2017b). This resource would include guidance for data collection and planning, assessment of the feasibility of proposed projects, financing options, and a spreadsheet tool to evaluate cost benefits of various infrastructure and technology opportunities.

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[3] https://www.dhs.gov/critical-infrastructure-sectors

TABLE 1 Proposed research and investment areas for future container terminals

Characteristic	Potential initiative
Technology advancement	***Equipment, automation, and engineering tools:*** • New types of container handling equipment in the yard • Retrofitting of existing container handling equipment • Clean or "green" technologies • Automation for inland container terminals and distribution centers • Building information modeling standard for port design engineering • Robotics for inspection and maintenance ***Pavement systems:*** • Automation • Repetitive heavy loads • Tracking of container and equipment movement ***Security and data collection in logistics chain:*** • Camera or sensor systems to track movement of equipment, containers, trains, and container handling equipment • Security and electronic integration of camera and sensor systems
Infrastructure resiliency	• Disaster prevention and mitigation • Protection of critical infrastructure, buildings, and lifelines • Risk, resiliency, and continuity of operation plans • Comprehensive national standards for consistency and reduced vulnerability
Multigeneration terminal operations	***Terminal operating systems:*** • Real-time control activities • Integrated optimization for terminal performance • Applied simulation for cargo movement logistics • Intelligent supply chains with advanced data sharing • Artificial intelligence functionality • Integrated future terminal and cargo systems from shipside to inland distribution ***Safety:*** • Safety by design, by automatic process, and for the separation of humans and machines • Remote operation of container handling equipment • Truck safety through advanced technology ***Information technology:*** • Resolve big data issues • iCloud data storage • Data sharing through blockchain or other technology • Machine learning
Sustainability	• Environmentally acceptable integration of the whole transportation system (railroads, ports, highways, distribution networks) • Environmental development to reduce air and water emissions and noise • Compliance with federal, state, and local standards • Energy management (conservation, storage, renewables) • Minimization of environmental challenges in high-risk communities impacted by cargo movement • Electrification of container yard and over-the-road equipment for air quality benefits • Community and social engagement and outreach

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Infrastructure modifications could enhance and expedite the development and deployment of AV technology to support the vision of zero road traffic fatalities.

The Role of Infrastructure in an Automated Vehicle Future

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Automated vehicles (AVs) have the potential to revolutionize road transportation. In the United States, approximately 94 percent of all crashes can be attributed to human error (Singh 2015) and the cost of crashes is more than $250 billion annually (Bamonte 2013). Automated vehicles are anticipated to reduce the number of crashes and also improve mobility for underserved segments of the population, reduce commute burdens, and increase road use.

As AV development and deployment continue to advance, a parallel and synergistic opportunity to improve roadway infrastructure exists. This article

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considers opportunities and challenges associated with the improvement of roadway-related infrastructure to support automated vehicles.

Introduction

In 1997 the government of Sweden announced Vision Zero, a national target of zero traffic deaths (Swedish Ministry of Transport and Communications 1997). Since then, a number of other countries have adopted this goal. In the United States the National Highway Traffic Safety Administration (NHTSA), Federal Highway Administration (FHWA), Federal Motor Carrier Safety Administration, and National Safety Council are collaborating to achieve the goal (NHTSA 2016). The FHWA, which has oversight of the construction and maintenance of the nation's highways, bridges, and tunnels, plays an important role in any improvements to this infrastructure, which can help maximize the safety benefits of automated vehicles.

Accidents can be contextualized in terms of contributions from the human, vehicle, and environment. Progress toward removing the human from the operation of a fully automated vehicle will increasingly emphasize the roles of the vehicle and the environment, including the roadway and other infrastructure. Infrastructure improvements might help address challenging operational design domains (ODDs) such as driving in the snow at night with little visibility or correctly interpreting differing traffic controls and signage across the 50 states.

While the technology is still maturing, the aging US infrastructure, which also faces funding uncertainty, is being pressured by continuously and quickly evolving AV technology. Fortunately, although automation is posing challenges, it is also revitalizing the conversation around infrastructure and its role in the transportation ecosystem.

This article briefly describes the state of AV technology, the levels of automation for AVs, and the sensing suites used to perceive the environment, including the surrounding infrastructure. It explains how the current infrastructure can be modified to improve AV performance, and then reviews challenges to continued progress.

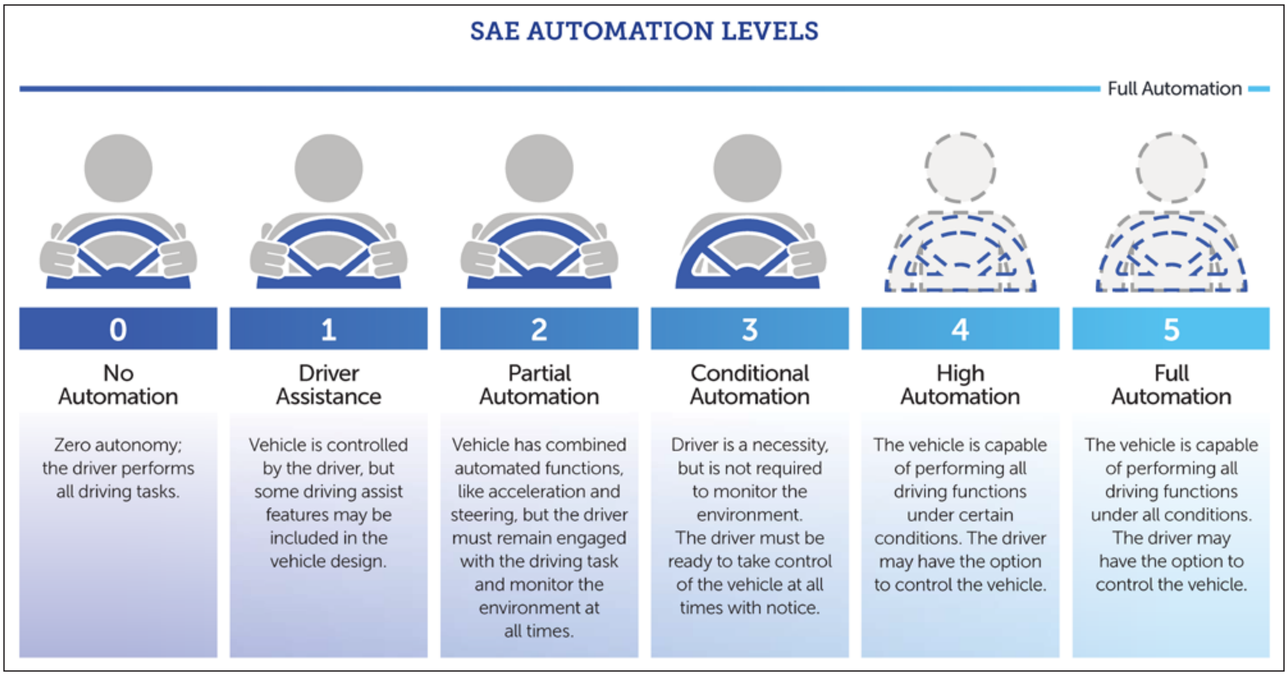
The State of AV Technology

The last few decades have seen the emergence and deployment of active safety systems throughout the automotive industry. Unlike passive safety technologies, such as airbags and seatbelts, which aim to protect occupants in the event of a crash, active safety systems aim to proactively mitigate or eliminate crashes altogether. AV technologies comprise the most advanced active safety systems. Rather than relying solely on the driver, they are designed to assist or take full control of safely operating the vehicle.

> *Operation of a fully automated vehicle will increasingly emphasize the roles of the vehicle and the environment, including the roadway and other infrastructure.*

A vehicle's level of automation is defined by the level of human monitoring and supervision required and the ODD in which the vehicle is capable of operating. The available technologies to achieve a certain level of automation vary in complexity, and different combinations of sensors and actuators can be used to achieve the same level of automation. In other words, a given level of automation is not defined by the suite of sensors and actuators installed on a vehicle. The technologies involved are highly proprietary and at times cost sensitive, so systems differ across manufacturers and vehicle models.

The current standard adopted by NHTSA, SAE J3016 (SAE International 2016), defines six levels of automation (figure 1), ranging from none (level 0) to a fully automated vehicle (level 5). The simplest active safety systems (SAE level 0) rely solely on the driver to operate the vehicle. Common examples of level 0 automation are lane departure warning (LDW) and forward collision warning (FCW) systems that deliver an alert to the driver in the event of an imminent lane departure or frontal impact, respectively, but rely on the driver to take evasive action (General Motors 2018; Mercedes-Benz USA 2018; Tesla 2018; Volvo Car Corporation 2015).



0	1	2	3	4	5
No Automation	Driver Assistance	Partial Automation	Conditional Automation	High Automation	Full Automation
Zero autonomy; the driver performs all driving tasks.	Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.	Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

FIGURE 1 Levels of automation set forth in SAE J3016 standard (SAE International 2016). Reprinted from NHTSA (2017).

The most advanced technologies on the market are SAE level 2, partial automation; SAE level 3 systems, for conditional automation, are slated to enter the market later in 2018 (Audi Media Center 2017). An example of level 2 automation is adaptive cruise control in conjunction with a lane keeping assist (LKA) system (Audi Media Center 2017; General Motors 2018; Mercedes-Benz USA 2018; Tesla 2018; Volvo Car Corporation 2015); together, they maintain the vehicle's position on the roadway and relative to other vehicles. However, to ensure the safe operation of the vehicle, the driver must continue to monitor the driving environment.

Although several companies are testing highly automated vehicles, consumers cannot currently purchase vehicles that are capable of operation without any driver supervision (SAE levels 4 and 5).

How AV Systems Work

The function, hardware, and objective of AV systems vary widely across the industry, but the framework for how they help navigate vehicles is largely consistent:

1. The environment is monitored using a combination of sensors (e.g., cameras, radar, ultrasound, and lidar).
2. The vehicle's onboard computer processes the information relayed from the sensors and combines it with global positioning system (GPS) data, the known vehicle state (e.g., speeds, orientation, steering, brake application), and 3D mapping data to estimate the vehicle's absolute position.
3. These steps create a virtual representation of the world, which includes the subject vehicle as well as all other road users (including bicyclists, pedestrians, and other vulnerable road users), objects, and their intended path.
4. The vehicle determines an appropriate course of action (e.g., avoiding a collision) while obeying traffic laws.

In the most basic systems (SAE level 0) the vehicle monitors only a narrow set of variables (e.g., distance from the closest-in-path vehicle) and simply delivers a warning to the driver when certain conditions are met. The most advanced technologies actively plan the path of the vehicle and can modify the lateral and longitudinal dynamics of the vehicle within that space.

AV technologies rely on information sent from vehicle-based sensors to provide the driver with extra "eyes" that continuously scan the area around the vehicle. Cameras, for example, are widely used in AV systems. With machine vision techniques, incoming video data can be processed in real time to identify objects (including their location and trajectory) or determine the position of the vehicle in the roadway (Dabral et al. 2014; Lee 2002; Papageorgiou and Poggio 1999). LKA and LDW both use cameras to detect lane markings for determining the lateral position of the vehicle in the roadway. But when the camera is unable to detect lane markings—during poor weather conditions (e.g., snow), inadequate lighting conditions, or on roads without lane markings—LKA technologies may be ineffective. This is a particularly limiting factor given that a third of drift-out-of-lane road departure events occur on roads without lane markings (Scanlon et al. 2016a).

Radar, lidar, and ultrasonic sensors are also involved in AV technologies to determine the location of roadway obstacles and other roadway users (Hatipoglu et al. 2003; Pakett 1994; Schubert et al. 2010; Tesla 2018). They are capable of varying detection ranges, field of view, and resolution, but all require line of sight and are therefore of limited effectiveness in detecting oncoming vehicles in certain driving scenarios.

As an example, a vehicle making a left turn at a signalized intersection may encounter sightline restrictions due to vehicles in the opposite lanes (Scanlon et al. 2017). And when vehicles approach from lateral directions at intersections, line of sight may be impaired by roadside objects such as signs or foliage, or by roadway geometry such as curves or hill crests (Scanlon et al. 2016b).

GPS data are used to determine vehicle position in the roadway, but accuracy limitations and degraded signal near buildings or other obstructions compromise the reliability of these data (DOD 2008). Automated vehicles will use data fusion techniques to incorporate GPS data with other sensing equipment, such as cameras or inertial measurement units, to improve reliability (Caron et al. 2006; Chang et al. 2010; El Faouzi et al. 2011; Milanés et al. 2008).

Automated vehicles are expected to eventually close the gap with humans in terms of adaptability and resilience to unstructured environments and to be capable of operating, initially, in selected "geofenced" environments and under prescribed ODDs.[1]

The Role of Infrastructure

Current infrastructure is designed and built to accommodate human abilities and information needs. Road signs, for example, are sized and positioned based on human perception capabilities in relation to speed limits and local traffic patterns.

To align with advances in AV technologies, the infrastructure will likely need to evolve in three ways: (1) account for AV sensing capabilities, (2) provide complementary sensing capabilities, and (3) adapt to the requirements of transportation modes enabled by AVs. AV technologies are currently being designed to operate with little or no support from the infrastructure, but the burden of perception and path planning will be increasingly shared and integrated with the infrastructure.

> *Technologies can equip AVs with sensing range and accuracy beyond human drivers' capabilities.*

Some argue that AVs should be capable of navigating using the same infrastructure that human drivers use today. But technologies can equip AVs with sensing range and accuracy beyond human drivers' capabilities. For instance, humans drive with limited exchanges of information with other human drivers, but vehicle-to-vehicle communication can facilitate AV navigation and planning by sharing information, even in the absence of line of sight. Deeper integration of vehicles and infrastructure will increase AV sensitivity to infrastructure conditions and inconsistencies, while at the same time granting additional layers of robustness, making AVs arguably safer.

Technological Enhancements for Infrastructure

Certain physical infrastructure elements such as lane markings, signage, and signals can be designed to facilitate AV perception and interpretation. Infrastructure can also act as a distributed sensor network, supporting data sharing and providing information to vehicles. And technologies such as variable speed limits, traffic detection at signalized intersections, and traffic signal coordination are already moving the infrastructure in this direction.

It is expected that this digital infrastructure will become the cyberphysical backbone for AVs: using an

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[1] The 2019 Audi A8 "Traffic Jam Pilot," for instance, allows drivers to travel hands-free up to 35 mph on a limited-access divided highway.

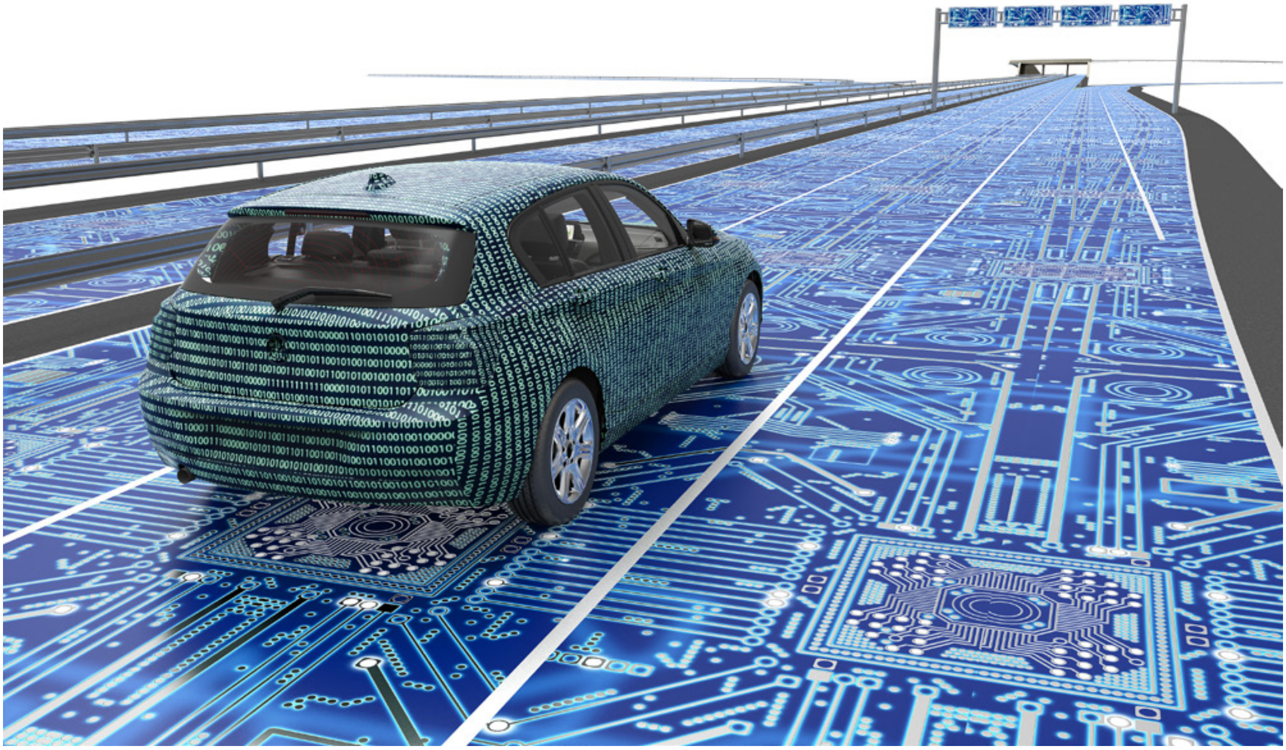

FIGURE 2 The infrastructure of the future will be able to seamlessly exchange data with vehicles and other road users. Source: Getty Images.

Internet of Things approach, it will be capable of sensing the environment and sharing useful information with vehicles (figure 2). For instance, precipitation sensors may alert AVs to potentially hazardous driving conditions, and smart traffic cones may be capable of repositioning themselves safely on the road while communicating to nearby vehicles about their placement and the reason for their presence.

A constant exchange of information between vehicles and the infrastructure will facilitate the updating of digital maps in real time. Many AVs now rely heavily on such maps to ascertain precise location and safely navigate the environment. With the environment continuously changing—because of road work, local road closures, weather, and other factors—access to updated maps in real time has direct repercussions on AV performance. The constant exchange of information between infrastructure and AVs can facilitate the identification of nonconformities and road hazards, establishing a virtuous cycle of data sharing that benefits the safety and mobility of both drivers and the public at large.

Finally, with the introduction of AVs, the infrastructure will have to accommodate new driving behaviors and traffic patterns. A prime example is parking. In London, an estimated 8,000 hectares of land are occupied by parked cars. However, in a driving landscape dominated by AVs it may not be necessary to find a parking spot close to the drop-off location since vehicles will be able to drive away to park (if necessary) where space allows, thus operating similarly to a taxicab. As an additional benefit, AVs will enable better use of land allocated for parking by parking closer to each other.

Challenges

As AV technology is continuously progressing, infrastructure changes will have to accommodate new and unforeseen technologies. The increased interaction between technologically sophisticated vehicles and infrastructure will require closer collaboration between the automotive, technology development, and infrastructure communities as well as road owners and operators, transportation planners, and federal, state, and local agencies. Although updating the infrastructure can be daunting and expensive, its benefits will likely extend beyond AVs to human drivers as well.

The difference in the deployment time horizons for sensor and vehicle technologies, often measured in years, and for infrastructure, measured in decades, will create planning, design, and funding challenges. Current infrastructure decisions will impact and define AV operation for decades to come, so communication and coordination among the automotive, technology development, and infrastructure communities will be essential:

- The infrastructure community will benefit from a better understanding of current and future AV technology needs, which will allow the implementation of infrastructure enhancements that can support the safe and efficient operation of AVs into the future.
- The automotive and technology development communities should consider and design within the context of infrastructure planning, funding, and maintenance.
- Technology developers should plan for the availability and deployment of future infrastructure.
- The infrastructure community needs to stay abreast of vehicle and sensor technology development to understand how infrastructure may impede or accelerate the adoption of sensor technologies and AVs.
- As data sharing between vehicles and infrastructure expands, securing and leveraging these data communications will require coordination among the three communities.

In the short term, the most relevant infrastructure features for AV safety, efficiency, and performance should be identified and evaluated in the context of the level of automation. For instance, well-maintained lane markings are critical for LKA technologies. Harmonization of lane markings, signage, and traffic signals across all states is equally important.[2]

The type and periodicity of maintenance and repairs (e.g., road markings and pavement quality) need also to be considered for the effective implementation of AV technology. As an example, careful attention should be paid to the conditions of road signs to ensure maximum visibility in all seasons and weather. As technology evolves, some constraints may be relaxed, but even if a new technology is more robust to infrastructure inconsistencies, full market penetration will be gradual and could take decades. Therefore the needs and limitations of the current AV fleet must be considered well into the future.

Will AVs increase or reduce road use? How will they affect traffic flow and volume?.

The infrastructure community also needs to assess the impact of AVs on road capacity and land use. Will AVs increase or reduce vehicle miles traveled (VMT) and thus road use? How will AVs affect traffic flow and volume? How will land use change as the need for surface and garage parking evolves? These are only a handful of questions that need to be addressed in anticipation of the release and widespread adoption of AVs.

Finally, infrastructure for automotive transportation is under pressure from increasing vehicle electrification. AVs are not necessarily electric, but electrification in the automotive field is gaining traction and the infrastructure must account for this regardless of AV penetration. Electrification can offer synergies with certain aspects of AVs—for instance, by streamlining data sharing—and will play an increasingly important role in infrastructure.

Conclusion

In a fast-paced technological landscape, it is challenging to identify the needs of the next 50 years. And at a time of uncertainty in infrastructure funding, it may be even more difficult to plan and implement infrastructure for AV technologies that are still in development. In remote areas with low traffic volume, for example, it may be cost prohibitive to install adequate infrastructure to fulfill current AV needs. On the other hand, future AVs are expected to be more robust and resilient to infrastructure deficiencies and may be capable of navigating those remote areas even without particular infrastructure support.

Given the current trajectory of AV technology, infrastructure modifications could enhance and expedite the development and deployment of these systems to sup-

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[2] The *Manual of Uniform Traffic Control Devices* (FHWA 2012) defines standards and recommendations for state and local authorities.

port the vision of zero road traffic fatalities. Achieving this vision will require collaboration between the automotive, technology development, and infrastructure communities as well as federal, state, and local agencies. It is vital to plan for and implement infrastructure solutions that are agnostic to specific technologies, benefit both AVs and human drivers, and prioritize short- and medium-term needs while keeping a long-term view.

Areas for immediate action include traffic control harmonization, continuous engagement between parties, and pilot demonstration projects. Uniform signage and road marking across jurisdictions can be achieved through the updating and implementation of the *Manual of Uniform Traffic Control Devices*. Infrastructure planners and engineers should maintain constant communication with AV developers to make sure they have their finger on the pulse of the industry and understand AV needs. This process will necessarily evolve through pilot demonstration projects that can inform the interaction between infrastructure and AVs while offering opportunities to engage and educate the public.

The limitations of today may be overcome by the breakthroughs of tomorrow.

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An Interview with . . .

Sylvia Acevedo, CEO, Girl Scouts of the USA

Sylvia Acevedo

RON LATANISION (RML): We are very happy to talk with you today, Sylvia. I think you are an inspiration to a lot of people and especially to young women given the work you do on their behalf with the Girl Scouts. I'd like to begin with some of your background. I understand you have a BS in industrial engineering from New Mexico State and a master's in systems engineering from Stanford. And you practiced as an engineer. Is that correct?

SYLVIA ACEVEDO: Yes, I even had my PE license for a while.

RML: That's wonderful! Tell us a little about what you've done in terms of your engineering experiences.

MS. ACEVEDO: I was really fortunate to have had a work-study program through college at Sandia Labs, so I got hands-on experience in the field in human factor testing. That was fantastic. Then my first job out of college was working at the Jet Propulsion Labs as a rocket scientist. I joined at an opportune time, right when the Voyager II was doing a flyby of Jupiter and its moons, so I got to analyze reams and reams and reams of data.

In addition to that, I worked on the Parker Solar Probe Missions, where I did some complex algorithm analysis of the payloads of test equipment versus how it would impact with gravity, with radiation, with all sorts of things.

Then I worked in Silicon Valley as a facilities engineer. That was really fantastic. I got to do a state-of-the-art building for IBM, a 765,000 square foot plenum clean room. I still remember that, and I can probably tell you where every outlet was. It became the showcase for IBM in terms of manufacturing. Besides high-end disc storage there, IBM was trying to sell more of its computers for the fast-growing technology industry, so it needed people who were comfortable with the technology and with engineers, and able to talk to engineers—who are now the decision makers in Silicon Valley. I was selected to join their marketing and sales team, using my technology background.

Then I saw how other people, especially men, were being groomed and I realized that there weren't people grooming me. So I went out of my way to figure out what were the skills I needed to move up in my career. I had sales experience, and I knew I needed product marketing and P&L experience, so I began developing my career in the technology field along that line. I then created opportunities to develop as an executive and worked at a variety of companies, like Apple, Autodesk, and then I was recruited to work at Dell to launch its server business. That was a very exciting opportunity.

After that I got the startup bug, partly due to my Girl Scouts cookie program skills of entrepreneurship. I got my opportunity to start, with three other people, a startup called REBA Technology, which we ended up selling and having a successful exit. Because of the successful exit I had some time and opportunity to think about what's next.

I could have jumped right back into technology, but I saw the demographic shift and that I had the skills and capability of understanding the analytics, so I became involved in education, creating mobilization campaigns that got families much more involved. And tying the impact of improved educational attainment to workforce development.

The educational impact of this was noticed and I was selected to be on the Presidential Initiative for Hispanic Educational Excellence; I was chair of the Early Childhood Committee.

To scale the impact, I decided to take some time to write what I knew, and I wrote a curriculum of family engagement, mostly directed at English language learners or those who are new to the US educational system, from pre-K to 12th grade, through Houghton Mifflin Harcourt.

Everything I did was with a systems approach. I had the analytical capability but I also had the systems thinking. I'm always thinking, How does this scale? Educators are really great one-on-one and one-on-a-few—which is the best way to learn, frankly; they are doing what they are supposed to do—but sometimes with demographic changes the scale overwhelms them.

I professionally trained in scale and analytics, so I was able to create solutions that scaled. For example, a quarter of a million books were successfully distributed across the country. I think we did the largest single-day book giveaway in California's history—60,000 books. That's the size of a bookstore. Most people were overwhelmed by that number, but as a systems person and a process person, I knew how to break it down so that we could easily deliver those books in one day. Every time somebody came in we handed them a bookbag with the appropriate age-level book.

I took the same approach with vision, and with dental. I found out that 20 percent of the kids in a Title I school didn't have glasses even though they needed them, and that this need was overwhelming the capabilities of the local nonprofits. If you can't see you can't learn. I created a consortium and created another way of doing that and in just a couple of years, 11,000 kids got glasses that normally wouldn't have had them.

RML: You mentioned being part of a presidential initiative. When was that? During the Obama years?

MS. ACEVEDO: Yes. I was chair of the Early Childhood Subcommittee. I was a Head Start baby and I knew how important Head Start was for me. Taking a systemic approach, we realized that, while we had a lot of great organizations and people focused on making a difference, we needed to make sure there were data and analytics. We put data and analytics in research reports so the information was available—especially the demographics—to funders.

We also got a policy changed. Before our work, if you were running a Head Start or other early childhood program, you could not use federal funds to teach children in their native language. You immediately had to put them in English immersion, and couldn't bridge to a child's native language using the child's native skills. If you think about the global market, where being bilingual is a competitive advantage, we were taking off the table one of the competitive advantages of our nation's workforce being bilingual. So we were able to get that policy changed.

Everything I do is with a systems approach. I'm always thinking, How does this scale?

CAMERON FLETCHER (CHF): Are you still on that commission?

MS. ACEVEDO: No, and I wouldn't have time for it now, being CEO of the Girl Scouts.

RML: Do you know if that commission is still active?

MS. ACEVEDO: As in other areas with this administration, I don't think they've quite filled all the positions yet.

RML: I asked because I was speaking recently with someone about the current absence of a presidential science advisor. In fact, a lot of the science advisory capacity in the Trump administration is basically inactive. So I'm curious about this commission because, obviously when you're talking about education and young people, that's a very important role.

CHF: Sylvia, you mentioned that you appreciated that you had benefited from Head Start and other programs, and what struck me earlier was when you said that in the corporate world you realized you were not getting the kind of professional grooming that your male colleagues got. Are you doing anything to help young professional women with mentoring or that kind of grooming, sort of paying it forward in the ways that you've done in other areas?

MS. ACEVEDO: That's a great question. In the Girl Scouts we have an acronym "GIRL": Go-getter, Innovator, Risk taker, Leader. The reason I immediately sought out how I could move ahead in my career is that Girl Scouts taught me how to create opportunity and to problem solve.

As an engineer I know the importance of a scalable business model. How can you scale something if you don't have a model? In Girl Scouts our "business model" is to take girl potential, develop skills, and provide leadership experience. You learn something and have to do something with it—you have to take action, you have to problem solve. There also has to be a caring adult who is a troop leader and is interested in developing the girls' potential.

Here is a real-world example. When I first started working at Sandia Labs they didn't have a bathroom available for me. Instead of being angry, I immediately went into problem-solving mode. I thought, 'When did I have another instance like that?' And I remembered in Girl Scouts when we were going on an all-day hike and my troop leader asked us, "What do we need?" We said, "a hat," "comfortable shoes." She kept saying, "What else do you need?" Finally, she said, "How are you going to go to the bathroom on an all-day hike?" As a kid, you're thinking, 'I don't know.' So we had to problem solve.

Almost 80 percent of all women US senators were Girl Scouts, as were all three female secretaries of state.

At Sandia I said to myself, 'Okay, how am I going to problem-solve this?' I identified where the closest women's bathrooms were and realized that if I had an emergency I'd have to bring a bike. So I did. In 6 weeks they finally bought me my own Porta-Potty that said 'Hers.'

As an engineer, I wanted to get ahead and I noticed my managers didn't always help me. In typical Girl Scout fashion I didn't start blaming or complaining. I went immediately into problem solving.

As a Girl Scout I realized, here I am in the corporate environment where I see the informal and formal networking and mentoring they are doing for my male colleagues. No one's doing it for me, so I figured out for myself what I needed to do to advance my career.

Recently I was in Silicon Valley talking with some of the top female tech leaders. They mentioned that Girl Scouting helped them realize that it's okay to have a mentor, it's okay to ask for support and guidance. If you grow up with that in Girl Scouts, it becomes embedded in how you think about things. A lot of times girls grow up thinking, 'If I ask a question that means I don't know something.' Instead, Girl Scouts realize, 'I can ask something and I can be a go-getter and go after that.'

RML: There seems to be a great deal of interest among women today in running for elected office, and *Time* magazine just had an extensive article on women who were considering running for elected office. Do you happen to know any of these women and whether they were Girl Scouts?

MS. ACEVEDO: Let me give you the numbers. I love these numbers! Girl Scouts are 8 percent of this country's girl population but we represent more than half of all female elected officials. Almost 80 percent of all women US senators were Girl Scouts. I think all but one female elected governor, historic and current, were Girl Scouts. As were all three female secretaries of state.

RML: As the grandfather of four girls I'm delighted to hear this. Do you have any contact in your current life with any of those folks?

MS. ACEVEDO: Yes, we reach out to the senators and representatives. But to look at your question in a slightly different way, I didn't initially realize the impact of Girl Scouts in my own life.

About 10 or 12 years ago I got a phone call from Stanford. Somebody was working in the archives department and doing a study and said, "I want to talk to you because frankly you're one of the first Hispanics, male or female, to have gotten your graduate engineering degree from Stanford and you are still one of the few. We want to find out why you knew about Stanford, because Stanford wasn't actively recruiting in southern New Mexico at the time, so how is it that you had the right training, the right skills, the right aptitude to be prepared to excel at Stanford. Did you have wealthy parents? Did you have college professors as parents?" I said, "No. We lived paycheck to paycheck." They kept asking me, "Well, why was it that you took advanced calculus? And chemistry physics?" At the time girls like me weren't even graduating from high school much less going on to college much less becoming an engineer.

That was when I made the connection with Girl Scouts. I was out on a camping trip, and after we finished eating our s'mores I stayed looking at the beautiful night sky—we were in Las Cruces, New Mexico. My troop leader saw me and sat next to me and pointed out the constellations, the different stars, and the planets. My parents had seen me looking at the stars but they had never pointed out the Big Dipper or Little Dipper. I learned that there are systems up in the night sky.

The troop leader remembered that and later, when we were earning our badges and I wanted to do what all my friends were doing—earning their cooking badge—she encouraged me to also earn my science badge. I demurred but she said, "I remember you looking at the stars. Why don't you do something with space?" So I made an Estes rocket. It took several tries to make it. I learned you have to get the chemicals right, you have to get the heat source right. And when you get all of that right you can have success just like in cooking. By doing that, I realized I liked science and I was good at it.

That prompted me to continue to take math and science. So when the opportunity presented itself, I said, "I'm going to be an engineer." Even though my college counselor didn't encourage me I still went ahead and did that. And I'm so grateful that that historical archivist called me because at that point I realized, 'Oh my gosh,

Sylvia Acevedo with Brownies and Girl Scouts in Central Park.

if I look at my cousins, if I look at my friends, I'm the only one that has taken this path and that was thanks to Girl Scouts and thanks to my troop leader pointing out the stars and me having that hands-on science activity.' Then I became very active in volunteering and being on the board and now I'm the CEO.

CHF: This started from looking at the stars—you could have gone into astronomy or a science and yet you chose engineering. What led you in that direction?

MS. ACEVEDO: That's easy. I remember back in the day, pre-Google, you could get college books about different careers, and I realized I liked people but I also liked systems and processes. Business didn't strike me as particularly interesting, and neither did theoretical fields, for the sake of theory, like physics and chemistry. But wow, having a blend of both people and process, that really interested me. And that's why I decided to study industrial and then systems engineering.

RML: So you've had academic experience, experience in the corporate world, and experience in terms of social engineering and social issues, I suppose is a way of characterizing it. I know you've been a lifelong Girl Scout but what was the decision point that led you to become the CEO of the Girl Scouts?

MS. ACEVEDO: There were two. One was from the Stanford interview, helping me understand how pivotal Girl Scouts was in my life. The other was from thinking how I could contribute at scale to make a difference.

> *For me what's exciting is the scale of the challenge of reaching more girls in a contemporary way.*

A neighbor had asked me to volunteer reading at a local Title I school. I was helping a young girl and noticed she had terrible dental hygiene, so I began bringing in a toothbrush and some goldfish crackers (even though we weren't supposed to). We'd eat the goldfish crackers and then I'd say, "Okay, let's go brush our teeth." I told her to keep her toothbrush and next week we would do the same thing. Well, the next week came and she didn't have the toothbrush, so I went to Target and bought a whole bunch of toothbrushes. Every week I brought another one with me. After 6 weeks, she remembered her toothbrush. I said, "I'm so proud of you, you remembered your toothbrush." And she said, "No, now everybody in my family has a toothbrush."

At the time I was working in technology so I went to talk to the teacher and sort of indignantly said, "Did you know that child had horrible dental hygiene?" She looked at me and said, "Sylvia, do you have $35?" I said, "Huh?" She said, "Well, one of the kids just broke his eyeglasses and his family can't afford to fix them, so can you give me $35 to fix the glasses?" I did, but then I had an epiphany: The school and teachers were overrun with tens of thousands of kids that needed glasses, toothbrushes, books. I'm really good as a systems thinker and this is a systems challenge. It doesn't overwhelm me—it's actually fun for me, it's a problem to solve.

In Girl Scouts what I'm really excited about is that there are millions of girls who are underserved and underrepresented in rural areas, across every single zip code in America, and they would benefit from Girl Scouts. For me what's exciting is the scale of the challenge of reaching more girls in a contemporary way.

RML: What's the relationship between the Boy Scouts of America and the Girl Scouts of the USA? I understand that recently the Boy Scouts announced that girls could become Cub Scouts and I think eventually they will have the opportunity to earn Boy Scout badges and even the rank of Eagle Scout. Was there a conversation with the Girl Scouts in the evolution of that concept or policy on behalf of the Boy Scouts?

MS. ACEVEDO: We were incredibly disappointed that they decided to become coed. We are a girl-only, girl-focused organization and we continue to be. Our number one focus is girl safety and providing exceptional programs for girls. That's what we're all about.

RML: I'm sort of surprised that there was no conversation between the organizations. Is that correct?

MS. ACEVEDO: They called to tell us they were going to do something. We disagreed vehemently but they went ahead. We're amazingly disappointed that they did it.

RML: Is there something equivalent to an Eagle Scout in terms of the Girl Scout ranks and badges?

MS. ACEVEDO: We have three levels: Bronze, Silver, and Gold Award Girl Scouts. Gold Award is the premier and probably one of the most challenging youth-serving awards that a youth can earn. You have to have sustainable impact in your community that lasts beyond you. The Gold Award Girl Scout is amazing.

RML: I have to say, Sylvia, I'm thinking back to the comment about women who have announced their intention to run for elected office. I think I'm speaking to one who should consider that. Have you given that any thought?

MS. ACEVEDO: I always laugh when people say, "Hey, Sylvia, you should run, you should be a politician." No, I am 100 percent engaged in what we're doing in Girl Scouts.

RML: Well, I asked not only because you have insights that I think are on a national scale but also because I'm very concerned about the direction of the country. I think, frankly, having more women in Congress and other elected offices and in responsible positions in our government is and will be a good thing.

MS. ACEVEDO: I agree with you. Civics has been taken out of schools in some states and there are now generations of parents who haven't been taught a formal process about civics. We're reenergizing our civic engagement with badges in this area all the way from Daisies (kindergarten and 1st grade) to 12th grade. And our results speak for themselves—half of all female elected officials are Girl Scouts. So civic engagement is a really important part of what we do.

We're also giving Girl Scouts the skills and the tools to be creators of their environment. We want to give girls the skills to design, to create their world, to be inventors, designers, and entrepreneurs in any field. The internet of things is going to change everything. I'll give you an example.

A surgical device called the Da Vinci helps surgeons operate, but the company that developed the technology hired video gamers to develop the software. Then the company spent a lot of time to make sure doctors accepted it, but they didn't have the same consideration about the nurses in the operating room—and they are absolutely vital. The average operating room nurse is (or at least used to be) 42 years old. She was not comfortable with video game technology. All of a sudden a new device is brought into the operating room. The doctor got trained; she didn't, and the device isn't natural or native to her. So hospitals decided to reach out to men, who are very familiar with the video game technology. But, given biases about men and nurses, they paid men more to be the surgical nurses running the Da Vinci.

That was about a decade ago. Now think about the internet of things: almost every device we're going to interact with is going to have embedded technology. And it's so important that women be there at the table with the right kinds of skills to ask questions, maybe do the coding, the design, the marketing, the legal, and other product functions. For certain businesses—marketing, legal, software—the questions are vital.

> *We want to give girls the skills to design, to create their world, to be inventors, designers, and entrepreneurs in any field.*

We want to make sure that our Girl Scouts have that training, so that is an area we're really scaling up. We now have 23 new STEM badges, 6 space badges, badges for robotics, civic engagement, and 18 new cybersecurity badges. And that's just the beginning! No matter what field you're in, technology is going to be embedded in it and we want girls to be not just the users but the designers and creators.

RML: What do the cybersecurity badges involve?

MS. ACEVEDO: When we were creating and test piloting our 23 STEM and outdoor badges, we asked the girls, "What else do you want?" They said, "We want to protect our lives digitally." That's cybersecurity. We looked for a partner and actually have two—Palo Alto Networks and Raytheon—in developing these 18 cybersecurity badges.

For the younger ages, such as the Daisies and Brownies, it's really about learning safe protocols. How do you establish your online presence? By the time girls are in middle school, it's about internet browsers, traffic, web crawlers, so they can manage who is putting code on their computer and how they can prevent that. And for seniors and senior ambassadors, they're going to be doing some pretty high-end hacking and coding.

RML: I think about what the internet was intended to be, which was basically a platform that allowed everyone everywhere on the planet to communicate and to have access to information. That was the intention. Now we see what it has morphed into in terms of hacking and even antisocial behavior. One of our other interviewees in this series, a writer named Henry Petroski, recently referred to social media as "antisocial media," and in many respects it is. When you think about the damage that can be done to young people, particularly by some of their counterparts who, for whatever reasons, want to be malicious, it can be a very dangerous thing. And the amount of time that kids spend with keyboards is staggering to me.

So I wonder, how do you instruct young women to manage their personal lives in the face of things like Facebook that can be friendly or very harmful?

MS. ACEVEDO: We train our volunteers and our girls about bullying, both in the real world and especially through social media. We help them find important tools to control the dialogue online.

But also an important part of Girl Scouts is being outdoors and unplugging. So even with a tremendous amount of effort around STEM, there will always be a component that is unplugged.

> *We want girls not only to know how to program, but also to unplug and develop interpersonal skills and a love of the outdoors.*

We want girls to be able to think without boundaries. When you're looking at a digital device, somebody has predescribed your environment and what you're going to see. We want girls not only to know how to program, to create digital solutions, but also to turn it off and develop interpersonal skills and a love of the outdoors. I think that's one of the great things about our cookie program: it teaches you how to talk to people, how to set goals, how to deliver good customer service, how to ask for the order. So there's a balance of stepping away from the computer and being in the real moment.

One of my favorite memories is of a bridging ceremony. We have bridging ceremonies all over the country, and I was invited to the one in San Francisco at the Golden Gate Bridge—11,000 girls walked over that bridge. Afterward, at Crissy Field, they had all sorts of fun hands-on activities, everything from robotics to crafts to dancing to singing. And there was a big circle and the girls threw their mobile devices there and for 6 hours they engaged in life, engaged with each other, and played. I loved that! I thought it was a good example of Girl Scouting. They may have used their mobile device to get there but then they were there engaged in activities, having fun with friends.

CHF: How wonderful! I want to go back, Sylvia, to your mention that you were involved in a startup. What was the nature of that startup? And also, while we're on that subject, was that what got you to be identified on the website as an award-winning entrepreneur?

MS. ACEVEDO: The company, REBA Technology, had software to manage client-side IP server traffic. With all this traffic coming into servers, how do you prioritize and manage it? We had software that did that and the company was purchased.

After that I got into doing more work in the education field and started a company, CommuniCard, and earned many awards for the impact we made there. That's also what got me on the White House Presidential Commission.

RML: You obviously speak frequently to groups about Girl Scout activities, is that correct?

MS. ACEVEDO: I love talking about Girl Scouts because I know the big difference it made in my life.

RML: I can see why the word "inspirational" is an apt characterization of what you do. You have boundless energy and the things that you're doing and have done are truly inspirational.

MS. ACEVEDO: Thank you.

RML: Where do you see the Girl Scouts heading in the next decade? What is your vision for the future of the Girl Scouts?

MS. ACEVEDO: We're really excited about the path we have for girls. We're staying with our pillars: the outdoors, STEM, life skills, and entrepreneurship. But we're going to reach even more girls from underserved and underrepresented areas. Continual lifelong learning is important, so there will be more types of badges in relevant areas. And I think we'll make the strong case of our economic impact on the workforce. So many women CEOs were Girl Scouts! Just name a top female leader and she was a Girl Scout. We haven't been as articulate as we need to be about that.

There's also the connection with our alumnae. I call the Girl Scouts "the forgotten leader" in women's leadership. Like me, I forgot the connection. So we're going to put a lot of effort into helping people remember the connection.

I was just speaking with a professor at Columbia University. She said, "Sylvia, I was a Girl Scout, but I don't know what you're talking about—I don't remember the connection." She went home and, to her credit, she called me and said, "Sylvia, I have to apologize. I started a stock photo digital photography business and I was able to sell it profitably. I went home and found my Girl Scout sash and what did I see but two camera badges and also top cookie seller!"

Just like me, she had forgotten that connection and had to be reminded. We want to remind others of that connection.

Sylvia Acevedo addresses the 2017 Girl Scouts National Convention, "G.I.R.L. 2017."

CHF: So you're going to build up Girl Scouts alumnae activities?

MS. ACEVEDO: You bet, we absolutely are. And use social media to do it.

CHF: That may also help to counter your concern about the fact that the Boy Scouts are now admitting girls. On that subject, I want to mention that I went to Bryn Mawr and we had coed classes, coed dorms, coed activities with Haverford College, which is about a mile down the road from Bryn Mawr. The last year I was there, Haverford decided to admit women. Well, of course, there was a hue and cry among us Mawrters—but it turns out not to have made any difference in the numbers of women applying to study at Bryn Mawr, which remains an all-women's school.

The other thing is that with all of the stories about abuses by men in power, there may be a particular attractiveness to an activity that is a haven for young women in the Girl Scouts.

I offer these as evidence that the Girl Scouts will remain strong as a girls-only program.

MS. ACEVEDO: Thank you, I appreciate that.

RML: Sylvia, we typically ask the folks we interview if there is any message they would like to convey to *Bridge* readers, who include not only the NAE members but also members of Congress and people at engineering schools and many other interested subscribers—about 7,000 in all. What message would you like to give our readers?

MS. ACEVEDO: Girls in the United States are an amazingly untapped resource for America and right now America needs all of its best talent to compete in the global economy. Girl Scouts is poised to develop girls: to encourage confidence and character and make the world better and with the right kinds of skills to succeed in the 21st century.

RML: That's a wonderful message. I think highlighting the impact that women have had on the legislative process, in terms of elected officials, and in other areas is something that most Americans are unaware of but would be delighted to know. I think that's something that your banners ought to fly because it's very, very important.

MS. ACEVEDO: The only other thing I would ask is if you could put in a plug for readers who were Girl Scouts to put it on their LinkedIn profile.

CHF: Before we close, Sylvia, I just want to ask, it looks like you went skydiving?

MS. ACEVEDO: Right, I did. I went with the Golden Knights. The Army was a partner in our grassroots campaigns and it had such an impact on helping the military that as a thank you they allowed me to go skydiving with the Golden Knights.

CHF: What did you think?

MS. ACEVEDO: Oh my gosh! I went with a guy who had 6,000 jumps so, although initially I was scared, once I met him I realized I could not be in safer hands. We did some pretty amazing things. We did the James Bond thing and did a dive bomb because we didn't release the smaller chute right away. I think we jumped from 3 miles and released the big parachute at 2 miles. When you jump out of a plane—

CHF: You're falling at 120 miles an hour.

MS. ACEVEDO: Yes, and when we dived I really did feel like I was in a James Bond movie. Then we released the smaller parachute so that it could be a little easier going down—that was fun because then you could see things—and then we put out the bigger chute. It was a great experience.

CHF: Wasn't it wonderful! Once the big chute opens the descent is actually very tranquil and serene.

MS. ACEVEDO: Yes, it really is. It is quite quiet.

CHF: I don't have any other questions. Thank you so much, Sylvia.

RML: Yes, thank you very much. I am so delighted to have had this conversation and to know that the Girl Scouts of the USA are in such good hands.

MS. ACEVEDO: And thank you very much for your time. I appreciate everything you're doing at the academy.

NAE News and Notes

NAE Newsmakers

Rod C. Alferness, Richard A. Auhll Professor and dean, University of California, Santa Barbara, and retired chief scientist, Alcatel-Lucent, has won the **2018 Frederic Ives Medal/Jarus W. Quinn Prize** from the Optical Society (OSA). He was chosen for "basic contributions and leadership in the development of integrated optics, high-speed optical modulation and switching, and configurable WDM networks that have provided significant economic and societal impact." The award, the highest OSA gives, will be presented at the 2018 FiO+LS meeting in Washington, DC, in September. OSA has also honored **Dieter Bimberg**, executive director, Technical University of Berlin, with the **2018 Nick Holonyak Jr. Award**, given for contributions to optics based on semiconductor-based devices and optical materials, including basic science and technological applications. Dr. Bimberg is honored "for fundamental discoveries on growth and physics of semiconductor nanostructures leading to novel nanophotonic devices for information science and communications." During the OSA BioMedical Congress held April 2–6 in Hollywood, Florida, **Lihong Wang**, Bren Professor, California Institute of Technology, received the OSA **2018 Michael S. Feld Biophotonics** Award for inventing the world's fastest two-dimensional receive-only camera and enabling real-time imaging of the fastest phenomena such as light propagation and fluorescence decay.

Frances H. Arnold, Linus Pauling Professor of Chemical Engineering, Bioengineering, and Biochemistry, California Institute of Technology, has been **elected to the American Philosophical Society** along with 34 other new members. The APS, the oldest learned society in the United States, was founded in 1743 by Benjamin Franklin for the purpose of "promoting useful knowledge."

Paul Bevilaqua, retired manager, Advanced Development Programs, Skunk Works, Lockheed Martin Aeronautics Company, received the **Guggenheim Medal** at the 2018 AIAA Aerospace Spotlight Awards Gala on May 2 in Washington, DC. He was recognized "For the conception and demonstration of the multicycle propulsion system and other technologies enabling the production of the F-35 supersonic V/STOL Strike Fighters."

Thomas P. Bostick, retired chief of engineers and commanding general, US Army Corps of Engineers, and **Edward Kavazanjian Jr.**, Regents Professor and Ira A. Fulton Professor of Geotechnical Engineering, Arizona State University, are in the **2018 class of ASCE Distinguished Members**. They will be honored at ceremonies this October at the ASCE Convention in Denver.

Charles Fairhurst, senior consulting engineer, Itasca Consulting Group Inc., and professor emeritus, University of Minnesota, was recognized with a **SME Presidential Citation** for "his longtime membership in SME and for his outstanding contributions to the science and technology of rock mechanics, which is fundamentally integral to SME's multiple disciplines."

On February 26 the Mining and Metallurgical Society of America awarded the **2018 MMSA Gold Medal** to **Thomas V. Falkie**, retired chair, Berwind Natural Resources Corporation, at its annual dinner in Minneapolis. Dr. Falkie received the medal "in recognition of a lifetime of contributions to the mining industry through education, industry management, and government service."

Eric R. Fossum, John H. Krehbiel Sr. Professor for Emerging Technologies, director of the PhD Innovation Program, and associate provost in the Office of Entrepreneurship and Technology Transfer at Dartmouth College, is the 2018 recipient of the **Yale Science & Engineering Award for Advancement of Basic and Applied Science**. He was cited for having "transformed the way that billions of people see and record their daily lives, and his work has revolutionized optical sensor array technology and made whole fields of research possible."

Brown University bestowed a **2018 Research Achievement Award** on **Huajian Gao**, Walter H. Annenberg Professor of Engineering. The award is given in recognition of outstanding scholarship. Professor Gao was chosen for lasting contributions in his primary field, the mechanics of solids and structures, such as in the mechanics of thin films and nanostructured and energy storage materials.

Graeme J. Jameson, Laureate Professor and director, University of Newcastle, Australia, has been **elected to the Royal Society of London**.

Dean Kamen, president, DEKA Research and Development Corporation, received the National Science Board's **2018 Public Service Award**, which honors exemplary public service in promoting public understanding of science and engineering. Mr. Kamen was recognized for his extraordinary body of work that has benefitted people around the world. The award was presented May 2 during the National Science Foundation's Annual Awards Ceremony in Washington.

F. Thomson Leighton, CEO and cofounder of Akamai Technologies Inc., is the recipient of the **2018 Marconi Prize**, awarded annually to individuals who have made a significant contribution to the advancement of communications for the benefit of humankind through scientific or technological discoveries. Recipients are designated Marconi Fellows and are expected to pursue further creative work that will add to the understanding and development of communications technology. Dr. Leighton is honored for his fundamental contributions to the technology and establishment of content delivery networks. The award will be presented October 2 at the Marconi Society's annual awards dinner in Bologna.

Benjamin Y.H. Liu, retired CEO and president, MSP Corporation, has been honored by TSI Incorporated: at the University of Minnesota, the chair of the Mechanical Engineering Department will be named the **Benjamin Y.H. Liu–TSI Applied Technology Chair in Mechanical Engineering**. The naming recognizes Dr. Liu, a university alumnus, as an award-winning researcher and entrepreneur who has dedicated his career to aerosols and particles research.

The American Institute for Medical and Biological Engineering (AIMBE) has inducted **Asad M. Madni**, retired president, chief operating officer, and CTO, BEI Technologies Inc., and independent consultant, into the **AIMBE College of Fellows**. Members comprise the top 2 percent of medical and biological engineers. Membership, among the highest professional distinctions accorded, honors those who have made outstanding contributions to "engineering and medicine research, practice, or education" and to "the pioneering of new and developing fields of technology, making major advancements in traditional fields of medicine and biological engineering, or developing/implementing innovative approaches to bioengineering education." The induction ceremony took place April 9 during the AIMBE annual meeting at the National Academy of Sciences in Washington.

James A. Miller, STA Senior Scientist, Argonne National Laboratory, and **Charles K. Westbrook**, retired senior scientist, Lawrence Livermore National Laboratory, are members of the inaugural class of **fellows of the international Combustion Institute (CI)**. Recognized by their peers for outstanding contributions to combustion in research or applications, they will be inducted during the 37th International Symposium on Combustion in Dublin, July 29–August 3.

Gérard A. Mourou, director, École Polytechnique, France, was awarded the **2018 Arthur L. Schawlow Prize in Laser Science** by the American Physical Society. The prize recognizes outstanding contributions to basic research using lasers to advance knowledge of the fundamental physical properties of materials and their interaction with light. Professor Mourou is cited for "fundamental contributions in ultrafast, ultrahigh-field laser inventions, such as chirped pulse amplification, that led to the new discipline of relativistic optics."

Elaine S. Oran, Glenn L. Martin Institute Professor, University of Maryland, College Park, has been **elected a member of the American Academy of Arts and Sciences**. Dr. Oran pioneered computational technology for the solution of complex reactive flow problems, unifying concepts from science, mathematics, engineering, and computer science in a new methodology. The class of 213 members will be inducted at a ceremony in October in Cambridge, Massachusetts.

Bruce E. Rittmann, Regents' Professor of Environmental Engineering and director, Biodesign Swette Center for Environmental Biotechnology, Arizona State University, and **Mark C.M. van Loosdrecht**, professor, Department of Biotechnology, Delft University of Technology, have won the **2018 Stockholm Water Prize**. This global award is given annually by the Stockholm International Water Institute to promote excellent water achievements and inspire future water-wise action. Drs. Rittmann and van Loosdrecht were recognized for "pioneering and leading the development of environmental biotechnology-based processes for water and wastewater treatment. They have revolutionized treatment of water for safe drinking, and refined purification of polluted water for release or reuse—all while minimizing the energy footprint." Crown Princess Victoria of Sweden will present the prize on behalf of King Carl XVI Gustaf at a royal award ceremony on August 29 during World Water Week in Stockholm.

William D. Strecker, retired executive vice president & CTO, In-Q-Tel Inc., was honored by Carnegie Mellon University with a **2018 Alumni Achievement Award**. The award is given for exceptional accomplishment and leadership in the field or vocation of the alumnus. Dr. Strecker received the award May 18 during commencement weekend.

The Western Society of Engineers celebrated Engineers Week by honoring **Ivan E. Sutherland**, visiting scientist, Department of Electrical and Computer Engineering, Portland State University, as the 96th recipient of the **Washington Award** at a celebratory dinner on February 23 in Rosemont, Illinois. The award is conferred on an engineer whose professional accomplishments have advanced the welfare of humankind. Dr. Sutherland earned the nickname "father of computer graphics" for his 1963 MIT PhD program, Sketchpad, an interactive computer-graphics program.

John A. White Jr., Distinguished Professor of Industrial Engineering and chancellor emeritus at the University of Arkansas, was honored with a **Distinguished Alumni Award** from the College of Engineering Education at Ohio State University. He was recognized for his contributions to the advancement of engineering education.

Sharon L. Wood, dean, Cockrell School of Engineering, University of Texas at Austin, has been named the **University of Virginia's 2018 Distinguished Alumna**. She was selected for her outstanding leadership in the work to diversify engineering, a crucial part of which is encouraging women to enter and remain in the field.

Wm. A. Wulf, AT&T Professor of Computer Science and University Professor Emeritus, University of Virginia, was selected for the **ACM Policy Award** for broad contributions bringing computing into the national agenda and leading computer scientists into public policy, where his inspirational leadership promoted key national priorities including diversity and ethics. He will be formally honored at the ACM awards banquet June 23 in San Francisco.

At the ACI Concrete Convention and Exposition this spring, **James R. Harris**, president, J.R. Harris & Company, was made an **Honorary Member** "for visionary leadership in the development of codes and standards for the design of safe and reliable buildings and for dedicated service to the structural engineering profession." **David W. Fowler**, Distinguished Teaching Professor Emeritus and Joe J. King Chair in Engineering No. 2 Emeritus, University of Texas at Austin, was awarded the **Arthur R. Anderson Medal** "for contributions in research and education regarding the effective use of materials to improve the durability and service life of new and existing concrete structures."

The Association for Computing Machinery (ACM) has honored four NAE members. **Andrea Goldsmith**, Stephen Harris Professor of Engineering, Stanford University, is the **2018–2019 Athena Lecturer**. This award was initiated in 2006 by the ACM Council on Women in Computing to celebrate women researchers who have made fundamental contributions to computer science. Dr. Goldsmith was chosen for her contributions to the theory and practice of adaptive wireless communications, and for the successful transfer of research to commercial technology. **Dina Katabi**, professor, electrical engineering and computer science, Massachusetts Institute of Technology, received the **2017 ACM Prize in Computing** for creative contributions to wireless systems. The prize recognizes early to midcareer contributions that have fundamental impact and broad implications. Professor Katabi is recognized as one of the most innovative researchers in the field of networking; among her contributions, she invented a device that seems to be lifted out of the pages of science fiction—she and her team pioneered the use of wireless signals in the environment to sense humans behind walls, determine their movements, and even surmise their emotional states. **John L. Hennessy**, director, Knight-Hennessy Scholarship Program, and former president, Stanford University, and **David A. Patterson**, Pardee Professor of Computer Science Emeritus, University of California, Berkeley, are recipients of the **2017 A.M. Turing Award**. The award, often referred to as the "Nobel Prize of Computing," carries a $1 million prize, with financial support provided by Google Inc. Drs. Hennessy and Patterson were awarded for pioneering a systematic, quantitative approach to the design and evaluation of computer architectures with enduring impact on the microprocessor industry, enabling the design of faster, lower-power, and reduced instruction set computer (RISC) microprocessors. Their approach led to lasting and repeatable principles that generations of architects have used for many projects in academia and industry. Awards will be presented at ACM's annual awards banquet June 23 in San Francisco.

The American Institute of Aeronautics and Astronautics recognized two NAE members during the Joint Conference of the AIAA International Communications Satellite Systems Conference and the Ka and Broadband Communications Conference, October 16–19, 2017, in Trieste. The members recognized were **C. D. Mote, Jr.**, NAE president, for his **Durand Lecture for Public Service** titled "NAE's Grand Challenges for Engineering and the Scholars Program," and **Kevin A. Wise**, senior technical fellow, Boeing Company, who received the **Intelligent Systems Award** for "his long history of developing intelligent autonomy and integrating intelligent systems into production aerospace systems."

Four NAE members recently received the **Albert Nelson Marquis Lifetime Achievement Award**, from *Marquis Who's Who*, presented for "demonstrated leadership, excellence, and longevity in their respective industries and professions." The honored members are **Edith M. Flanigen**, independent consultant and retired fellow, UOP LLC; **Theodore V. Galambos**, emeritus professor, University of Minnesota, Minneapolis; **Robert G. Gallager**, professor emeritus, Massachusetts Institute of Technology; and **John H. Perepezko**, IBM-BASCOM Professor of Materials Science and Engineering, University of Wisconsin–Madison.

The IEEE Computer Society has named **Daniel P. Siewiorek**, Buhl University Professor of Computer Science and Electrical and Computer Engineering, Carnegie Mellon University, the recipient of the **2018 Taylor L. Booth Education Award**. He is being recognized for "contributions to computer architecture, wearable computing, and human computer interaction education through his pioneering textbooks, mentoring, and leadership." The Society also selected **Bjarne Stroustrup**, managing director, technology, Morgan Stanley Group Inc., to receive its **2018 Computer Pioneer Award**. Dr. Stroustrup was chosen for "bringing object-oriented programming and generic programming to the mainstream with his design and implementation of the C++ programming language."

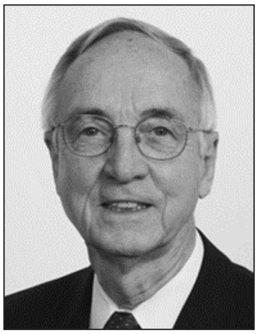
Two NAE members were honored by the National Academy of Sciences during the NAS' 155th annual meeting in April. **James P. Allison**, chair, Department of Immunology; director, Immunology Platform; and deputy director, University of Texas MD Anderson Cancer Center, received the **2018 Jessie Stevenson Kovalenko Medal** for important medical discoveries related to the body's immune response to tumors. **Dean Roemmich**, professor of oceanography, Scripps Institution of Oceanography, received the **Alexander Agassiz Medal** for his leadership in understanding the ocean's roles in climate variability and change.

NAE Chair, Vice President, and Councillors Elected

This spring the NAE reelected its chair, vice president, and one incumbent councillor, and elected three new councillors. All terms begin July 1, 2018.

Reelected to a two-year term as chair was **Gordon R. England**, chair of PFP Cybersecurity; and reelected to a four-year term as vice president was **Corale L. Brierley**, principal of Brierley Consultancy LLC. **John L. Anderson**, Distinguished Professor of Chemical Engineering at Illinois Institute of Technology, was reelected to a three-year term as councillor. Newly elected to three-year terms as councillors were **Nadine Aubry**, dean of engineering and University Distinguished Professor at Northeastern University; **Wesley L. Harris**, Charles Stark Draper Professor of Aeronautics and Astronautics at Massachusetts Institute of Technology; and **Edward D. Lazowska**, Bill & Melinda Gates Chair of the Paul G. Allen School of Computer Science & Engineering at the University of Washington.

On June 30, 2018, **Anita K. Jones**, University Professor Emerita of the School of Engineering and Applied Science at the University of Virginia, and **Richard H. Truly**, retired vice admiral of the US Navy and retired director of the National Renewable Energy Laboratory, will complete six continuous years of service as councillors, the maximum allowed under the Academy's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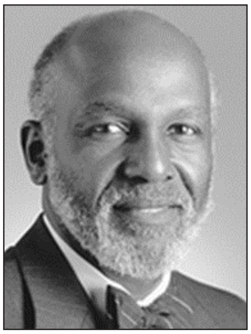
Wesley L. Harris


Edward D. Lazowska


Wanda M. Austin


Anita K. Jones


Richard H. Truly

bylaws; and **Wanda M. Austin**, retired president and chief executive officer of the Aerospace Corporation, will complete four years as councillor. They were recognized in May for their distinguished service and other contributions to the NAE.

NAE Honors 2018 Draper Prize Winner

Each year the NAE celebrates outstanding individuals for significant innovation, leadership, and advances in engineering. The winner of the 2018 Charles Stark Draper Prize for Engineering was honored at a black-tie dinner on February 20 at the National Academy of Sciences Building in Washington. The recipient, **Bjarne Stroustrup**, accepted his award before an audience of more than 90 guests, with NAE president **C. D. Mote, Jr.** at the podium. Assisting in the presentation was Dr. Kaigham (Ken) M. Gabriel, president and CEO of Draper Laboratory.

Charles Stark Draper Prize for Engineering

Bjarne Stroustrup was awarded the 2018 Charles Stark Draper Prize for Engineering "for conceptualizing and developing the C++ programming language."

Dr. Stroustrup is the designer and original implementer of C++, one of the most widely used and influential programming languages in the history of computing. After its official release in 1985, he guided its evolution through his research, involvement in the C++ ISO standards effort, books, and many academic and popular papers.

C++, based on C and originally inspired by Simula, provides general and flexible abstraction mechanisms that can be mapped directly and efficiently onto computer hardware. It revolutionized the software industry by enabling a variety of software development techniques, including object-oriented programming, generic programming, and general resource management, to be deployed at industrial scale. C++ remains among the most widely used programming languages, with applications in general systems programming, communications, computer graphics, games,

Ken M. Gabriel, Bjarne Stroustrup, and C. D. Mote, Jr.

user interfaces, embedded systems, financial systems, medical systems, avionics, scientific computation, and many other areas. Its influence and the ideas it pioneered and popularized are clearly visible far beyond the C++ community.

Dr. Stroustrup began his career at AT&T Bell Labs' Computer Science Research Center in Murray Hill, New Jersey, where he designed and implemented C++. He was head of AT&T's Large-scale Programming Research Department from its inception in 1996 until 2002. After that, he taught and did research at Texas A&M University, reaching the rank of University Distinguished Professor. Since 2014 he has been a managing director in the technology division of Morgan Stanley in New York City and a visiting professor at Columbia University. His research interests include design, programming techniques, distributed systems, performance, reliability, and maintainability.

His honors include ACM's Grace Murray Hopper Award (1993), election to the NAE (2004), Sigma Xi's William Procter Prize for Scientific Achievement (2005), Aarhus University's Rigmor og Carl Holst-Knudsens Videnskabspris (2010), and the Faraday Medal from the Institute of Engineering Technology (2017). He is a fellow of IEEE, ACM, and the Computer History Museum, and an honorary fellow of Churchill College, Cambridge.

Bjarne Stroustrup was born in Aarhus, Denmark, in 1950. He received a master's degree in mathematics and computer science from Aarhus University in 1975 and a PhD in computer science from Cambridge University in 1979.

Acceptance Remarks by Bjarne Stroustrup

When I heard that I was to receive the Draper Prize, I naturally looked up who had received it over the years and almost panicked. That's intimidating and extraordinary company! Those guys made the world we live in! I am truly honored to join this extraordinary group.

Receiving a high honor like the Draper makes you reflect. I want to say "thank you" to all who helped me get here and who made me what I am. To do that, I have to tell my story.

I come from a solid working-class background. My father and all of my uncles left school after 7th grade to work with their hands. So, toward the end of high school when I had to choose, I had no clue what to do next, and no one to ask. History? Architecture? Sociology? Engineering? Get a job like everybody else? I felt a strong need to build something concrete like my father and uncles did.

Engineering appealed to me: Engineers build things! I decided to go to the Technical University in Copenhagen; that's the best place for engineering in Denmark. But then I got cold feet! Copenhagen seemed a big scary city, and I'd have to pay for my living, so I'd have to take out significant loans. In Denmark education is free, of course, but you have to live. And what if I failed? There were no resources in my family to back me up. So I bicycled up to the University of Aarhus, my hometown university, and signed up for "Mathematics with Datalogy." I thought I was signing up for some form of applied math. Fortunately, I was wrong! I wasn't as good at math as I had thought I was, and "datalogy" is Danish for "computer science." After my first encounter with programming and machine architecture, I never looked back. That was great!

Aarhus gave me a solid grounding in math and computer science; I go back there as often as I can. It's a beautiful city! Denmark is a society that supports you when you follow your dreams. It's one of the nicest places on earth.

From there, I went to Cambridge. It's a magical place, it can inspire you. You look at the accomplishments of the people who came before you and think 'Oh! I have to do better, much better, or I don't belong here!' Also, it can give you the confidence to do something that really matters. My daughter was born in Cambridge and I'm still associated with the university as a fellow of Churchill College.

Bell Labs in New Jersey was another one of those magical places. Like Cambridge, it could inspire people and raise their ambition level to build great things. My colleagues there were scarily smart and accomplished. Many were also true gentlemen and patient teachers. I spent 24 years working at "the Labs." That's where I designed and implemented C++. My children grew up near the Labs.

Much of the credit for C++'s success goes to the C++ community. Nobody can do something like that just on their own. More than 4 million strong today, this community provides me with inspiration and a constant need to innovate. To help support and grow the community, I have spent more than 25 years working on the C++ standards committee, improving C++ as a stable, practical tool.

They say that you are what you eat. But really, you are who you eat with, learn with, work with, and have fun with. So thanks to the many people I met through my work and to my teachers, colleagues, and friends in Aarhus and Cambridge, and at Texas A&M, Morgan Stanley, Princeton, and Columbia. They made me what I am today and contributed to my work in so many ways. I am very happy to see some of you here tonight.

Also, a heartfelt "thank you" to the Draper family and Draper Labs, who made this event possible, and to the great National Academy of Engineering. And again, thank you to my family, who in so many ways made it all possible and worthwhile.

I was designing, implementing, and evolving C++, but I always saw it as a tool for building interesting things. The amazing applications of C++ are what keep me going! Whatever field you are interested in, software can get you there! "Distributed systems" was my PhD topic and is still much of what I do for Morgan Stanley today. After all, everybody has to get information from A to B, whether across a tiny chip or halfway around the world or beyond! I have always been interested in reliability, speed, maintainability, and affordability.

It is somewhat ironic that my determination to build "something concrete" led me to spend 40 years working on something you can't touch and that's completely invisible.

You can't just build things, though. For a tool to become useful, you must explain its proper use. For an invention to become pervasive, its principles must be articulated and popularized. A favorite Danish author of mine, who came from farming stock, wrote "He who does not plough must write." So along the way, out of necessity, I became an author and a teacher.

Bjarne Stroustrup

We must educate the community about what engineers do and why it matters. Engineering is not just applied science and not just tinkering with gadgets. We innovate, but we also build things to be useful, dependable, and affordable. We need to attract students and inspire them to work hard. The challenges of the future are daunting! We must show the young that they can have a good life, with good friends and a good work-life balance, while working hard to build a better world. We need to foster professionalism. We must show that there can be more to life than ruthlessly chasing money, climbing a career ladder, or becoming a politician. We have to inspire people to do great things! To do better than they imagined they could! To make a difference! Our civilization depends critically on good engineers and good engineering! And, of course, good software.

Again, thank you, all of you! Thank you!

NAE-NAM Regional Meeting on Technobiology at the University of Miami

The University of Miami hosted a regional meeting on "Engineering and Medicine: A Critical Partnership in Technobiology" on February 26. Organized by NAE members **Daniel Berg** and **James Tien**, the symposium was cosponsored by the National Academy of Medicine (NAM).

"Technobiology" is a recently coined term for the application of engineering or technology to biology or medicine. (The term "biotechnology" concerns the application of biology to technology, including, for example, neural networks, which characterize how neurons network and function to help model complex relationships between inputs and outputs of a large dataset.)

"The US healthcare system needs to become more efficient and more effective," said Dr. Tien, dean emeritus of UM's College of Engineering, in welcoming more than 175 students, faculty, and visitors to the symposium. "Just as engineering has made the manufacturing of goods and the delivery of services more productive, it must now focus its talents on health care."

The benefits of an engineering-medicine partnership in academia were underscored by several introductory comments, including those of NAE president **C. D. Mote, Jr.**, NAM home secretary Jane E. Henney, UM executive vice president and provost Jeffrey L. Duerk, UM executive vice president for health affairs Edward Abraham, and UM dean of engineering Jean-Pierre Bardet. Dr. Henney said she was especially pleased to see students in attendance at the symposium, describing them as "our future in terms of discoveries yet to come that will truly change our world."

During the 4-hour conference, attendees learned about several technobiology breakthroughs from a stellar group of three engineers whom Dr. Berg, Distinguished Research Professor at UM, lauded for creating fundamental knowledge in areas of societal need.

Dr. Berg reminded the audience that Louis Pasteur, the famous French biologist, microbiologist, and chemist, renowned for his discoveries of the principles of vaccination, microbial fermentation, and pasteurization, was actually a very successful technobiologist. Less well known is that Pasteur saved the French wine industry when he discovered two types of potassium tartrate that are mirror images with different optical activity. This breakthrough underscored the value of knowledge discovery that accompanies societal problem solving, which is often referred to as Pasteur's quadrant and which all three of the meeting's speakers acknowledged in their presentations.

Engineer, entrepreneur, and serial inventor **Leonard Pinchuk**, president and CEO of the medical device company Innovia LLC and an alumnus and Distinguished Research Professor of UM's College of Engineering, detailed how his company developed both the first commercially successful angioplasty balloon and the helical wire-based stent used on most stent grafts. His team also developed the first implantable elastomer, a polymer known as SIBS (styrene isoprene butylene styrene), and in collaboration with scientists at the UM Miller School of Medicine's Bascom Palmer Eye

Panelists at the Joint National Academies of Engineering and Medicine Regional Symposium on "Engineering and Medicine: A Critical Partnership in Technobiology," February 26, 2018, University of Miami. Pictured left to right: Dr. Daniel Berg, NAE; Dr. Ashutosh Agarwal; Dr. Matthew Tirrell, NAE; Dr. Leonard Pinchuk, NAE; Dr. C. D. Mote, Jr., NAE; Dr. Julio Frenk, NAM; Dr. Jane Henney, NAM; Dr. Jeffrey Duerk; Dr. Edward Abraham; Dr. Jean-Pierre Bardet; Dr. James Tien, NAE.

Institute, integrated that technology into ophthalmology with a device that bypasses obstructions in the eye's drainage pathways to treat glaucoma.

Matthew Tirrell, the founding Pritzker Director of the University of Chicago Institute of Molecular Engineering, discussed his work in versatile modular nanoparticles that patrol for diseases without telltale symptoms. He described the institute's organization and its focus on Pasteur's quadrant.

Ashutosh Agarwal, an assistant professor of biomedical engineering at UM, presented his organ-on-a-chip research, which involves simulating the function of organs such as the heart and pancreas on a chip about the size of a USB stick, allowing his team to conduct risk-free biomedical testing. These efforts are both informing the clinical trials that transplant human islets in Type 1 diabetic patients and enabling tools for precision oncology.

Following the three presentations, UM president Julio Frenk (NAM), a physician who served as Mexico's minister of health under former President Vicente Fox, made a few remarks and then coordinated a discussion by the three presenters, interspersed with insightful questions from the audience. President Frenk called for the creation of institutional structures at universities to support their "incredibly talented researchers." Institutions of higher learning, he said, should not only create knowledge but also transfer that knowledge to technology and maintain an open interface with those who can take creation to the next step.

The partnership of medicine and engineering isn't new, pointed out NAE president Mote. "But suddenly it's turned a corner where now engineering and medicine realize that their futures independently depend on their partnership together," he said. "From this point on, you can expect to see this around the country and around the world."

UCSD Regional Meeting: How Interdisciplinary Collaboration and Data Science Are Making the Invisible Visible

Members of the National Academy of Engineering gathered at UC San Diego in La Jolla on March 28 for a regional meeting and symposium. Participants engaged with university faculty on transformative research on the microbiome, genetics and computing, and the role of interdisciplinary collaboration and data science in advancing their studies.

Albert Pisano, dean of the Jacobs School of Engineering, welcomed attendees and briefly described the global reach of the engineering program at UC San Diego. He then introduced NAE president **C. D. Mote, Jr.**, who thanked the university for hosting the event and congratulated a group of UCSD students on their Student Day Business Model win at the 2017 Global Grand Challenges Summit. The summit, jointly organized by the NAE, UK Royal Academy of Engineering, and Chinese Academy of Engineering, was the third in a series that aims to inspire the next generation of engineers to address some of the most pressing issues of the time.

The first technical theme was a two-part presentation on the microbiome and the effects of microbes on human health and climate. Rob Knight, director of the Center for Microbiome Innovation and professor of both Pediatrics and Computer Science and Engineering, described his research on the microbial communities in the human body and their impacts on health and disease. He noted that there are more microbes on Earth than there are stars in the universe, and with the help of data science he has begun to catalogue the approximately 1 trillion microbial species on the planet. His goal is to expand knowledge of where they live and how they differ between individuals and continents. He also seeks to understand the role of factors such as sleep, age, diet, and exercise as well as the possibilities of modifying microbial communities to improve human and environmental health.

Kimberly Prather, Distinguished Chair in Atmospheric Chemistry at Scripps Institution of Oceanography and the Department of Chemistry and Biochemistry at UC San Diego and director of the Center for Aerosol Impacts on Chemistry of the Environment, spoke next. Her study of extreme weather events and precipitation redistribution led her to explore the impacts of pollution and microbes on climate change.

Dr. Prather explained how microbes affected by pollution can be ejected into the atmosphere as sea spray to circulate around the globe. She is working to understand how different aerosols mix with pollution to better understand their association with climate. UC San Diego was recently awarded $2.8 million from the National Science Foundation to construct a replica of an ocean-atmosphere system that will mimic the ocean with unprecedented accuracy and help further Prather's work.

The third speaker, Ethan Bier, holder of the Tata Chancellor's Endowed Professorship in Cell and Developmental Biology, discussed the possibilities of active genetics, a method of genome editing that results in the almost complete transmission of a genetic trait across generations. This gene modification technique could eradicate malaria through immunization of wild mosquitoes.

Rajesh K. Gupta, professor and holder of the Qualcomm Endowed Chair in Embedded Microsystems, Department of Computer Science and Engineering, led the final discussion about the significance of data science and interdisciplinary collaboration in transformative advances, as seen in the work of Drs. Bier, Prather, and Knight. As the recently appointed codirector of UCSD's new Halıcıoğlu Data Science Institute, he noted that the field is quickly becoming the backbone of many other disciplines and has an increasing significance for decisions of daily life. He lauded the precision afforded by data science, especially as the massive influx of data can yield important new insights.

Dr. Gupta cautioned, however, that, while more data and more math may make one feel more confident, data are not without bias. As the prevalence of data science grows, he made the case for the development of coding practices to correct against inherent biases, inequalities, and stereotypes in the data.

At the conclusion of the individual talks, Dean Pisano returned to the stage to invite the panel for a group discussion and questions from the audience. Guests and speakers then continued their conversations at a reception.

NAE Regional Meeting Hosted by Schlumberger

Oilfield services company Schlumberger hosted an NAE regional meeting in Houston on April 4. The theme of the meeting was Geoscience on Earth and Beyond. Houston is the epicenter of two major geoscience enterprises: the exploration and production of fossil fuels, and the exploration of space. The symposium featured seven talks on topics ranging from the depths of an oil well to the surface of Mars. The event also included an NAE business meeting before the symposium, chaired by NAE executive officer **Al Romig**, and a dinner at the end of the day.

Corale Brierley, NAE Vice President, and Home Secretary **Julia Phillips** opened with a review of the history, mission, composition, and structure of the National Academy of Engineering.

The first speaker, Ashok Belani, executive vice president for technology of Schlumberger Limited, showed how the company's use of data has, since the 1950s, closely tracked that of the broader digital world. Today the oil and gas industry generates hundreds of terabytes of data annually, but they are underused. Schlumberger's vision is to effectively use data to make hydrocarbon exploration and production safer and more efficient.

Robert Kleinberg, recently retired from Schlumberger, introduced the petroleum geology of shale gas after dispatching a preliminary question: Why are we still talking about fossil fuels? The answer: Even assuming rapid growth of renewable sources of energy, oil and gas consumption are expected to remain roughly constant for decades to come. He then went on to discuss the basic principles of geology and geochemistry behind the geographical distribution of oil and gas reservoirs, and explained why the exploitation of shale gas and tight oil require horizontal drilling and massive hydraulic fracturing of the subsurface.

Philip Singer of Rice University showed that nanometer-scale studies are crucial for understanding the complex behavior of hydrocarbons in rock. He reviewed recent research activities in this domain that integrate nuclear magnetic resonance measurements with molecular dynamics simulations and molecular density functional theory. The research aims to yield insights into the effects of nanopore confinement on hydrocarbons in organic-rich shale.

Geoff Downton of Schlumberger described the technology deployed underground to guide, monitor, and control the construction of an oil or gas well. In extreme cases, this borehole can extend horizontally more than 45,000 feet. Drilling complex trajectories requires measurements at or just above the drill bit, which identify formation and fluid types and communicate this information to the surface in real time so the borehole steering system can be commanded to follow the desired course.

Bridget Scanlon of the University of Texas Bureau of Economic Geology spoke about the Gravity Recovery and Climate Experiment (GRACE) satellites. These are used to monitor monthly changes in the Earth's gravity, which is controlled primarily by changes in water storage in response to wet and dry climates and human water extraction. GRACE satellite data show that there was a net increase in global land water storage of 60 to 70 cubic kilometers per year from 2002 to 2014. This result contrasts with global models, which underestimate the trends in water storage relative to GRACE satellites, indicating that model projections of climate- and human-induced water storage changes may be misleading.

John Gruener, of the NASA Johnson Space Center in Houston, predicted that the Moon will play a significant role in space exploration beyond low Earth orbit. Humans have not set foot on the lunar surface since 1972, but that is likely to change in the near future. Harnessing energy and material resources on the Moon will be critical to any long-term human presence, and resource development activities could provide commercial opportunities for private enterprise. Water ice, recently discovered in the lunar polar regions, is one of many resources that could be developed.

Doug Ming, also of the NASA Johnson Space Center, discussed the potential for Mars environments compatible with life. The rover Curiosity successfully landed in Gale Crater on Mars in August 2012. Since then it has traversed a variety of sedimentary rock types, revealing fluviolacustrine sediments that contain clay minerals, key biogenic elements (carbon, hydrogen, oxygen, sulfur, nitrogen, phosphorus), and variable redox states of iron and sulfur. These relatively young and Earth-like environments reveal the biologic potential of the Mars environment.

The symposium was organized by **Brian Clark**, Schlumberger Fellow Emeritus, with the assistance of **Fikri Kuchuk,** Schlumberger Fellow and chief reservoir engineer, and Robert Kleinberg. Schlumberger generously provided logistical and administrative support, and sponsored the symposium dinner.

2018 Yvonne C. Brill Lectureship in Aerospace Engineering

The American Institute of Aeronautics and Astronautics (AIAA) is pleased to announce that it has selected AIAA fellow Dr. Helen L. Reed, Regents Professor at Texas A&M University in College Station, for the third Yvonne C. Brill Lectureship in Aerospace Engineering. Dr. Reed will present her lecture, "Student Design-Build-Fly Micro- and Nano-Satellites," on October 2, in conjunction with the NAE annual meeting in Washington.

Dr. Reed has contributed to the discipline through her satellite design programs first at Arizona State University (ASUSat Lab) and then at Texas A&M (AggieSat Lab). She has found effective ways to create interdisciplinary teams of undergraduate and graduate students, with industry and government affiliates, to engage in design-build-fly of operational small satellites, while advancing new technologies that feed into national initiatives and learning industry practices in the university environment. Involving more than 1,000 students over the years, her team has launched four small satellites with the US Air Force and NASA and partnered on other projects. Her students have gone on to work at space-oriented businesses and the national laboratories.

Dr. Reed is also an acknowledged national and international expert in laminar-to-turbulent transition. Her technical expertise is reflected in pioneering contributions that integrate discernment of the fundamental physics of transitional flows with best-in-class simulations to reveal key phenomenological details.

Her work has not only provided essential insight into complex fluid dynamic processes but also strongly influenced the development of aerospace systems. Providing computational leadership, Dr. Reed has teamed with experimentalists to achieve a high degree of closure between theory and experiment. She has developed stability and transition tools that include linear stability theory, nonlinear parabolized stability equations, and direct numerical simulation of the Navier-Stokes equations. Her tools have supported and validated ground and flight experiments aimed at understanding the physics of transition and maturing drag reducing technologies.

Dr. Reed has been honored with the 2018 AIAA Fluid Dynamics Award for "lifetime achievements in the fundamental understanding, modeling, and control of boundary-layer laminar-to-turbulent transition for aerospace vehicles from subsonic to hypersonic"; the 2016 American Society of Mechanical Engineers (ASME) Kate Gleason Award for "lifetime achievements in the fundamental understanding and control of boundary layer transition for high-efficiency aerospace vehicles, and in pioneering small satellite design and implementation"; and the 2007 J. Leland Atwood Award for important contributions to space systems engineering and space systems design education. At Texas A&M she holds both the title of Presidential Professor for Teaching Excellence and the Edward "Pete" Aldridge '60 Professorship. In addition to AIAA, she is a fellow of ASME and the American Physical Society.

AIAA, with the participation and support of the NAE, created the Yvonne C. Brill Lectureship in Aerospace Engineering to honor the memory of the late, pioneering rocket scientist, AIAA Honorary Fellow, and NAE member Yvonne C. Brill, best known for developing a revolutionary propulsion system that remains the industry standard for geostationary satellite station keeping. The lecture emphasizes research or engineering for space travel and exploration, aerospace education of students and the public, and other aerospace efforts such as ensuring a diverse and robust engineering community.

2018 *EngineerGirl* Essay Contest on Infrastructure

The 2018 *EngineerGirl* essay contest asked students in grades 3–12 to pick a local infrastructure system—transportation, water treatment, energy, public safety, communication, financial security, health care, or recreation—and write about how it could be improved. Prizes—$500 for first place, $250 for second place, and $100 for third place—were awarded to students based on grade level, with certificates for honorable mentions.

In grades 3–5, Aditi Gokhale, a third-grader at J. Ackerman Coles Elementary School in Scotch Plains, NJ, placed first for her essay on using self-repairing roads to fix potholes in her hometown. Seventh-grader Anvitha Mahankali, from Stoller Middle School in Portland, OR, won first place among entries from grades 6–8 for her essay on creating sensors to detect bioswale maintenance problems. And Aditi Misra, an 11th-grader at St. Joseph Secondary School in Mississauga, Ontario, placed first in grades 9–12 for her essay on investing in flywheel energy storage systems in Mississauga to serve the Ontario energy grid. All the winning essays are posted at https://www.engineergirl.org/99787/2018-Winners.

The 2018 *EngineerGirl* essay contest was sponsored by Chevron Corp. and the Kenan Institute for Engineering, Technology, and Science.

New Staff at the NAE

LAUREN BARTOLOZZI is associate director of development for the NAE, providung donors with leadership, vision, and a connection to the causes they care about. She relocated to the DC metro area from Ohio, where she developed her career in fundraising first at her alma mater, Ohio University, and then as a champion for women's health care with Planned Parenthood of Greater Ohio/Advocates of Ohio. Her belief that each person's full potential is directly tied to their ability to access resources makes the National Academies a natural fit. Lauren earned her bachelor's degree in psychology and a master's of public administration from Ohio University. She enjoys yoga, travelling the globe, and exploring all that DC has to offer with her husband, Nick. She can be reached at LBartolozzi@nas.edu.

BRANDON GREEN has joined the staff of the Program Office as the new communications/media specialist, working on NAE's communications, media relations, public outreach, and social media activities. For the past five years he worked as a content producer and editorial researcher for *Transport Topics*, a weekly publication and website on the trucking industry. He has also worked as a production assistant with *WYPR-Maryland Morning with Sheila Kast*, a show on the NPR affiliate in Baltimore. While in college, he was a reporter for *The Voice* newspaper, multimedia reporter and web producer for *The Diamondback* (the University of Maryland's newspaper), and editor in chief of *La Voz Latina* newspaper (UM's only bilingual publication). Brandon is a graduate of the University of Maryland Philip Merrill College of Journalism (Multimedia). He can be reached at BGreen@nae.edu.

SIERRA HALL joined the NAE President's Office as office assistant. Before coming to the Academies, she worked at the accounting firm of Caldwell and Company, with responsibility for a variety of office assistant duties. Sierra is a graduate of McDaniel College, with a BA in psychology and a minor in accounting. She can be reached at SGHall@nae.edu.

Calendar of Meetings and Events

June 1	NAE Regional Meeting: Anticipating the Future: Historical Narratives, Imagination, and Innovation (rescheduled) Science History Institute, Philadelphia
June 4	Workshop on Engineering Societies' Activities in Promoting Diversity and Inclusion Cincinnati
June 18–20	Japan-America Frontiers of Engineering Tsukuba
July 16	NAE-CAE Symposium: Human and Artificial Intelligence 2.0 CAE Headquarters, Beijing
August 1–2	NAE Council Meeting Woods Hole, Massachusetts
August 14–16	Grand Challenges Scholars Program Workshop City University of Hong Kong
September 5–7	US Frontiers of Engineering Symposium Lexington, Massachusetts
September 28–29	NAE Council Meeting
September 29	NAE Peer Committee Meetings
September 30–October 1	**NAE ANNUAL MEETING**

All meetings are held in National Academies facilities in Washington, DC, unless otherwise noted.

In Memoriam

STIG A. ANNESTRAND, 84, retired manager, research and development, Bonneville Power Administration, died March 27, 2018. Mr. Annestrand was elected in 1989 for outstanding contributions to the development of economical and reliable high-voltage AC and DC transmission technology.

MARTIN BALSER, 88, Distinguished Technical Fellow, Northrop Grumman Corporation, died April 27, 2016. Dr. Balser was elected in 2014 for innovations in technologies from fundamental physics that significantly advanced military communications.

DAVID P. BILLINGTON, 90, Gordon Y.S. Wu Professor of Engineering Emeritus, Princeton University, died March 25, 2018. Dr. Billington was elected in 1986 for outstanding contributions to the advancement of public and professional appreciation of engineering history and design aesthetics, and for contributions to the design of concrete shell structures.

P.L. THIBAUT BRIAN, 87, retired vice president, engineering, Air Products and Chemicals Inc., died April 2, 2018. Dr. Brian was elected in 1975 for contributions to both theory and engineering practice of desalination, mass transfer in chemically reactive systems, and the technology of liquefied gases.

PHILIP R. CLARK, 87, retired president and CEO, GPU Nuclear Corporation, died March 28, 2018. Mr. Clark was elected in 1993 for contributions to the design, manufacture, and operation of naval nuclear reactors and to the recovery from the effects of the Three Mile Island 2 accident.

DON U. DEERE, 95, independent consultant, engineering geology and rock mechanics, died January 14, 2018. Dr. Deere was elected in 1967 for rock mechanics.

DEAN E. EASTMAN, 78, professor of physics, University of Chicago, died March 4, 2018. Dr. Eastman was elected in 1988 for early work in photoemission measurements and interpretation, and for subsequent leadership in process and packaging technologies.

REX A. ELDER, 100, consulting hydraulic engineer, died February 28, 2018. Dr. Elder was elected in 1978 for innovations in hydraulic research, design, and operation of large water reservoirs, river navigation facilities, and hydro and thermal power systems.

PER K. ENGE, 64, Vance D. and Arlene C. Coffman Professor of Aeronautics and Astronautics, Stanford University, died April 22, 2018. Dr. Enge was elected in 2005 for leadership in the development of augmentations to marine and aviation global positioning systems that have become worldwide standards.

DONALD P. GAVER JR., 91, Distinguished Professor of Operations Research Emeritus, US Naval Postgraduate School, died February 11, 2018. Dr. Gaver was elected in 2009 for contributions to reliability, maintainability, and queuing concepts, with applications to telecommunications and military systems.

ROBERT K. GRASSELLI, 87, adjunct professor, University of Delaware, died January 11, 2018. Dr. Grasselli was elected in 1995 for the invention of catalysts and catalytic processes having commercial significance.

ARAVIND K. JOSHI, 88, Henry Salvatori Professor of Computer and Cognitive Science, University of Pennsylvania, died December 31, 2017. Dr. Joshi was elected in 1999 for contributions to natural language processing.

JOHN F. KNOTT, 78, retired professor of metallurgy and materials, University of Birmingham, United Kingdom, died October 5, 2017. Dr. Knott was elected as a foreign member in 2003 for advancing understanding of the mechanisms and microstructure of fracture and fracture mechanics with application to the failure of engineering alloys and structures.

JAMES LAGO, 96, consultant and retired vice president, process R&D, Merck & Co. Inc., died January 1, 2018. Mr. Lago was elected in 1990 for pivotal engineering and management contributions to the development of new processes for manufacturing medicines.

MILTON LEVENSON, 95, consultant and retired vice president, Bechtel International, died

March 31, 2018. Dr. Levenson was elected in 1976 for contributions to fast reactor technology, nuclear fuel reprocessing, and especially the first remote-handling completely closed fuel-cycle plant.

THOMAS S. MADDOCK, 89, consulting engineer, died February 3, 2018. Dr. Maddock was elected in 1993 for contributions to the development of management systems required for design of complex water resource projects.

CORDELL REED, 79, retired senior vice president, Commonwealth Edison Company, died December 4, 2017. Mr. Reed was elected in 1992 for outstanding leadership and contributions to the advancement of engineering, operations, and management of commercial nuclear power.

DALE F. RUDD, 82, professor emeritus, University of Wisconsin–Madison, died February 16, 2018. Dr. Rudd was elected in 1978 for research and leadership on process engineering strategy and systems analysis of large economic units such as the petrochemical industry.

MURRAY B. SACHS, 77, professor of biomedical engineering, neuroscience, and otolaryngology, Johns Hopkins University School of Medicine, died March 4, 2018. Dr. Sachs was elected in 2002 for contributions to the understanding of the neural encoding and signal processing of complex sounds, and for leadership in bioengineering education.

LUCIEN A. SCHMIT JR., 89, Rockwell Professor of Aerospace Engineering Emeritus, University of California, Los Angeles, died March 16, 2018. Dr. Schmit was elected in 1985 for pioneering work in structural synthesis, combining finite element analysis and nonlinear programming algorithms to create a powerful class of modern structural design methods.

BAL RAJ SEHGAL, 84, emeritus professor of nuclear power safety, KTH Royal Institute of Technology, Sweden, died February 26, 2018. Professor Sehgal was elected in 2013 for contributions to predicting accident behavior of nuclear reactor systems.

PAUL G. SHEWMON, 85, professor emeritus, Ohio State University, died November 26, 2015. Dr. Shewmon was elected in 1979 for contributions to metals science and engineering in the areas of diffusion and phase transformation.

BURTON J. SMITH, 77, technical fellow, Microsoft Corporation, died April 3, 2018. Dr. Smith was elected in 2003 for contributions to the development of parallel computer architecture.

LEROY H. SMITH JR., 89, consulting technologist, Turbomachinery Aerodynamics, died March 28, 2018. Dr. Smith was elected in 1988 for leadership and major contributions in advanced fan and compressor design, and for development of methods for analysis of turbomachinery aerodynamics.

METE A. SOZEN, 87, Kettelhut Distinguished Professor of Structural Engineering, Purdue University, died April 5, 2018. Dr. Sozen was elected in 1977 for contributions to understanding the structural design and behavior of buildings and bridges subjected to earthquake motions.

CHARLES E. TAYLOR, 93, professor emeritus of engineering sciences, University of Florida, died February 18, 2018. Dr. Taylor was elected in 1979 for pioneering developments in three-dimensional photo elasticity and in the use of lasers and holography in experimental mechanics.

JAMES S. THORP, 81, Hugh P. and Ethel C. Kelly Professor Emeritus, Virginia Polytechnic Institute and State University, died May 2, 2018. Dr. Thorp was elected in 1996 for contributions to the development of digital techniques for power system protection, monitoring, and control.

PING KING TIEN, 98, fellow emeritus, Bell Labs, Alcatel-Lucent, died December 27, 2017. Dr. Tien was elected in 1975 for inventor and engineering contributions to microwave amplifiers and integrated optical circuits and devices.

GEORGE L. TURIN, 84, professor emeritus, University of California, Berkeley, died March 14, 2014. Dr. Turin was elected in 1985 for outstanding contributions to communication theory and practice and for leadership in engineering education.

Publications of Interest

The following reports whose authoring committees included **NAE members** were recently published by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academies Press (NAP), 500 Fifth Street NW–Keck 360, Washington, DC 20055. For more information or to place an order, contact NAP online at <*www.nap.edu*> or by phone at (888) 624-6242. *(Note: Prices quoted are subject to change without notice. There is a 10 percent discount for online orders when you sign up for a MyNAP account. Add $6.50 for shipping and handling for the first book and $1.50 for each additional book. Add applicable sales tax or GST if you live in CA, CT, DC, FL, MD, NY, NC, VA, WI, or Canada.)*

In-Time Aviation Safety Management: Challenges and Research for an Evolving Aviation System. Decades of effort to address both known hazards in the national airspace system (NAS) and problems illuminated by analysis of incidents and accidents have made commercial airlines the safest mode of transportation. But the task of maintaining their high level of safety is complicated by the dynamic nature of the NAS: the number of commercial transport flights is rising, air traffic control systems and procedures are being modernized to increase NAS capacity and efficiency, autonomous systems are being developed for aircraft and ground systems, and small aircraft—especially unmanned aircraft systems—are becoming more prevalent. As the NAS evolves to accommodate these changes, aviation safety programs also need to evolve to ensure that changes to the NAS do not inadvertently introduce new risks. Real-time systemwide safety assurance (RSSA) is one of six focus areas for the National Aeronautics and Space Administration (NASA) aeronautics program. NASA envisions that an RSSA system would provide information, analysis, and assessment that support awareness and action to mitigate risks to safety. This report identifies challenges to establishing an RSSA system and the high-priority research that should be implemented by NASA and others in government, industry, and academia to expedite development of such a system.

Meyer J. Benzakein, assistant vice president, Aerospace and Aviation Research, Ohio State University, and **R. John Hansman Jr.**, T. Wilson Professor of Aeronautics and Astronautics and director, MIT International Center for Air Transportation, Massachusetts Institute of Technology, served on the study committee. Paper, $50.00.

Indicators for Monitoring Undergraduate STEM Education. Science, technology, engineering, and mathematics (STEM) professionals generate a stream of scientific discoveries and technological innovations that fuel job creation and national economic growth. Ensuring a robust supply of these professionals is especially critical at a time of intense global competition. But many capable students who intend to major in STEM switch to another field or drop out of higher education altogether, partly because of documented weaknesses in STEM teaching, learning, and student supports. Improving undergraduate STEM education to address these weaknesses is a national imperative. This report outlines a framework and indicators that document the status and quality of undergraduate STEM education at the national level over multiple years. It also indicates areas where additional research is needed in order to develop appropriate measures. The report will be useful to government agencies that make investments in higher education, institutions of higher education, private funders of higher education programs, industry stakeholders, and researchers who study higher education.

Stephen W. Director, provost and University Distinguished Professor, Northeastern University, was a member of the study committee. Paper, $55.00.

Making Medicines Affordable: A National Imperative. The United States is facing a seemingly uncontrolled rise in the cost of health care. Total medical expenditures are approaching 20 percent of GDP and crowding out other national priorities. Expensive prescription drugs are a significant part of the problem. Affordability is a complex function of factors, including not just the prices of the drugs themselves but also the details of an individual's insurance coverage and medical conditions. This report examines patient access to affordable and effective therapies, with emphasis on drug pricing, inflation in the cost of drugs, and insurance design. It explores structural and policy factors that influence drug pricing, drug access programs, the role of comparative effectiveness assessments in payment policies, changing finances of medical practice with regard to drug costs and reimbursement, and measures to prevent drug shortages and foster innovation in drug development. It recommends policy actions that could address drug price trends, improve patient access to affordable and effective treatments, and encourage innovations that address significant needs in health care.

Norman R. Augustine (chair), retired chair and CEO, Lockheed Martin Corporation, and **Vinod K. Sahney**, Distinguished University Professor, Northeastern University, and retired senior vice president and chief strategy officer, Blue Cross and Blue Shield of Massachusetts, served on the study committee. Paper, $65.00.

Envisioning the Data Science Discipline: The Undergraduate Perspective: Interim Report. Data science, which addresses the accumulation of data and the need to manage and understand them, draws on diverse fields and encompasses topics in ethics and privacy. The ability to use these data and tools requires a workforce with the necessary skills and expertise. Although undergraduate and graduate data science programs have been established, the field is still in its infancy, suggesting the need to plan for what it might look like in the future and determine steps to move data science education in that direction. This study will set forth a vision for the discipline of data science at the undergraduate level. This interim report offers perspectives on the state of data science education and poses questions to help shape the way it evolves. The final report will lay out a vision for future data science education.

Laura M. Haas (cochair), dean, College of Information and Computer Sciences, University of Massachusetts Amherst, and **David E. Culler**, professor, electrical engineering and computer science, University of California, Berkeley, served on the study committee. Ebook, $34.99.

Report 2 on Tracking and Assessing Governance and Management Reform in the Nuclear Security Enterprise. The congressionally mandated report *A New Foundation for the Nuclear Enterprise* (the "Augustine-Mies report"), released in November 2014, concluded that "the existing governance structures and many of the practices of the [nuclear security] enterprise are inefficient and ineffective, thereby putting the entire enterprise at risk over the long term." Following the release of that report, the National Defense Authorization Act for FY 2016 called for DOE to develop an implementation plan for the recommendations in that and similar reports. The NDAA also called for a 4½-year joint study, by the National Academies of Sciences, Engineering, and Medicine and the National Academy of Public Administration, to evaluate the implementation plan, track the actions proposed in the plan, and assess progress. This report is the second in a series of reports to be issued over 2017–20 as part of that study.

Paul A. Fleury, Frederick William Beinecke Professor of Engineering and Applied Physics and professor of physics, Yale University, was a member of the study committee. Ebook, $29.99.

Bolting Reliability for Offshore Oil and Natural Gas Operations: Proceedings of a Workshop. A workshop in April 2017 was designed to advance awareness of issues associated with subsea fastener material failures and equipment reliability. Speakers and participants also discussed possible paths for addressing risks associated with fasteners used for subsea critical equipment in oil and gas operations. This publication summarizes the workshop presentations and discussions.

Robert E. Schafrik Sr. (chair), retired general manager, Aviation Engineering Division, General Electric Aviation; **Clyde L. Briant**, professor of engineering, Brown University; **Thomas W. Eagar**, professor of materials engineering and engineering management, Massachusetts Institute of Technology; **David W. Johnson Jr.**, retired editor in chief, *Journal of the American Ceramic Society*; **David K. Matlock**, University Emeritus Professor, George S. Ansell Department of Metallurgical and Materials Engineering, Colorado School of Mines; **Jyotirmoy Mazumder**, Robert H. Lurie Professor of Mechanical Engineering, University of Michigan; **Roger L. McCarthy**, consultant, McCarthy Engineering; and **Pol D. Spanos**, L.B. Ryon Endowed Chair in Engineering, Rice University, served on the study committee. Paper, $55.00.

Assessing and Responding to the Growth of Computer Science Undergraduate Enrollments. The field of computer science (CS) is experiencing a surge in undergraduate degree production and course enrollments, straining program resources at many institutions and causing concern among faculty and administrators about how best to respond to the rapidly growing demand. This report examines drivers of the enrollment surge, relationships between the surge and current and potential gains in diversity in the field, potential impacts of responses to the increased demand for computing in higher education, and likely effects of those responses on students, faculty, and institutions. The report provides recommendations for institutions of higher education, government agencies, and the private sector to respond to the surge and plan for a strong and sustainable future for CS, the health of institutions of higher education, and the prosperity of the nation.

Jared L. Cohon (cochair), president emeritus and University Professor, Department of Civil and Environmental Engineering, CMU–Engineering and Public Policy, Carnegie Mellon University, and **David E. Culler**, professor, electrical engineering and computer science, University of California, Berkeley, served on the study committee. Paper, $70.00.

Decrypting the Encryption Debate: A Framework for Decision Makers. Encrypted communications are provided by computing devices and services—such as smartphones, laptops, and messaging applications—that are used by individuals, organizations, and governments. At the same time, criminals use encryption to avoid investigation and prosecution, and encryption complicates law enforcement and intelligence investigations: when communications are encrypted “end to end,” intercepted messages cannot be understood, and the contents of a locked and encrypted smartphone cannot be read if the phone is seized by investigators. This report reviews applications of encryption to cybersecurity, the role of encryption in protecting privacy and civil liberties, the needs of law enforcement and the intelligence community for information, technical and policy options for accessing plaintext, and the international landscape. It describes the context for decisions about giving authorized government agencies access to the plaintext version of encrypted information, and characterizes possible mechanisms and alternative means of obtaining information.

Dan Boneh, professor, computer science and electrical engineering, Stanford University; **Frederick R. Chang**, Bobby B. Lyle Centennial Distinguished Chair in Cyber Security, Southern Methodist University; **Shafrira Goldwasser**, professor, Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology; and **Steven B. Lipner**, executive director, SAFECode, served on the study committee. Paper, $45.00.

A Decision Framework for Managing the Spirit Lake and Toutle River System at Mount St. Helens. The 1980 eruption of Mount St. Helens in southwest Washington state radically changed the region’s physical and socioeconomic landscapes. It sent large amounts of debris into the North Fork Toutle River and blocked the sole means of drainage from Spirit Lake 4 miles north of Mount St. Helens. As a result of the blockage, rising lake levels put the downstream population of approximately 50,000 at risk of catastrophic flooding and mud flows. The legacy of that eruption and the prospect of future volcanic, seismic, and flood events mean that risk management in the Spirit Lake–Toutle River system will be challenging for decades to come. This report offers a decision framework to support the long-term management of risks in light of regional economic, cultural, and social priorities and the roles of federal, tribal, state, and local authorities, among others.

Gregory B. Baecher, Glenn L. Martin Institute Professor of Engineering, Department of Civil and Environmental Engineering, University of Maryland, College Park, chaired the study committee. Paper, $75.00.

Understanding and Predicting the Gulf of Mexico Loop Current: Critical Gaps and Recommendations. The Gulf of Mexico Loop Current System (LCS) consists of the loop current (LC) and loop current eddies (LCEs), and their position, strength, and structure affect hurricane intensity, offshore safety, harmful algal blooms, oil spill response, the entire Gulf food chain, shallow water nutrient supply, the fishing industry, tourism, and the Gulf Coast economy. It is therefore essential to understand both the dynamics of the LCS and the Gulf of Mexico’s full oceanographic system. This report recommends a strategy to address gaps in understanding of LCS processes in order to improve the ability to predict LC/LCE position, evolving structure, extent, and speed as well as overall Gulf of Mexico circulation. The strategy calls for a long-term observational campaign and complementary data assimilation and numerical modeling efforts. The resulting knowledge will promote safe oil and gas operations and disaster response in the gulf.

Paul G. Gaffney II, president emeritus, Monmouth University, chaired the study committee. Paper, $36.00.

Designing Safety Regulations for High-Hazard Industries. This TRB Special Report (324) examines factors relevant to government safety regulators when choosing regulatory design types, particularly for preventing low-frequency, high-consequence events. In such contexts safety regulations are often scrutinized after an incident, but their effectiveness can be inherently difficult to assess when their main purpose is to reduce catastrophic failures that are rare to begin with. Nonetheless, regulators of high-hazard industries must have a reasoned basis for design choices. Asked to compare the advantages and disadvantages of so-called "prescriptive" and "performance-based" regulatory designs, the study committee explains how these labels are often used in an inconsistent and misleading manner that can obfuscate regulatory choices. The report focuses on whether a regulation requires the use of a means or the attainment of some ends, and whether it targets individual components of a larger problem (micro level) or directs attention to the larger problem (macro level). Four main types of regulatory design are identified, and the rationale for and challenges associated with each are examined under different high-hazard applications. The report concludes that too much emphasis is placed on simplistic lists of generic advantages and disadvantages of regulatory design types. It explains that a safety regulator should choose a regulatory design (or combination of designs) suited to the nature of the problem, characteristics of the regulated industry, and the regulator's capacity to promote and enforce compliance.

Kenneth E. Arnold, senior technical advisor, WorleyParsons, and president, K Arnold Consulting Inc., and **Louis Anthony Cox Jr.**, president, Cox Associates LLC, served on the study committee. Paper, $49.00.

The Frontiers of Machine Learning: 2017 Raymond and Beverly Sackler US-UK Scientific Forum. The field of machine learning is advancing rapidly, thanks to increased computing power, better algorithms and tools, and greater availability of data. Machine learning is used in a range of applications, including transportation and the development of automated vehicles, health care and understanding of the genetic basis of disease, and criminal justice and the ability to predict recidivism. As the technology advances, it promises additional applications that can contribute to individual and societal well-being. The Raymond and Beverly Sackler US-UK Scientific Forum "The Frontiers of Machine Learning" took place January 31–February 1, 2017, in Washington. Participants included industry leaders, machine learning researchers, and experts in privacy and the law, and this report summarizes their discussions.

Cynthia Dwork, Gordon McKay Professor of Computer Science, John A. Paulson School of Engineering, Harvard University, was a member of the planning committee. Ebook, $29.99.

Safely Transporting Hazardous Liquids and Gases in a Changing US Energy Landscape. TRB's Special Report 325 reviews how the pipeline, rail, and barge industries have fared in safely transporting increased volumes of domestically produced energy liquids and gases. The report examines the safety assurance and record of the three transportation modes in moving these hazardous shipments. It urges the US Department of Transportation's Pipeline and Hazardous Materials Safety Administration to further the development of robust safety assurance systems to ensure more timely and effective responses to future safety challenges. The recommendations include advice on traffic and safety data reporting, industry and local community consultation, and the creation of risk metrics.

Paul G. Gaffney II (chair), president emeritus, Monmouth University; **Ali Mosleh**, Distinguished Professor and Evelyn Knight Chair in Engineering, University of California, Los Angeles; and **Craig E. Philip**, research professor and director, VECTOR, Department of Civil and Environmental Engineering, Vanderbilt University, served on the study committee. Paper, $47.00.

Review of NASA's Evidence Reports on Human Health Risks: 2017 Letter Report. This is the fifth and final in a series of letter reports reviewing the more than 30 evidence reports that NASA has compiled on human health risks for long-duration and exploration spaceflights. In its review of five evidence reports, this letter report examines the quality of the evidence, analysis, and construction of each; identifies gaps in report content; and provides suggestions for additional sources of expert input.

Laurence R. Young, Apollo Program Professor of Astronautics and professor of health sciences and technology, Massachusetts Institute of Technology, was a member of the study committee. Ebook, $34.99.

Interim Report of the Committee on a Strategic Plan for US Burning Plasma Research. In January 2003 President George W. Bush announced that the United States would begin negotiations to join the International Thermonuclear Experimental Reactor (ITER) project and noted that “if successful, ITER would create the first fusion device capable of producing thermal energy comparable to the output of a power plant, making commercially viable fusion power available as soon as 2050.” The United States and the other ITER members are now building ITER, but the construction schedule has slipped and its costs have increased significantly, leading to questions about whether the United States should continue its commitment to participate. This study will advise how to best advance the fusion energy sciences in the United States given developments and international investments in the field, and the priorities for the next 10 years developed by the community and the DOE Office of Fusion Energy Sciences (FES). It will address the scientific justification for strengthening the foundations for realizing fusion energy given a choice of US participation or not in the ITER project, and develop future scenarios in either case. This interim report assesses the current status of US fusion research and of the importance of burning plasma research to the development of fusion energy as well as to plasma science and other science and engineering disciplines.

C. Paul Robinson, president emeritus, Sandia National Laboratories, is a member of the study committee. Ebook, $34,99.

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