NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

MEASUREMENT SCIENCE FOR

Advancing Infrastructure Delivery

What is the problem?

The U.S. physical infrastructure is enormous and aging poorly. How the nation renews and expands the infrastructure will help determine the quality of life for future generations, our competitiveness in the global economy, and our capability to reduce dependency on foreign oil.[1] The U.S. government and public recognize the critical importance and benefits of renewing and expanding the nation's physical infrastructure.

The nation and the construction industry face a projected $2.2 trillion cost-burden for renewal of existing, critical physical infrastructure.[2] More than a quarter of the nation's 600,000 bridges are either structurally deficient or functionally obsolete. Replacement of America's aging drinking water systems has an annual shortfall of at least $11 billion. Projected power generation and distribution investment needs could be $1.5 trillion by 2030. Initiating infrastructure renewal and expansion by continuing to use the same processes, practices, technologies and materials that were developed in the 20th century will likely yield the same results: increasing instances of cost overruns, delays, service disruptions, higher operating and repair costs, and the possibility of cascading failures.[1]

As part of advancing infrastructure delivery, engineering, construction, manufacturing, and research, organizations must address the eroding productivity demonstrated on many construction projects. During the past 40 years, studies have illustrated how construction productivity at the industry level has declined at an average annual rate of 0.6 percent.[3] This trend is in stark contrast to all other non-farm industries (e.g., manufacturing), which have improved labor productivity at an average rate of 1.8 percent per year. Industry studies have identified inefficiencies ranging from 25 percent to 50 percent in coordinating labor and managing, moving, and installing construction materials.[4]

Other industries have realized their productivity advances largely due to new or improved work processes and the integration of information, communication, automation, and sensing technologies.

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[1] NRC Report," Sustainable Critical Infrastructure Systems – A Framework for Meeting 21st Century Imperatives". Available at *http://www.nap.edu/catalog.php?record_id=12638*

[2] ASCE 2009 Report Card for America's Infrastructure. Available at *http://www.asce.org/reportcard2009*

[3] Teicholz, P., "Labor Productivity Declines in the Construction Industry: Causes and Remedies," AECbytes Viewpoint, Issue 4, April 14, 2004.

[4] Chapman, R. E., Butry, D.T., "Measuring and Improving the Productivity of the U.S. Construction Industry: Issues, Challenges, and Opportunities," NIST White Paper, May 2008.

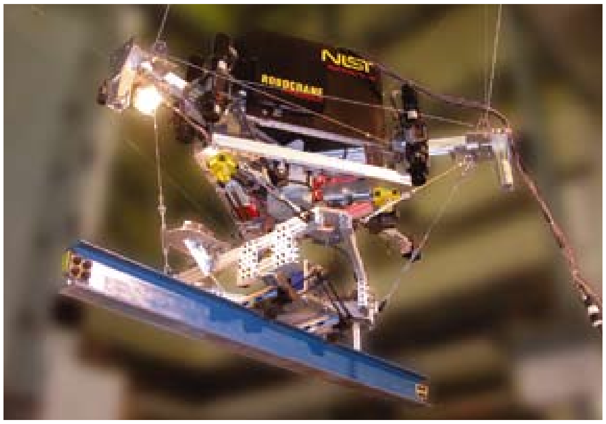
Leading construction industry groups, such as the American Institute of Architects (AIA), Associated General Contractors of America (AGC), Construction Industry Institute (CII), Construction Users Roundtable (CURT), Electric Power Research Institute (EPRI), and FIATECH have identified the critical need for fully integrated and automated project delivery processes. The application of these advanced methods and technologies could enable breakthrough improvements in the delivery, quality, and reliability of the nation's infrastructure.

There is a lack of measurement science for: 1) enabling automated access to and integration of diverse information systems; 2) enabling real-time monitoring and control of construction processes; 3) determining productivity of industry work processes, discrete tasks and aggregate tasks levels; and 4) evaluating the performance of promising automation and integration technologies in construction. Creating and validating the needed measurement science requires a neutral, representative, and accurately monitored environment in which the application of new technologies and processes can be evaluated.

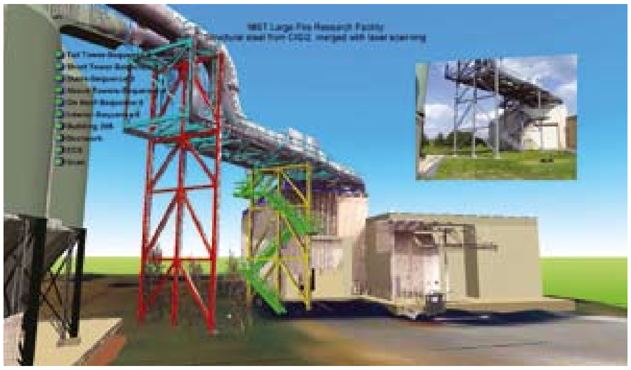
Why is it hard to solve?

These measurement problems are hard because of the complexity and variability of design and construction (both the work process and the built product), the unstructured environment of a construction site, and the inefficient processes in place for coordinating labor and movement of components. Large infrastructure projects involve the design, selection, and installation of millions of individual products. Some are manufactured off site, some are manufactured on site, and some are assembled on site from manufactured components. Designing, constructing, and commissioning a complex infrastructure project involves hundreds to thousands of contractors, each with unique roles and relationships to the others. Each contractor uses unique processes, software tools and technologies to execute their portion of the work. Variability comes from the fact that each project is one-of-a-kind, each project is a unique combination of participating organizations, and construction site conditions change continuously. This distinguishes construction from manufacturing, which is characterized by an environment that is carefully designed and controlled to efficiently and precisely repeat operations that produce multiple copies of the same product.

Innovation in construction project delivery is currently being addressed by a patchwork of industry associations, government/private research organizations and consortia. Progress is hampered by the reluctance of the construction industry and most owners of constructed facilities to adopt innovative technologies that will initially add risk and cost. Advancements in measurement sciences and quality assurance techniques are needed to enable firms to evaluate and deploy potential improvements and cost savings of integration and automation technologies over traditional approaches.



BFRL researchers successfully equipped a unique cable-suspended six degree of freedom robotic crane — the RoboCrane™ — with real-time laser tracking and demonstrated an autonomous steel assembly process. This capability is one of many that BFRL is developing as part of the Intelligent and Automated Construction Job Site Testbed.



BFRL is developing methods and metrics for combining 3D imaging and building information modeling (BIM) to improve construction productivity and enable automated construction control. This image shows the combination of technologies as applied to the NIST Large Fire Research Facility.

Why BFRL?

The Building and Fire Research Laboratory (BFRL) is uniquely positioned to:

- analyze the construction industry's measurement science needs;
- identify and generalize major barriers and opportunities to improving infrastructure delivery;
- synthesize and apply relevant advancements from other research and industries; and
- develop and validate the missing measurement science needed for achieving improvements in the renewal of the nation's physical infrastructure.

This strategic goal leverages the BFRL core competency in information, communication and automation technologies for intelligent integration of building design, construction and operation and the BFRL network of industry and research partnerships. The development of the needed measurement science and the use of testbeds provide tools and catalysts for a broad range of improvements in infrastructure delivery.

Now is the time for BFRL to succeed in delivering the needed measurement science because the enabling technologies are sufficiently mature to be applied to design and construction processes, the cost of computing is no longer a barrier, and the industry and the public are demanding new capabilities for assessing and improving infrastructure project delivery and construction productivity. Industry organizations have confirmed the importance of this goal and are committed to working with BFRL to achieve success. Leaders in the construction industry know the benefits that have accrued from the investments in measuring and monitoring construction safety and see similar potential for improving infrastructure delivery and construction productivity.

By working with industry and the research community, BFRL will enable industry to achieve integrated and automated collaboration and work processes, measure construction productivity at discrete and aggregate levels, incorporate automated access to and integration of diverse information systems, and leverage real-time control systems to fully integrate and automate construction processes, resulting in:

- reduction of infrastructure project delivery times and construction costs;
- increased capabilities to identify and implement productivity-improving practices and technologies;
- reduced uncertainty, unpredictability and risk in construction processes; and
- new construction processes and capabilities.

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Automated and Integrated Infrastructure Construction Processes

This program was initiated with the investigation of the challenges and evolving technologies applicable to construction integration and automation. The program strategy is to develop, in parallel, metrics for multifactor construction productivity, real-time sensing and control, data model characterization and validation, and interoperability testing. These new metrics are being applied to priority work processes and technologies identified in collaboration with industry. Those processes and technologies serve as test cases for evaluating the application of the measurement science in the

Intelligent and Automated Construction Research Testbed (described later) and in collaborative projects with industry partners.

BFRL is developing and using baseline measures and data on project cost, schedule, and field work and rework to identify tasks and processes (e.g., automated assembly, real-time control, materials tracking) for targeting improvements in infrastructure project delivery. BFRL is partnering with the Construction Industry Institute (CII) to measure how combinations of industry best practices and automation and integration technologies impact task and project productivity. In collaboration with the Bureau of Labor Statistics (BLS), BFRL is using a multifactor productivity approach to produce industry-level metrics for selected construction industry sectors (e.g., steel erection). Multifactor productivity metrics enable separable estimates of the contribution of labor, capital, and technology.

The U.S. manufacturing industry has successfully developed integration and automation technologies to gain real-time control of its processes, resulting in increased productivity, decreased time-to-market of new products, and greater customer satisfaction. The U.S. construction industry has tried to employ many of these same technologies but with only limited success. A key contributor to this failure is the lack of an overall conceptual framework and supporting reference model architecture for the end-to-end monitoring and control of the construction process. NIST is adapting its open and scalable reference model architecture for real-time control systems (RCS) to support the construction domain's loosely coupled, distributed system components and arbitrary mixes of automated and manual task work. To achieve this level of monitoring and control, BFRL is developing the enabling measurement science and performance metrics for evaluating individual sensors (e.g., 3-D imaging, calibrated camera networks, RFID, ultra-wideband tracking), construction object recognition and tracking algorithms, and combined real-time sensing and control systems for maintaining robust situational awareness of cluttered and dynamic construction sites.

One of the features of the construction industry's complexity and variability is the extraordinarily large number of highly diverse information systems that are used over the lifecycle of the built product. BFRL is developing and evaluating data model characterization techniques and measurement science to determine commonalities, differences and alignment mechanisms for enabling interoperability and integration. BFRL is also developing measurement science to enable validation of data models and data exchange protocols, conformance assessment of construction information systems and interoperability testing. The ultimate goal is enabling automated access to and integration of those systems.

BFRL is developing an Intelligent and Automated Construction Job Site Testbed to demonstrate and transfer the resulting productivity metrics and tools to industry. In addition, industry, academia, and other research organizations are partnering with BFRL to use the testbed for measuring the productivity impacts of new construction technologies and processes, and for testing new construction standards and protocols. The capabilities of the testbed under development include: world-class sensing for monitoring real-time status of construction processes; control of construction equipment and processes (real, scaled, and simulated); advanced communication and information exchange; and modeling, simulation and visualization. The Intelligent and Automated Construction Job Site Testbed will enable the transfer of construction productivity measurement science to the field, which will enable industry to develop best practices, protocols, and standards to achieve breakthrough improvements in construction productivity and the delivery of physical infrastructure.

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