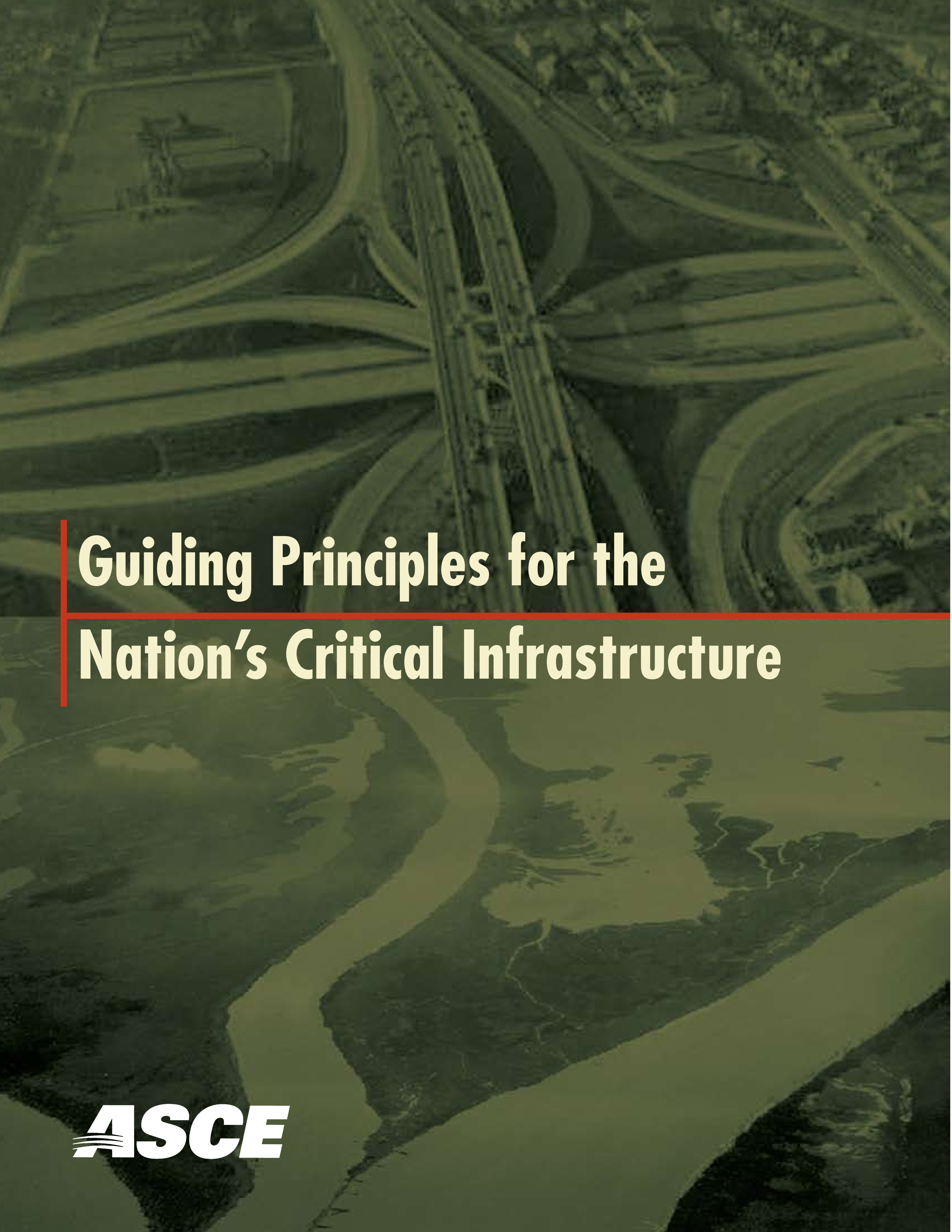

Guiding Principles for the Nation's Critical Infrastructure

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Guiding Principles for the Nation's Critical Infrastructure

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On the Cover:
(top) Los Angeles's Four Level Interchange between the Hollywood Freeway (US 101) and the Pasadena Freeway (SR 110) was the first stack interchange in the world and is today one of the busiest, with more than 455,000 cars per day passing through it.

(bottom) Considered an engineering marvel at the time, the Eads South Pass Navigation Works, New Orleans, Louisiana, opened a channel (in 1879) at the mouth of the Mississippi River that allowed large boats easy access to the Port of New Orleans.

[FOREWORD]

The devastating consequences of the levee failures in New Orleans focused the nation's and the civil engineering profession's attention on the root causes of what is considered one of the worst infrastructure disasters in our nation's history. As reported in the American Society of Civil Engineers (ASCE) *Report Card for America's Infrastructure*[1], the nation is beginning to acknowledge the fact that its aging infrastructure is in need of repair or, in some cases, replacement.

After months of intense analysis of the New Orleans disaster, the ASCE Hurricane Katrina External Review Panel urged that "organizations responsible for critical life-safety facilities be organized and operated to enable, not to inhibit, a focus on safety and that engineers continually evaluate the appropriateness of design criteria, always considering how the performance of individual components affects the overall performance of a system."[2]

These insights have become an imperative to all organizations and individuals involved in planning, funding, designing, constructing, and operating critical infrastructure. This report is an important step in addressing the types of engineering and institutional failures that were brought to light by the studies following Hurricane Katrina and other recent infrastructure disasters.

The ASCE Board of Direction established the Critical Infrastructure Guidance Task Committee to develop this guide to ensure quality in critical infrastructure systems that may involve multiple constituents, multiple jurisdictions, and complex financing. The Critical Infrastructure Guidance Task Committee formulated the guiding principles that are the focus of this document. Although this document uses critical infrastructure to illustrate the importance of the guiding principles, they apply to all infrastructure systems.

I am grateful to all of the individuals involved in this effort for their hard work, initiative, and insight. Success in working with critical infrastructure depends on each one of us.

D. Wayne Klotz, P.E., F.ASCE, D.WRE
ASCE President 2008-2009

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1 *American Society of Civil Engineers, Report Card for America's Infrastructure (Reston, Virginia, ASCE).*
2 *American Society of Civil Engineers Hurricane Katrina External Review Panel, "The New Orleans Hurricane Protection System: What Went Wrong and Why," (Reston, Virginia: ASCE Press, 2007), p. vii.*

[EXECUTIVE SUMMARY]

Critical infrastructure systems are facilities and assets – such as roads and bridges, water supply, wastewater treatment, flood-reduction structures, telecommunications, and power grids – so vital that their destruction or incapacitation would disrupt the security, economy, safety, health, or welfare of the public. Well functioning infrastructure systems are vital to the nation's prosperity and well-being.

Recent catastrophic failures of critical infrastructure systems in this country have served as a stark reminder of the vital importance of our nation's critical infrastructure. These failures (including the collapse of the I-35W Bridge in Minneapolis and the levee failures in New Orleans after Hurricane Katrina) resulted in loss of life and extensive property damage as well as severe disruption to regional and national economies.

The first Fundamental Canon of the American Society of Civil Engineers' (ASCE's) Code of Ethics states, "Engineers shall hold paramount the safety, health, and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties."[3] Other engineering and professional societies have similar clauses in their respective codes of ethics.

To better protect public safety, health, and welfare, the ASCE Critical Infrastructure Guidance Task Committee developed a set of interdependent guiding principles to inform the planning, funding, design, construction, and operation of critical infrastructure systems. The guiding principles were then validated by a group of more than 65 leading infrastructure experts and stakeholders at the ASCE Summit on Guiding Principles for Critical Infrastructure along with strategies to implement them.

The four guiding principles, developed to protect public safety, health, and welfare, are:

1. Quantify, communicate, and manage risk.
2. Employ an integrated systems approach.

3 American Society of Civil Engineers, "2008 Official Register," (Reston, Virginia: 2008), p. 13. The Code of Ethics was adopted on September 2, 1914 and was most recently amended on July 23, 2006.

3. Exercise sound leadership, management, and stewardship in decision-making processes.
4. Adapt critical infrastructure in response to dynamic conditions and practice.

These guiding principles are fully interrelated. No one principle is more important than the others and all are required to protect the public's safety, health, and welfare. The following paragraphs provide a brief overview of the intent of each guiding principle.

Quantify, communicate, and manage risk: Risk management is the application of a systematic process for identifying, analyzing, planning, monitoring, and responding to risk so that critical infrastructure will meet service expectations. Within the context of these guiding principles, risk is defined as the probability that an event may occur multiplied by the magnitude of consequences that would result from that event.

For most critical infrastructure projects, risk has not been quantified nor communicated to the end-users (typically, the public). Without this information, end-users are not prepared to make decisions about the risk and the consequences associated with critical infrastructure failures. A major shift in thinking is needed within the critical infrastructure sector to make risk analysis, management, and communication the standard basis on which projects are developed and implemented.

Employ an integrated systems approach: Critical infrastructure must be planned, funded, designed, constructed, and operated as a system that is appropriately integrated with all other interdependent systems. Critical infrastructure systems must also be resilient and sustainable throughout the system's life cycle. The systems must be properly maintained, operated, and modified, as necessary, to perform effectively under changing conditions. A life cycle systems management approach – as developed and endorsed by the project stakeholders – will help ensure that appropriate political will, organizational structures, and funding mechanisms are established and implemented throughout the entire life of the project.

Exercise sound leadership, management, and stewardship in decision-making processes: The long-term viability of any critical infrastructure system – no matter how resilient and sustainable it is – will ultimately rely on the human and organizational stewardship the infrastructure system receives. Effective organizations can control program outcomes through technical oversight, coordination with related projects and activities, appropriate control and change management, and effective communication with project stakeholders. Conversely, without sound leadership and management of critical infrastructure projects, the nation's safety, health, and welfare are at risk.

Adapt critical infrastructure in response to dynamic conditions and practice: Critical infrastructure systems typically have a long life cycle that often spans decades. These projects are normally designed to meet performance expectations deemed appropriate at the time of design. However, conditions continually evolve and change, and project owners must adopt change-management systems that can effectively address new conditions. Change management systems need to be flexible and robust, and must establish discipline in the way critical infrastructure systems are operated, reviewed, maintained, and upgraded throughout their life cycle.

> Engineers shall hold paramount the safety, health, and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.
>
> *— First Fundamental Canon of ASCE's Code of Ethics**

Public safety, health, and welfare are at stake. The nation's economic well-being is at stake. The investment that the nation has made in its built and natural environments is at stake. The leaders of our nation, the owners of our critical infrastructure, design and construction professionals, and the public as end-users must take these matters seriously. To be successful, they all must embrace the guiding principles and embed them in their decision-making and organizational cultures. And they must hold paramount the safety, health, and welfare of the public.

* *American Society of Civil Engineers, "2008 Official Register," (Reston, Virginia: 2008), p. 13. The Code of Ethics was adopted on September 2, 1914 and was most recently amended on July 23, 2006.*

[CHAPTER 1]

Critical Infrastructure

Critical infrastructure includes systems, facilities, and assets so vital that their destruction or incapacitation would have a debilitating impact on national security, the economy, or public safety, health, or welfare.[4] Critical infrastructure may cross political boundaries and may be built, natural, or virtual. Built critical infrastructure includes energy; water and wastewater treatment, distribution, and collection; transportation; and communications systems. Natural critical infrastructure systems include lakes, rivers, and streams that are used for navigation, water supply, or flood water storage, as well as coastal wetlands that provide a buffer for storm surges. Virtual critical infrastructure includes cyber, electronic, and information systems.

> "Those who cannot remember the past are condemned to repeat it."
>
> *George Santayana, The Life of Reason, 1905-1906*

Critical infrastructure projects or programs are often large in breadth and scope. Depending on their purpose and the population they serve, smaller projects may also be considered critical. Critical infrastructure projects often take a long time to develop and construct, and are intended to perform over an extended period of time. They may be funded from multiple sources over many years. On some projects, funding might be sporadic or insufficient to build the projects to adequate levels of service. Critical infrastructure systems often cross geographic, political, cultural, and organizational boundaries. Critical infrastructure systems, in short, are complex and interdependent, and may require special treatment to provide the intended level of service. If built and maintained properly, infrastructure works as planned and life goes on, uninterrupted. Investment in infrastructure typically has an "invisible" payoff.

Unfortunately, our nation has been lulled into a false sense of security. Human nature is such that it can take a disaster to wake people up to the less-than-optimal situations that surround them.

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4 *U.S. Department of Homeland Security, National Infrastructure Protection Plan: Partnering to enhance protection and resiliency, 2009, www.dhs.gov/xprevprot/programs/editorial_0827.shtm (Accessed June 1, 2009) p. 7*

As civilizations have become more complex and engineered solutions more sophisticated, the public has come to rely on the integrity of built projects for safety and well-being. When those projects fail, the consequences have become commensurately more devastating. Notable infrastructure disasters that have occurred over the past century serve as a stark reminder of the importance of critical infrastructure to public safety, health, and welfare.

What Went Wrong In New Orleans

On the morning of August 29, 2005, Hurricane Katrina struck southeast Louisiana and triggered what would become one of the worst infrastructure disasters in the U.S. The storm overtopped levees and floodwalls throughout southeast Louisiana, and also caused the levees and floodwalls in the New Orleans area to fail or breach in more than 50 locations. Water flooded over 80 percent of the city – more than 10 feet deep in some neighborhoods. [5]

Many factors led to the catastrophic flooding during Hurricane Katrina, but they can be readily grouped into four broad categories. First, experts knew that a hurricane like Katrina was inevitable, and that when it occurred the city would be flooded. No one heeded their warnings or effectively communicated the risks to decision makers, government officials, or the people who lived in New Orleans.

Second, although the southeast Louisiana hurricane-protection system was a complex assemblage of earth levees, concrete and steel walls, pump stations, drainage-ways, and flood gates, it was a system in name only. It was not designed as a system, nor operated as one. It was planned, designed, constructed, and operated without a system-wide approach or integration with land use, emergency evacuation, or recovery plans.

Third, everyone was in charge, and yet no one was in charge. The U.S. Congress authorized construction and appropriated federal funds. The U.S. Army Corps of Engineers planned the projects and prepared the designs. Local levee boards paid the local share; influenced the planning, design, and construction process; and were responsible for operation and maintenance. No single agency or organization was empowered to provide system-wide oversight or a focus on critical life-safety issues. The result was management by committee, and no one could say, "The buck stops here."

The levee failure in New Orleans caused by Hurricane Katrina left 1,118 people dead (as of August 2, 2006) and resulted in over $27 billion in property damage.

5 American Society of Civil Engineers Hurricane Katrina External Review Panel, "The New Orleans Hurricane Protection System: What Went Wrong and Why," (Reston, Virginia: ASCE Press, 2007), p. v.

Finally, the hurricane-protection system was designed and constructed over a 40-year period with little adjustment to changing regional conditions. Despite new meteorological information, the standard project hurricane (the design hurricane) was not updated. Despite knowledge of regional subsidence, design elevations were never adjusted. And despite field test data that showed unacceptable deflections in I-walls resisting loads from floods, I-wall designs were not revised.

Could this disaster have been avoided? In short, it would have required time and money: first, to manage and communicate risk; second, to design and operate it as a system; third to put someone in charge; and fourth to make adjustments based on new knowledge. Cutting corners on cost and schedule had the inevitable effect of compromising public safety, an unfortunate outcome in which more than 1,100 people died and billions of dollars of property damage occurred. Some of these same themes are present in the root causes of other infrastructure disasters, all of which illustrate the need to protect public safety, health, and welfare.

The Value Proposition

The United States has achieved great prosperity in large measure because of our investments in infrastructure. Highway, waterway, air, and rail systems have allowed unparalleled mobility of people and goods. Water-borne diseases are virtually nonexistent because of water and wastewater treatment, distribution, and collection systems. In addition, telecommunications and power systems have enabled our economic growth.

What if irrigation were no longer viable in the arid west? What if the water supply to most of California, the seventh largest economy in the world, was interrupted for more than two years? What if our agricultural goods were not price competitive in international markets? What if our energy infrastructure systems were frequently incapacitated, interrupting the flow of energy? What if much of the critical infrastructure of our coastal counties and cities, home to more than half of the nation's population, had to be physically moved?

These are not just future possibilities; in some cases they are already part of our nation's infrastructure challenges. According to the U.S. Geological Survey, the Ogallala aquifer, a vital natural infrastructure and principal source of irrigation water in the arid west, has declined significantly since large-scale irrigation began. Some sources estimate only 25 years of continued viability. Urban and agricultural areas protected by a fragile system of levees in the California Delta (the confluence of the Sacramento and San Joaquin rivers) could experience losses of more than $40 billion from seismic induced levee breaches. The breaches could inundate much of the Delta with saline water, cutting off the fresh water supply to Southern California for more than 24 months.

Our agricultural products remain price competitive in part because of our inland navigation system and the ease of moving bulk products from farms to ports. Yet this navigation infrastructure is aging, challenged by new demands from increased high flows, greater throughput requirements, and environmental restrictions. Fuel prices spike whenever a hurricane hits the Gulf and our energy infrastructure is highly vulnerable to these events. The complex and interdependent infrastructure required to maintain the production and transmission of energy is faced with increasing challenges from maintenance demands, security, and natural hazards. Sea level rise presents a multi-faceted problem. It increases risk dramatically by magnifying the impact of severe storms on infrastructure systems, a growing population, and assets in coastal zones.

The nation's overall risk of suffering from the consequences of critical infrastructure failures is now greater than ever. Yet people are rarely aware of these risks because the risks have not been quantified in most communities, and if quantified, not communicated adequately. To serve as intended, individual projects must be treated as part of an overall integrated system, recognizing dependencies and interdependencies. Meeting these challenges will require a new kind of leadership that redefines governance of critical infrastructure systems and restores the focus on public safety, health, and welfare. Finally, infrastructure systems must be adaptable to unexpected changes in order to be sustainable. In short, we will have to plan, develop, and manage infrastructure as risk-based systems that can adapt to change through enlightened and collaborative leadership.

From lessons learned, we have the opportunity to regain our focus on the importance of critical infrastructure systems in protecting public safety, health, and welfare. As the ASCE Hurricane Katrina External Review Panel concluded, "The lessons learned from the engineering and engineering-related policy failures triggered by Hurricane Katrina have profound implications for other American communities and a sobering message to people nationwide: we must place the protection of

When talking about the American Recovery and Reinvestment Act of 2009, President Barack Obama had this to say about stewardship of our nation's transportation infrastructure: "But what makes this investment so important is not simply that we will jump-start job creation, or reduce the congestion that costs us nearly $80 billion a year, or rebuild the aging roads that cost drivers billions more a year in upkeep. What makes it so important is that by investing in roads that have earned a grade of D- by America's leading civil engineers – roads that should have been rebuilt long ago – we can *save some 14,000 men and women who lose their lives each year* due to bad roads and driving conditions. Like a broken levee or a bridge with a shaky foundation, poor roads are a public hazard – and *we have a responsibility to fix them*."

March 3, 2009 (italics added for emphasis) safety, health, and welfare at the forefront of our nation's priorities. To do anything less could lead to a far greater tragedy than the one witnessed in New Orleans."[6]

Who Leads the Charge?

Meeting these varied challenges to upgrade our critical infrastructure systems will require new kinds of leadership and new ways of thinking at all levels. The performance of critical infrastructure is everyone's responsibility. This includes design and construction professionals, elected officials, regulators, owners, and the public, as end-users.

The infrastructure sector includes organizations and people who have a vested interest in ensuring that critical infrastructure is planned, built, and operated such that the safety, health, and welfare of the public is protected. The infrastructure sector is not a formal entity and unfortunately, at present, its stakeholders are disconnected and may not have a shared vision. The guiding principles represent a framework within which the infrastructure sector can work together to create a shared vision for protecting public safety, health, and welfare.

Each of the infrastructure sector stakeholders plays an important but distinct role. These roles are both collaborative and hierarchical, and the responsibilities are necessary and cannot be delegated. Owners must ensure that critical infrastructure meets its intended purpose of protecting and enhancing the safety, health, and welfare of its users in a sustainable manner over the life cycle of the project. Regardless of whether owners are public or private entities, they must provide leadership and advocacy for their respective projects.

Design professionals are responsible for the conceptual and detailed design of critical infrastructure. As such, the safety, health, and welfare of the general public are dependent on engineers' sound judgment, decisions, and practices during the planning and design phases of a project. Design and construction professionals are uniquely positioned to serve as the catalyst for improvements in the way critical infrastructure is designed and constructed.

Government officials who establish policy and provide funding for critical infrastructure projects must understand, support, and adequately fund these projects so that public safety, health, and welfare are not compromised.

The public, as end-users of critical infrastructure, is responsible for understanding the performance of critical infrastructure systems and the consequences of failure. Through this understanding, individuals can make informed personal decisions based on the risks associated with living in their communities and can advocate for adequate investment in critical infrastructure.

6 American Society of Civil Engineers Hurricane Katrina External Review Panel, "The New Orleans Hurricane Protection System: What Went Wrong and Why," (Reston, Virginia: ASCE Press, 2007), p. viii.

[CHAPTER 2]

Guiding Principles for Critical Infrastructure

Any single critical infrastructure disaster should be proof that we as a nation need a new collective imperative for planning, designing, building, and operating our critical infrastructure systems. However, it was the devastating consequences of the levee failures in New Orleans during Hurricane Katrina that focused the nation's and the civil engineering profession's attention on the root causes of what is considered one of the worst infrastructure disasters in our nation's history. At the same time, the nation is waking up to the fact that its aging infrastructure is in need of repair or replacement.

The ASCE Critical Infrastructure Guidance Task Committee was charged with developing a guide for engineers and nonengineers to ensure quality in critical infrastructure systems that involve multiple constituents, multiple jurisdictions, and complex financing. After much discussion and deliberation, the Critical Infrastructure Guidance Task Committee formulated the guiding principles that are the focus of this report.

> Overarching Principle – The design, construction, operation, and maintenance of critical infrastructure systems must hold paramount the safety, health, and welfare of the public it serves or affects.

The guiding principles were validated by a group of more than 65 leading infrastructure experts and stakeholders at the ASCE Summit on Guiding Principles for Critical Infrastructure in December 2008. During two days of presentations, breakout groups, and discussions, participants also developed prioritized implementation strategies for each guiding principle. Summit presentations and a list of participants are available at www.asce.org.

The process of dissecting critical infrastructure failures and successes and formulating these guiding principles led task committee members and summit participants to a much more fundamental realization about the true importance of critical infrastructure to our nation's safety and well-being.

Guiding principles are necessary to inform decisions, drive actions, and align behaviors for all types of infrastructure projects and systems. These principles provide a strategy to address public safety, health, and welfare throughout the life cycle of critical infrastructure systems from planning through decommissioning. Use of these guiding principles is appropriate when assessing whether existing critical infrastructure systems are performing to the proper levels of service. These guiding principles should be used for self-assessments and external evaluations and can be applied to both existing and new projects.

Over the past few decades, the focus on public safety, health, and welfare has been overshadowed by project costs and schedules. Appropriate infrastructure investment and project life-cycle performance have also been compromised by a focus on election cycles and short-term gains. When planning, designing, constructing, and operating a project, the overarching principle must be applied.

Adherence to the overarching principle is a responsibility of all stakeholders and is a fundamental canon in codes of ethics for design professionals, including ASCE, the National Society of Professional Engineers, the Institute of Electrical and Electronics Engineers, the American Society of Mechanical Engineers, and the American Institute of Chemical Engineers.

In support of this overarching principle there are four pillars or guiding principles. These guiding principles are fully interrelated – no one principle is more important than the others, and all are required to achieve the overarching principle. The four guiding principles are:

1. Quantify, communicate, and manage risk.
2. Employ an integrated systems approach.
3. Exercise sound leadership, management, and stewardship in decision-making processes.
4. Adapt critical infrastructure in response to dynamic conditions and practice.

Together, these guiding principles create a framework within which the effectiveness, adaptability, and resilience of critical infrastructure systems can be assessed and managed. By effectively applying these principles, critical infrastructure systems will be resilient and sustainable throughout their life cycle. Each guiding principle is described in subsequent chapters, including recommendations on how they should be implemented through best practices and policy.

[CHAPTER 3]

Quantify, Communicate, and Manage Risk

Infrastructure projects are created, from inception through construction and operation, by a series of decisions, such as those regarding project location, design criteria, funding, and designer and contractor selections. Each decision contributes to the adequacy of the finished project and its resulting level of service and safety. However, many decisions are constrained by funding or schedule considerations. They can also be constrained by limits in the technical understanding of how a project will perform under unknown conditions. Decisions can be influenced by philosophical differences between the net benefits of competing objectives (e.g., value for people versus value of the natural environment).

These compromises represent the gap between the best possible project or program that could be implemented and the actual project or program that is created. They also represent the risk of less-than-optimal project performance that, in turn, increases the likelihood of compromises to the safety, health, and welfare of the project's users.

Risk Management

We live in a world filled with risk. Regardless of the level of care and stewardship invested in a critical infrastructure project, a perfect (i.e., "risk-free") solution cannot be created. Real projects will always include some level of residual risk that requires quantification, management, and communication.

Risk management is the application of a systematic process for identifying, analyzing, planning, monitoring, and responding to risk so that critical infrastructure will meet service, safety, health, and welfare expectations.

Within the context of these guiding principles, risk is defined as the probability that an event may occur, multiplied by the magnitude of consequences that would result from that event:

$$\text{Risk} = (\text{Probability}) \times (\text{Consequences})$$

Probability includes two components: the probability that an event (such as an earthquake or flood) will occur, and the probability that the critical infrastructure will not perform to required levels. These probabilities reflect significant uncertainty. For example, it is difficult to predict the timing and magnitude of events such as hurricanes, tornadoes, and earthquakes. It is also difficult to foresee human-caused events such as maintenance failures or terrorist acts.

Consequences represent the range of possible effects of an event, such as loss of life, economic impact, environmental damage, or cultural loss. Assessing consequences means that we must work with disciplines outside of engineering and ultimately with the stakeholders and the public. While challenging, the inclusion and integration of multiple perspectives in assessing risk is our ethical responsibility and will provide the greatest value of our profession to society.

The inclusion of risk as a performance criterion is a fundamental shift in the approach to critical infrastructure development and operation. Risk-based design will require a greater understanding of the anticipated physical behavior of infrastructure systems under a wide range of events that may occur. Such detailed analyses were not practical or even possible a few decades ago, but can be readily accomplished today.

Perhaps more challenging than technical analyses are the determinations of "acceptable" risk levels by decision makers. Risk-based design requires owners and stakeholders to decide, in advance, the level of economic damage and human hardship that is acceptable.

Considering these challenges, leaders with short-term vision may see little value in tackling these important questions. However, the risks remain, and avoiding these questions will not resolve them. Without a thorough and candid risk management approach, the people at risk will continue to be uninformed about the economic and physical threats that they face.

Understanding Risk

For most critical infrastructure projects, risk has typically neither been quantified nor communicated to the end-users (typically, the public). Without this information, end-users are not prepared, either technically or politically, to make decisions about the risks and consequences associated with critical infrastructure failures. End-users are, consequently, not demanding an adequate level of protection for their critical infrastructure systems. Without adequate information about the risks, an uninformed public must make uninformed decisions about their level of protection.

Every American should have the opportunity to choose the risk they are individually willing to accept. Traditional infrastructure design practices in the U.S. have not helped citizens make such choices. Although not widely available, we now have the analytic and communication capabilities to support individual assessments and better engage the public, as stakeholders, in events that affect their security and safety.

A Shift in Thinking

Unlike the overarching principle or other guiding principles, risk analysis, risk management, and risk communication represent a new approach to infrastructure design, construction, and operation that is now viewed as the best way to bring decision makers and stakeholders to a common, informed frame of reference. The following are recommendations on how to effectively integrate risk assessment, risk management, and risk communication strategies into our nation's critical infrastructure programs.

I. Produce a best-practices guide and develop and publish codes, standards, and manuals for assessing and communicating risk.

Risk assessment and management is a relatively new tool as applied to critical infrastructure systems. A team of qualified risk experts and stakeholders from within and from outside the infrastructure field should come together and "write the book" on how risk should be analyzed, managed, and communicated for critical infrastructure projects. This guide needs to be supplemented by a suite of learning tools, such as curriculum modules, workshops, workbooks, and classroom materials.

> A major shift in thinking is needed within the critical infrastructure sector to make risk analysis, management, and communication a standard basis on which projects are developed and implemented.

In assessing risk, it is necessary to consider tradeoffs. These tradeoffs need to be evaluated by using common metrics, one of which is monetary cost. It is challenging, however, to assign costs to intangible items such as the value of an endangered species or a human life. Similar assessments are also necessary for issues such as social, economic, political, and environmental quality. Standard and accepted methodologies for intangible tradeoff analyses are needed as part of a best-practices guide.

Acceptance of risk management methodologies will be difficult unless regulatory agencies sanction and require them. To attain widespread use of these risk management methodologies, portions of a best-practices guide should be integrated into applicable federal, state, and local design standards and codes.

II. Develop a public-policy framework that establishes tolerable risk guidelines and allocates costs for managing risks and consequences.

Many industries, such as the insurance and financial sectors, have developed methodologies and analytical tools to evaluate and manage risk profiles. These industries have also developed standards for what constitutes tolerable and intolerable levels of risk. Such baseline risk values will provide a framework for identifying projects that exceed acceptable risk guidelines, so that those projects can be restructured.

Within the infrastructure sector, established and accepted guidelines regarding appropriate risk levels for engineering design as they pertain to loss of life, loss of property, or economic loss are rare. One notable exception is the Reclamation Safety of Dams Act of 1978, which led to the development (by the U.S. Department of the Interior, Bureau of Reclamation) of guidelines for achieving public protection in dam safety.

Appropriate professional organizations and agencies within the federal and state governments (with input from local governments) should develop systematic approaches to establishing tolerable risk guidelines and standards for all types of critical infrastructure systems. After systematic approaches are established, regional and local government agencies can facilitate discussions with critical infrastructure stakeholders, including the public, about acceptable levels of risk to economics, public safety, health, and welfare for that community. These guidelines can then be codified through the public-policy framework at the appropriate state and local levels.

The public-policy framework should also include a discussion of which entities or organizations should be responsible for managing risk, how risk should be dealt with in the context of a risk-management strategy, and who should pay the costs of risk management.

The I-35W Bridge in Minneapolis, Minnesota, collapsed into the Mississippi River and riverbanks on August 1, 2007, killing 13 people and injuring 145.

III. Provide professional education and training to members of the design and construction industries on identifying, analyzing, and mitigating risk.

Most planners, architects, engineers, and constructors did not learn risk management methodologies in their formal education. A continuing education program of risk management best practices is needed to educate individuals in the design and construction industry. In addition, a formal university-level program of study on risk analysis, risk communication, and risk management is needed to educate future generations of design and construction professionals.

IV. Screen all existing critical infrastructure projects to determine if updated risk analyses are warranted. Require that risk analyses be performed for all proposed critical infrastructure projects.

Project owners are ultimately responsible for the success or failure of their projects during design, during construction, and over the project's life cycle. It is in the project owner's best economic interest – as well as the owner's responsibility as a good citizen – to fully understand the level of risk inherent in each critical infrastructure project and to inform the communities that the project serves about this level of risk.

Given the rapid changes our nation is undergoing, evaluating the sufficiency of existing critical infrastructure is increasingly important. The consequences of failure of critical infrastructure projects built even 20 or 30 years ago may now be significantly different from the consequences of failure when the project was originally developed. New predictive and analytical tools can now enable a much more comprehensive view of the probability of failure.

V. Publicize the risk of individual critical infrastructure projects and illustrate the impacts to society if an infrastructure system were to fail.

Many people choose to live and work in high-risk areas – for example, in ocean-side communities at risk from hurricanes and coastal erosion, river-front communities at risk from flooding, or hillside developments at risk from earthquakes or landslides. These citizens often make these choices because they perceive that the benefits (jobs, commute time, views, prestige, etc.) outweigh the risks.

People and communities often expect the presence of critical infrastructure to compensate for the choice of high-risk land use. They expect critical infrastructure systems to adequately protect their families and investments. This protection is assumed to be absolute, and they do not appreciate the possible consequences that could result from infrastructure failure. However, there are no risk-free solutions.

Three Mile Island Nuclear Generating Station is the site of the worst civilian nuclear accident in United States history which occurred on March 28, 1979.

The public, as end-users of critical infrastructure systems, deserves an opportunity to learn about the risks associated with critical infrastructure in their communities. Decisions regarding tolerable risk must include input from public stakeholders. The public should be active participants in how residual risk is managed through risk acceptance, disaster preparedness, evacuation policies, increased fortification of critical infrastructure systems, or other strategies to "buy down" the risk.

Although owners, designers, and constructors typically intend for their critical infrastructure projects to provide adequate protection, the risk of failure remains. Although federal, state, or local governments provide project oversight and reconstruction assistance, this does not alleviate the individual end-users' responsibility for making wise decisions.

There are a number of ways to incentivize wise choices for appropriate risk-management strategies. Federal, state, and local program funding for critical infrastructure could be given preferentially to communities that implement land-use policies that limit development in high-risk areas. An organization's bond rating or insurance rates could be tied, in part, to a demonstration of how well the organization reduces, manages, mitigates, and communicates risk in its projects. For example, the National Flood Insurance Program, administered by the Federal Emergency Management Agency, provides flood insurance premium subsidies for those homes and businesses located in communities that implement zoning and building codes that minimize damages to structures affected by a flood event. The adoption of similar regulatory and short-term financial incentives for other natural and human-caused disasters may effectively reduce human and property risks.

[CHAPTER 4]

Employ an Integrated Systems Approach

In the past, owners, designers, and end-users often thought of critical infrastructure as isolated projects designed to perform a finite set of functions. The interrelationship between critical infrastructure and the surrounding physical and societal web was not always taken into account, and the long-term viability and adaptability of a project was not always fully explored.

It has become increasingly apparent in our complex world that almost everything is interrelated, and critical infrastructure is no different. To be effective, critical infrastructure must be considered within the context of all other elements that may affect it or that it may affect. Infrastructure projects must be developed using a systems approach with an understanding of all connections, interactions, and interdependencies between system components.

This is more difficult than it might seem. Critical infrastructure projects – and, indeed, our sociological and political structures – are complex. There are many moving parts, the interdependencies of which may not be well understood. Humans have a natural propensity for breaking down projects into smaller, more manageable pieces, and it takes effort to integrate them again as a whole. Also, the many players on large projects may not have the same motivations and may even be at odds with each other.

Regardless of the challenges, every critical infrastructure project should be planned, designed, constructed, and operated as a system that is appropriately integrated with all other interdependent systems. The system must also be properly maintained, operated, and modified, as necessary, to perform effectively under changing conditions throughout its life cycle.

A life-cycle systems management approach, developed and endorsed by the project stakeholders, will help ensure that appropriate political will, organizational structures, and funding mechanisms are established and implemented throughout the entire life of the project.

Sustainability, Redundancy, and Resiliency

Sustainable development is defined as "the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base essential for future development."[7] To be sustainable, critical infrastructure must be considered within the context of the resources needed to build and maintain it, and within the context of the impacts to the surrounding ecosystems, now and in the future.

Redundant systems include having backup systems in place that will help mitigate consequences if critical infrastructure fails to perform. Redundancy is, by definition, a consideration of the potential performance of the critical infrastructure system within the context of surrounding systems that might act as back-ups. Those backup systems could consist of some combination of land use, secondary infrastructure, evacuation plans, and other strategies that would help mitigate the risk to public safety, health, and welfare and damage to the environment.

Resilient critical infrastructure systems are able to withstand and recover from extreme conditions (such as greater-than-designed-for loading conditions). Resilient systems are more likely to perform well over the long term and under unforeseen conditions that may arise. A resilient critical infrastructure system and the communities it serves is more likely to "bounce back" or recover more quickly and efficiently than a nonresilient system.

Developing resilient critical infrastructure systems may require additional up-front project funding. However, the long-term costs, especially if disaster strikes, will be far less. Consider that an additional $2 billion investment in the levees surrounding New Orleans may have reduced the tragic loss of life caused by Hurricane Katrina.

A double-deck freeway in Oakland, California, collapsed during the Loma Prieta earthquake on October 17, 1989, crushing the cars on the lower deck and killing 42 people.

Integral Solutions

Clearly, future critical infrastructure projects will be shaped by a need to accommodate expanding populations and associated economic development. Most infrastructure systems have more than one acceptable configuration or design. The most effective designs will be those that work in concert with other infrastructure projects, the evolution of surrounding population and economic centers, and the changing natural environment. Engaging project stakeholders is a key requisite to ensuring that the appropriate political support, organizational structures, and funding mechanisms are established and implemented throughout the life cycle of a project.

The challenges of implementing a life-cycle, integrated systems approach are well known. Critical infrastructure projects are typically large and complex. Organizations and systems must be in place to ensure that critical infrastructure is properly operated and maintained over time. The following items outline broad-based ways to achieve this.

7 *ASCE, "The Role of the Civil Engineer in Sustainable Development," ASCE Policy Statement 418, Adopted April 24, 2007.*

I. For each program or project, create a regional framework, develop a statement of unified vision among stakeholders, and define a life-cycle management and funding approach.

A well-defined regional organizational framework is the first step in establishing a context for discussions concerning critical infrastructure. Such a framework should encompass all activities and stakeholders that are relevant to, and potentially affected by, a critical infrastructure system. The framework should consider the surrounding built and natural environments, socioeconomic conditions, organizational jurisdictions, and broader implications such as impact to regional commerce. A timely decision-making process must be employed.

Regions or communities may have several interrelated critical infrastructure projects within their boundaries. Therefore, it will be important to find a mechanism to facilitate coordination. A coalition of critical infrastructure project owners – along with regional planning agencies – is a logical starting point for such collaboration. For critical infrastructure projects that involve land-use considerations, local and state government involvement may also be required.

Such organizations can quickly become unwieldy as competing interests, authorities, and jurisdictions of participants come into conflict. However, the growing interdependency of critical infrastructure systems, population centers, and economic development will require effective leadership and collaboration.

II. Integrate and apply technological tools, such as systems-driven dynamic simulations and asset-management models, to assess the interdependencies and the range of benefits and costs associated with critical infrastructure projects.

Within complex systems, the many components may each follow simple rules on an individual level, but have no view of the overall system behavior. When those components interact, however, they can generate complex system-level behaviors that, based on their individual behaviors, may not be expected.

Dynamic models and tools that can simulate and predict this emergent behavior are becoming more available and widely used. Simulating the many components associated with critical infrastructure systems and the interdependencies between them can support the strategic decision-making process and thus can help enhance public safety, health, and welfare.

Project owners are ultimately responsible for the success (or failure) of their projects, not only during design and construction, but over a project's entire life cycle. The success or failure of a critical infrastructure project will hinge on how well the project is integrated into its surroundings and on how resilient and sustainable it is. Project owners should use the available models and tools on existing critical infrastructure projects to understand these complex interdependencies. These models and simulations can enable designers to portray various design alternatives and their implications in an engaging and informative way, so that project stakeholders can effectively weigh in on the project.

Public funds often comprise a significant portion of critical infrastructure project funding. Elected executives and legislators should become engaged in the dialogue about critical infrastructure to ensure projects are implemented using a systems-based approach that seeks to balance long-term benefits with short-term costs. While cost is often a primary consideration when designing and constructing a project, officials should consider safety, aesthetics, and sustainability of the various alternatives with equal care. The use of models and simulations can greatly help stakeholders understand and balance various and competing outcomes.

[CHAPTER 5]

Exercise Sound Leadership, Management, and Stewardship

The long-term viability of any critical infrastructure system – no matter how sustainable and resilient it is – will ultimately rely on the human and organizational stewardship the infrastructure system receives. We cannot simply build infrastructure and then neglect to adequately maintain it, hoping that it will continue to perform adequately.

History has shown that failure to adequately communicate and collaborate, by both individuals and organizations, may lead to misunderstandings, omissions, and grievances. With complex critical infrastructure systems, the problems are often magnified.

Notable infrastructure failures have been caused in part by a lack of definition of who is in charge and by not having in place a clear or effective decision-making process. Critical decisions are sometimes made at an inappropriate level of an organization's hierarchy (either too low or too high).

Without sound leadership, management, and stewardship of critical infrastructure projects, the nation's safety, health, and welfare are at risk. On the other hand, strengthening the leadership and decision-making processes will support a proper level of protection and service from critical infrastructure. Below are several suggestions on how this can be accomplished.

The Infrastructure Leader

Leadership is an ability to direct, motivate, and influence others to perform in a particular manner. Good leaders provide a long-term vision and are characterized by their ability to organize and encourage those they lead to effectively accomplish tasks, while creating and sustaining a positive work environment. Management is the ability to plan, organize, and direct a series of activities required to accomplish a task.

While definitions differ, the main difference between leadership and management is the motivational aspect of leadership. It is this motivational aspect and related innovative decision making that moves individual activities and entire projects forward.

Not every person working on a critical infrastructure systems will be comfortable in a leadership position. However, for a system to perform adequately, appropriate leadership and management needs to be applied in strategic positions throughout an organization's workforce. Critical infrastructure projects must be led by motivated, innovative, and skilled leaders to be successful. In return, society should reward those leaders commensurate with the valuable services they offer.

Strong, Flexible Organizations

While strong leadership and management may help achieve an organization's mission, the organization itself must be structured to enable and empower employees to make appropriate decisions at their levels of responsibility. Complex projects often require complex management structures to oversee them. Management responsibility may reside within a single organization or may cross several entities. Management structures may be well established, or may have evolved organically with some residual disorganization.

Most problems concentrate at the interfaces between people and between organizations. Through these interfaces, however, problems can be solved. Effective organizations can control program outcomes through technical oversight, coordination with related projects and activities, appropriate control and change management, and effective communication with project stakeholders. The early and consistent use of external reviews can also help identify areas for improved coordination. However, no amount of engineering can offset a dysfunctional organization.

The Teton Dam in southeastern Idaho collapsed on first filling on June 5, 1976, causing the deaths of 11 people and $2 billion in damages.

Without strong leadership and management to facilitate critical infrastructure stewardship, the nation's continued economic development in addition to the safety, health, and welfare of its citizens is at risk. On the other hand, strengthening the leadership and decision-making processes will support a proper level of protection and service from the critical infrastructure. Given the importance of this aspect of organizational health, summit participants identified the following suggestions.

I. Establish or upgrade organizational structures, use inter- and intraorganizational communications and collaboration mechanisms, and apply organizational change management techniques.

A project owner's responsibility, when considering critical infrastructure, is to establish or implement a vision for the project (with appropriate input from stakeholders); champion the project through its life cycle; facilitate good decision making that supports the vision and purpose of the project; garner and allocate the resources needed to implement, operate, and maintain the project; and manage change. An owner, public or private, can delegate authority to act on various issues, but cannot abrogate their overall responsibility for the project.

Within the complexities of many critical infrastructure projects, a clear project champion is sometimes difficult to identify. At a minimum, project owners need to make sure that there is one entity or individual in charge, that there are clear lines of authority and responsibility, and that there are unambiguous definitions of what that responsibility entails.

Organizations should strive to improve communication skills and protocols among project teams and with stakeholders, including the public. It is critical to effectively communicate important issues and implications pertaining to a project.

II. Educate and cultivate engineers and other design professionals to be better leaders, and urge others to honor the engineers' assessments on issues pertaining to safety, health, and welfare.

Critical infrastructure systems require many engineering decisions to properly design, build, operate, and maintain. However, project owners are often nonengineers. Similarly, projects are often led and managed by non-engineers. This is acceptable, except in instances in which nonengineers make engineering decisions and inappropriate management decisions overcome sound engineering practice. For critical infrastructure projects, the result can be deadly.

Engineers need to exercise a stronger voice within organizations that develop and manage critical infrastructure projects. During the value-setting process, engineers must advocate for public safety, health, and welfare, and must communicate the risks associated with various project alternatives. Throughout the life cycle of the project, engineers need to remain active, engaged, and respected members of decision-making and management teams to ensure that the safety, health, and welfare considerations are not overlooked, downplayed, or misunderstood.

There will always be trade-offs between cost and risk. For example, cost-cutting measures may affect the resiliency of the project and lead to a decreased level of service and safety. These types of decisions need to be based on a thorough understanding of the risks posed by the changed plan or operating condition. Knowledgeable and qualified engineers should make such assessments.

Engineers rightfully dedicate a large portion of their college education and postcollege careers to the technical aspects of their respective disciplines. Summit participants suggested that future engineers also demonstrate proficiency in topics such as public policy, business and public administration, teamwork, and leadership in addition to their technical expertise.

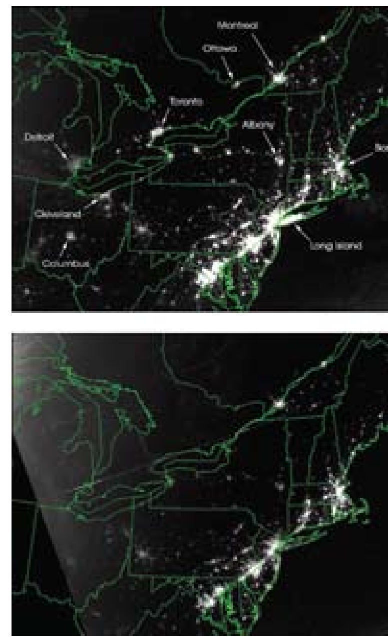
Today's critical infrastructure systems cannot wait for the engineers of tomorrow, however. Engineers need to take the initiative to learn leadership and management principles and apply them more proactively in their daily work. Furthermore, the owners, developers, and managers of today's critical infrastructure need to help elevate the engineer's role in the project and respect the engineering perspective as important to the decision-making process.

III. Engage and form coalitions to advocate for critical infrastructure, and ensure the process of establishing priorities and allocating resources is disciplined, fair, rational, and transparent.

The nation's safety, health, and welfare – as afforded by the nation's critical infrastructure – should be placed higher on the list of national and local priorities. No single group of people can effect this change. Rather, coalitions that include a broad range of policy makers, design professionals, owners, decision makers, and stakeholders are needed to advocate for critical infrastructure. These coalitions create power in numbers and richness in perspectives. They can serve as voices of reason to highlight issues, and provide a sound basis of opinion to assist elected officials, agency representatives, and other decision makers.

Even if coalitions are understood to be an optimal (and perhaps the only) means by which positive change can occur, a number of inherent barriers can make coalition forming difficult, including the lack of effective contacts in other professions or organizations. There may also be a concern that conflicts could arise between groups. It takes committed leadership to manage those conflicts.

Regardless, the formation of a coalition can shift the balance of power and alter the future course of an issue. People who pool their resources and work together are generally more powerful and better able to advance their interests. A coalition can bring more expertise and resources to bear on complex issues, when the technical or personnel resources of any one organization would not be sufficient. And a coalition can build a lasting base for change.



The northeast blackout of August 2003 left 50 million people across eight states and one Canadian province without power, causing a cascading failure of interdependent critical infrastructure systems. (top image – 20 hours before the blackout; bottom – about 7 hours after.)

IV. Create adaptable, nimble, and progressive learning organizations.

Change is difficult for almost all organizations, but is especially challenging for those with long-established or rigid hierarchies and those hamstrung by outdated protocols. But change is absolutely necessary to address the challenges of protecting the nation's safety, health, and welfare. Organizations within the infrastructure sector need to strive to be more adaptable and nimble in order to negotiate these changes – and to continue to incorporate best practices and innovation into their critical infrastructure-related work.

Organizations within the infrastructure sector – including project owners, government agencies, professional organizations, and design-construction firms – must be willing to perform a complete bottom-to-top examination of their existing policies and programs. They will need to implement new programs and garner additional expertise. They will need to build partnerships with new people and organizations. They will need to think creatively to develop new funding sources. In short, organizations must be willing and able to adapt to change.

[CHAPTER 6]

Adapt to Dynamic Conditions and Practice

The world is continually evolving and changing. Consider, for example, the profound changes to society from the industrial revolution a century ago and from the information age and globalization today. Consider the dramatic potential changes that climate change may cause.

The traditional approaches to the development and operation of critical infrastructure projects have not necessarily taken this mosaic of change into account. Critical infrastructure systems have a very long life cycle – spanning decades or even centuries. These projects have traditionally been designed to conform to performance levels deemed appropriate at the time of design.

Dramatic changes in the latter half of the 20th century and the beginning of the 21st century necessitate a new approach – considering critical infrastructure within the context of dynamic conditions – to ensure that projects adequately protect public safety, health, and welfare over their life-cycles.

> "It is change, continuing change, inevitable change, that is the dominant factor in society today. No sensible decision can be made any longer without taking into account not only the world as it is, but the world as it will be."
>
> *Sir Isaac Asimov, 1981*

For example, U.S. population grew from 152 million in 1950 to 304 million in 2008.[8] U.S. population is expected to continue to grow and some estimates place 80 percent of this growth within 100 miles of coastlines that are often subject to severe storms. Clearly, the consequences of failure are increasing.

Concurrent with these types of changes, the design profession

8 U.S. Census Bureau, International Database, "Total Midyear Population for the World: 1950-2050" http://www.census.gov/popest/archives/1990s/popclockest.txt Accessed June 10, 2009.

has increased its understanding of how infrastructure performs through improved analytical and predictive techniques and analyses. We can now better observe potential deficiencies that we may not have been able to see before. The combination of increasing consequences and the ability to rapidly assess infrastructure performance has created a new imperative to fortify the nation's infrastructure before disaster strikes.

Knowns and Unknowns

In any project, there are knowns and unknowns. For critical infrastructure projects, typical knowns include current site conditions and surrounding land use, reasonable predictions of near-future conditions, and short-term expectations regarding the level of protection provided by the project. Unknowns include future population growth and proximal development, changes in technology, changes in geopolitical jurisdictions, and the possible effects of climate change.

In the past, project owners and engineers have done a fairly good job of working with the current knowns to develop and design critical infrastructure systems. This is no longer sufficient. Consider the example of a dam originally built in a relatively rural area to design standards that afforded a certain level of protection. If significant land development occurs downstream, the dam should be reassessed and possibly retrofitted with additional protection features to adequately protect the people downstream or the development would have to be limited.

A systems approach includes designs that anticipate future events and their consequences, construction that is adaptable to future conditions, and the operation and maintenance of the project throughout its life cycle. Critical infrastructure requires conscientious operation and consistent, adequate maintenance investments to provide the levels of service and protection developed by the designer and expected by the customer and affected public.

It is equally important that project owners adopt change management systems so that current and future unknowns can be effectively addressed. Change management systems must be flexible and robust, and must establish discipline in the way critical infrastructure systems are operated, maintained, and upgraded throughout their life cycle.

Overcoming the Resistance to Change

The most difficult challenges to refocusing our critical infrastructure to be adaptable to future conditions are not technical in nature, but political, social, and organizational.

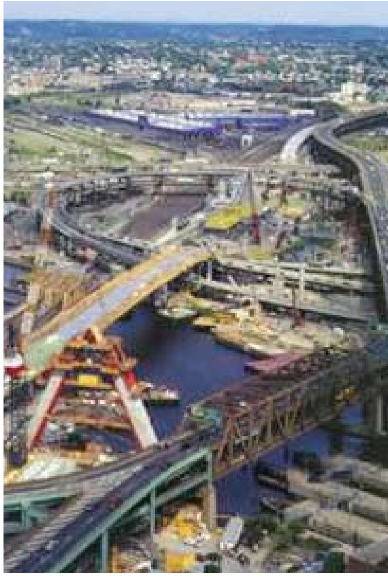
Given funding limitations and project complexities, it can be daunting to obtain additional resources to implement necessary changes. Regular reviews of risk and expected performance can be compared with current best practices to engage stakeholders and guide informed decision making.

Such a shift in construction and operational philosophy requires leadership by project owners and elected officials. The following suggestions by the participants in the Summit on Guiding Principles build on this concept.

I. Raise awareness and understanding among policy makers and the general public about the importance of long-term stewardship and advocacy for critical infrastructure.

Once a critical infrastructure project is in operation, the public is often lulled into a false sense of security. They either forget about the project altogether, or assume that the project is too robust or too large to fail. They turn their attention to the next new issue where their input can have an immediate and observable affect, rather than considering that the original project requires periodic reevaluation, maintenance, and upgrades.

Education and awareness-enhancing activities are needed to ensure that policy makers and the public give proper attention to those issues that affect the long-term performance of critical infrastructure. They must be routinely reminded that proper resources – especially funding – need to be allocated to long-term stewardship. They must also be reminded of the associated risks if that support is not provided.



The Central Artery/Tunnel Project (also known as the "Big Dig") in Boston, Massachusetts, is considered the most expensive highway project in the U.S, costing more than $14.6 billion. On July 10, 2006, a concrete ceiling panel weighing 3 tons fell onto a car, killing a passenger.

II. Increase research and development to refine tools and models that will anticipate future technical and societal needs and requirements.

Adapting to dynamic conditions and practice means applying a rigorous methodology to envision scenarios, consider and analyze possible outcomes, and develop potential courses of action. Possible future physical conditions, such as sea level rise, and possible future sociological conditions, such as population growth, must be considered.

Better wisdom and vision are needed to develop probable scenarios and potential outcomes. Better tools and models are needed for analysis. Stronger leadership (as described in the previous chapter) is needed to guide this process and implement solutions.

Investing in research and development will lead to more powerful tools and models. More thorough and extensive evaluations of "if-then" scenarios could then be performed efficiently and cost-effectively. Advances in remote sensors, infrastructure instrumentation, and field data collection devices can provide better input for more accurate modeling results. An emphasis should be placed on using powerful graphics and 3-D visualization and animation tools to communicate information more readily to stakeholders, including the public.

III. Adapt current public-investment models to incorporate future conditions. For example, require life-cycle management and stewardship as prerequisites for obtaining funds for critical infrastructure.

Project funding can be used as an incentive to encourage stewardship for critical infrastructure over its life cycle. Project capital funding could be predicated, for example, on a clear demonstration that systems are in place to ensure ongoing funding for life cycle operation and maintenance. Funding could also be predicated on demonstrating that change-management systems are established and institutionalized over the life of the project.

Funds could be set aside in escrow for long-term project stewardship, or special long-term taxes, user fees, or assessments levied. Special infrastructure districts could be established to provide the requisite stewardship, or existing agencies or organizations chartered to do so. Regardless of how the "proof" of stewardship is structured, project capital funds should not be allocated until it is has been demonstrated that the project will be funded throughout its life cycle.

IV. Apply adaptive management, life-cycle management, or similar working models and techniques to manage, assess, and reevaluate project risks and performance.

Adaptive management is a structured, iterative decision-making process for projects that have elements of uncertainty associated with them. One of the objectives when using adaptive management techniques is to reduce the amount of uncertainty over time via system monitoring.

Under an adaptive management approach, performance and capability goals are established at the outset. Over the course of time, more information is learned about uncertainties through observation and experimentation to determine the best management strategy.

For critical infrastructure projects, the project's current conditions should be evaluated periodically in light of any new developments or situations. The results of this evaluation can then be compared to the project's original objectives and requirements. Success (or failure) should be measured against the metrics established in the planning phases, and any deficiencies would need to be addressed.

New knowledge must be continually incorporated. This means not only keeping abreast of and applying new technologies, but also mining and capturing institutional knowledge.

[CHAPTER 7]

Strategies for Change

Applied together, the guiding principles represent an opportunity to develop and improve critical infrastructure systems throughout their entire life cycle. New ways of thinking, changes in education, and ongoing dialogue are required. The strategies described in Chapters 3 through 6 for implementing each of the guiding principles may be challenging and difficult to implement. Each will require considerable time, energy, and resources – and sustained leadership to see them through. However, ensuring successful performance of critical infrastructure is not only good business, but a responsibility of decision makers and those placed in oversight positions. Each stakeholder, owner, designer, constructor, and user has unique responsibilities in this process. They must all embrace the guiding principles and embed them in their decision-making and organizational cultures.

Strategies for End-Users, Voters, and Citizens

- Be aware of infrastructure systems serving your community, their condition, and their inherent risks.
- Consider the inherent risks associated with living or working in a particular location and become engaged in the dialogue about how much (or how little) critical infrastructure systems can help to mitigate those risks.
- Become engaged in the dialogue about how critical infrastructure can best perform to enhance public safety, health, and welfare.
- Participate in the dialogue to establish tolerable risk guidelines for critical infrastructure systems serving your community.
- Abide by and advocate for the guiding principles.

Strategies for Design and Construction Professionals

- Take a leadership role within and outside the infrastructure sector to ensure that a strong design and construction perspective is used in shaping policy and project priorities.
- Work with professional and technical organizations to produce a best-practices guide, codes and standards, as appropriate, and related learning materials for assessing and communicating risk.
- Lead in developing coalitions that advocate for critical infrastructure systems as a high priority issue at both the national and local level.

- Use adaptive management to improve critical infrastructure systems to enhance public safety, health, and welfare.
- Abide by and advocate for the guiding principles.

Strategies for Elected Officials

- Work with organizations representing design and construction professionals (including ASCE) to develop coalitions that advocate for critical infrastructure systems as a high priority issue at both the national and local level.
- Condition funding on life-cycle planning for all critical infrastructure projects.
- Rely on the knowledge and skills of design and construction professionals to help set policy, prioritize projects, and allocate resources.
- Support science and engineering education, research, and development to keep our nation competitive.
- Implement checks and balances that reward actions that are in accordance with these guiding principles and that penalize actions that are contrary.
- Facilitate dialogue among stakeholders and develop a systematic approach to establish tolerable risk guidelines for critical infrastructure systems.
- Abide by and advocate for the guiding principles.

> "We don't have great highways because we are a great nation. We are a great nation because we have great highways."
>
> *Attributed to Dewitt C. Greer (1902-1986), former head of the Texas Transportation Commission.*

Strategies for Regulators

- Facilitate dialogue among stakeholders and develop a systematic approach to establish tolerable risk guidelines for critical infrastructure systems.
- Condition funding on life-cycle planning for all critical infrastructure projects.
- Require periodic risk assessments of critical infrastructure systems and public dissemination of results.
- Work with owners to establish a framework that promotes a systems approach for all critical infrastructure projects.
- Work with organizations representing design and construction professionals (including ASCE) to develop coalitions that advocate for critical infrastructure systems as a high priority issue at both the national and local level.

- Use adaptive management to improve critical infrastructure systems to enhance public safety, health, and welfare.
- Abide by and advocate for the guiding principles.

"…the greatest advances in improving human health were the development of clean drinking water and sewage systems. So we owe our health as much to civil engineering as we do to biology."

Attributed to Dr. Lewis Thomas (1913-1993), former Dean, Yale Medical School.

Strategies for Owners

- Condition funding on life-cycle planning for all critical infrastructure projects.
- Require periodic risk assessments of critical infrastructure systems and public dissemination of the results.
- Lead the effort to enact a systems approach for each critical infrastructure project.
- Apply tolerable risk guidelines to all critical infrastructure projects.
- Promote effective leadership and stewardship of critical infrastructure projects.
- Rely on the knowledge and skills of design and construction professionals to help prioritize projects and allocate resources.
- Work with organizations representing design and construction professionals (including ASCE) to develop coalitions that advocate for critical infrastructure systems as a high priority issue at both the national and local level.
- Use adaptive management to improve critical infrastructure systems to enhance public safety, health, and welfare.
- Implement independent peer reviews for the design and construction of critical infrastructure systems to ensure adequate public safety, health, and welfare.
- Facilitate dialogue among stakeholders and develop a systematic approach to establish tolerable risk guidelines for critical infrastructure systems.
- Abide by and advocate for the guiding principles.

The success of critical infrastructure in protecting the public and promoting economic development depends on a wide range of individuals and groups fulfilling their unique responsibilities.

Public safety, health, and welfare are at risk. The nation's economic well-being and the investment that the nation has made in its built and natural environments are at risk. The leaders of our nation, the owners of our critical infrastructure, design and construction professionals, and the public as end-users must take these matters seriously. Each group must embrace the guiding principles and embed them in their decision-making and organizational cultures to fulfill their responsibilities to protect public safety, health, and welfare.

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Page 9: New Orleans Levee Failure, New Orleans, LA, 2005, courtesy of U.S. Army Corps of Engineers.

Page 18: I-35 Bridge Collapse, Minneapolis, MN, 2007, courtesy of Minnesota Department of Transportation, found at http://www.dot.state.mn.us/i35wbridge/photos/.

Page 19: Three Mile Island Nuclear Reactor, courtesy of the U.S. Department of Energy, found at http://www.energy.gov/news/4728.htm?photo=4755.

Page 21: Loma Prieta Earthquake Cyprus Freeway Collapse, Oakland, CA, 1989, courtesy of H.G. Wilshire, U.S. Geological Survey.

Page 25: Teton Dam Failure, photo by Mrs. Eunice Olson, taken June 5, 1976, courtesy of University of California Department of Engineering and Geological Sciences, found at http://www.geol.ucsb.edu/faculty/sylvester/Teton_Dam/welcome_dam.html.

Page 27: Northeast Blackout, 2003, image courtesy NASA, by Chris Elvidge, U.S. Air Force, found at found at Visible Earth (http://visibleearth.nasa.gov/).

Page 31: The Big Dig, Boston, MA, courtesy of the Turner – Fairbank Highway Research Center, found at http://www.tfhrc.gov/pubrds/julaug00/along.htm.

Guiding Principles for the Nation's Critical Infrastructure

OVERARCHING PRINCIPLE

Hold paramount the safety, health, and welfare of the public.

GUIDING PRINCIPLES

Quantify, communicate, and manage risk.

Employ an integrated systems approach.

Exercise sound leadership, management, and stewardship in decision-making processes.

Adapt critical infrastructure in response to dynamic conditions and practice.

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