Investing in intelligent infrastructure

Advanced sensing and computing technologies enable structures and systems to self-monitor, self-diagnose, and self-correct throughout their life cycle.

By Cathy Chatfield-Taylor

In a world where all infrastructure is intelligent, bridges signal for maintenance before unsafe conditions develop, rail networks predict equipment failures before trains are delayed, and levees alert authorities about flood risks before waters rise. Smart highways charge motorists a fee to avoid traffic congestion, and intelligent drinking-water distribution systems detect impurities and adjust dosing. Electricity grids monitor wind and solar power and automatically ramp up or reduce other power sources to compensate. By using advanced sensing and computing technologies to monitor conditions, diagnose problems, and correct operations — often without human intervention — intelligent infrastructure improves safety and performance.

In the United States, movement toward investments in intelligent infrastructure has been cautious traditionally, but now that the U.S. government is spending billions of dollars on various infrastructure projects to boost its sagging economy, the time is right to invest in technologies that make structures work smarter. The 2009 Report Card for America's Infrastructure issued by the American Society of Civil Engineers assigned a cumulative D-grade to the nation, based on capacity, condition, safety, and other factors. The lack of significant improvement since the previous assessment in 2005 indicates a need for wise investment of resources to raise the grade of roads, bridges, and other public works.

A 3D information model is a data repository that not only stores existing knowledge about an infrastructure system, but also processes incoming data about emerging conditions.

"As we launch a new investment cycle, we have the opportunity to symbiotically combine physical and digital investments into intelligent infrastructure," explained Greg Bentley, CEO of Bentley Systems, Inc. "By using information modeling to leverage our extensive digital infrastructure to fuller advantage, I am confident that we can achieve higher return on investment at lower risks than ever, enabling our physical structures to work smarter. The resulting intelligent infrastructure will, in turn, sustain renewed growth in economic activity and productivity."

Physical + digital = intelligence

The physical structures built 50 to 100 years ago are rapidly deteriorating and in need of repair or replacement. These aging structures lack the information technology and communication networks that add brains to the brawn, such as the 3D information model, which functions as the central nervous system of contemporary infrastructure by storing existing knowledge about the system and processing incoming data about emerging conditions.

The 3D information model converts raw data compiled by instrumentation deployed throughout the system into useful knowledge, allowing real-time adjustments to prevent malfunctions and maintain safe operating conditions. When real-time information from sensors in the physical infrastructure is combined with as-built information stored in the data model, the system becomes "self aware." It is truly *intelligent* infrastructure, interacting with the owner/operator to improve safety and sustainability.

According to Hojjat Adeli, an Abba G. Lichtenstein Professor in Infrastructure Engineering at The Ohio State University, intelligent infrastructure "will result in improved automation, better safety, and more effective use of natural resources; thus better sustainability." Adeli is co-author of the new book "Intelligent Infrastructure — Neural Networks, Wavelets, and Chaos Theory for Intelligent Transportation Systems and Smart Structures" (CRC Press, 2009). He also co-authored "Control, Optimization, and Smart Structures — High-Performance Bridges and Buildings of the Future" (Wiley, 1999). Adeli notes that the required technologies are not quite there yet, but are being rapidly developed.

For example, in the United Kingdom, Network Rail is testing a network of sensors that will predict when rail equipment requires maintenance. The pilot project on the Edinburgh-to-Glasgow line includes 250 sensors that collect data about mechanical and thermal operations such as switches opening and closing, or equipment overheating. Wireless nodes placed on the track and on the trains transmit the point data, which is processed in the data center. Software identifies patterns of behavior that precede equipment failure, and then builds models that predict future failure. If successful, Network Rail reports that the program could cut operations and maintenance costs 20 percent by 2014.

Research raises IQ

Adeli attributes the trend toward intelligent infrastructure to three

Three benefits of intelligent infrastructure

1) Faster time to market

- Shortened design/engineering cycle through data reuse and sharing
- Design and construction coordination streamlines safer construction
- Direct from design to industrial fabrication

2) Optimized delivery process

- Design and engineering resource utilization optimized
- Material resource utilization optimized in construction
- Reduced cost of delivery

3) Better-performing infrastructure

- Leveraging technology in ways not possible before
- Infrastructure becomes productive faster
- Designed and built for lifecycle operations
- Return on investment is increased and more predictable

Adding intelligence to the bridge lifecycle

Bentley's bridge information modeling (BrIM) fosters the use of data beyond bridge design and engineering needs to inform downstream processes such as fabrication, construction, operation, maintenance, and inspection. A bridge information model can be an information definition of the bridge asset, co-created by many people using an array of technologies to answer broad-ranging needs. BrIM can benefit the entire bridge lifecycle — project selection through rehabilitation — resulting in development of new best practices. A 3D model of the bridge can serve as a window into the vast bridge information asset.

The cornerstone of BrIM is data reuse, with an emphasis on purpose-ready information delivery. With more flexible access to information about the bridge, organizations can begin to optimize business processes that cross the bridge lifecycle. Bridge model data is developed in earnest during planning, design, and construction. The close cooperation required of stakeholders during these phases depends on not only data reuse but also smooth interoperability between software/data systems. The information that is developed during these phases informs downstream processes and is, in fact, essential to bridge lifecycle sustainability.

technological advancements: sensor technology; sophisticated computational intelligence algorithms; and more-powerful computers that allow researchers to correlate past and present data and predict future behaviors of complex systems. Such advancements will enable owner/operators to save long-term operations and maintenance costs as well as protect against natural and manmade threats.

Emerging technologies that have the potential to raise the IQ of the world's infrastructure include the following:

- actuators embedded in structures to apply forces that counteract the forces of nature;
- smart fibers and carbon nanotubes that create lighter, stronger, blast-resistant materials;
- biosensors that transmit data about biological, physiological, and chemical changes;
- laser scanners that measure deformations at the structural and member level; and
- pervasive computing that connects transportation controls with in-vehicle systems.

Researchers aim to improve the safety and service-life of infrastructure by automating routine detection and emergency response processes. For example, rather than relying on an inefficient visual inspection cycle for bridges, smart bridges use embedded sensors to continuously monitor their health. Adeli cites the 2007 collapse of the I-35W Bridge in Minneapolis as an example of a disaster that could have been averted by smart bridge technology. In fact, the replacement bridge designed by Figg Bridge Engineers, Inc. (FIGG) uses smart sensors that detect the wear and tear of daily traffic and transmit real-time data to the Minnesota Department of Transportation (MnDOT) for instant analysis. The new I-35W St. Anthony Falls Bridge sets an example for the achievements that are possible.

Models get smart

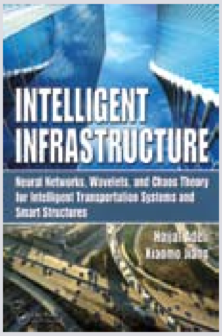
Smart structures start with intelligent design. FIGG's designers used MicroStation to build a 3D model of the structure and communicate with the builders, Flatiron-Manson Joint Venture. This integrated design process delivered an information model that was used throughout construction and into the operation and maintenance of the bridge. Coupled with advanced computing capabilities in the MnDOT control center, the information model became the brains behind the 1,223-foot-long, 10-lane bridge.

Building intelligent infrastructure like this requires the convergence of multiple disciplines. "These are very advanced technologies requiring cross-disciplinary approaches using computer science, electrical engineering, mechanical engineering, system engineering, and structural engineering," Adeli said.

If the vision for intelligent infrastructure is to become reality, civil and environmental engineering programs need to provide a multidiscipline education. Meanwhile, today's professionals can adopt available technologies to design and build smart structures and intelligent transportation systems.

"The last several decades have been dominated by an economic investment in digital infrastructure for computing and communicating," concluded Greg Bentley. "The fortuitous opportunity now — as we determinedly launch a new investment cycle — is to continue coalescing physical and digital investments into intelligent infrastructure." ■

Brain waves and controlled chaos



In the new book, "Intelligent Infrastructure — Neural Networks, Wavelets, and Chaos Theory for Intelligent Transportation Systems and Smart Structures" (CRC Press, 2009), authors Hojjat Adeli and Xiaomo Jiang envision a better way to design and manage the world's infrastructure. The book presents a holistic approach to the intelligent infrastructure that includes both structures and transportation systems. The authors present novel technologies, methodologies, and algorithms for creating structures that continuously monitor their own health, and actively control their behavior.

Smart structures such as these provide early warning of structural failure to reduce loss of life and property, improve understanding of structural systems under duress, and facilitate proactive decision-making for maintenance and repair.

Following introductory chapters on the underlying technologies, "Intelligent Infrastructure" presents ingenious mathematical models for scenarios ranging from freeway incident detection to damage control in high-rise buildings.

Adeli is an Abba G. Lichtenstein Professor of Civil Engineering at The Ohio State University, a Distinguished Member of the American Society of Civil Engineers, author of 12 books, and editor-in-chief of three scientific journals. Jiang is lead engineer at Gas Turbine CBM/PHM, General Electric Company, and author of more than 40 research articles.

Cathy Chatfield-Taylor is a Florida-based freelance writer/editor doing business as CC-T Unlimited since 1989. As a member of the International Association of Business Communicators since 1999, she has served at the chapter level as communications director, public service committee chair, and program director for independent communicators.