Justification for ISHMII: A US Perspective

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Infrastructures and Civil and Environmental Engineering

In the last decade, the US experienced earthquakes, hurricanes, tornadoes, floods, terrorist attacks, power blackouts and major traffic accidents leading to damage and destruction of infrastructures as well as large numbers of casualties in the U.S. These Events / Meetings increased our awareness of how our critical infrastructures such as transportation, water, power, fuel, communication, government, health-care, etc. greatly impact our well-being and how the expense of their maintenance greatly strains our economy.

For example, a 2002 report by the USDOT to the Congress indicates that the average annual investment required by all levels of government to maintain highways and bridges so that critical indicators of overall conditions and performance in the year 2020 will match their year 2000 values is $106.9 billion dollars. Meanwhile, 21.5% of bridges on the Strategic Highway Network remained deficient, wasted fuel and lost productivity resulting from traffic congestion cost the nation $69.5 billion, http://mobility.tamu.edu/ums/ and traffic accidents led to more than 42,000 casualties in the year 2001.
http://www.bts.gov/publications/national_transportation_statistics/2003/index.html
These statistics reveal that shortcomings in the day-to-day operational performance and the condition of infrastructures significantly affect our economic productivity and well-being.

Since many infrastructure systems are owned by local governments, and some are not operated directly under the auspices of a federal agency, data on the conditions and performance of all critical infrastructures are difficult to obtain. However, examples such as the challenges faced by the City of Atlanta due to aging water systems, requiring the rehabilitation of 1,583 miles of sanitary sewer pipe that is approaching 100 years of age are common. Atlanta issued a $1.1 billion water and sewer bond sale to finance the rehabilitation of the sewer system. Such challenges faced by the local, state and federal government agencies and other infrastructure owners to maintain and preserve their various infrastructures are pervasive.

While the challenges we face due to infrastructure performance and conditions are clear and formidable, the role and responsibility of the civil and environmental engineering community for addressing these challenges require further clarification. For example, in 1998 NSF awarded a Center for Civil Infrastructures to NYU School of Government. A significant number of NSF grants from CMS related to infrastructure research have been awarded to non-civil engineers. Although the community of engineering mechanics, aerospace, mechanical, materials, electrical and computer engineers conducting research on advanced infrastructure technologies such as sensing is increasing and this is most welcome, whether infrastructure system problems may be addressed without the leadership of civil and environmental engineers is a valid question. Many researchers specialized in engineering mechanics consider themselves civil engineers but they have not actually experienced the various stages in the creation of a constructed system, and especially, observe an actual structural failure, hence may not recognize the distinctions between the role that civil engineers have to play versus the roles that other disciplines may play in the engineering and management of infrastructures. We therefore assert that “renaissance” civil engineers are essential for properly identifying, articulating and formulating solutions to infrastructure problems and in fact should be taking the leadership of multi-disciplinary teams for researching such solutions.

Challenges facing Civil and Environmental Engineers

Civil and environmental engineers have made considerable progress in our understanding of the infrastructure problem. We now recognize that all infrastructures are complex interconnected systems made up of interacting engineered (further classified as constructed, e.g. buildings, bridges, fabricated, e.g. elevators, HVAC systems, or manufactured e.g. autos), natural (soil, water, weather, climate, etc.) and human (users, organizations, agencies, industries, social, economical, political, etc.) sub-systems (Fig. 1). Civil engineers design, construct, operate, manage and maintain the “civil-engineered facilities” or “constructed systems” that are commonly integrated with fabricated and/or manufactured mechanical and electrical systems and serve as vital elements of every one of the critical infrastructure systems.

Many civil engineering professionals have asserted that the fragmented and often disconnected approach to the design, operation and maintenance of most civil engineered facilities is a fundamental concern. The least-price bid based contract delivery mechanism common in the US has been recognized as a major barrier to a more integrated design-operation-maintenance process. Meanwhile, construction industry’s accountability is very different from other industries. In the US, common civil infrastructure facilities such as buildings, bridges and pavements are presently designed, constructed, operated, maintained and managed by a large number of fragmented sub-industries, and these facilities are regularly delivered with a minimal or no warranty of performance. This is in contrast to many other US industries. For example, even many used automobiles now come with warranties.

Many large civil-engineering infrastructure projects in Europe, the Far East and more recently North America are now being planned and contracted with innovative contract-delivery mechanisms such as design-build-warrant and design-build-operate. Such innovative approaches to planning and delivery of constructed systems in fact serve as drivers towards “performance-based” approaches in civil engineering practice. Civil engineers are recognizing the need for describing performance in terms of objective, measurable indices. Concepts such as integrated asset management, design-built-warrant and design-built-operate are recognized by policy-makers and many civil engineers as innovative measures for mitigating a lack of infrastructure performance. For example, ASCE has already embarked on “Performance-Based Engineering” as an initiative involving both technical committees and standards.

In various parts of the world, engineers have been ahead of the US in the implementation of novel concepts such as health-monitoring, adaptive-systems, structural-control, intelligent materials, and intelligent systems. For example, in Japan, the Building Standard Law has changed and is now permitting “Performance-Based Design” to take advantage of novel technologies (Mita, 2000). The European Community has been encouraging and sponsoring collaborative research in construction. Networks such as SAMCO (Structural Assessment, Monitoring and Control) have been funded to foster innovation through collaborations by engineers throughout the union. The leadership of research, technology development and demonstrations shown by government agencies such as EMPA and BAM, and various universities in Europe are exemplary. China, Korea and other Asian Countries have also formed academe-government partnerships and embraced advanced technology in their major construction projects to advance their state-of-practice.

Although the shortcomings in the civil and environmental engineering practice discussed in relation to Fig. 1 are significant, it is not possible to mitigate these shortcomings without full participation and in fact the leadership of civil and environmental engineers. Unfortunately, the critical distinctions between constructed and other engineered systems are often subtle. In many cases, only civil and environmental engineers who are used to dealing with very large-scale systems can conceptualize and then properly incorporate these distinctions as they seek realistic solutions to infrastructure concerns. For example, only experienced civil and environmental engineers may fully conceptualize the mechanisms leading to different levels of uncertainty and risk that impact the design, construction, operation and maintenance of constructed systems and their interactions with natural systems. Naturally, social scientists and experts in engineering management are also essential elements in a holistic research on infrastructures and they should also be included in a multi-disciplinary research team.

Knowledge and insight on the actual day-to-day performance, loading environment and behaviors of infrastructures is essential before we may integrate and apply systems-engineering concepts and tools for solving complex infrastructure problems. We further note that observations, measurements and experiments involving actual infrastructures and constructed systems in the field constitute essential steps for acquiring the knowledge and wisdom that is necessary for effectively addressing many infrastructure concerns. Civil and environmental engineers who are capable of observing and conducting reliable measurements and controlled experiments on actual constructed systems are especially critical for advancing the state-of-practice in infrastructure engineering and management.

A Holistic Systems Approach to Integrative Infrastructure Research

Reductionism is a principal shortcoming in any thinking or approach related to infrastructures that are very large and complex heterogeneous hyper-systems. Such a fragmented approach is inapt as it fails to recognize and incorporate the fundamental attributes of infrastructure systems. A holistic approach is required to properly consider the interacting engineered, natural, and, human sub-systems and elements that define our civil infrastructures.

Successful engineering and management of such large and heterogeneous hyper-systems require new knowledge and technology tools. The transformation and integration of systems engineering principles and implementations that have been developed for various systems by their respective disciplines in electrical, industrial and other disciplines is the logical starting point for creating a new and much needed discipline for the engineering and management of large hyper-systems. Such a discipline must address the size, complexity, cost, heterogeneity, incremental constructions (over decades to centuries), and long life-cycles of infrastructures which make it difficult to observe, measure, model and simulate, analyze, synthesize and control them using generic systems engineering tools. The result will be a new systems engineering and management toolbox for dealing with unobservable, non-stationary, highly dynamic heterogeneous hyper-systems governed by many complex mechanisms of uncertainty and risk.

Current education, research and practice regarding any aspect of infrastructure operation, preservation or protection are greatly fragmented. For this effort to be successful, integrative, multi-disciplinary education, research and practice is essential, however, we have not yet fully discovered the keys to integration. Although many examples of inter-discipline collaboration exist, these are often ad-hoc and by serendipity. Policy and strategy changes are essential at university and government for designed and problem-focused integrative approaches. Just tactical and fragmented measures are inadequate given the fundamental nature of the enormously complex challenges we face. Many university programs and funding agencies continue to preferentially fund the development of technology products such as nano-technology and sensor technologies. We submit that this must be complemented with programs that address problem-focus and integration concerns.

A Problem-Focused Agenda for Infrastructure Research at Field Test Sites

Our understanding of the infrastructure hyper-systems engineering and management has been dynamic, especially as evidenced after the Events / Meetings of 9/11/2001. We do not have common terminology and metrics related to most of the concerns outlined previously. We need to learn how to conduct scientific research on actual operating infrastructures before we may formulate meaningful metrics for life-cycle cost and performance, for example, analogous to the metrics that are now available for crash-worthiness, fuel-consumption, engine power and torque, etc. for automobiles. The challenge is to clearly understand, conceptualize and frame the problem, and articulate the critical issues and their possible resolutions clearly. We need to bring together an expert community representing the broad spectrum of stakeholders and reach consensus on the definitions, issues and their possible resolutions. In addition to the identification of performance metrics, the success of this effort will depend upon adopting technology for implementing promising paradigms such as performance-based engineering and intelligent systems to infrastructures. This cannot happen by hypothesis, or just by computer simulations. Again, research and demonstrations on actual operating infrastructure systems are necessary since we cannot yet properly simulate infrastructure systems analytically or physically.

In 2003, a committee of experts came together in the US (Drs. Aktan (Drexel, field research on large constructed systems), Frangopol (UColorado, integrated asset management), Madanat (UC, Berkeley, intelligent transportation systems and operations), Shinozuka (UC, Irvine, lifeline infrastructure systems fragility and security), Shenton (UDelaware, bridge health monitoring) and Ghasemi (FHWA, research director on bridge health monitoring and seismic performance) under the NSF's auspices to explore how various infrastructures may be connected into a distributed network as field laboratories for problem-focused infrastructure research. This committee organized and conducted two international workshops first at Palo Alto and then at Tokyo, Japan, bringing together a large number of infrastructure experts from academe, government and industry and from America, Europe and the Far East. The workshops led to a research agenda (Aktan et al, 2004) and also became instrumental for the US efforts and participation towards establishing the International Society for Structural Health Monitoring and Intelligent Infrastructures (ISHMII). We believe that ISHMII has been established to bring together researchers interested in problem-focused, integrative research by taking advantage of actual infrastructure test-beds that will be developed into field laboratories.

As the US participants we are grateful for the enormous enthusiasm and support of our civil engineer colleagues at Canada, Europe, China, Korea and Japan as we worked together to establish ISHMII. We are also encouraged and grateful for the FHWA and NSF's strong participation and support of ISHMII and anticipate that this organization will successfully serve as an International Nexus to all renaissance engineers who are concerned about the performance, protection and preservation of our critical infrastructures and who share an interest in taking an active role for bringing effective solutions to this pressing societal problem.

References:

Aktan, A.E., "An Effective Integrated Approach to the Operational Efficiency, Structural Preservation and Security of Transportation and Other Infrastructure Systems," Presentation to CMS Division of the National Science Foundation, VA, April 23, 2003.

Aktan, A.E., Dan M. Frangopol, Hamid M. Ghasemi, Masanobu Shinozuka, Samer Madanat and Harry W. Shenton III., "A Problem-Focused Agenda for the Highway Transportation Infrastructure: A Holistic Systems Identification and Integration Approach Using Field Test Sites," Final Report: NSF Grant CMS 0338817, March, 2004

Status of the Nation's Highways, Bridges and Transit: 2000 Conditions and Performance Report. FHWA Website, http://www.fhwa.dot.gov/policy/2000cpr/es11.htm

Chase, S. "Delivering Infrastructure for America's Future. Vision: Leadership for 21st Century," Presentations to the CMS Division of the National Science Foundation, VA, April 23, 2003, and, at the Workshop on NSF- FHWA joint Research, Palo Alto, CA September 14, 2003

A Research Initiative on Transportation Infrastructure, Bridges and Bridge Components," Workshop on NSF- FHWA joint Research, Palo Alto, CA September 14, 2003

Mita, A., and Iwaki H., "Performance-Based Design and Health-Monitoring System" Report on Workshop on Health-Monitoring of Long-Span Bridges, UCI, Irvine, CA, March, 9-10, 2001.