Bringing Information Technology to Infrastructure

A Workshop to Develop a Research Agenda

www.nyu.edu/icis/itworkshop

June 25 - 27, 2001
Arlington, VA

Funded by the National Science Foundation

FINAL REPORT

(July 2002)

By Rae Zimmerman, Nathan Gilbertson and Carlos Restrepo

Institute for Civil Infrastructure Systems (ICIS)
Robert F. Wagner Graduate School of Public Service
New York University
411 Lafayette Street, Room 300
New York, NY 10003-7032
(212) 992-ICIS (4247)
www.nyu.edu/icis

Professor Rae Zimmerman, Director

Partnering Institutions
New York University • Cornell University • Polytechnic University of New York • University of Southern California

This material is based upon activities supported by the National Science Foundation under award No. CMS-0091482. Any opinions, findings, and conclusions or recommendations expressed in this document are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Table of Contents

Section I - Report

Section II - Workshop Materials

Section III - Participant Papers

(listed by author alphabetically)

Section IV - ICIS White Paper

SECTION ONE

FINAL REPORT

BRINGING INFORMATION TECHNOLOGY TO INFRASTRUCTURE: A WORKSHOP TO DEVELOP A RESEARCH AGENDA

EXECUTIVE SUMMARY

Over the last decade, the development and operation of conventional infrastructure, such as transportation, water and power systems, has increasingly become dependent on information technologies (IT). Due to the rapid rate of advances in IT, especially compared to the rate of infrastructure advances, the examination of its impacts and potential benefits for other infrastructure have not been fully examined or understood. Civil infrastructure research and IT research have largely advanced along separate paths, and although the connections and interdependencies are more apparent now than ever, no comprehensive agenda for merging these research areas exists. This is the context in which the idea for a National Science Foundation funded workshop emerged. The Institute for Civil Infrastructure Systems (ICIS) at New York University organized and led, "Bringing Information Technology to Infrastructure: A Workshop to Develop a Research Agenda," as a starting place to identify research that would bring IT and infrastructure research closer together.

The working premise for the workshop was that, "Information technology holds the promise of enhancing the performance of infrastructure along many dimensions. It should not interfere with infrastructure performance." The overarching charge to the group was to identify research and researchable issues with respect to needs or problems and solutions as a framework or starting point for research. Specifically, the interdisciplinary group of participants was charged with developing a series of critical research issues in three broad areas: 1) policy; 2) management; and 3) technology. These were the three areas that emerged from the initial group discussions as the most important for advancing the connections and synergies between infrastructure and IT research. A brief summary of the key points in each of these three areas is presented below.

Policy

Three research themes emerged out of the policy area discussions and debate. The first was <u>differential access</u> to IT technologies. Access to new technologies and their benefits is a research area that highlights the need to account for the complexities of equity and institutional structure, as well as human behavior issues. The second theme dealt with <u>security and privacy</u> concerns. The policy research in this area should address the integration of infrastructure reliability and security as well as tradeoffs between user security and privacy. The third policy theme was the opportunity for <u>computer simulation and other analytical tools</u> to aid policy development. Future research should gain a better understanding of how computer simulation and analytical tools support the relationship between IT and infrastructure systems, possibly building off of work being done around extreme events.

Management

The discussion of management issues focused on identifying research that could support the development and use of IT in ways that improve how civil infrastructure systems (and the

organizations responsible for them) deliver services to users and communities. These discussions centered around three themes as well. The first theme focused on organizations and the need to research how IT is restructuring both organizational and management processes. The second theme was jurisdictions and how IT can break down jurisdictional boundaries that hamper infrastructure development and management. The third theme dealt with customers, whose daily lives depend on infrastructure systems. Research needs here focus on the potential for IT enhanced infrastructure management solutions to better deliver services to the public end-users.

Technology

Finally, in the technology area, three key research themes were also identified. The first pertained to consumer-oriented technologies, which focused on research questions that could better assess and understand consumer needs and demands and the role of technology in consumer decision-making for infrastructure services. Equity and distribution issues were also considered in these discussions. A second theme was integrative modeling. New models and refinements in existing models have the potential to provide insights into a host of complex infrastructure challenges, ranging from system design and vulnerability assessment to consumer behavior. The third research theme was system diagnosis, which centered on sensing capabilities for improved condition assessment and system status. Potential results of this research could improve infrastructure management and control.

FINAL REPORT

BRINGING INFORMATION TECHNOLOGY TO INFRASTRUCTURE: A WORKSHOP TO DEVELOP A RESEARCH AGENDA

INTRODUCTION

The usage of information technologies (IT) to plan and manage infrastructure has been escalating at a phenomenal rate for more than a decade. As a result, infrastructure systems have become increasingly dependent upon these technologies. Infrastructure performance is not only influenced by this situation, but IT advances have brought difficult to grasp social, economic and environmental effects that are both positive and negative. There is an expectation that IT will increase our diagnostic capabilities and ability to control our infrastructure, and provide the means for interconnecting complex systems in a seamless manner. Inadequate integration of IT into infrastructure systems, however, can produce the opposite results, increasing the vulnerability of infrastructure, with effects ranging from intermittent outages to total system failure with associated social and economic spin-offs.

Given the precariousness of the relationship between IT and infrastructure and its growing prevalence, more attention must be paid to the nature of these relationships. Little is known about the research needed to support IT use in infrastructure. Research is needed to understand how these systems interface and interconnect with one another, to control unwanted side effects ranging from local to global scales, and to identify what institutional capacity is needed to manage the use of IT, including the role of users in the decision-making process.

"Bringing Information Technology to Infrastructure," a Workshop organized by ICIS and funded by the National Science Foundation, was held June 25-27, 2001 in Arlington, VA to begin to identify those research areas. The Workshop drew individuals in engineering and social science disciplines, in academia, government and the private and not for profit sectors from various different infrastructure areas throughout the country who have worked closely with IT applications in infrastructure. Participants were given the opportunity to present their thoughts in short papers prior to the Workshop. At the Workshop, NSF provided contextual insights, followed by two keynote addresses. The first keynote address was presented by William Mitchell, Dean of MIT's School of Architecture and Planning, and author of *E-Topia: Urban Life Jim -- But Not as We Know It*. Mitchell focused on how digital telecommunication infrastructure is characterized by more spatial dispersion and greater asynchronous formats than other kinds of infrastructure and this, combined with other factors such as increased miniaturization, has influenced urban design in very new and unique ways. Dr. Joseph Bordogna, Deputy Director of the National Science Foundation, presented the second keynote address on the direction of the Foundation in the area of information technology. According to its strategic plan, NSF's outcome goals are to develop people, ideas, and tools through its core strategies of developing intellectual capital, integrating research and education, and promoting partnerships. NSF will emphasize a number of capabilities to accomplish these goals and strategies. These include the ability to work at the nano-scale level to manipulate matter at the molecular and the terascale that enables access from many different places and new means of visualization. Key parts of the strategy are cognition, or taking into account the fact that different people absorb information differently, complexity, or what the components are like, and holism to understand how the components fit together.

The Workshop adopted as a working premise that, "Information technology holds the promise of enhancing the performance of infrastructure along many dimensions. It should not interfere with infrastructure performance." The overarching charge to the group was to identify research and researchable issues with respect to needs or problems and solutions as a framework or starting point for research.

For the purposes of organizing the research agenda, participants in the Workshop proposed three groups: policy, management and technology. In an initial brainstorming session at the outset of the Workshop, specific disciplinary areas were identified with each of these three areas for the purpose of providing a preliminary focus for the discussions. Presentations at the outset of each group session stimulated the discussions. Each group addressed the problems that research should target, potential solutions, and finally, specific research topics.

ISSUE AREAS

Policy

The policy group aimed at identifying research ideas and discussing research needs and gaps in our understanding of how to shape policies that bring *information technology (IT)* to infrastructure systems. In order to discuss policy options the group began by defining some of the terms used. For the purposes of the discussion, *policy* was described as a set of actions to plan, finance, and manage infrastructure systems. The term policy also encompasses how society should deal with issues of scale, externalities and interdependencies. *Infrastructure* was defined as a set of networks and systems that includes telecommunications, transportation, energy, water, and other similar services.

The use of IT in infrastructure systems will often result in new and unknown demands and developments. IT brings new information about performance to these complex systems. However, IT is often imposed on poorly integrated systems. The group agreed that in order to develop policies, a greater understanding is needed of how these systems are evolving or how they evolved in the past. In addition, new IT systems create externalities and unintended impacts that are poorly understood.

Three main themes related to IT and public policy were discussed throughout the Workshop: 1) Differential access to new IT technologies 2) Security and privacy related to new IT technologies and 3) Computer simulations and other analytical tools to aid policy analysis. These are summarized below.

Differential Access to IT Technologies

One of the most important issues facing IT technology and its use is that of empowering users. This refers to user access to new technologies and their benefits, as well as to users' responsibilities to pay for the externalities that accompany improved services. The fact that some people are empowered and others are not will probably result in a two-class system, and raises serious and complex equity issues. In order to prevent this, the group discussed the need for research to explore the possibility of designing incentive structures based on taxes, subsidies or other market mechanisms.

Differential access to these technologies will depend on the institutional structure in which these technologies are placed. Whether they are privately or publicly managed will surely have an impact on access and on who benefits from them. The institutional structure to manage these technologies will also determine how taxes, subsidies and other policies are designed and used to ensure or improve access. An inadequate institutional structure can frustrate the intentions of policy. Research is needed on the types of institutional structures and public/private partnerships to manage these technologies that are emerging and how they improve or hinder access to IT technologies and the distribution of their potential benefits.

Security and Privacy

Security and privacy issues include a host of areas related to infrastructure reliability, social equity, and user security and privacy. Some of these issues may be addressed by education. This includes, but is not limited to, the dissemination of real-time information and the provision of open access to relevant information. Privacy was also described as an economic and cultural issue. In addition, the removal of confidentiality (this refers to corporations not individuals) was considered relevant in areas that are important to maintain infrastructure systems that use IT.

The most important research question related to these issues, as discussed by the group, was: what are the ways in which the introduction of IT to infrastructure systems has affected privacy and security concerns? Once this research question has been addressed additional research can concentrate on whether user privacy can be salvaged as security is improved. In addition, it was suggested that research can be done on how criminals protect their privacy. This may have broad applications to user privacy and security.

Computer Simulation and Other Analytical Tools to Aid Policy

The main concern in this area is that the analytical tools currently used in policy analysis imply simple systems. These tools are not a good match for the complex infrastructure systems that are evolving today, especially with respect to real-time management. Two areas of research were suggested in this area. One is the use of computer simulations based on IT to aid policy analysis. The other is the use of analytical tools used to study and understand extreme events for the same purpose.

Computer simulations can serve as the basis for policy formulation. Such tools can provide visualization and experimentation aids that have the potential to vastly improve policy analysis. An example from Cornell University related to energy markets provides a good example. Emerging energy markets after deregulation and other policy measures were simulated with great success. Policy analysts and infrastructure managers were invited to participate in these simulations. In each case, their response was initially shaped by preconceived notions about how they thought markets would behave. However, as policy analysts and managers saw the results of their actions in real time their behavior began to change. They gained a better understanding of how energy markets behave under new rules. Such experiences suggest that in-silico testing can be a viable alternative to testing policies in real life situations.

Additional tools with a potential to aid policy analysis in this area were also discussed. These included the possibility of looking at extreme events analytically from a risk perspective in order to gain a better understanding of the risks. In particular, valuable recent experiences with earthquake relief efforts can provide new insight into how policy analysis can better deal with uncertainty and complexity. Such tools may prove useful in studying the complex relationship between information technology and infrastructure systems.

Management

The “information” component of the convergence of IT and infrastructure brings with it numerous management opportunities and obstacles. At the most basic level, the sheer amount of information that can be gathered presents a major management challenge. What do managers do with all of this information? The question becomes, “Now that we have it, what do we do with it?” What analysis must be done in order for decisions to be made based on new information flows? What constitutes “good” information? How should it be collected? While these questions must be addressed, there is a general recognition that information and the technology to provide it have the power to change entire management as well as business practices and processes.

The discussion of Management issues at the workshop focused on identifying areas where research could aid the development and use of IT to improve how civil infrastructure systems and the organizations responsible for them deliver services to users and communities. Ultimately, the Management problems, solutions and research areas discussed centered around three interrelated themes: 1) Organizations (including education and training) 2) Jurisdictions and 3) Customers.

Organizations

The process of developing and delivering infrastructure facilities and services is highly fragmented, in part because of the historic way in which these systems were developed without the recognition that these services are often connected and serve a common customer base. The organizations responsible for infrastructure services often reflect this fragmentation. However, advances in IT now allow for increased connectivity and the possibility of re-shaping processes for infrastructure design and operation, along with the power to fundamentally re-shape infrastructure organizations and how they relate to one another as well as to users.

The group discussions highlighted the need for research to be done on how IT tools were restructuring management processes. New organizational models are emerging, and infrastructure organizations need assistance in how to re-think themselves. There is a movement towards integrating infrastructure systems, and whole new organizational designs are likely needed to adapt to these changes. The division of roles and responsibilities are changing, as are workforce opportunities and demands. IT is helping to streamline organizational processes, reduce inefficiencies, and improve service integration and delivery, but organizational structures, cultures and processes must fundamentally change and adapt in order to support the new integrated modes of operation, integrating IT into these operations rather than adding them incrementally. It was also pointed out that much is unknown about how new, totally intelligent systems will need to be managed. Emerging complex IT-dependent systems may require entirely new management systems or conversely, be easier to "manage" because of built in intelligence.

Education and training issues arose in the context of organizations and organizational management as critical areas in need of research. Questions such as, "What are the core competencies needed for infrastructure management in the information age," have yet to be answered. Research in these areas should aim to impact university curriculum, professional development and other knowledge delivery and learning mechanisms.

Ultimately, new information flows should have a positive impact on decision-making and management capabilities in infrastructure organizations. Examples include new e-government applications that help improve service delivery. GASB 34 issues were raised in connection with how they might reshape the management of infrastructure and the use of IT.

Jurisdictions

Jurisdictional boundaries--political, organizational, budgetary, etc.--have often hampered the development and management of infrastructure. Effective communication and coordination across and within organizations, states, regions or cities has been the exception rather than the rule from infrastructure planning through operations. However, it is widely recognized that IT has the power to transcend such boundaries and barriers, and to make multi-jurisdictional (multi-state, multi-county, multi-city, multi-agency, multi-organization, etc.) coordination much more effective.

There are powerful political and social forces that keep these jurisdictional boundaries in place, but research can provide answers and solutions on how multiple jurisdictions could optimize infrastructure projects and operations through the use of IT systems. Increasingly intelligent and flexible systems will make it easier to span traditional boundaries. Regional Metrocard and EZ-Pass systems are examples of how jurisdictional boundaries can be spanned with IT.

Customers

At the core of sound infrastructure management is the effective and efficient delivery of services to people and communities. While this "customer" focus has gained more attention in recent years, the public demand for information and access to information has presented infrastructure organizations with new challenges. Information being gathered about individual users of infrastructure can be used for the benefit of the public at large, but these advances have also raised thorny privacy and proprietary questions that are still unresolved.

The group discussed the need for public end-users to be involved in every phase of the conceptualization, design and implementation of IT uses in infrastructure systems. This type of "concurrent engineering" would enhance the quality of the service these IT applications produce, as well as increase the likelihood of widespread public adoption of new technologies. Research could help identify effective practices (both using IT and using non-IT outreach and involvement practices) for involving and continuously engaging the public in IT decision-making.

Technology

Technologies for the interoperability and integration of IT and infrastructure provide enormous research opportunities that are as diverse as the technologies themselves. Particularly challenging is research that looks at social impacts and the impacts of technology across different types of infrastructure. Several prerequisites were identified as a context for the discussion of technologies that integrate IT and infrastructure, pertaining to knowledge about:

- The extent to which integration is wanted and needed, and is possible given variations in the degree of sophistication of individual systems.
- The manner in which integration occurs, which has wide implications for management, for example, new peer to peer organizations may be needed to coordinate integration.
- The utility of system integration through the use of IT for life cycle concepts across planning – design – construction – operation and maintenance – renewal – removal of infrastructure.

An initial general discussion of the context for developing technological research agendas included technologies that: 1) take into account interactions among components of a system; 2) promote choice; 3) are customer oriented and take demand into account; 4) are flexible and avoid treating outcomes as foregone conclusions; 5) are either market driven or drive demand; and 5) focus on system prognostics that emphasize predictive modeling at all levels and scales. Research topics discussed in more detail were in three areas: 1) Customer oriented research 2) Integrative modeling, and 3) System diagnosis.

Consumer-Oriented Technologies

Infrastructure ultimately serves consumers and much of the research on infrastructure technology directly or indirectly relates to consumers. As such, research is needed on how infrastructure professionals are educated in the area of IT to understand and meet consumer needs, how consumer needs and demand can best be understood, and in what way the distribution of infrastructure services that are IT enabled raises issues of equity.

Education and training needs for the professions serving infrastructure (at the 2 year, 4 year and graduate levels) need to be identified in order to produce the IT enabled workforce of the future. These needs include curricula to support technological needs that make distinctions between those educational needs that are fundamental, those that facilitate life-long learning and adaptability and flexibility of the workforce (however complex), and static knowledge that might have a short life span. Recommendations would include changes to existing curricula or realistic cross-cutting educational programs.

Research on consumer demand and the role that IT would play in meeting that demand is needed. This involves microanalysis in laboratory and other settings of the relationship between consumer decision-making and IT enabled infrastructure services. Such research would draw upon disciplines such as experimental economics and cognitive psychology; field studies of aggregate demand decision making and impact on system performance; computational modeling of consumer behavior to assess management strategies and system operations. Cognitive aspects of real-time control are a part of demand-oriented research. Such research would address human-system interfaces for the “user” e.g. consumer, system operators and system managers, information overload and how users deal with it, and a consideration of stress and emotion, particularly in incident management. Intelligent agent technology based upon cognitive science will have to be developed to support users. Results would be a better understanding of consumer behavior and decision-making given increased availability of information and more effective, user-friendly human-system interface resulting in better system operations.

Research on equity and distribution issues involves the design of technology such that all segments of society can access, use and benefit from it. Moreover, physically and mentally handicapped should have access to benefits of technology. Literacy issues are among the equity issues that need to be incorporated in the design and implementation of technology. Economics must also be considered an equity issue, i.e., who will pay. The outcome of research in these areas would be approaches to taking equity into account in the use of IT in infrastructure.

Integrative Modeling

Modeling potentially provides the means to integrate many different system components along with consumer needs. Some of the research topics addressed in this area included new modeling needs as well as refinements in existing modeling efforts.

Research on large-scale system evolution and development was identified as an important area with a focus on case studies and simulations of infrastructure system development, including origins and initial conditions, development paths and dynamics, maturation, and decommissioning, and displacement or replacement by successor technologies. The outcome of such research would be the development of descriptive tools, patterns of development, barriers and impediments to development, simulation tools, and techniques.

Data sharing is fundamental to research that integrates IT and infrastructure through modeling. Infrastructure systems often interact physically in space (e.g., under streets, in manholes) and temporarily (e.g., power failures impact water pumping). They also interact with other processes of development (land use and construction). Yet the infrastructure community as a whole has not been a strong participant in data sharing initiatives. This is often attributed to issues of security and competition. Although data sharing might produce more efficient and cost effective system management, it is difficult institutionally. Research might study successful “best practice” cases of data sharing, to identify factors in successful sharing, evaluate cost/benefits of sharing, and generate ideas of new institutional structures to facilitate sharing computer science issues of semantic interoperability and open standards are related research topics.

Data visualization and data mining was identified as a means of making use of data for models. Infrastructure systems are inherently complex. As we deliver more real-time information from a complex monitoring system of sensors and other data collectors we compile a vast amount of spatio-temporal data. In order to make effective use of the data to make system decisions in near real time, we need research on data mining techniques from IT suitable for the infrastructure problems; visualization tools to allow operators to quickly grasp system status; and visualization tools to help monitor system change over time.

System vulnerability models were identified as an important area of research that provides probabilistic physical and economic models for the behavior of interconnected, intelligent infrastructure systems subjected to actions (loads, etc.) from normal service and natural, accidental and willful hazards. Such research would include characterizations of actions, characterization of infrastructure systems, methods of modeling physical, economic and societal responses, and laboratory and field studies verifying models including post disaster/post event investigations.

The construction and maintenance of infrastructure systems requires temporary works that may affect the system. This needs to be included in models for control and interpretation of sensory datum. Knowledge is needed that leads to improved management of temporary works in these systems.

Modeling of behaviors of systems of intelligent and complex physical systems would include activities to formalize the actions, states, and decisions of the agents (human and autonomous) in infrastructure systems. A research outcome is the ability to validate and effectively simulate systems of this type.

Given a set of actions/controls (plus data) possible on the system, mathematical models are needed to formalize the control status of the infrastructure. Examples of outcomes are safe operation of infrastructure from first principals (mathematics) and improved diagnostic/prognostic capabilities.

Empirical evaluation of model constructs and benchmark algorithms is needed using data repositories and test data sets. Test beds need to be developed that simulate real-time operations to assess simulation models, facilities are needed to conduct "gaming" simulations – with unobtrusive measurement of input, processes and output variables, for testing cognitive models and decision support technologies. The outcome would be validated models for understanding the behavior of physical and human systems.

System Diagnosis

In order for modeling as well as performance measurement to be effective and targeted to consumers, a knowledge of system condition is needed. Research topics identified in this area included various sensor systems, and at the same time a need to link data systems to such diagnostic tools to make better use of the information they collect.

Sensor suites and reliability approaches to obtain better data for condition assessment and system status data were identified as a research need. The result would be potentially better infrastructure management and control.

IT or robots in hazardous environments would be among the enabling technologies developed for remote access for condition assessment and repair. They would include robust design principles, effective sensor suites, prototypical symptoms, etc. Results would be low cost and less disruption as well as safe maintenance and condition assessment of utilities, etc.

Accelerated construction and maintenance process research would involve development of non-disruptive methods, quicker automatically controlled processes, modular systems, quick setting materials, etc. For example, GPS receivers and graphical interfaces can be used to automatically control grading, compacting, and paving equipment for safer, faster, higher quality operation.

Algorithms for data processing and control and demonstrated methods would result.

Optimized communications for infrastructure sensing and control of infrastructures includes the specification of protocols and standards; selections of mediums; and economic considerations in selection of communications or use of existing communications resources and infrastructures. The expected products of this work may include specific recommendations of protocols, mediums, and methods. The work may also produce structured guidelines for the specification of infrastructure supporting communications.

The development of infrastructure system prognostics incorporates methods and techniques that will yield accurate, predictive reports on infrastructure integrity. Prognostics can be developed for individual components, sub-systems, and complete infrastructure systems. These techniques can take advantage of all available data, historic and/or current, and may interface with condition based maintenance systems to provide a comprehensive support system for infrastructure maintenance.

CONCLUSION AND NEXT STEPS

A common theme emerged out of the Workshop pertaining to the need for better integration between infrastructure research and IT research given the different rates at which the two technologies typically develop. The Workshop also emphasized the importance of collaborative research projects and research approaches that address these issues from multiple disciplines. Given the multidisciplinary nature of research themes discussed, participants identified ICIS as an ideal institution to coordinate and organize research efforts in this area.

An important immediate next step after the Workshop, which is already underway, is a more in-depth analysis into how IT has transformed individual areas as "infrastructure's infrastructure," what common themes exist across different types of infrastructure, and a broad dissemination of the findings of this analysis. This is especially critical at a time when the reliance of infrastructure on IT is increasing and since the workshop was held, security, as an IT driven function, has become critically important. This more in-depth and interdisciplinary analysis will occur through the production of a book edited by ICIS Director Rae Zimmerman and Thomas A. Horan (Associate Professor and Executive Director, Claremont Information and Technology Institute, School of Information Science, Claremont Graduate University) entitled *Digital Infrastructures: Enabling Civil and Environmental Systems through Information Technology*. The following is a preliminary outline of the book:

Part I: Overview

I.A A Conceptual Framework
I.B Policy Issues
I.C Management Challenges and Directions
I.D Technology and Engineering Dimensions

Part II: Infrastructure Cases

II.A Water
II.B Transportation

II.C Electricity
II.D Telecommunications

Part III: Crosscutting Issues and Direction

III.A Earth Systems Engineering
III.B Green Design Principles
III.C Economics of Information Technology
III.D Global Challenges and Developments

Part IV: Summary

IV.A Themes and New Directions

Most of the authors have been identified, largely drawn from the Workshop, and reviews by potential publishers are underway.

Finally, participants stressed the importance of federal funding initiatives for relevant research in the following federal agencies because they support major users of IT in infrastructure: U.S. Department of Energy, U.S. Department of Transportation, U.S. Environmental Protection Agency, and the National Science Foundation. There are many state and local agencies that would have similar interests.

Future themes that could be addressed in the IT and infrastructure research area include international dimensions, extreme events and security.

APPENDIX

RESEARCH TOPICS AND PROBLEM STATEMENTS

Participants individually identified topics and problem statements they wanted to see addressed in any research effort aimed at IT and infrastructure. Below is an essentially unedited version of those ideas organized by the three major topic areas – policy, management and technology.

Policy

1) Title: A Behavior Model of Infrastructure Use

Description: New IT intensive infrastructures are premised on real-time information use and, in particular, assumptions about user behavior in reaction to information and price. Yet a reliable model for user responsiveness does not exist. This research project would investigate human factors, price elasticity, cognitive dimensions, and user interface design issues to engaging users in information based infrastructure systems. Such research would provide insight, for example, to the use and limitations of pricing as a means to alter infrastructure use, as well as the cognitive issues and challenges to comprehending information and feedback on infrastructure use.

Product/Outcome: A behavior model for use in demand estimations and infrastructure design and deployment decisions.

2) Title: Institutional Capacity for New Infrastructure Systems

Description: Infrastructure networks typically encompass a range of organizations across a number of regional and local scales. As these networks become more technologically-intensive, the capacity challenges in managing the system become considerable. This investigation would examine institutional capacity challenges across the phases of infrastructure/technology decision-making (planning, finance, operations, maintenance). It would also look more broadly at the governance issues, including issues of public-private partnerships in infrastructure IT development, reliability of cross-organizational systems and policy formation-implementation gaps.

Product/Outcome: New organizational models and training recommendations for creating next generation information systems.

3) Title: The Relationship between Culture, Technological Evolution and Infrastructure

Description: Many infrastructure decisions are made in an incremental fashion without specific regard to the cultural assumptions underlying the interventions. While this approach may be sufficient in the short-term, in the long-term, a better understanding of the cultural conditions surrounding infrastructure change and use is needed. This analysis can include the role of markets and governments as well as social and cultural differences in terms of human factors, willingness to pay, use of information, and concerns about privacy.

Product/Outcome: Improved theoretical understanding for deploying infrastructure across cultures.

4) Title: The Technical and Non-technical Dimensions of Infrastructure Privacy

Description: The use of infrastructure—telecommunications, transportation and electricity, for example—can involve information transfer between the user and system about user behavior. This transfer raises significant privacy issues as the data can include information about travel, use of systems, purchasing behavior, etc. This research would be a comprehensive examination of the legal, sociological, cultural and psychological concerns of the privacy dimension of infrastructure.

Product/Outcome: Findings to be used in crafting infrastructure designs and policies relative to privacy.

5) Title: Societal Systems and Policy

Description: Computational simulation modeling, experimentation and visualization to aid policy decisions. Flexible, easy to use yet rapidly adaptable complex system simulation to aid policy:

- *In Silico* simulation testing of new devices and policies in the context of the whole system instead of *in Vivo* testing (analogous to high-fidelity flight simulators)--prediction of unintended consequences of designs and policies.
- Provide a greater understanding of how policies, economic designs and technology might fit into infrastructure, as well as guidance for their effective deployment and operation.
- An understanding of emergent behaviors, and analysis of multi-scale and complexity issues and trends in the future growth and operations.
- Underlying causes, distributions, and dynamics of and necessary/sufficient conditions for cascading breakdowns (metrics).
- Understanding what constitutes a problem and ability to ask "what if" questions: Visualization tools, vulnerability assessment, risk analysis and management (deciding what to do).
- Understanding extreme events (including non technical) and determining what actions could solve the problem - Contingency plans.

Product/Outcome: Software, visualization tools and techniques.

6) Title: Systems Benefits

Description: Understanding of true dynamics of interconnected/coupled networks and their impact on the interdependent infrastructure efficiency, robustness and reliability. Ability to do faster analysis, look-ahead simulation, and deal with greater complexities. This research would move toward a systems approach and robust theory of complex interactive networks:

- Modeling (including identification and reduction of dynamic models) and analysis of hybrid and Discrete-Event Dynamical Systems for infrastructures (those combining continuous dynamics with the discrete dynamics in switching elements, e.g. FACTS devices in power systems).

- Systems analysis, integrated assessment, modeling and control strategies: Cascading phenomena, dynamics and identification, failure models and dynamics; as well as interaction among information, communication, markets, and power networks.
- Identification, characterization and quantification of failure mechanisms.
- Fundamental understanding of interdependencies, coupling and cascading.
- Development of predictive models.
- Development of prescriptive procedures and control strategies for mitigation or/and elimination of failures.
- Design of self-healing and adaptive architectures.
- Identify trade-offs between robustness and efficiency.
- Interactions of markets and infrastructure are not well understood nor fully integrated: Modeling and analysis of couplings between market dynamics on the physical control; e.g., impact of restructuring and deregulation on power system analysis, control, and security monitoring.

Product/Outcome: Software, analytical methodologies, algorithms and visualization tools.

Management

1) Title: Understanding Dynamics and Forces Affecting Successful and Unsuccessful (failures) Inter-jurisdictional Infrastructure Deployment.

Description: Examine infrastructure projects deployed among multiple political jurisdictions (multi-state, multi-county, multi-city) to determine the facilitators and obstacles to such projects.

- Examine how each jurisdiction for each infrastructure project sub-optimizes for its boundaries.
- How can multiple jurisdictions optimize projects with use of IT systems?
- What is the role of public-private partnerships in facilitating inter-jurisdictional projects?
- Use simulations to understand organizational elements influencing decision-making on infrastructure across jurisdictions.

Product/Outcome:
- Knowledge of what type of infrastructure systems would be successful on an inter-jurisdictional deployment.
- Identification of organizational design and public-private partnership models that facilitate inter-jurisdictional projects.
- Best practices volume.
- Simulation models.

2) Title: Core Competencies in Infrastructure Management

Description: Develop an initial compendium of the core competencies needed for infrastructure management in the information age (a useful model may be the software engineering "body of knowledge" being developed by the Association for Computing Machinery). The compendium is to serve multiple uses:

- Curriculum planning in universities and colleges.
- Continuing education delivery.
- Exploration of suitability for a variety of knowledge delivery and learning mechanisms.
- Support the development of system-specific appendices (e.g. pertaining to transport, water, fire response, etc. infrastructure subsystems).
- Support the development of IT system-specific appendices (e.g. pertaining to wireless, etc. IT technologies).

Product/Outcome: A compendium of knowledge/competencies ready for adoption/promulgation by infrastructure management and educational organizations.

3) Title: Integrating Customers Into IT Applications Development In Infrastructure

Description: Involving public end-users in every phase of the conceptualization, design and implementation of IT uses in infrastructure systems ("concurrent engineering") would enhance the quality of the service these IT applications produce, as well as increase the likelihood of widespread public adoption of new technologies.

Product/Outcome: This research would identify effective practices (both using IT and using non-IT outreach and involvement practices) for involving and continuously engaging the public in IT decision-making.

4) Title: New Organizations for Complex Infrastructure Systems

Description: The process of developing and delivering infrastructure facilities and services is highly fragmented because of the historical way in which they were developed. Information technology now allows connectivity and the possibility of re-shaping processes for infrastructure design and operation, and also fundamentally re-shaping the organizations that do this. IT should be viewed as an enabler of these changes. This is a three-step process: 1) technology transfer; 2) IT becomes the "glue", holding the process together; 3) new process is created for integrating previously fragmented systems. These new processes are reshaping infrastructure organizations in fundamental ways. They will change the division of roles and responsibilities; create new opportunities for public/private partnerships; new workforce opportunities and demands; and new human/system interfaces. Research would seek to:

- Identify where fragmentation exists in both organizations and processes.
- Identify ways to overcome fragmentation (fill gaps), streamline organizational processes, reduce inefficiencies, improve service integration and delivery—all through the use of IT.
- Identify changes in organization structure, culture and processes that would be necessary to support this new integration model.
- Develop implementation strategies.

Product/Outcome: New organizational designs and processes for complex infrastructure systems.

Compelling Argument: Movement is toward integrating infrastructure systems, and whole new organizational designs are needed. The most immediate benefits are improved organizational effectiveness and efficiency. The long term benefits are creating organizations that are prepared and capable in terms of mind-set, culture and outlook for the infrastructure of the 21st century. This is the type of organization where the new infrastructure manager thrives and contributes in ways not easily possible in today's fragmented processes and institutions.

5) Title: Vulnerability of Complex Systems

Description: The research would seek to understand:

- Design and performance requirements of infrastructure components.
- How infrastructure components inter-relate (how they interact, possible failure models, impact of failure).

Product/Outcome: Design tools including performance-based simulations and multiple decision criteria.

6) Title: Decision Tools for Life-cycle Management of Coupled Infrastructure Systems

Description: Coupling IT with traditional infrastructure raises significant questions regarding the management of the physical assets over their design lives. Improved capabilities for determining customer utilization, predicting remaining life, and assigning value to services promises increased management flexibility, but will also challenge decision-makers to deal with risk and uncertainty. Tools need to be developed that will permit the decision-makers to assess risks and rewards of alternative management approaches and identify solutions that meet changing customer expectations and operating requirements.

Product/Outcome: A range of decision tools designed for validation, reliability, applicability and case of use.

Technology

1) Title: Large-scale System Evolution and Development

Description: Case studies and simulations of infrastructure system development, including origins and initial conditions, development paths and dynamics, maturation, decommissioning, and displacement or replacement by successor technologies.

Product/Outcome: Development of descriptive tools, patterns of development, barriers and impediments to development, simulation tools, and techniques.

2) Title: Data Sharing

Description: Infrastructure systems often interact physically in space (e.g., under streets, in manholes) and temporarily (e.g., power failures impact water pumping). They also interact with other processes of development (land use and construction). Yet the infrastructure community as a whole has not been a strong participant in data sharing initiatives. This is often attributed to issues of security and competition. Although data sharing might produce more efficient and cost effective system management, it is difficult institutionally. Research might study successful "best practice" cases of data sharing, to identify factors in successful sharing, evaluate cost/benefits of sharing, and generate ideas of new institutional structures to facilitate sharing computer science issues of semantic interoperability and open standards are related research topics.

Product/Outcome: Best Practices volume.

3) Title: Visualization/Data Mining

Description: Infrastructure systems are inherently complex. As we deliver more real-time information from a complex monitoring system of sensors and other data collectors we compile a vast amount of spatio-temporal data. In order to make effective use of the data to make system decisions in near real time, we need research on: data mining techniques from IT suitable for the infrastructure problems; visualization tools to allow operators to quickly grasp system status; and visualization tools to help monitor system change over time.

Product/Outcome: Visualization and data mining tools and techniques.

4) Title: System Vulnerability

Description: The research objective is to provide probabilistic physical and economic models for the behavior of interconnected, intelligent infrastructure systems subjected to actions (loads, etc.) from normal service and natural, accidental and willful hazards. Research will include characterizations of actions, characterization of infrastructure systems, methods of modeling physical, economic and societal responses, and laboratory and field studies verifying models including post disaster/post event investigations.

Product/Outcome:

5) Title: Modeling Temporary Works Needed in Infrastructure Systems

Description: The construction and maintenance of infrastructure systems requires temporary works that may affect the system. This needs to be included in models for control and interpretation of sensory datum.

Product/Outcome: Improved knowledge of, leading to improved management of, temporary works in these systems.

6) Title: Modeling of Behaviors of Systems of Intelligent and Complex Physical Systems

Description: Activities to formalize the actions, states, and decisions of the agents (human and autonomous) in infrastructure systems.

Product/Outcome: Ability to validate and effectively simulate these styles of systems.

7) Title: Process Algebras for Determination of Infrastructure Control Status

Description: Given a set of actions/controls (plus data) possible on the system, a mathematical model is needed to formalize the control status of the infrastructure.

Product/Outcome: Safe operation of infrastructure from first principals (mathematics); improved diagnostic/prognostic capabilities.

8) Title: Sensors for Condition Assessment (method, systems for optimal and imperfect information)

Description: Different sensors, sensor suites, and reliability approaches would be developed to get better condition data, system status data, etc.

Product/Outcome: The result would be potentially better infrastructure management and control.

9) Title: IT for Robots in Hazardous Environments

Description: Enabling technologies for remote access for condition assessment and repair would be developed. They would include robust design principles, effective sensor suites, prototypical symptoms, etc.

Product/Outcome: Results would be low cost and less disruption as well as safe maintenance and condition assessment of utilities, etc.

10) Title: Accelerated Construction and Maintenance Processes

Description: This would involve development of non-disruptive methods, quicker automatically controlled processes, modular systems, quick setting materials, etc. For example, Geographic Positioning System (GPS) receivers and graphical interfaces can be used to automatically control grading, compacting, and paving equipment for safer, faster, higher quality operation.

Product/Outcome: Algorithms for data processing and control and demonstrated methods would result.

11) Title: Education of Infrastructure-Serving Profession (2 year, 4 year, graduate).

Description: Look at existing curriculum in fields that serve these roles currently. Identify education and training needs and make distinctions between these where appropriate, i.e. identify those things that are fundamental, those things that facilitate life-long learning and adaptability and flexibility of the workforce, and form (however complex) static knowledge that might have a short life span.

Product/Outcome: Recommendations for changes to existing curricula or realistic cross-cutting educational programs that could produce the IT enabled infrastructure workforce of the future.

12) Title: Optimized Communications for Infrastructure Sensing and Control

Description: The development of communications to specifically serve the sensing and control of infrastructures. This includes the specification of protocols and standards; selections of mediums;

and economic considerations in selection of communications or use of existing communications resources and infrastructures.

Product/Outcome: The expected products of this work may include specific recommendations of protocols, mediums, and methods. The work may also produce structured guidelines for the specification of infrastructure supporting communications.

13) Title: Infrastructure System Prognostics

Description: The development of methods and techniques which will yield accurate, predictive reports on infrastructure integrity. Prognostics can be developed for individual components, sub-systems, and complete infrastructure systems. These techniques can take advantage of all available data, historic and/or current, and may interface with condition based maintenance systems to provide a comprehensive support system for infrastructure maintenance.

Product/Outcome: Not specified.

14) Title: Research on Demand

Description: Microanalysis in laboratory settings of consumer decision making on infrastructure services drawing upon disciplines such as experimental economics & cognitive psychology; field studies of aggregate demand decision making and impact on system performance; computational modeling of consumer behavior to assess management strategies and system operations.

Product/Outcome: Gain better understanding of consumer behavior and decision making given increased availability of information.

15) Title: Research on Equity/Distribution Issues

Description: Design of technology such that all segments of society can access, use and benefit from it; physically and mentally handicapped should have access to benefits of technology; understanding the literacy issues in the design and implementation of technology; economics must be considered, i.e., who will pay.

Product/Outcome: Equity/distribution is taken into account in use of IT in infrastructure.

16) Title: Empirical Evaluation of Models

Description: Data repositories and test datasets need to be created to validate model constructs and bench mark algorithms; test beds need to be developed that simulate real-time operations to assess simulation models; facilities are needed to conduct “gaming” simulations – with unobtrusive measurement of input, processes and output variables, for testing cognitive models and decision support technologies.

Product/Outcome: Validated models for understanding the behavior of physical and human systems.

17) Title: Cognitive Aspects of Real-Time Control

Description: Human-system interfaces need to be developed for the "user" e.g. consumer, system operators and system managers; information overload and how users deal with it – again, as consumers, operators and managers; stress and emotion must be considered, particularly in incident management; intelligent agent technology based upon cognitive science will have to be developed to support users.

Product/Outcome: A more effective, use-friendly human-system interface resulting in better system operations.

"LEAP FORWARD TOPICS"

In the morning session on the final day of the workshop, participants were asked to break out of conventional thinking about infrastructure research and think about what topics might be addressed that are beyond any current scope of investigation. These topics were dubbed "Leap Forward Topics."

1) Title: Infrastructure Market Simulation

Description: Create and simulate infrastructure markets, i.e., ones we have not thought of yet.

2) Title: Sensors and Prediction

Description: Sensor development for prediction, primarily in the form of software.

3) Title: Intelligent Agents for Infrastructure Networks

Description: How do we design smart nodes and intelligent agents that operate in a distributed spatial/temporal network that:

- Is beyond a tera-scale
- Has changing missions over the long term, and
- Is highly dynamic and complex

How do we design systems that have non-premeditated interfaces with multiple actors over space and time? What technology is needed to support cultural change in an adaptable way over a long time period while also dealing with rapid, real-time decision making? What are the technologies needed to support cultural change—short term, medium term and long term?

4) Title: Smart System Solutions for Legacy Infrastructure and Environmental Systems

Description: This requires identification and integration of the current legacy systems. How are current social, environmental, and constructed/engineered systems intertwined? How can we formulate proper interfacing of these legacy systems and intelligent IT systems that will: adapt, renew, maintain, monitor health, operate, etc., the legacy and new infrastructure?

5) Title: Barrier-free Intelligent Infrastructure Service Delivery

Description: Many infrastructure services (e.g. fire protection, emergency response, zoning and building permitting services, para-transit services) are hampered by the existence of multiple, often overlapping jurisdictions. There are many social and political reasons for the continuing existence of these jurisdictions. However, there is the potential that IT can alleviate some of the jurisdictional barriers by letting the user interact with the service as if it was provided by a single entity (e.g. in dialing 911, the system would determine which jurisdictions to connect to, etc.). Research is needed to determine what infrastructure services may be thus augmented by IT, what jurisdictional barriers could thereby be overcome and what user needs for infrastructure can be enhanced. This may lead to the deployment of flexible, intelligent infrastructure systems that transcend the limits of existing jurisdictions.

6) Title: Determining Basic Infrastructure Needs

Description: As infrastructure becomes smarter and more flexible, and market pricing schemes replace universal-service commitments, access to services becomes increasingly differentiated. From the simple logic of connection or disconnection to infrastructure networks, we move to a situation where many packages of quality and reliability can be offered based on willingness to pay, political capital, etc. This changes the political and policy making processes that motivate civil infrastructure planning. What is the basic level of infrastructure services needed to sustain marginalized urban and rural communities? How can we ensure that these communities receive the level of infrastructure services in education, recreation, telecommunications, and transportation that are necessary for economic and social development, not just mere subsistence? A definition of basic infrastructure services and description of a mechanism could result that can provide these services in a cost-effective manner.

7) Title: Fail-safe Intelligent Infrastructure

Description: Research to permit development and deployment of intelligent infrastructure systems that are under human control (by users and operators) resistant to progressive collapse and gracefully degrading when subject to extreme loads, whether from service, accidents, or natural or willful attack. Research will include system architecture, encryption, sensors, control logics, interface for communication and control, etc. The objective would be to make systems more reliable and test methods for system vulnerabilities.

8) Title: Local Self-sufficient/Autonomous Infrastructure

Description: Identify technology and methods for infrastructure at user-scale units. Examples are water and waste, electric/energy. Investigate the interdependencies and synergistic opportunities among and between these systems (fuel cells in your car that also generate electricity for your house). Cultural and social implications also need to be addressed. Equity, land use, financing, governance. Designing solutions into the hardware and software. A critical dimension is user friendly interface—much easier than programming your thermostat. Dynamic systems that anticipate user needs and desires. What are the new infrastructure needs and capabilities that are created by these scenarios? A new telecommunications architecture? Landing pads for heli-travel? How do we configure pan-handling in cyberspace? An important outcome would be more direct relationships between users and infrastructure.

9) Title: Architecture for Self-organizing and Self-healing Infrastructure

Description: 1) Develop a high-level architecture that lays out principles and organizations of infrastructure (e.g. distributed, self-healing, responsive). 2) Cyber studies that exemplify promise and barriers to maximally self-healing systems.

10) Title: Sophisticated Prognostics for Infrastructure Demand, Supply and Condition

Description: Sensors that look forward to what is likely to occur, which relate to time sensitive actions. This could lead to more responsive, dynamic systems.

11) Title: Underground Space for Infrastructure

Description: How do we design underground space for infrastructure?

12) Title: Changing Values and Demands on Infrastructure

Description: Changing values and demands on infrastructure. Research on synchronicity.

13) Title: Infrastructure and the Brain

Description: How can advances in our understanding our minds and brains work impact the way infrastructure works, is designed, managed, etc.? For example, can this information be used to deal with road rage? This could be used for users, operators, and managers.
How can cognitive information be used?

14) Title: Use of IT for Un-tethering People from Physical Infrastructures

Description: What are the social, economic political effects of un-tethering people?

15) Title: Understanding Human-Infrastructure Physical Interaction

Description: Infrastructure is created by humans to serve humans. Look at infrastructure in terms of how many times humans touch and use infrastructure (and what infrastructure) intentionally and un-intentionally. IT can enable connection of infrastructure to customers to infrastructure allowing assessment and feedback. There is possibly a need to segment by type of infrastructure. This research would deal with human, physical, natural, social systems, and produce new inputs, processes and technologies to manage, maintain, and upgrade infrastructure.

16) Title: Evaluating Alternative Integrated Infrastructure Delivery Systems Using IT

Description: How can we use emerging IT to design and implement truly integrated systems where none exists? Possibly use developing countries at test pads (fewer institutional and physical constraints). The research is to evaluate IT enabled alternatives and evaluate integrated systems. This is a unique opportunity to work on a "blank slate." The research is necessarily interdisciplinary (including social and political implications) as well as physical systems (water, roads, etc.). Many people do not have access to safe, healthy systems. This could lead to opportunities for a holistic view of systems. Using IT, the ability to measure performance and provide constant feedback for policy decisions could be promoted.

17) Title: IT Capabilities Research

Description: IT capabilities for the following: 1) optimize the supply/demand balance for production and use of services; 2) real-time pricing differentials; and 3) IT systems allowing for continuous adjustments.

18) Title: Seamlessness

Description: Seamless ability to move between modes, jurisdictions. Real-time issues arise.

19) Title: Design for Security Enhancement (DFSE)

Description: Infrastructure development as a national security component. This is compelling because it involves critical resource management issues. For example, water issues in the Gaza strip are increasingly important in conflict management. Infrastructure should be designed and deployed to support robust national security capabilities (where appropriate). Note: This is a positive goal, not a negative (defense against attack) goal. How do we use infrastructure to enhance security in a positive way. One result would be enhanced national security.

20) Title: Design for Earth Systems Management (DESM)

Description: Infrastructure as a main component of earth systems engineering and management. Infrastructure in global (e.g. IT and local urbanized systems) configuration is increasingly the means by which humans interact with and manage critical natural systems:

- Climate and oceanic systems
- Hydrologic cycles
- Carbon, Nitrogen, Sulfur and Phosphorous (C, N, S, P) systems
- Biosphere and bio-diversity
- Land use

We need to learn how to design and structure energized infrastructure as it reflects our goals and intentions for the human earth. One outcome would be economically, environmentally and socially efficient infrastructure, infrastructure as a part of earth systems management, the design and construction of environmentally sound infrastructure.

21) Title: Infrastructure Planning for Differential Deployment

Description: There will be differential deployment of technology and information flows. Where it is going, where it is not going? What are the unintended consequences? Issues arise such as wealth concentration, Cyber-rights, and Cyber-right pressure groups. Supply does not equal enabling.

22) Title: Education and Learning Skills

Description: What kind of education and learning skills are needed at what kind of scale or place. A link to the entertainment industry is possible.

SECTION TWO

The Institute for Civil Infrastructure Systems	**BRINGING INFORMATION TECHNOLOGY TO INFRASTRUCTURE** **A WORKSHOP TO DEVELOP A RESEARCH AGENDA** June 25-27, 2001

Key Bridge Marriott Hotel
Georgetown Ballroom
1401 Lee Highway
Arlington, VA 22209
(Rosslyn Metro stop)

WORKSHOP AGENDA
(as of June 22, 2001)

The goal of the workshop is to generate a research agenda for cross cutting issues on infrastructure and IT. The workshop will be highly interactive. Topics and issues will be identified and driven by participants, who will offer insight and expertise from a range of infrastructure and IT areas.

MONDAY June 25 – Day 1

1:00 pm - 2:00 **Introductions**
- Group Introductions and Statements of Interest
- Workshop Purpose, Objectives, and Organization
- Brief Overview of White Paper Issues
- Remarks by NSF

2:00 - 3:45 **Scoping and Organization** of Topics for Small Group Discussion Sessions

3:45 - 4:00 **Break**

4:00 - 5:30 **Keynote Address**
William Mitchell, Dean of the School of Architecture and Planning, MIT (author of *E-Topia: Urban Life Jim -- But Not as We Know It*)

Output of Day 1: Topic lists divided into discussion groups with individuals identified for each session. Session presenters, leaders, rapporteurs are identified.

Reception follows at 5:30pm in the *Madison Room.*

TUESDAY June 26 – Day 2

8:00 am - 9:00 **Continental Breakfast** *(in the Georgetown Ballroom)*

9:00 - 10:00 **Keynote Address**
Dr. Joseph Bordogna, Deputy Director of the National Science Foundation

Small Group Discussions
The format for all small group discussion sessions is planned to include:

- short presentation by a group member or members (10 minutes)
- full group discussion (1 hour), and
- group write up of session issues (20 minutes)

The sessions are:

Session I: Needs and Problems
Session II: Preliminary Solutions/Approaches
Session III: Research Agenda Items
Session IV: New Needs and Problems and Potential Solutions
Sessions V: Research Agenda Items

Session I: Needs and Problems

10:00 - 11:30 **Small Group Discussions**
Sample Needs and Problem Areas (These are examples only - specific problem areas for sessions will be identified on Day 1 by workshop participants):

- Institutional and technical barriers to IT use in infrastructure systems
- Interoperability and seamlessness
- Constraints and opportunities for community and workforce capacity-building
- Understanding implications of IT for public services access and urban development patterns

11:30 - 12:00 **Plenary Reporting**

Output of Session I: Set of needs and problems will be identified and categorized by topic area.

TUESDAY June 26 – Day 2 *(con't)*

12:00 pm - 1:30	**Lunch** at Key Bridge Marriott - J.W.'s View Steakhouse **Keynote Address** Braden Allenby of AT&T

Session II: Preliminary Solutions/Approaches (to Session 1 Problems)

1:30 - 3:00 **Small Group Discussions**
Sample Areas for Solutions/Approaches
- Research and development, including innovative technologies
- Education, training and outreach
- Institutional capacity building and change

3:00 - 3:30 **Plenary Reporting**

Output of Session II: Set of solutions linked to the needs and problems discussed earlier, separating solutions that require research from others that do not.

Session III: Research Agenda Items

3:30 - 5:00 **Small Group Discussions** (addressing and linking needs and problems to preliminary solutions/approaches and also generating new solutions)

5:00 - 5:30 **Plenary Reporting**

Output of Session III: Set of research items that specifically address and link to the needs, problems and solutions discussed earlier.

WEDNESDAY June 27 – Day 3

Discussions in Days 1 and 2 will produce additional needs and problem areas or subsets of needs and problems to be addressed more fully in Day 3.

8:00 am - 9:00 **Continental Breakfast** *(in the Georgetown Ballroom)*

9:00 - 10:00 **Overview** of Days 1 and 2 and directions for Day 3

Session IV: New Needs and Problems and Potential Solutions

10:00 - 12:00 **Small Group Discussions**

12:00 pm - 1:30 **Lunch** at Key Bridge Marriott - J.W.'s View Steakhouse

Session V: Research Agenda Items (from Session IV)

1:30 - 3:00 **Small Group Discussions**

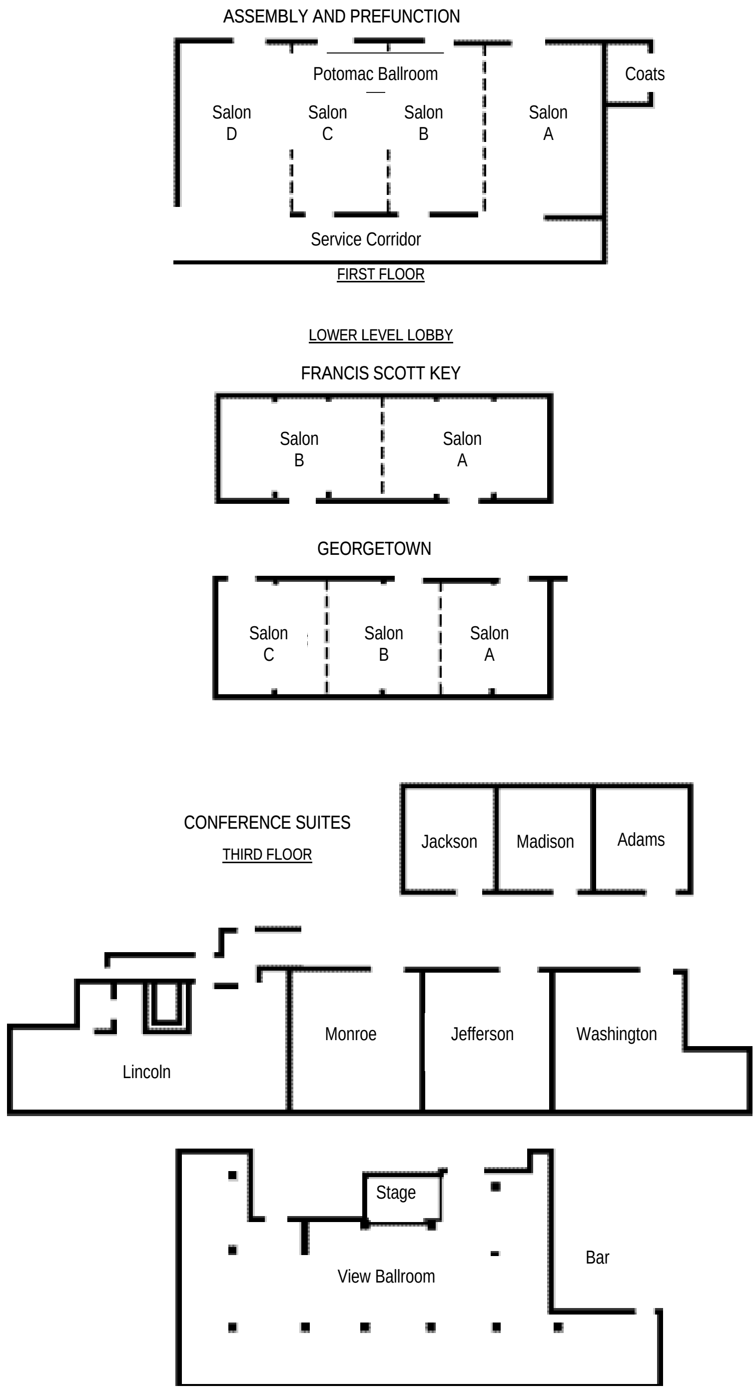
3:00 - 3:15 **Break**

3:15 - 5:00 **Closing Plenary** – Open discussion, review, and prioritization of the full list of research agenda items

Output of Day 3: Set of Research Agenda Items addressing and linking problems and potential solutions

KEY BRIDGE MARRIOTT
PHONE: 703-524-6400 FAX: 703-524-8964

PLENARY SESSIONS: Georgetown Ballroom, Salons B & C (Lower Lobby Level)
GROUP DISCUSSION SESSIONS: Madison Room and Adams Room (3rd Floor)
MEALS: JW's View Steakhouse (Top Floor--View Room "VR")
MONDAY'S RECEPTION: Madison Room (3rd Floor)



Bringing Information Technology to Infrastructure:
A Workshop to Develop a Research Agenda

The Institute for Civil Infrastructure Systems (ICIS)
Robert F. Wagner Graduate School of Public Service, New York University

Roads and bridges, pipes and pumps, and other components of our civil infrastructure systems have traditionally relied upon mechanical systems to support them. A dramatic shift is now underway, as advances in the use of information and communications technologies are changing the way infrastructure is developed, deployed and managed. Opportunities for the use of information technology (IT) in infrastructure planning, construction, operation, management and maintenance are emerging at a rapid rate, and are transforming both the way infrastructure services are provided and how they impact users and communities:

- *Transportation* infrastructure has been a leader in the use of IT for roadway design, traffic management, customer services, and improved rail safety and capacity.
- *Water supply and wastewater treatment systems* use advanced information technologies for detection, data management, system control, and to track compliance with water quality standards, and maintain the reliability of distribution systems.
- *Electric power* infrastructure relies heavily on information technology to track system performance and energy use, improve efficiency and reliability of fieldwork, improve customer service, and manage energy markets.

Efforts to wire our roads, transit, water, and energy systems are mainstreaming "smart" infrastructure that promises to change the way we manage and use our natural and built resources. Although IT is critical to the performance of civil infrastructure systems throughout their entire life cycle, little is known about the research needs to support IT use in infrastructure. As the IT sector continues to develop rapidly and change the pace and nature of our infrastructure systems, research must be targeted to address the broad range of opportunities and implications of these systems for infrastructure and the communities they affect.

The Institute for Civil Infrastructure Systems (ICIS) will conduct a workshop in Arlington, VA June 25-27, 2001, with primary funding from the National Science Foundation (NSF) to provide the basis for a research agenda connecting IT and infrastructure for the NSF and other potential funders. Final results will be disseminated as a report to shape research agendas for the NSF and other institutions that engage in issues about infrastructure and information technology.

The workshop will convene professionals in infrastructure, IT, and social science disciplines from academia, industry, government and the not-for-profit sectors. The group will explore IT/infrastructure connections from system- and user-specific issues to more global perspectives on the role of IT-enabled infrastructure and urban development. New materials for IT systems, construction management, workforce adaptation to new IT skills, IT-enabled infrastructure for hazard prevention and response, integration and interaction of rapidly changing IT systems with older, more slowly changing infrastructure, and changes in urban development as a result of IT-enabled infrastructure are among the research areas the workshop will address.

The Institute for Civil Infrastructure Systems (ICIS), funded by NSF, is a multidisciplinary partnership of four universities – NYU, Cornell, Polytechnic U. of NY, and the U. of Southern California – located at NYU that focuses on infrastructure services for communities, users, and infrastructure managers. http://www.nyu.edu/icis.

PAPER AUTHORS, PRESENTERS AND PARTICIPANTS

A. Emin Aktan
Director, Drexel Intelligent Infrastructure and Transportation Safety Institute
John Roebling Professor of Infrastructure Studies
Drexel University
aaktan@drexel.edu

Braden Allenby
Vice President, Environment, Health and Safety
AT&T
ballenby@att.com

Massoud Amin
Manager of Mathematics and Information Science
Electric Power Research Institute (EPRI)
mamin@epri.com

Michael Bobker
Director of Strategic Planning
Association for Energy Affordability, Inc.
Mbobker@aol.com

P.S. Brandon
Pro-Vice Chancellor for Research
University of Salford, Manchester, UK
P.S.Brandon@salford.ac.uk

Christopher Cluett
Senior Research Scientist, Transportation Division
Battelle Seattle Research Center
cluett@battelle.org

Jeremy Crampton
Associate Professor, Department of Anthropology and Geography
Georgia State University
President, North American Cartographic Information Society (NACIS)
jcrampton@gsu.edu

Richard J. Delaney
President
The Delaney Policy Group
r.delaney@delaneypolicy.com

John E. Durrant
Executive Director, Geo-Institute
American Society of Civil Engineers (ASCE)
jdurrant@asce.org

Ingrid Ellen
Assistant Professor of Public Policy and Planning
Robert F. Wagner Graduate School of Public Service
New York University
ingrid.ellen@nyu.edu

Claire Felbinger
Associate Professor and Chair, Department of Public Administration
School of Public Affairs
American University
claire@american.edu

Steven Fenves
Senior Research Associate, National Institute of Standards and Technology (NIST)
Professor Emeritus of Civil and Environmental Engineering, Carnegie Mellon University
sfenves@cme.nist.gov

Jesus de la Garza
Professor, Department of Civil and Environmental Engineering
Virginia Tech
chema@vt.edu

Jonathan L. Gifford
Associate Professor of Public Management and Policy
Department of Public and International Affairs
George Mason University
jgifford@gmu.edu

Carl Haas
Liedtke Centennial Fellow and Associate Professor of Civil Engineering
Department of Civil Engineering
University of Texas at Austin
haas@mail.utexas.edu

Darrene Hackler
Assistant Professor, Department of Public and International Affairs
George Mason University
dhackler@gmu.edu

Richard Hanley
Professor, New York City Technical College/City University of New York
Editor, *Journal of Urban Technology*
r.e.hanley@worldnet.att.net

Thomas A. Horan*
Executive Director, Claremont Information and Technology Institute
Associate Professor, School of Information Science
Claremont Graduate University
tom.horan@cgu.edu

Peter Kissinger
Senior Vice President
Civil Engineering Research Foundation (CERF)
pkissinger@cerf.org

DeWitt Latimer IV
Student Trainee, Construction Metrology and Automation Group
National Institute of Standards and Technology (NIST)
dlatimer@nist.gov

Richard G. Little
Executive Director, Board on Infrastructure and the Constructed Environment (BICE)
National Research Council
RLittle@nas.edu

David J. Lovell
Assistant Professor, Department of Civil and Environmental Engineering
University of Maryland
lovell@eng.umd.edu

Elliot Maxwell
Senior Fellow for the Digital Economy
Director, Internet Policy Project
Aspen Institute
emaxwell@aspeninstitute.org

William J. Mitchell
Dean, School of Architecture and Planning
Professor of Architecture and Media Arts and Sciences
Massachusetts Institute of Technology
wjm@mit.edu

Patricia L. Mokhtarian
Professor, Department of Civil and Environmental Engineering
University of California-Davis
plmokhtarian@ucdavis.edu

Charles W. Newton
President
Newton-Evans Research Company
cnewton@newton-evans.com

William O'Brien
Assistant Professor, Department of Civil & Coastal Engineering
University of Florida
wjob@ce.ufl.edu

Michael D. Royer
Physical Scientist, National Risk Management Research Laboratory (NRMRL)
U.S. Environmental Protection Agency
Royer.Michael@epamail.epa.gov

Jeffrey S. Russell
Chair of Program and Professor, Construction Engineering & Management
Department of Civil and Environmental Engineering
University of Wisconsin-Madison
russell@engr.wisc.edu

Richard Schuler
Director, Cornell Institute for Public Affairs (CIPA)
Professor, Department of Civil and Environmental Engineering
Cornell University
res1@cornell.edu

Kathleen E. Stein*
Principal
Howard Stein/Hudson Associates
kstein@hshassoc.com

Vincent C. Thomas
New York State Assembly
vctofdc@hotmail.com

Costis Toregas
President
Public Technology, Inc.
toregas@pti.org

Anthony Townsend*
Research Scientist, Taub Urban Research Center
Lecturer, Robert F. Wagner Graduate School of Public Service
New York University
anthony.townsend@nyu.edu

John Voeller
Chief Knowledge Officer and Senior Partner
Black and Veatch
voellerjg@bvsg.com

William Al Wallace
Research Director, Center for Infrastructure and Transportation Studies
Professor of Decision Sciences and Engineering Systems
Rensellaer Polytechnic University
wallaw@rpi.edu

Richard M. Wiesman
Vice President, Electrical and Electronic Systems Group
Director, GridCom International, Inc.
Foster-Miller, Inc.
rwiesman@foster-miller.com

Lyna Wiggins
Chair and Professor, Department of Urban Planning
Rutgers University
President, Urban and Regional Information Systems Association (URISA)
lyna@rci.rutgers.edu

Lawrence E. Wood
Ph.D. Student, Department of Geography
Penn State University
lew125@psu.edu

Richard N. Wright
Chair, Board on Infrastructure and the Constructed Environment (BICE)
National Research Council
dickwrig@erols.com

Rae Zimmerman
Director, Institute for Civil Infrastructure Systems (ICIS)
Professor of Planning and Public Administration
Robert F. Wagner Graduate School of Public Service
New York University
rae.zimmerman@nyu.edu

* ICIS greatly acknowledges and thanks Thomas Horan, Kathleen Stein and Anthony Townsend for the facilitation roles they played during the workshop.

<u>National Science Foundation</u>

Joseph Bordogna
Deputy Director and Chief Operating Officer
National Science Foundation
jbordogn@nsf.gov

Miriam Heller
Program Director, Information & Technology for Infrastructure Systems
Division of Civil and Mechanical Systems
National Science Foundation
mheller@nsf.gov

Priscilla Nelson
Director, Division of Civil and Mechanical Systems
National Science Foundation
pnelson@nsf.gov

Ronald L. Rardin
Program Director, Operations Research and Production Systems
Division of Design, Manufacture, & Industrial Innovation
National Science Foundation
rrardin@nsf.gov

Frank Scioli
Program Director, Political Science
Division of Social and Economic Sciences
National Science Foundation
fscioli@nsf.gov

PAPER AUTHOR, PRESENTER AND PARTICIPANT BIOGRAPHICAL SKETCHES

A. Emin Aktan is John Roebling Professor of Infrastructure Studies and Director of Drexel University Intelligent Infrastructure and Transportation Safety Institute since 1997. Prior to this position, Dr. Aktan founded and served as Director of University of Cincinnati's Infrastructure Institute for a decade. Dr. Aktan received a PhD in Earthquake-Structural Engineering from the University of Illinois at Urbana-Champaign in 1973, and also worked as a research engineer at the University of California, Berkeley during 1979-1984. He has held academic appointments of METU, Ankara, and at LSU, Louisiana. After more than a decade of research in the laboratory on seismic resistant design of buildings, after 1984 Dr. Aktan's research interest turned to real life for systems identification and health-monitoring of actual constructed systems. His contributions to the field include controlled testing for structural identification of more than a dozen actual constructed facilities at service, damage and ultimate limit states. His research objectives include the identification and integration of social, political, legal, organizational, natural and mechanical systems affecting infrastructure management, integration of information technology with a spectrum of analytical and experimental research tools from various engineering disciplines for effective health-monitoring, full-scale demonstrations of structural control and health-monitoring on actual highway bridges, and generating knowledge regarding the actual behavior and loading environments of operating constructed facilities and correlating this with the underlying assumptions of design and evaluation guidelines.

Brad Allenby is the Environment, Health and Safety Vice President for AT&T, an adjunct professor at Columbia University's School of International and Public Affairs, and the inaugural Batten Fellow at Darden Graduate School of Business at the University of Virginia. From 1995 to 1997, he was Director for Energy and Environmental Systems at Lawrence Livermore National Laboratory. He graduated cum laude from Yale University in 1972, received his Juris Doctor from the University of Virginia Law School in 1978, his Masters in Economics from the University of Virginia in 1979, his Masters in Environmental Sciences from Rutgers University in the Spring of 1989, and his Ph.D. in Environmental Sciences from Rutgers in 1992. During 1992, he was the J. Herbert Holloman Fellow at the National Academy of Engineering in Washington, DC. He is a member of the editorial boards of The Journal of Industrial Ecology, The Journal of Sustainable Product Design, The Bulletin of Science, Technology and Society, and Environmental Quality Management; and a former member of the Secretary of Energy's Advisory Board and the DOE Task Force on Alternative Futures for the DOE National Laboratories. Dr. Allenby has authored a number of articles and book chapters on industrial ecology and Design for Environment; is co-editor of The Greening of Industrial Ecosystems, published by the National Academy Press in 1994, and of Environmental Threats and National Security: An International Challenge to Science and Technology, published by Lawrence Livermore National Laboratory; and is co-author or author of several engineering textbooks, including Industrial Ecology, published by Prentice-Hall in January of 1995, Design for Environment published by Prentice-Hall in 1996, Industrial Ecology and the Automobile, published by Prentice-Hall in 1997, and Industrial Ecology: Policy Framework and Implementation, published by Prentice-Hall in 1998. He is a Fellow of the Royal Society for the Arts, Manufactures & Commerce. He works with information systems and technology from an earth systems engineering and management perspective, studying the environmental and social implications of communications products, infrastructure, and services.

Massoud Amin is manager of mathematics and information science at the Electric Power Research Institute (EPRI) in Palo Alto, California, where he leads strategic research in modeling, simulation, optimization, and adaptive control of complex interactive networks, including national infrastructures for energy, telecommunication, transportation, and finance. Prior to joining EPRI in January 1998, he held positions of associate professor of systems science and mathematics and associate director of the Center for Optimization & Semantic Control at Washington University in St. Louis, Missouri. During his twelve years at Washington University, he was one of the main contributors to several projects with United States Air Force, NASA-Ames, Rockwell International, McDonnell Douglas, Boeing, MEMC, ESCO, Systems & Electronics Inc. and United Van Lines. While at Washington University, he focused on theoretical and practical aspects of intelligent controls, on-line decision making, system optimization, and differential game theory for aerospace and transportation applications.

At EPRI, Dr. Amin has developed collaborative research initiatives with diverse groups, including electric power industry, the government, universities and other stakeholders (including EPRI and its members, the US DOD, DOE, NSF, National Governors' Association, and the White House OSTP). He has been responsible for leadership in all aspects of planning and management of strategic R&D, creation of inter-disciplinary initiatives and application of advanced technologies to decision-aiding and engineering problems from conceptual design through implementation for energy and other large-scale networks. This has primarily involved creation and successful launch of the Complex Interactive Networks/Systems Initiative (CIN/SI), which was initiated in mid-1998 in response to growing concerns over the vulnerability of national infrastructures. CIN/SI is a 5-year, $30 million program funded equally by EPRI and—through the Army Research Office—the Deputy Under Secretary of Defense for Science and Technology. Six research consortia consisting of 26 universities are involved, along with two energy companies.

Dr. Amin has industry specific knowledge of energy systems, power delivery, energy information systems, aerospace, and transportation networks. In addition, his technical areas of expertise include applied mathematics, information and systems science for modeling, analysis, simulation, optimization, intelligent and adaptive control of uncertain and large-scale systems, as well as complex adaptive systems, research project planning, evaluation and management with applications to energy, aerospace, and transportation. He is the author or co-author of more than 85 research papers and the editor of five collections of manuscripts, and serves on the editorial boards of four academic journals. At Washington University, students voted him Mentor-of-The-Year (Assoc. of Graduate Engineering Students, Feb. 1996), the Leadership Award (voted by the senior engineering class, May 1995), and three times Professor of the Year (voted annually by seniors in the School of Engineering and Applied Science at Washington University, 1992-1995). He also received the Chauncey Award (the highest annual EPRI Award in recognition for the "creation of a world-class analytical capability for electricity market design" by the six-member power market design team, March 2001), 1999 Performance Recognition Award (for leadership in launching the EPRI/DoD Complex Interactive Networks/Systems Initiative, EPRI, July 1999), 2001 Performance Recognition Award ("for commitment to society in the development and advocacy of the Common Information Model (CIM) and the Application program Interface (API) standards and the application of API to Grid Operations and Planning software Products", EPRI, June 2001) Best Session Paper Presentation Awards (American Control Conference, 1997) and an AIAA Young Professional Award (St. Louis section, 1991).

He is a member of Sigma Xi, Tau Beta Pi, Eta Kappa Nu, AAAS, AIAA, ASME, IEEE (senior member), NY Academy of Sciences, SIAM, and Informs.

Dr. Amin holds B.S. (cum laude) and M.S. degrees in electrical and computer engineering from the University of Massachusetts-Amherst, and M.S. and D.Sc. degrees in systems science and mathematics from Washington University in St. Louis, USA.

Michael Bobker has been involved in the energy services industry for over twenty years in capacities such as community organizer for pilot demonstration projects, boiler mechanic, project manager for consulting engineering and turnkey construction services for major public agency clients, and chief operating officer of an independent esco. He is presently working on the strategic opportunities presented by energy deregulation for a network of community-based low-income weatherization agencies and researching at Columbia University implications of the "knowledge revolution" for the emerging global utility industry. He is a Certified Energy Manager (CEM) and holds graduate degrees in Sociology, Energy Management, and International Business. Mr. Bobker can be contacted by e-mail at "mbobker@aol.com".

P.S. Brandon is Pro-Vice-Chancellor for research at the University of Salford, Manchester, UK. His background is that of a surveyor who then took a Masters in Advanced Architectural Design Techniques and subsequently he was awarded a DSc for his work in Information Systems applied to Construction. He was the Head of the Department of Surveying at Salford and took it to the highest research grading possible under the UK research assessment exercise involving all Universities. Over a period of fifteen years he has developed through his research teams several software systems which have been at the leading edge of the applied technology at that time. These include major knowledge based systems for strategic planning of construction projects involving procurement selection, budgeting, development appraisal and time estimates and large scale object orientated programmes for management of construction projects. More recently his research teams have been working on the development of virtual environments applied to construction and development, engaging multi-disciplinary teams from engineering to sociology. The UK national network for IT in Construction called CONSTRUCT IT which he set up has just been awarded the Queens Anniversary award for Higher Education. He is the author and/or editor of fifteen books and he has presented over 150 papers in around 30 countries of the world. His current interest is the evaluation of sustainability.

Christopher Cluett is a Senior Research Scientist with the Battelle Transportation Division in Seattle, Washington. He has over 24 years of experience with Battelle in behavioral science research and project management and has been manager of numerous Intelligent Transportation Systems (ITS) research and evaluation projects over the past six years. His recent work focuses on the evaluation of traveler response to ITS technologies and the institutional and societal aspects of ITS. His areas of specialization include evaluation, institutional and societal analysis, public outreach and involvement, survey research, and data collection and analysis. Previously he conducted extensive research on the community and societal impacts of technology. Recent research includes two studies for the NCHRP (Transportation Research Board) on the impact of information technologies (IT) on state DOTs and innovative organizational strategies DOTs are using in response to IT. For the past five years he served as Chairman of the Societal Issues Task Force for ITS America and served on the Coordinating Council of that organization. He is an active member of the Environment and Technology Section of the American Sociological Society. He has published in a variety of professional journals, and made numerous presentations at professional meetings.

Jeremy Crampton received his PhD in geography from Penn State University in 1994 and has taught at Portsmouth University (UK) and George Mason University in Northern Virginia. He is currently on the faculty at Georgia State University in Atlanta where he teaches digital cartography and Internet GIS (geographic information systems). His research interests include the geography of the digital divide using GIS, and he is currently in the early stages of a GIS analysis of the divide in Atlanta at the local level.

Atlanta makes an interesting case study as it is both one of the leading technopoles in the South (only Austin comes close), is the center of a burgeoning Internet industry (eg., Mindspring/Earthlink) but also has a long history of uneven access to resources. A view of the downtown and midtown skyline with cranes in every direction, loft and condo conversion and gentrification proceeding rapidly belie the fact that many Atlantans are digitally divorced. A recent initiative by the Mayor's Office to create 15 "cybercenters" would seem to be a suitable response, but it is an open question whether these centers (costing $8.1m) are suitably located to serve neighborhoods in need. New Census Bureau data coming onstream over the next year will be a tremendous asset in properly addressing some of these critical geographic problems, however, it is clear that many of these issues of the digital divide are not just technological but structural.

Richard J. Delaney is the founder and President of The Delaney Policy Group, a firm that develops public affairs and management strategies to help private and public organizations successfully meet the public policy challenges presented by emerging information technology. He has worked with numerous private firms and government agencies to help secure public policies and organizational strategies that enhance organizational results. He has produced research reports, training programs, and public affairs strategies in a diverse array of fields, including economic and community development, air transportation, education, tax policy, and civic infrastructure.

His recent work has focused on the impact of emerging information technologies on industry dynamics and public policies. In the past year, he has: promoted increased use of electronic commerce applications to improve how local governments collect taxes and issue permits; helped a real estate client assess the changes in residential and commercial development being created by Internet technologies; developed an agenda for local economic incentives to attract technology firms to the District of Columbia; and authored a report reviewing the impact of Federal legislative proposals on the growth of e-commerce.

Richard has extensive experience in management training, conducting sessions for public and private sector leaders in the United States, Russia, Ukraine, Poland, and the Czech Republic. He is a lecturer in public administration at New York University’s Robert F. Wagner Graduate School of Public Service, where he has taught courses in strategic planning and project management. Prior to founding the Delaney Policy Group in 1995, Richard served as a senior official in New York City government, working with the Office of Management and Budget and the Department of Sanitation. While working for the City, he was awarded one of six annual commendations for outstanding management performance. He also has served as an administrator at New York University and the University of Pennsylvania.

Richard has earned a Bachelor of Arts degree from Swarthmore College and a Master of Public Policy degree from Harvard University's John F. Kennedy School of Government. He lives in Washington, DC with his wife, Heather Weston, who is a vice president at the Council for Excellence in Government. He serves as Chair of the Board of Trustees of the Cesar Chavez Public Charter High School for Public Policy, a charter school serving District of Columbia public school students.

John E. Durrant, , P.E., M.ASCE, is the Executive Director for the Institutes of the American Society of Civil Engineers. Mr. Durrant is a licensed civil engineer with over twenty (20) years experience in engineering project management and program development. Prior to joining the American Society of Civil Engineers, Mr. Durrant, in his capacity as Manager of Philadelphia Water Department's Materials Engineering Laboratory, led a number of diverse teams in the realization of various administrative and engineering projects, including the development of a Laboratory Information Management System and the planning and construction of a new facility.

Mr. Durrant holds both Masters and Bachelors degrees in civil engineering from Villanova University. In 1983, he received ASCE's Edmund Friedman Young Engineer Award for Professional Achievement, in 1995, the Philadelphia Section's Engineering Manager of the Year Award, and in 1998, the Section's President's Award.

Ingrid Gould Ellen is an Assistant Professor of Public Policy and Urban Planning at the Robert F. Wagner Graduate School of Public Service at New York University. Her research centers on neighborhoods, housing, and residential segregation. Her current research projects include a study of how telecommuting affects residential patterns, an examination of how various neighborhood services influence surrounding property values, and a study of the experience of immigrant children in New York City public schools. Dr. Ellen is author *of Sharing America's Neighborhoods: The Prospects for Stable Racial Integration* (Harvard University Press, fall 2000) and has published such journals as in Urban Studies, Brookings-Wharton Papers on Urban Affairs, Housing Policy Debate, and the Journal of Urban Affairs. Prior to coming to NYU, Dr. Ellen held visiting positions at the Urban Institute and the Brookings Institution, served as a research analyst at Abt Associates, and worked at the New York City Department of Housing Preservation and Development. Dr. Ellen attended Harvard University, where she received a bachelor's degree in applied mathematics, an M.P.P., and a Ph.D. in public policy.

Claire L. Felbinger, Ph.D. (Political Science, University of WI-Milwaukee, 1986) is Associate Professor and Chair of the Department of Public Administration at the School of Public Affairs, American University.

Professor Felbinger has written extensively in public works management, urban service delivery, economic development, and evaluation methodology. The second edition of her book, Evaluation in Practice: A Methodological Approach, will be published this year. She is the founding Editor of Public Works Management & Policy, a refereed, multidisciplinary journal concerned with infrastructure systems and the environment. PWMP is the Journal for the American Public

Works Association. She consults regularly for public and non-profit organizations particularly as it involves survey research and data analysis.

Professor Felbinger is active in a number of professional associations including the National Association of Schools of Public Affairs and Administration (President, Pi Alpha Alpha, Chair, Doctoral Committee), the American Society for Public Administration (Chair, Publications; Chair, Goal One Strategic Plan; Board, Section for Women in PA), American Public Works Association (Board, Public Works Historical Society), the Accreditation Board for Engineering and Technology (Board and Engineering Accreditation Commission), National Academy of Sciences (Board on Infrastructure and the Constructed Environment).

Steven J. Fenves is University Professor Emeritus of Civil and Environmental Engineering at Carnegie Mellon University and is currently a Senior Research Associate at NIST in Gaithersburg, MD. Dr. Fenves received his degrees in Civil Engineering from the University of Illinois. He has taught at the University of Illinois (1958-71), Carnegie Mellon University (1972-1998), MIT (1962-3), National University of Mexico (1965, 1975), Cornell University (1969-70), and Stanford University (1997-8). Dr. Fenves' research has dealt with computer-aided engineering, design standards, engineering databases, knowledge-based systems, structural analysis, and design environments. Dr. Fenves is the author of six books and over 300 articles. He is a member of the National Academy of Engineering and an Honorary Member of the American Society of Civil Engineers.

Jesus M. de la Garza is Professor of Civil and Environmental Engineering at Virginia Tech. His areas of interest and teaching include: Construction Engineering and Management, Highway Infrastructure Management, Information Technology in Construction, and Design-Construction Integration. Recent research projects include: A Mobile Tool for Acquisition of Activity Progress Data and Updating of P3/Expedition Project Files, Development of a Highway Maintenance Management System for the Swedish National Road Administration, and Wireless Communication and Computing at the Jobsite. de la Garza has published papers in the ASCE’s Journal of Management in Engineering, Journal of Computing in Civil Engineering, and Journal of Infrastructure Systems. He received the ASCE Faculty of the Year Award and the ASCE Best Paper Award (for Technical Council on Computer Practices, in the Journal of Computing Engineering) in 1998. Before coming to Virginia Tech, de la Garza served as Project Engineer with the ICA Group in Mexico City from 1978-1982. He holds a B.S. in Civil Engineering from Tecnologico de Monterrey and an M.S. and Ph.D. in Civil Engineering from the University of Illinois.

Jonathan L. Gifford directs George Mason University’s master’s program in Transportation Policy, Operations and Logistics in the School of Public Policy. His formal training is in civil engineering (M.S., Ph.D., U.C. Berkeley, 1983; B.S. Carnegie Mellon, 1976). His faculty appointments have been in public policy and management.

He specializes in civil infrastructure systems and public policy. His work examines these complex, often large-scale systems in the context of their social, economic, political and environmental impacts. His work pays particular attention to determining appropriate roles for public, private and non-profit organizations.

He teaches graduate and undergraduate courses in transportation infrastructure policy and planning, policy analysis, information resources, and urban planning. His research has examined the planning and design of large-scale infrastructure systems such as the Interstate highway program, urban transportation systems, and intelligent transportation systems. His publications include four books and more than thirty articles, book chapters and papers. Recent research areas include:

- Asset management institutional and implementation issues;
- Improving public acceptance of urban transportation projects;
- Lessons from institutional restructuring in electric power, telecommunications, highways and air traffic control;
- Institutional issues in technical standard setting; and
- Regional organizations for transportation operations and service delivery.

His professional activities include the Transportation Research Board's committees on Transportation History (secretary), Transportation and Land Development and Strategic Management; the American Society of Civil Engineers, where he chaired the Committee on Urban Transportation Economics and Policy; and the Intelligent Transportation Society of America.

Carl Haas is the Liedtke Centennial Fellow and an Associate Professor of Civil Engineering at The University of Texas at Austin. His research, teaching and consulting are in the areas of advanced construction and transportation technology, and construction workforce issues. He teaches courses in Construction Automation, Sensing in Civil Engineering, Heavy Construction, Engineering Economics, Scheduling, and Project Management. His most recent research is in the areas of rapid local area sensing and modeling for construction automation, 3D scanning and analysis of aggregates, teleoperated robots for hazardous environments, critical construction operations planning, automated infrastructure maintenance, trenchless technologies, remote highway condition and incident detection, and construction workforce issues.

He has received several research awards and recently a UT graduate teaching award. He consults in the area of construction and transportation technology issues. He has over one hundred publications and serves on a number of professional committees such as the Construction Industry Institute Breakthrough Committee. He chairs the TRB A2F09 Committee on Applications of Emerging Technologies, and he directs the UT Construction Automation Laboratory.

Darrene Hackler is an Assistant Professor of Government and Politics in the Department of Public and International Affairs at George Mason University in Fairfax, Virginia. Her current research interests include information technology and economic development in regional economies and information technology innovation in government and non-profits. Her primary research analyzes industrial location patterns of high-technology industry vis-à-vis regional and local economic development policies and telecommunications infrastructure. She has also consulted real estate developers in the implementation of advanced telecommunications infrastructure for master-planned communities, resorts and commercial buildings. Dr. Hackler has published chapters in Annals of Cases on Information Technology, Innovation Policy in the Knowledge-Based Economy, edited by Maryann Feldman and Albert Link, and Cities in the

Telecommunications Age: The Fracturing of Geographies, edited by James O. Wheeler, Barney Warf, and Yuko Aoyama. Dr. Hackler received her M.A. in public policy and Ph.D. in political science and economics from the Claremont Graduate University in Claremont, California.

Richard Hanley is the founding editor of the *Journal of Urban Technology,* a faculty associate of the City University of New York's Institute for Urban Systems, and professor of English at New York City Technical College of the City University of New York. He is currently editing Moving People, Goods, and Information in the Twenty-First Century: Urban Technology, the New Economy, and Cutting-Edge Infrastructures, which will be published in late 2001 by Spon Press. That book emerged from a June conference cosponsored by JUT and the New York Academy of Sciences.

Thomas A. Horan is an internationally recognized expert on the planning of high-technology systems and communities. Dr. Horan currently serves as Executive Director of the Claremont Information and Technology Institute and Associate Professor in the School of Information Science at the Claremont Graduate University, Claremont, California.

Dr. Horan has led a number of major studies and consultations on the impacts of technology on the design of systems and communities in the U.S. and abroad. These activities have include ITS National Systems Architecture development, telecommunications systems analysis in California, Minnesota, Colorado and Mexico, and federal transportation policy analysis for the U.S. government. In addition to his research, Dr. Horan teaches graduate courses on telecommunications networks and information design. Over the last decade, Dr Horan has also held visiting positions at UCLA, University of Minnesota, Harvard University, and MIT.

Dr. Horan has published an array of technical, academic, and professional works on transportation, telecommunications and information technology. Dr. Horan's recent book, *Digital Places: Building Our City of Bits* provides a framework for incorporating digital technology into the design of homes, commercial centers, communities, and regional systems.

Prior to joining Claremont Graduate University, Dr. Horan spent seven years in the Washington, D.C. area. From 1992-94, Dr. Horan was a Senior Fellow at George Mason University and from 1988-1992, Dr. Horan was a Senior Analyst at the U.S. General Accounting Office (GA0). Dr. Horan has both his Master’s and Doctorate degrees from the Claremont Graduate University.

Peter Kissinger is the Senior Vice President of the Civil Engineering Research Foundation (CERF) with executive level responsibility in a range of programs within CERF's mission. Most notably, Mr. Kissinger oversees the day to day management of the CERF Innovation Centers which provide technology verification (evaluation) services for a wide range of technologies across the spectrum of the design, construction, engineering and environmental markets. Mr. Kissinger joined the CERF staff in January 1993, as the Director of Highway Innovative Research. He was responsible for organizing and implementing the first CERF Innovation Center - HITEC (the Highway Innovative Technology Evaluation Center), which serves the highway and bridge community. In January of 1994 when HITEC became operational, Mr. Kissinger became Center's Director, a position that he still holds. In 1994, Mr. Kissinger was named a Vice-President of CERF, assuming executive level responsibilities in several areas, and in 1999 he was named Senior Vice President. In that capacity, Mr. Kissinger's primary focus has been in expanding and refining the collaborative evaluation center concept developed for HITEC so that it could be applied to other markets. Presently, in addition to HITEC, the CERF Innovation Centers include CeITEC (buildings, public works and underground construction technologies), and EvTEC, the Environmental Technology Evaluation Center. Presently, he also has responsibility for working with the CERF Committee on Technology and expanding CERF's business in the information technology arena.

DeWitt Latimer is Co-Investigator on data communication protocols and practices for Construction process integration and construction metrology data integration. Lead on software architecture development for construction process integration to building life-cycle efforts at NIST.

Relevant Publications:

- DeWitt T. Latimer IV, et al, "Automation of Road Surface Quality Assessment: Requirements and Current Technologies", 18th International Symposium on Automation and Robotics in Construction (ISARC), to appear 2001
- DeWitt T. Latimer IV, "Initial Results in Digital Communication of Construction Measurement", 18th ISARC, to appear 2001
- DeWitt T. Latimer IV, "Work towards an Application Protocol to Support Information Exchange in Construction Metrology Applications (LiveView)", NIST Internal Report, pending publication 2001
- DeWitt T. Latimer IV, et al, "Automatic Detection of Significant Variation from Designed Intent Utilizing Survey Data / CIAMS: Construction Information and Management System", 17th ISARC, 2000
- Lawrence E Pfeffer, DeWitt T Latimer IV, "Toward Open Network Data-Exchange Protocols For Construction Metrology and Automation: LiveView", 16th ISARC, 1999

Education:

- MS Civil Engineering (expected 2002), under direction of James Garrett and Burcu Akinci, Carnegie Mellon; topic: automation of inspection tasks on commercial jobsites
- MS Robotics (2001), under direction of William "Red" Whittaker, Carnegie Mellon; topic: multiple robotic coverage techniques for terrain mapping
- BS Mathmatics/Computer Science (1997), Carnegie Mellon

Richard G. Little is Director of the Board on Infrastructure and the Constructed Environment (BICE) of the National Research Council. In the capacity of Director, he develops and directs a program of technical studies in building and infrastructure research. The BICE's program of studies and activities addresses major issues of national significance such as infrastructure and community building; human factors and the built environment; buildings and health; infrastructure systems performance; provision of facilities and services; security and protection of facilities and infrastructure; construction and utilization of underground space; and the economics and financing of infrastructure. Mr. Little has over thirty years experience in the planning, management, and policy development relating to public facilities and infrastructure. He is a member of the Editorial Board of Public Works Management & Policy, the Advisory Board of the National Clearinghouse for Educational Facilities, guest lecturer on infrastructure issues in the Department of Civil, Environmental and Infrastructure Engineering at George Mason University, and reviews books on infrastructure and the built environment for the Journal of

Urban Technology. He has been certified by examination by the American Institute of Certified Planners and is a member of the American Planning Association. Mr. Little holds a B.S. in Geology and an M.S. in Urban-Environmental Studies, both from Rensselaer Polytechnic Institute.

David J. Lovell is an Assistant Professor with the Department of Civil and Environmental Engineering, and an Affiliate with the Institute for Systems Research, at the University of Maryland, College Park, where he has worked for the last four years. His teaching responsibilities include undergraduate and graduate courses in civil and general engineering, including traffic engineering, highway design, traffic flow theory, statistics, and numerical analysis.

Dr. Lovell's research interests are primarily in the areas of traffic flow and control. Currently, he has several grants with the State of Maryland to evaluate rural interchange design alternatives, to evaluate cellular geolocation based traffic surveillance methods, and to design integrated maintenance and traffic plans for construction. He has a grant with Intelligent Automation, Inc., to work on autonomous agent-based traffic signal control and distributed simulation. His other research activities include automation and fault-detection in heavy vehicle convoys, optimal control of freeway entrance metering schemes, algorithms for topographic and sight distance problems related to highway design, algorithms for matching license plate recordings, and aggregate congestion prediction methods for collaborative decision making in the national airspace.

Dr. Lovell serves as Associate Editor of the IEEE Transactions on Vehicular Technology. He reviews papers for many other journals, including Transportation Research, Transportation Science, the Journal of Transportation Engineering, ITS Journal, the Journal of Computing in Civil Engineering, the European Journal of Operational Research, the Journal of Networks and Spatial Theory, and the Journal of Systems and Control Engineering. Dr. Lovell holds memberships in ASCE, IEEE, TRB, ITE, and INFORMS.

Dr. Lovell received a B.A. degree in mathematics from Portland State University, and M.S. and Ph.D. degrees in civil engineering from the University of California, Berkeley.

Elliot Maxwell is presently Senior Fellow for the Digital Economy and Director of the Internet Policy Project for the Aspen Institute's Communications and Society Program. The Communications and Society Program promotes integrated, values-based decision making in the fields of communications, media and information policy and focuses on the impact of communications and information technologies on democratic institutions, the economy, individual behavior, and community life.

Prior to joining the Institute, Maxwell was Special Advisor to the Secretary of Commerce for the Digital Economy. In this position he served as principal advisor to the Secretary on the Internet and Electronic Commerce. He coordinated the Department's efforts to establish a legal framework for electronic commerce, ensure privacy, protect intellectual property, increase Internet security, encourage broadband deployment, expand Internet participation, and analyze the impact of electronic commerce on all aspects of business and the economy. He was part of the U.S. Government Interagency Working Group on Electronic Commerce since its creation.

Previously, Maxwell worked for a number of years as a consultant and as Assistant Vice President for Corporate Strategy of Pacific Telesis Group where he combined business, technology, and public policy planning. He served at the Federal Communications Commission as Special Assistant to the Chairman, Deputy Chief of the Office of Plans and Policy, and Deputy Chief of the Office of Science and Technology and as Director of International Technology Policy at the Department of Commerce. Maxwell also worked for the U.S. Senate as Senior Counsel to the U.S. Senate Select Committee on Intelligence Activities.

Maxwell graduated from Brown University and Yale University Law School. He has written and spoken widely on issues involving electronic commerce, telecommunications, and technology policy.

William J. Mitchell is Dean of the School of Architecture and Planning at MIT, where he holds a joint Professorship in Architecture and in Media Arts and Sciences. He teaches courses and conducts research in design theory, computer applications in architecture and urban design, and imaging and image synthesis. A Fellow of the Royal Australian Institute of Architects, Mitchell taught previously at Harvard's Graduate School of Design and at UCLA. His most recent book, *E-Topia: Urban Life Jim — But Not As We Know It*, explores the new forms and functions of cities in the digital electronic era. His earlier books include: the edited volume *High Technology and Low-Income Communities* (with Donald A. Schon and Bish Sanyal); *City of Bits: Space, Place, and the Infobahn* (also published on-line at http://www-mitpress.mit.edu/City_of_Bits); *Digital Design Media* (with Malcolm McCullough, two editions); *The Reconfigured Eye: Visual Truth in the Post-Photographic Era*; and *The Logic of Architecture: Design, Computation, and Cognition.*

Patricia L. Mokhtarian has specialized in the study of travel behavior for more than 20 years. A key research interest has been the impact of telecommunications technology on travel behavior, with additional interests in congestion-response behavior, attitudes toward mobility, adoption of new transportation technologies, land use and transportation interactions and the transportation/air quality impacts of transportation demand management measures. She has directed or participated in more than a dozen projects related to these areas, involving extramural funding totaling about $4 million. She has authored or co-authored more than 90 refereed journal articles, technical reports, and other publications.

Recent studies focus on modeling the individual decision to telecommute, implementing and evaluating the institutional viability and transportation effectiveness of telecommuting centers, modeling the transportation and air quality impacts of telecommuting, and analyzing the travel and communications impacts of computer-mediated communication. She has explored conceptual issues relating to whether telecommunications and travel are substitutes or complements (or both), examined the potential transportation impacts of tele-shopping, and conducted a small empirical study of the transportation impacts of teleconferencing. She is currently directing a study of travelers' responses to congestion, and a new study of individuals' attitudes toward mobility.

Dr. Mokhtarian has presented her research on telecommuting and telecommunications planning in numerous classroom and professional society meeting settings throughout the United States and abroad. She has given invited presentations in Delft, the Netherlands; Mexico City, Mexico; Tokyo and Yokohama, Japan; Singapore; Sydney and Brisbane, Australia; Stockholm and Linkoping, Sweden; Jerusalem and Haifa, Israel; Ottawa, Canada; and Vienna, Austria.

Dr. Mokhtarian joined UC Davis in 1990, after nine years in regional planning and consulting in Southern California. She obtained her Ph.D. in Operations Research from Northwestern University in 1981, and an M.S. in OR from Northwestern in 1977. Her undergraduate degree (summa cum laude) is in Mathematics, from Florida State University.

Charles W. Newton is the President of Newton-Evans Research Company, a Maryland-based research firm that studies technology trends affecting the world's electric, gas and water utility industries. His company has been actively researching global utility markets on a proprietary and multi-client basis for more than 25 years. The company is known primarily for its work related to SCADA technology and related IT market research.

Prior to forming Newton-Evans Research Company, Chuck spent five years as an applications planning manager with General Electric's Information Services business. From 1969-1973, Chuck was a product manager with Control Data's OCR Division.

Mr. Newton received an MBA from Loyola College in Maryland and a BA degree in Economics from Fordham University in New York City, and is a graduate of the U.S. Army's Non-Commissioned Officers Academy. Professional memberships include CIGRE, AWWA, AMRA, CASRO and the IEEE Power Engineering Society.

Mr. Newton is the ***Automation Perspectives*** columnist for **Transmission & Distribution World** magazine and is a frequent participant in national and international energy industry conferences.

William J. O'Brien is currently Assistant Professor of Civil Engineering at the University of Florida where he teaches in the Construction Engineering and Management program. Dr. O'Brien holds a Bachelor of Science in Civil Engineering from Columbia University and a Master of Science and Ph.D. in Civil Engineering from Stanford University. He also holds a Master of Science in Engineering-Economic Systems from Stanford University.

Dr. O'Brien was the first employee and Vice President of Marketing and Product Development for Collaborative Structures, a venture capital financed, Internet start-up company based in Boston, Massachusetts. He oversaw the design definition and development of two generations of collaborative web-site tools. Dr. O'Brien also worked widely with customers to understand deployment issues and value to client organizations. The assets of Collaborative Structures were recently acquired by E-Builder, Inc., a related firm.

At the University of Florida, Dr. O'Brien focuses his teaching and research in construction information and systems engineering. He leads research projects in understanding the use and assessing the value of information in project environments. This research is conducted collaboratively with users and developers of information tools and is directed at improving software products. As part of this effort, Dr. O'Brien teaches a class on "Collaborative Design Processes" where multi-disciplinary student teams use commercial information tools to deliver a small design project. Dr. O'Brien also participates in a research project to develop next generation enterprise systems that can be rapidly deployed in project environments. His contribution to this National Science Foundation sponsored research is to formalize cost and resource information models, enabling scalable links to legacy systems.

Dr. O'Brien is active in many professional organizations including the ASCE, where he is chairman of the Scalable Enterprise Systems task group of the Intelligent Computing Committee. He is also a member of the CIB Benchmarking Construction Performance Task Group.

Michael Royer is a physical scientist with the U.S. Environmental Protection Agency's National Risk Management Research Laboratory, Water Supply and Water Resources Division in Edison, New Jersey. His main area of research responsibility and interest is the potential for preventing structural integrity failures in drinking water distribution and wastewater collection systems through improved condition assessment monitoring technology that enables proactive, cost-effective maintenance, rehabilitation, and replacement.

Jeffrey Russell, **P.E.** (BSCE, University of Cincinnati, MSCE, Purdue University, PhD, Purdue University) is a Professor in the Department of Civil and Environmental Engineering at the University of Wisconsin-Madison. He has served on the faculty at the UW since 1989.

He is the recipient of the 1991 ASCE Collingwood Prize, 1993 ASCE Edmund Friedman Young Engineer Award, 1996 ASCE Walter L. Huber Civil Engineering Research Prize, 1996 ASCE Thomas Fitch Rowland Prize, 1996 One of Top 25 Newsmakers in Engineering News Record (ENR), and 1997 National Society of Professional Engineers (NSPE) Southwest Chapter Engineer of the Year in Education.

He is the author of numerous journal papers on predicting construction contractor failure prior to contract award and contractor prequalification. He has authored two books, both published by ASCE Press entitled," Constructor Prequalification: Choosing the Best Constructor and Avoiding Constructor Failure, 1996, and Surety Construction Contract Bonds, 2000.

Dr. Russell is currently the District 8 Representative on the ASCE National Board of Direction. He has served as Editor-in-Chief of the ASCE Journal of Management in Engineering from 1995-2000 and is currently the Editor-in-Chief of the ASCE Leadership and Management in Engineering publication.

Richard E. Schuler currently directs the Cornell Institute for Public Affairs, a cross disciplinary professional program with five core faculty members that enrolls 55 candidates for the MPA degree. His teaching and research at Cornell have emphasized the location, management, pricing and environmental and regional economic consequences of public infrastructure and utilities. He holds a joint faculty appointment as Professor of Economics in the College of Arts & Sciences and Professor of Civil and Environmental Engineering in the College of Engineering since 1972. He organized and directed for six years both the Cornell Waste Management Institute and the affiliated New York State Solid Waste Combustion Institute, interdisciplinary programs of research, outreach and teaching that were funded at $5 million.

A registered professional engineer, Dr. Schuler, while on leave from Cornell, served as a Commissioner and Deputy Chairman of the New York State Public Service Commission from

1981 to 1983 where he was instrumental in implementing structural changes in the regulation of utilities. Prior to that, Dr. Schuler was Director of the New York State Public Service Commission's Office of Research. Before returning to graduate school, he was senior fuels and energy economist with Battelle Memorial Institute for two years, and from 1959 to 1968 he was an engineer and manager with the Pennsylvania Power and Light Company. Dr. Schuler is a frequent contributor to scholarly journals with articles in the American Economic Review, Transportation, Journal of Economic Theory, Journal of Regional Science, and Journal of Industrial Economics, among others. His book, The Future of Electrical Energy: A Regional Perspective of an Industry in Transition, co-authored with Sid Saltzman, was published in October 1986. His current research includes conceptual analyses of efficient size and complexity of institutions; the role of infrastructure in supporting modern societies; developing voluntary international accords to reduce greenhouse gases; optimal pricing structures over space and time for solid waste disposal, telecommunication systems, and natural gas pipelines; analyses of alternative organizations and practices for the electric utility industry in the United States under evolving technologies, originally funded by the National Science Foundation; and an exploration of the lagged adjustment of price differences in oligopolistic (formerly regulated) markets.

He is currently on the executive committee for the NSF-sponsored Institute for Civil Infrastructure Systems and he serves on the editorial board of the Journal of Industrial Ecology. Dr. Schuler has been a visiting scholar at the Center for Operations Research and Econometrics at the Catholique Universite de Louvain, Belgium, a visiting professor at the Fuqua School of Business at Duke University, and a visiting Fellow at Princeton University. He has served as a consultant to numerous government and regulatory agencies and to private industries on long-range planning, pricing, economic forecasting, and regulatory issues, and he is a member of the National Institute of Standards and Technology's advisory panel for Building and Fire Research. He served on the Cornell Board of Trustees as a member of their executive committee for four years, and he is currently a board member of the New York State Independent System Operator (responsible for overseeing transmission operation and electricity markets in a deregulated environment). The Washington Monthly named him one of twelve "stars of state government" in 1982.

Kathleen E. Stein is a Principal and founding partner of Howard/Stein-Hudson Associates, a transportation planning and public involvement firm based in Boston and New York City. For ICIS, Kathy has assisted in developing its strategic plan and has participated in its performance measurement and public involvement best practices projects. Kathy leads her firm's work in intelligent transportation systems, including projects for the I-95 Corridor Coalition on integrated, multi-modal electronic payment services and, for the National 511 Coalition, on deployment of a nationwide traveler information system.

She led HSH's work to develop guidelines on public involvement in transportation planning and decision making for the Federal Highway Administration and Federal Transit Administration. Throughout her career, Kathy has designed and implemented innovative public involvement programs for long range transportation plans and highway, transit, and airport projects. She is Principal Investigator for a National Cooperative Highway Research Program project on customer-based decision making in state departments of transportation.

Kathy is past chair of the Transportation Research Board's Public Involvement, Strategic Management, and Management and Productivity Committees. She recently completed service as chair of the Board's Division A Council, overseeing the work of TRB's 180 committees. She also served as President of the Greater New York chapter of Women's Transportation Seminar. She holds a BA with Distinction from Mount Holyoke College and a Master of Regional Planning from the University of North Carolina.

Vincent C. Thomas is an Economic Development Specialist for New York State Assemblyman Albert Vann. Mr. Vann is Chairman of the Standing Assembly committee of Corporations, Authorities and Commissions that has legislative oversight of the New York State Public Service Commission, the regulatory body for telecommunications and cable television. Mr. Thomas also supports the Assemblyman's role as Chairman of Telecommunications and Energy for the National Black Caucus of State Legislators, specializing in the identification of opportunities for minority and non-profit businesses in the converging telecommunications marketplace.

Mr. Thomas is also a member of the Board of the Alliance for Public Technology. APT is an umbrella organization of non-profit institutions, state and local government and advocacy groups dedicated to insuring that the public generally and at risk populations specifically have access to the new information technologies to enhance opportunity and civic participation by all. The Alliance sponsors conferences and forums on a nationwide basis to achieve these aims.

Mr. Thomas' current work follows his recent activity as the Telecommunications Policy Analyst for the New York State Department of Economic Development. He provided staff support to the Governor's Telecommunications Exchange, a blue ribbon panel of Telecommunications providers and users chaired by John Phelan, formerly president of the New York Stock Exchange. The Exchange report, delivered to Governor Mario M. Cuomo, December 28, 1993, is considered a ground breaking policy document on how the telecommunications future should be approached. He was also responsible for the development of telecommunications initiatives on behalf of the Department's Global New York export program. This included a telecommunications business exchange between New York State and the Jiangsu Province in China.

Prior to joining New York State Government, Mr. Thomas has led an active career in broadcasting and communications advocacy. He spent most of his career in Public Broadcasting. As General Manager or management consultant, he has upgraded or placed on the air 5 non-commercial radio stations in major markets along the Northeast corridor, including Pacifica Foundation stations in Washington, D.C. and New York City.

Mr. Thomas' international experience includes organizing and leading business and cultural delegations to Brazil. He has lectured on the utilization of telecommunications as a strategic industry for global competitiveness and as a spur for technology transfer opportunities at an international conference on technology transfer in Bahia, Brazil.

Vincent C. Thomas is a graduate of Brown University with a BA in Communications. Mr. Thomas is a native Washingtonian currently living in New York City and Albany N.Y.

Costis Toregas has worked at Public Technology, Inc. (PTI) for more than 30 years, dedicating his exceptional energy and skills to his unwavering vision: that of strengthening local governments through the harnessing and effective use of technology. Since becoming President of PTI in 1985, he has steered the organization to unprecedented success by creating innovative public/private partnerships which satisfy PTI's technology development and transfer mandate and develop strong rewards for both sectors. He has inspired innovative leadership among elected and appointed local government officials, both through lectures to their national assemblies and by working with them individually to define bold new directions for their jurisdictions using technology.

Dr. Toregas recently spearheaded a broad national awareness campaign on the Year 2000 computer problem, as well as one on the National Information Infrastructure (NII) and its potential for local governments. Striving to establish partnerships among government entities, he helped found the Intergovernmental Enterprise Panel, a partnership of federal, state and local governments supporting the provision of seamless service to citizens through advanced information technology. Dr. Toregas supports the concept of sustainability, or balancing economic development with environmental concerns, as an important local theme.

Dr. Toregas is a fellow of the National Academy of Public Administration, the International City/County Management Association, the National Forum for Black Public Administrators, and the National Press Club. As an ICMA member, Dr. Toregas is an officer of its DC chapter; as an NFBPA member, he sits on its Policy Committee for the Washington, DC Chapter.

In order to foster business opportunities among organizations similar to PTI worldwide, Dr. Toregas was instrumental in establishing, and serves as Program Director of, the International Daughter Companies Network (IDCN) within the framework of the International Union of Local Authorities (where he served as North America Secretary General). He also was a founder of the International Council for Local Environmental Initiatives (ICLEI) and recently completed an 8 year service on its executive committee.

He participates on the Board of Directors of the Advanced Networked Cities and Regions Association based in Eindhoven, the Netherlands, and on the Board of the Dynatem Corporation.

Dr. Toregas has a strong reputation for a dynamic speaking style, inspiring his audiences with his vision for change in service to citizens. He frequently keynotes sessions and moderates workshops on technology, innovation, and change for PTI's three national sponsors, the National League of Cities, the National Association of Counties, and the International City/County Management Association, and for many local, national and international groups. Dr. Toregas has actively raised awareness of local government technology issues at conferences of state municipal leagues, state county associations, Government Technology's Conference and large corporations. Dr. Toregas is a regular lecturer at NFBPA's Executive Leadership Institute (ELI).

Dr. Toregas holds PhD, MSc and BSc degrees in Environmental and Electrical Engineering from Cornell University. Dr. Toregas is married and has two children.

Anthony Townsend is a Research Scientist and Lecturer of Public Administration at the Taub Urban Research Center at New York University. He has served as a technology consultant to major information technology companies including Nortel Networks, Quova, and Telegeography, Inc and has developed relationships with research groups at Ericsson, Intel Corporation, and AT&T. Prior to graduate school, Anthony worked as a technical support manager for several years at a regional Internet Service Provider in New Jersey and AT&T WorldNet. He is the author of over a dozen scholarly articles and book chapters on the impacts of new information and communications technologies on urban and regional development. His articles have also appeared widely in the trade press, including Computerworld, On (Corporate magazine of Ericsson), and Wired News. Currently, he is completing a Ph.D. dissertation at Massachusetts Institute of Technology on information technology and urban design. He holds a Masters of Urban Planning from New York University, and a Bachelor of Arts from Rutgers University.

John Voeller is a Senior Vice President and Chief Knowledge Officer and Chief Technology Officer at Black & Veatch. He is a member of the corporate management team and has responsibility for all strategic technology decisions. He is currently focused on creation of a completely new knowledge management approach that is termed decision-centric which is designed to enable the fifth generation of engineering and construction advancement for the firm.

Mr. Voeller is responsible for the creation of five and ten year automation strategies. He is the principal architect of POWRTRAK, the automated engineering system of Black & Veatch that fueled its movement from thirteenth to first in the U.S. and the world in power plant design and delivery. This unique system has been reviewed in articles in ENR, Forbes ASAP, and CIO.

During his tenure as head of computing for the firm, has overseen the migration of all data domains from a VAX minicomputer/VT-100 terminal environment using a proprietary relational database engine called a Britton-Lee to a Windows/NT/Sun heterogeneous client server and web-based environment using C++, Java, agents, and AI and using an SEI/CMM development regimen. This environment has received awards from Network World, Computerworld, CIO, InfoWorld, etc.

Mr. Voeller is CEO and President of Data Discovery, Inc. which sells his recursive search technology. He is CEO and President of General Integration Corp., specializing highly collaborative environments. He is Board member of Design Build Partners and e-Builder, two e-commerce start-ups. He is a Board member of the Civil Engineering Research Foundation. He was recently named by governor of Kansas as Board member of Kansas Technology Enterprise Corp. He was also a Board member of Digital Archaeology and advises boards of several other new firms. He has also advised ASME, AISC, ASCE, CII, CERF, NRC and NIST on automation.

He has patented a new kind of scanning technology, has invented a new LADAR-based 3D environment scanning technology, and a new interface that works like the human eye. Mr. Voeller has invented recursive persistent web search technology not yet seen in any commercial tools and agent-based anomaly discovery and correction technology for multi-enterprise collaboration coordination. He has been president of PlantSTEP, a consortium focused on creating data exchange standards for the process and power industry. He also advises the PIEBASE global consortium.

William Wallace is Professor, Decision Sciences and Engineering Systems, Rensselaer Polytechnic Institute and Research Director of Rensselaer's Center for Infrastructure and Transportation Studies. As a researcher and a consultant in Management Science and Information Systems, Professor Wallace has over 25 years experience in and research on the development of decision technologies for industry and government. He is presently engaged in research on the application of artificial intelligence to problems in incident management and emergency response, issues in trust and ethical decision making, and in studying the impact of visualization technologies on problem solving and decision making. Professor Wallace has, since 1990, authored and edited 6 books and over 70 articles and papers - out of a total of over 200 archival publications. He has held academic positions at Carnegie-Mellon University and the State University of New York at Albany, was a research scientist at the International Institute of Environment and Society, Science Center, West Berlin, Germany and a project engineer at Illinois Institute of Technology Research Institute; was Visiting Professor, Polyproject: Risk and Safety of Technical Systems, Swiss Federal Institute of Technology, Zurich, and Visiting Professor, Faculty of Systems Engineering and Policy Analysis, Delft University of Technology, Delft, Netherlands. He was selected as a Visiting U.S. Faculty, Management Information Systems, Decision Support Systems, National Center for Industrial Science and Technology Management Development, Dalian, People's Republic of China. Professor Wallace recently was an Expert, Division of Civil and Mechanical Systems, National Science Foundation, and Consultant, Board on Infrastructure and the Constructed Environment, National Research Council, National Academies. His awards include the International Emergency Management Conference Award for Outstanding Long-Term Dedication to the Field of Emergency Management and Third Millennium Medal from The Institute of Electrical and Electronics Engineers (IEEE). His educational background includes a B.Ch.E. from Illinois Institute of Technology and a Master of Science and Doctorate in Management Science from Rensselaer Polytechnic Institute. Professor Wallace is a Navy veteran.

Richard Wiesman is Vice President of Foster-Miller, Director of Foster-Miller's Electrical and Electronic Systems Group (EES), and a Director of GridCom International, Inc. He has an extensive background in program management; systems engineering; computer modeling and simulation; electromechanical design and analysis; and distributed controls, smart sensors and communications. He joined Foster-Miller in 1983, and has utilized his expertise in a number of areas including:

- Distributed controls, smart sensors and communications systems.
- Mobile robotic systems.
- Automatic high speed manufacturing and testing systems.
- Heavy machinery and industrial equipment.
- Power generation and conditioning.
- Active and passive magnetic shielding methods.

Foster-Miller is a 45-year-old company that develops and designs new processes, products and technologies for commercial, utility and government customers. The Electrical and Electronics Systems Group at Foster-Miller develops electro-mechanical and electro-magnetic products and systems; special electric actuators; active and passive electro-magnetic shielding systems; advanced distributed sensor networks and controls; photonics; and distributed power controls.

Dr. Wiesman has managed the development of intelligent sensor systems. These intelligent sensors and sensor networks utilize a wide range of sensing and information processing techniques to monitor, supervise, and communicate conditions and functional parameters of many infrastructures and processes. These infrastructures and processes may include: electric power distribution systems; water distribution networks; data and telecommunications installations and networks; industrial processes and facilities; transportation systems including highways, bridges, rail, and transmission piping; and vehicle systems including aircraft and ship health monitoring.

GridCom International produces effective intelligent sensing systems for electric power distribution automation. GridCom sensor systems can perform sensing operations, prioritize sensed conditions and communicate sensed conditions to supervising or decision making stations. Sensors can be installed in overhead or underground systems and provide sensing of current, voltage, harmonic distortion, power factor, temperature, and virtually any other desired system parameters. The embedded micro-controller-based sensors are inexpensive, require no maintenance, are extremely simple to install, and incorporate communications. The sensors form the base of a hybrid hierarchical control and communications architecture for monitoring and controlling power distribution infrastructures.

Dr. Wiesman received his Science Bachelors, Science Masters and Ph.D. degrees in Mechanical Engineering from The Massachusetts Institute of Technology.

Lyna Wiggins received a Ph.D. in City and Regional Planning from the University of California, Berkeley in 1981, a M.S. in Statistics from Stanford University in 1972, and a B.S. in Mathematics from California Polytechnic State University, San Luis Obispo, in 1971. She taught at Stanford University (civil engineering) from 1981 to 1989, at MIT (Urban Studies) from 1989 to 1993, and is currently at Rutgers University. At Rutgers, she is an Associate Professor of Urban Planning and Policy Development, and Chair and Graduate Director of the Department. Her teaching responsibilities include courses in planning methods, computer applications in planning, and Geographic Information Science.

Wiggins' research interests focus on planning methods and computer applications in planning, particularly expert systems and urban Geographic Information Systems. She is the co-editor of two books on expert systems applications in planning (Expert Systems: Applications in Urban Planning, Spinger-Verlag, 1990; Expert Systems in Environmental Planning, Springer-Verlag, 1992). Recent funded research includes work on GIS applications in transit planning (University Transportation Center, MIT; National Transit Institute, Rutgers University), in housing and crime analysis (U.S. Department of Housing and Urban Development), hazards modeling (NJ State Police) and urban brownfields redevelopment (Office of State Planning, New Jersey) and historical and cultural resources (State Historic Preservation Office, New Jersey). Wiggins has also conducted a number of GIS user needs assessments for local governments and state agencies in California, Massachusetts, New Jersey, and New York.

Wiggins is a member of the Mapping Science Committee of the National Academy of Sciences/National Research Council. She is on the editorial board of Geospatial Solutions. Wiggins is currently the President of the Urban and Regional Information Systems Association, and a Board member of the International Geographic Information Foundation.

Lawrence Wood is a Ph.D. student in the Penn State Department of Geography. Lawrence received his B.S. degree from Franklin and Marshall College and an M.S. degree in Geography from Penn State University. While working on a Ph.D., he is also pursuing a concurrent M.S. in Agricultural Economics. His research interests include economic geography, rural development, regional development, and telecommunications. Lawrence has worked as a consultant for the

Appalachian Regional Commission as well as the Economic Development Administration, and he has also worked as a research assistant for the Center for Integrated Regional Assessment as well as for the Institute for Policy Research and Evaluation, both of which are affiliated with Penn State University. His advisor is Dr. Amy Glasmeier, with whom he has completed a variety of research projects.

Lawrence has various publications, including the following: *On Hold: Telecommuniations in Rural America* (co-authored with Dr. Amy K. Glasmeier and published by the Economic Policy Institute); *Will Rural America be Left Permanently "Off-Line" in an Era of Rising Telecommunications Connectivity? Telecommunications Options and Challenges for Rural Communities* (co-authored with Dr. Amy K. Glasmeier and published by the Institute for Policy Research and Evaluation); and *Growth Centers in Regional Planning: The Experience of Appalachia and the Appalachian Regional Commission* (Published in *Environment and Planning A*, March 2001). His doctoral dissertation research is focusing upon equity in regional development, while his M.S. research in Agricultural Economics will assess the current status of telecommunications infrastructure in rural Pennsylvania.

Richard Wright's professional experience includes: junior engineer with the Pennsylvania Railroad, 1953 to 1955; U.S. Army 1955 to 1957; instructor to professor of civil engineering at the University of Illinois at Urbana from 1957 to 1974; and, at the National Institute of Standards and Technology: Chief of the Structures Section, Building Research Division 1971 to 1972; Deputy Director-Technical, Center for Building Technology, 1972 to 1973; Director, Center for Building Technology 1974 to 1990; and Director, Building and Fire Research Laboratory 1991 to 1999.

Dr. Wright has published over 100 articles on building and fire research, computer-integrated construction, formulation and expression of standards, performance of structures, structural design methods for earthquakes and other dynamic loads, flow and fracture in structural metals and mechanics of thin-walled beam structures.

He is Chairman of the Board on Infrastructure and Constructed Environment of the National Academies; member of the Technical Activities Committee of the American Society of Civil Engineers; President of the Board of Montgomery Village Foundation; founding and past Co-chairman of the Subcommittee on Construction and Building of the National Science and Technology Council; past Chairman of the Interagency Committee on Seismic Safety in Construction; past U.S. Chairman of the U.S.-Japan Panel on Wind and Seismic Effects; past president of the International Council for Research and Innovation in Building and Construction (CIB); fellow of the American Society of Civil Engineers and the American Association for Advancement of Science; and member of the Earthquake Engineering Research Institute, the American Association for Wind Engineering, Sigma Xi, Phi Kappa Phi, and Tau Beta Pi. He registered as a professional engineer in New York in 1958 and as a structural engineer in Illinois in 1974.

He received the Gold Medal Award of the Department of Commerce in 1982 for distinguished achievement in the Federal Service, the Rank of Meritorious Executive from the President in 1988; the Special Presidential Award of the Illuminating Engineering Society of North America in 1983 for contributions to the organization of the Lighting Research Institute; the Federal Engineer of the Year 1988 award of the National Society of Professional Engineers, the 1998

Charles Mahaffey Award of the National Conference of States on Building Codes and Standards, and the 1999 Henry L. Michel Award for Industry Advancement of Research from the Civil Engineering Research Foundation

Rae Zimmerman is Professor of Planning and Public Administration, Director of the Urban Planning Program and the Director of the Institute for Civil Infrastructure Systems (ICIS). ICIS promotes collaboration among disciplines and interests around urban infrastructure issues. She teaches and conducts research in environmental management and planning, urban infrastructure, and environmental health risk management and impact assessment, and the socioeconomic dimensions of environmental and transportation infrastructure. Specific research areas have included the social and environmental performance measures of urban infrastructure services, adaptability of agency decision-making in the NY region to global climate change, farmer attitudes toward the environment and adoption of agricultural practices that protect water quality, and social and economic characteristics of communities with inactive hazardous waste sites.

She is a Fellow of the American Association for the Advancement of Science and a past president and Fellow of the international Society for Risk Analysis. Current and recent professional appointments include the U.S. EPA National Drinking Water Advisory Council (NDWAC) Working Group on Drinking Water Research, the U.S. EPA Board of Scientific Counselors, U.S. EPA Science Advisory Board Subcommittee on Residual Risk, and the National Research Council Board on Infrastructure and the Constructed Environment. Professor Zimmerman has directed research projects for the U.S. Environmental Protection Agency, the National Science Foundation, the U.S. Department of the Interior, the Joint Economic Committee of the U.S. Congress, and the New York State Department of Transportation.

Her publications have appeared in several edited works as well as in numerous planning, environmental and public administration journals. Relevant publications in infrastructure include the following areas: impacts of the 1993 Mississippi Floods (*The Sciences*, 1994); environmental equity (*Fordham Urban Law J.*,1994; *Risk Analysis,* 1993; chapters in *Fundamentals of Risk Analysis and Risk Management*, 1997 and *Better Environmental Decisions*, 1999); global warming impacts on infrastructure (NY Academy of Sciences, 1996); and risk methodology (co-author, risks of extreme events in *Risk Analysis*, 1999). Other relevant publications are on environmental attitudes associated with agricultural pesticides (*Water Resources Research*, 1999; *Risk Analysis*, 1999; *Agriculture, Ecosystems and Environment*, 1999). Selected earlier publications include chapters in books such as *Dimensions of Hazardous Waste Politics and Policy* (Greenwood, 1988), *Public Health and the Environment* (Guilford, 1987), *Risk Evaluation and Management* (Plenum, 1986), *Risk Analysis in the Private Sector* (Plenum, 1985), and *Low Probability/High Consequence Risk Analysis* (Plenum, 1984). She has been a consultant to the U.S. Environmental Protection Agency's Superfund program (Region II office) conducting studies of environmental equity around hazardous waste sites, and a consultant to various engineering and planning consulting companies on environmental and social aspects of infrastructure projects. Prior to that, she was with U.S. EPA in water resources management and then was a consultant on environmental impact assessment until 1977. Education: A.B., Chemistry, U. of California (Berkeley); Master of City Planning, U. of Pennsylvania; Ph.D., Planning, Columbia University.

Participants from the National Science Foundation

Dr. Joseph Bordogna is Deputy Director and Chief Operating Officer of the National Science Foundation (NSF), having served previously as head of NSF's Directorate for Engineering. Complementary to these tasks, he has chaired committees on Manufacturing, Environmental Technologies, and Automotive Technologies in the President's National Science and Technology Council (NSTC) and served as a member of the NSTC Committees on Environment and Natural Resources (CENR) and on Technological Innovation (COT). He was also a member of the U.S.-Japan Joint Optoelectronics Project.

In addition to his recent government service, his career includes experience as a line officer in the U.S. Navy, a practicing engineer in industry, and a professor. Immediately prior to his appointment at NSF, he served at the University of Pennsylvania as Alfred Fitler Moore Professor of Engineering, Director of The Moore School of Electrical Engineering, Dean of the School of Engineering and Applied Science, and resident Faculty Master of Stouffer College House, a living-learning student residence. He also served his profession as worldwide President of the Institute of Electrical and Electronics Engineers (IEEE).

He holds the B.S.E.E. and Ph.D. degrees from the University of Pennsylvania and the S.M. degree from the Massachusetts Institute of Technology.

Dr. Miriam Heller directs the National Science Foundation's Civil and Mechanical Systems Program on Civil Infrastructure Information Systems, which targets cutting-edge research in information technology at the interface of construction engineering and management, transportation systems management, and integrated hazard management.

Prior to joining NSF, Dr. Heller was with Université Aix-Marseille III in France as a 1999-2000 Fulbright Scholar researching life cycle assessment of semiconductor manufacture. She was on leave from the Industrial Engineering faculty at the University of Houston, where her research broadly addressed the use and adaptation of systems engineering methodologies and tools to civil infrastructure and environmental systems problems, such as decision support tools for the design of industrial wastewater systems, systemic costing of innovative potable water treatment plants, life cycle costing tools for sewers, forecasting potable water demand, environmental accounting in the petrochemical and refining industries, and the use of life cycle assessment for product climate neutrality evaluation. Dr. Heller's industry experiences include Digital Equipment Corporation, Citibank Credit Services, and a French subcontractor for Lyonnaise des Eaux. She is an active member of the American Society of Civil Engineers TAC Subcommittee on Sustainability, the American Water Works Association (Computer Research and the Utility Communications Committees), the American Water Works Association Research Foundation as a frequent Project Advisory Committee member, and the Natural Disaster Roundtable. Additionally, Dr. Heller's professional memberships include ASCE, ACS, IEEE, INFORMS, Institute for Industrial Engineers, and Society for Women Engineers. She has participated in Yale's: Environmental Reform-The Next Generation, Houston Advanced Research Center's Foresight Panels for Comparative Risk Assessment, and the Steering Committee of Houston's Gulf Coast Institute. Miriam earned her Ph.D. at The Johns Hopkins University in the Department of Geography and Environmental Engineering.

Dr. Priscilla Nelson is Director of the Civil and Mechanical Systems (CMS) Division in the Directorate for Engineering at the National Science Foundation (NSF). She has been at NSF since 1994, and previously served as Program Director for the Geotechnical Engineering program, and as Program Manager for the NEES (Network for Earthquake Engineering Simulation) project which represents an $82 million federal investment in earthquake experimentation equipment to be completed between FY2000 and FY2004.

Dr. Nelson was formerly Professor of Civil Engineering at The University of Texas at Austin. Her undergraduate degree is from the University of Rochester in Geological Sciences, and she has received three earned advanced degrees including Master's degrees in both Geology (Indiana University) and Structural Engineering (University of Oklahoma). In 1983, she received her Ph.D. from Cornell University in Geotechnical Engineering. Dr. Nelson has a national and international reputation in geological and rock engineering, and the particular application of underground construction. She has more than 15 years of teaching experience and more than 120 technical and scientific publications to her credit.

Dr. Nelson is Past-President of the Geo-Institute of the American Society of Civil Engineers, and a lifetime member and first President of the American Rock Mechanics Association. Among many professional affiliations, she is an active member of the American Underground-Construction Association, the Association of Engineering Geologists, and the International Tunneling Association. She has served as a member of several National Research Council boards and committees.

Dr. Ronald L. (Ron) Rardin is Program Director for Operations Research and Production Systems with the National Science Foundation, on rotator assignment from his permanent position as Professor of Industrial Engineering at Purdue University in West Lafayette, Indiana. Born and raised in the Kansas City area, he obtained his B.A. and M.P.A. degrees from the University of Kansas. After working in city government, consulting and distribution for five years, he continued his education at the Georgia Institute of Technology, receiving a Ph.D. in Industrial and Systems Engineering in 1974. Then he remained as a faculty member at Georgia Tech for nine years before moving to Purdue in 1982.

Professor Rardin's teaching and research interests center on optimization modeling and algorithms, particularly large-scale integer and combinatorial problems. He is co-author of numerous research papers in that field, as well as a graduate text Discrete Optimization, published in 1988, and a comprehensive undergraduate textbook Optimization in Operations Research. His many honors include three times winning Purdue University's Pritsker Award for outstanding undergraduate teaching in industrial engineering, serving as an Associate Editor for Management Science and the INFORMS Journal on Computing, and sabbatical appointments at the Center for Operations Research and Econometrics in Louvain La Neuve, Belgium and the University of Michigan at Ann Arbor. He is a member of the Institute of Industrial Engineers, the Institute for Operations Research and Management Sciences, and the Mathematical Programming Society, and has served IIE as an ABET accreditation visitor for industrial engineering programs.

Dr. Frank P. Scioli is Program Director, Political Science Program of the Division of Social and Economic Sciences at the National Science Foundation.

Federal Government Experience:

- Program Director, Political Science Program, 1981-present.
- Program Director, Urban Research Initiative, 1998-99.
- Section Head, Division of Social Sciences, 1981-85.
- Acting Division Director, Division of Applied Research, June 1980-January 1981.
- Section Head, Division of Applied Research, September 1978-March 1981.
- Program Manager, Research Applied to National Needs Directorate, December 1975-September 1978.

Academic and University Experience:

- Visiting Professor, Department of Political Science, Howard University, 1986-97. Taught Research Methods in Public Administration (Fall) and Public Policy Evaluation (Spring).
- Adjunct Professor, Department of Public Administration, George Washington University, 1979-82.
- Adjunct Professor, Graduate School of Management and Urban Professions, New School for Social Research.
- Associate Professor, Department of Political Science, University of Illinois, Chicago, 1973-77 (on leave, NSF, December 1975-December 1977).
- Acting Head, Department of Political Science, University of Illinois, Chicago, 1973-74.
- Scholar-in-Residence, Department of Political Science, Northern Illinois University, Spring 1973.
- Assistant Professor, Department of Political Science, University of Illinois, Chicago, 1971-73.
- Assistant Professor, Department of Political Science, Drew University, 1970-71.

Education:

- Ph.D., Political Science, Florida State University, 1970.
- M.A., Political Science, Temple University, 1967.
- B.A., Political Science, Temple University, 1966.

KEYNOTE SPEECH

Joseph Bordogna
Deputy Director
National Science Foundation

"Infrastructure for the Future: Assembling the Pieces"

Bringing Information Technology to Infrastructure:
A Workshop to Develop a Research Agenda
June 26, 2001

Good morning to everyone. I'm delighted to be here with you today. I'm especially grateful to ICIS for organizing this workshop, and to all of you for joining us to discuss this very important topic.

Some of you will recall that we convened the first NSF workshop on civil infrastructure systems research and education in January 1992. We met to consider the need for a national focus, and to develop the basis for a broad-based, interdisciplinary CIS research and education program.

At the time, we emphasized the advantages of viewing civil infrastructure in all its diversity as an integrated system. And we cautioned that tinkering with the parts would give us only incremental improvements. We talked about the need to work across disciplinary boundaries, and to integrate social, economic, and political perspectives in CIS research.

We must have done something right! All of these research and education strategies are still central to our discussions today. Our research and education agenda continues to reflect the importance of a boundary-crossing, systems approach.

That was almost a decade ago. And what a decade it's been! In the last ten years, the winds of change have literally swept across our institutions. They have reshaped the once familiar landscape of the economy and have forced us to clear new paths in business, in research, in science and engineering, and in education. The information age is fully upon us.

The world of the 21st century is very different from the world of only 10 or 15 years ago. We have witnessed an outpouring of new knowledge and technological innovation that is unprecedented in its scope. Today, advances in science and engineering and technological change are the driving forces of the economy and the key to our social prosperity.

These changes have occurred at a speed that has left many of our research and education programs in the dust. Whether we welcome it or not, the pace of change is unlikely to lessen anytime soon. We haven't seen the end of the information revolution, and we're only beginning to feel the impact of other new technologies that the IT revolution has made possible.

Last year, the National Academy of Engineering unveiled a list of the 20 most influential engineering achievements of the 20th century. The criterion for judging the nominations was the impact each advance had on improving the quality of life across the nation. Electrification was voted number one. The NAE noted that it "...powers almost every pursuit and enterprise in society....including food production and processing, air conditioning and heating, refrigeration, entertainment, transportation, communication, health care, and computers." Our electric power distribution system has become a civil infrastructure component of critical value to today's way of life.

And new modes of transportation appeared also at the top of the top 20. The automobile came in at number two, the airplane at number 3. Safe and abundant water was fourth for preventing the spread of disease and increasing life expectancy. I'm sure many of you are familiar with the list so I won't belabor it. However, it is instructive to note that the high-speed electronic digital computer, which emerged in society only a few decades ago, came in at number five, with the Internet, an explosive infrastructure element just born, at number thirteen.

The electronic computer and the pervasive Internet have fueled the information revolution and made the past decade so productive – and so prone to change. We have begun referring to those new computer-communications infrastructure capabilities as Information Technology.

It's no accident that our civil infrastructure system underpins all of the top five advances – and also a number of others throughout the top 20. None of us could enjoy the benefits that science and these major engineering achievements have made possible without it. Our security, safety, health, and economy all depend upon its seamless operation.

The newcomer to the field, information technology, has had an increasingly powerful impact on our infrastructure system. We're all aware of the effects – from its use in management and control to customer service, from the use of GPS and GIS to increasingly sophisticated sensors that provide a wealth of new data on system conditions.

While IT has produced extraordinary opportunities for improving the performance of the infrastructure system, it has also introduced new vulnerabilities. Finding ways to resolve this conundrum is part of what motivates our discussions during this workshop.

Information technology has also irreversibly altered the research and education enterprise. It's given us powerful new tools to handle the ever-growing volume of data and to grasp its complexity. IT also offers us new opportunities to collaborate on research and education around the globe.

When we discuss research and education strategies for CIS, we need to consider not just how IT can be better integrated into our infrastructure system, but how we can use it in our research and education activities themselves.

Today I will focus on a theme of "Infrastructure for the Future: Assembling the Pieces." I want to discuss some of the "big picture" issues – how CIS research melds into NSF's overall strategic plan. Then I plan to talk about CIS in the context of some of the territories that the National Science Foundation has identified as emerging fields and trends of over-arching potential.

At NSF we are all about science and engineering. Our task has been to foster the nation's science and engineering strength in order to brighten our economic and social future – even though we don't know what that future will be.

With the community's peer advice, we do this by choosing the most capable people with the most insightful ideas. That's you. With you and through you, we provide the risky opportunity to advance a field in a new direction, accelerate its pace and, increasingly, help it build bridges to new territories.

The NSF vision statement is direct and crisp: enabling the nation's future through discovery, learning, and innovation. Not too long ago you would not have seen the words learning and innovation in an NSF vision statement. Now they are there together with discovery.

We know that scientific research not only drives technological innovation, but that it can also happen the other way around. In the larger sense, innovation depends upon a mutual, synergistic set of interactions that includes not only science, engineering and technology, but social, political and economic interactions as well. These are all systems that interact and influence each other.

We've developed a set of goals to complement our vision, a sharply focused set on which we can concentrate our investments, and by which we can be held accountable. We call these People, Ideas, and Tools.

You'll notice that People are at the top of the list. That's intentional. NSF is as much about building a world-class workforce as it is about discovery. Although we continually break new ground with the research we support, we need *people* to carry forward the continual process of discovery and innovation.

Of course, Ideas, the new knowledge that is powering innovation and productivity in our economy today, will always be central to everything NSF does. And, finally, we need sophisticated Tools to advance the frontiers in nearly every field.

I've taken this brief jaunt through NSF planning territory to arrive at my next point.

We've adopted three core strategies to accomplish our goals. I like to think of these as three questions we should ask ourselves when we devise research and education strategies in any field: Does it develop intellectual capital? Does it integrate research and education? And does it promote partnerships?

This is where the rubber meets the road. It's where we design the solutions to get the job done effectively. This is what we are about today as we consider a research and education agenda on civil infrastructure and information technology. Let me explain. Developing intellectual capital keeps our sight on the frontiers of research. Adding to the stock of knowledge requires that we continually explore new territories and break new ground. Increasingly, these frontiers are located at the boundaries between disciplines.

The second core strategy is "integrating research and education." Linking support for research with training the next generation of scientists and engineers has been the intent of NSF from the start. It's a powerful way to ensure that the two-way road between the academic research laboratory and the larger world stay open and engaged. That's one place where we welcome heavy traffic!

In a larger sense, integrating research and education allows us to develop the skills needed by 21st century scientists and engineers: flexibility and agility in adapting to change, the capacity for risk taking and for imagination, and a tolerance for unfamiliar and uncertain territory. These are all characteristic of the research and education enterprise at its best, and there is no better way to teach them than to engage in that creative process.

I like this quote from the book *Perfect Symmetry* by Heinz Pagels, because it captures the spirit of what continuous learning and innovation are about. "The capacity to tolerate complexity and welcome contradiction, not the need for simplicity and certainty, is the attribute of an explorer."

We're all explorers here, and we all know that these skills reside throughout society – in academe, in business, in government.

Much has been written about the barriers that prevent integration and collaboration in the civil infrastructure arena – specialized tracts of study, autonomous institutions that manage infrastructure, different – and sometimes competing social, economic and political agendas. Integrating education and research is the place to begin breaching these barriers.

The third core strategy – building partnerships – is another. One of the strengths of partnerships is simply the differences that partners bring to the table – differences in perspective, in experience, in institutional culture, and in goals.

Something *new* happens in the process of integrating the different intellectual skills, experience, and perspectives of the partners. A singular or separate dynamic emerges from the interaction. You could say that the whole is greater than the sum of the partners! This is what energizes and gives value to collaboration across disciplines and fields, institutions, and sectors.

How do these core strategies relate to our task at hand and to the civil infrastructure system? We all know the problems – an aging system, the parts of which are increasingly interdependent, with new levels of complexity, opportunity, and vulnerability added by information systems and technology.

As we address the needs of today, we also need to think about and plan a future infrastructure that is oriented to 21st century needs and goals. We should think in terms of an infrastructure that can be envisioned from whole cloth, designed for some specific long-term goals, and remain flexible to the unpredictable. It would be an *infrastructure of anticipation*. This will require thinking beyond the here and now, an infrastructure for the far future.

In a speech several years ago at the centennial celebration of the famous cathedral of St. John the Divine in New York City, William McDonough, a dean of architecture, said, " ...design [is] the manifestation of human intent."

Our infrastructure system may have grown through an ad hoc process of accretion. We now have an opportunity to consider the *ends* and to design an infrastructure to meet them.

Of course, this isn't an entirely new concept. Today, for example, we routinely take into account environmental impacts when we design systems. Only in this way, will we be able to bring the quality of creativity and innovation to infrastructure that is the hallmark of 21st century science and engineering, technology, and education.

How does NSF help realize this aim? Let me sum up what I've just discussed. Mindful of our goals of investing in people, ideas, and tools, we choose to invest, with the community's advice, in the most capable people with the most insightful ideas and provide them with the tools to enable their work.

With this team we provide the opportunity to advance a field in a new direction, accelerate its pace and help it build bridges to other fields. In this way, we address intellectual territories that hold the most promising potential for our future. We jointly identify these territories as over overarching capabilities that help to connect and expand the core science and engineering disciplines.

For the start of the 21st century we have identified a set of five. They encompass the concepts and expertise that our present and future workforce of scientists sand engineers will require to succeed and help the nation prosper. As we look toward the future of our infrastructure system, we should look toward coupling our research and education agenda to these key capabilities.

They are nanoscale, terascale, cognition, complexity, and holism. I'll address each of them in the context of CIS in the remainder of my remarks.

The new nano capability brings together many disciplines of science and engineering to work in collaboration. Its scope and scale create an overarching, enabling field, not unlike the role of information technologies today. Nanotechnology gives us the ability to manipulate matter one atom or molecule at a time. Now, we will be able to build a "wish list" of properties into structures large and small.

This technology could lead to a future of dramatic breakthroughs. For example, molecular computers could store the equivalent of the U.S. Library of Congress in a device any of us could wear. Perhaps of more interest to you will be the nano-capability to design materials with properties of strength and endurance orders of magnitude greater than those available today.

This could create a revolution in the built environment, which still relies on technologies that have changed very little for generations. We can begin to *really* think of intelligent materials with the capacity to repair themselves.

On the smallest end of the scale, nanotechnology holds the promise of a vastly expanded capability to gather data, detect faults, and even repair them. Imagine a distributed, hierarchical system of sensors and nanobots that would continuously monitor infrastructure health.

If nanoscale allows us to design three orders of magnitude smaller, terascale gives us the capability to do things three orders of magnitude *faster*. When we dramatically advance the speed of our capability in any area we give researchers and industrialists the mechanism to get to a frontier much faster, or better yet in terms of NSF's mission, to reach a frontier that had been, heretofore, unreachable, as well as unknowable. The revolution in information technologies has connected and integrated researchers and research fields in a way never before possible. The nation's IT capability has acted like "adrenaline" to all of science and engineering. An important result has been to build the most advanced computing infrastructure for researchers and educators to use, while simultaneously broadening its accessibility.

Let me give you an example. The NSF Network for Earthquake Engineering Simulation, or NEES, uses a computer-communications network to bring a complete collection of state-of-the-art facilities under one ‘virtual roof.’ Using remote access, the entire earthquake engineering community can access a complete system of testing and experimental facilities. The system will use models and databases to develop modelbased simulation. NEES sets a new paradigm in research and education tools, offering a shared instrumentation system greater than the sum of its parts.

Another example of how terascale opens new research vistas is in the development of visualization tools and techniques to address multidisciplinary challenges. Visualization helps in the development of complex models and simulations. Some examples are: creating roadmaps of the structures and connections within the human brain, and visualizing the human heart. The potential for modeling infrastructure interdependencies is huge.

This brings me to the third capability we intend to expand, cognition. The dictionary defines cognition as the mental process by which knowledge is acquired. Most of us would simply say, this is learning. Learning is the foundation territory of all other capabilities, human and institutional. Our understanding of the learning process holds the key to tapping the potential of every child, empowering a 21st century workforce, and realizing smart civil infrastructure.

From the last 30 years of research, we know that people, both young and old, absorb and assimilate knowledge in different ways, and in more than one way. So the ”science of learning” is a critical inquiry into *how people learn.*

By focusing on cognition, we will advance our capability in everything from teaching the highly skilled workers we will need to operate and manage infrastructure to building human-like computers and robots to assist us with complex decisions involving risk and uncertainty. It can deepen our understanding of what it will mean to put more control in the hands of individual consumers of infrastructure services.

Complexity is the next capability on the list. Mitch Waldrop, in his book *Complexity*, writes about a point we often refer to as “the edge of chaos.” That is, “where the components of a system never quite lock into place, and yet never quite dissolve into turbulence either...The edge of chaos is where new ideas and innovative genotypes are forever nibbling away at the edges of the status quo.” This territory of complexity is ‘a space of opportunity,’ a place to make a marriage of unlike partners or disparate ideas. The awareness of ‘complexity’ makes us nimble and opportunistic seekers. If we operate with this awareness we will be able to identify and capitalize on those fringe territories which have so much potential.

Modeling our infrastructure system puts us right into the complexity soup. We will need a deeper understanding of dynamic, non-linear systems, with new mathematical tools to deal with the ever-increasing complexity of CIS. The study of emergent phenomena – and the corresponding bane of cascading events – is only one of the areas that hold great potential for our understanding and control of CIS.

The final capability, holism, is the “flip side” of the complexity coin. Holism and complexity have a symbiotic relationship. Complexity teaches us to look at places of dissonance or disorder in a field as windows of possibility. This workshop addresses one of those places: the disorder created by the imposition of new information technologies on an existing, already poorly integrated infrastructure.

When we take a holistic view of infrastructure, we might picture it as it's represented in this slide. The built environment is at the hub of continuous interactions – with humans and our institutions (economic, political, educational, and social), with the natural environment, and with our new territory, cyber infrastructure.

When we think about complexity and holism as two sides of a coin, we develop a pattern or attitude to search for the disordered fringes of a field and to pick out fragments of possibility. With these pieces of potential, different 'wholes' can be created in new integration. The possibilities are endless when you think about the flexible building power that nanotechnology will provide, the enormous insight from research in cognition, and the ratcheting up of speed that terascale computing offers.

Let me conclude with this final thought. I've given you the "big picture" because we can often lose sight of ends when the urgency of our task is compelling. This is a risk with CIS research. We're all too aware of the potential for disaster and breakdown and the economic and social costs they entail. We need to be equally aware of the great potential for healing these ills that our new science and technology capabilities provide us. I know that many of you here today are pioneers in these efforts, and they are welcome.

I am fond of this quote from Cornell West that expresses the public character of infrastructure and the value we place upon it.

"The vitality of any public square ultimately depends on how much we care about the quality of our lives together. Our public infrastructure reflects our economic policies and the priority we place on our common life."

How infrastructure fits into our communities and landscapes, its design and beauty, has been an important feature of cultural life for as long as we humans have been builders. It reminds us that we are engaged in an enterprise that makes a difference in the lives of everyone, and one that requires our best and brightest efforts. I am grateful to all of you for your participation in this workshop, and thank you for your help and insight.

KEYNOTE SPEECH

Braden Allenby
Environment, Health and Safety Vice President
AT&T

"Infrastructure as Earth Systems"

Bringing Information Technology to Infrastructure:
A Workshop to Develop a Research Agenda
June 26, 2001

What I thought about when I was first asked to do this was: what can I tell you that you're not going to be talking about here yourselves? Accordingly, I'd like to start with a quote from Heidegger: "So long as we do not, through thinking, experience what is, we can never belong to what will be. The flight into tradition, out of a combination of humility and presumption, can bring about nothing in itself other than self deception and blindness in relation to the historical moment."

Now for those of you that are familiar with Heidegger, this is a relatively accessible bit of writing. Even so, it's a little bit daunting. But I think what he's saying is very important, and applicable to several fundamental issues regarding infrastructure and research involving infrastructure.

Most importantly, we have a fundamental problem thinking about and perceiving difficult, complex systems. Think about a city, with engineered systems like water, or gas or whatever. These used to be separately, but are now coming together in ways that are perhaps enabled by IT, but are independent of IT and are symptomatic of a far higher degree of complexity in our society than we have experienced before or how we know how to manage.

The second is – go to Heidegger – I think that we fail, for the large part, to even perceive how challenging the world we live in right now actually is. Let me give you a couple of examples. First, combine just a couple of ideas that came up this morning: sensor systems, nano-technology and enhanced IT, and what you easily come up with is a world which is constantly monitored on virtually all scales and along all relevant human and natural parameters: CO2, nitrogen, heavy metals, product lifecycles, infrastructure performance, etc. Now ask yourself a couple of questions. One question ought to be: when you wire a world like that what do you do to our perception of the world? What do you do to culture? If you know that you are in the middle of Yellowstone, but you are surrounded by sensors that are feeding into a NASA or DOE computer tracking in real time the environmental parameters of where you are, do you get the same sense out of being there? Does nature mean the same thing to you when there is no wilderness left in the world? And what does that do the way you think about infrastructure in altering human culture and human responsibility and human morality? And you say to yourself, wait a minute, "infrastructure?" Right. What I'm suggesting is that the most profound infrastructure we're going to have to deal with is infrastructure that finally admits that we live in a human world. We live in an anthropogenic world, a world made by humans. We don't control it, but we have made it.

Think about yourself as an alien. No, think about me as an alien, that might be easier. I'm flying around in space, then I look at this world. What is the predominant impression I would get? That it has been designed for the benefit by one species. We may all say to ourselves individually, "whoa, I didn't design this world though. Don't pin that one on me." But our institutions and the species itself have created what amounts to a monoculture. Are there areas of wilderness? Sure. Do they exist at our suffrage? You bet. So knowing that we have a human world, I think we ask the second question which is equally difficult for me, and that is "what is infrastructure?"

I think you can make a good argument that the kinds of things we traditionally think about our infrastructure clearly are and remain important, but because of the scale of human activity and because of the increasing inner-connection, what we find is that natural systems – the carbon cycle, the sulfur cycle, certainly the hydrologic cycle - more and more become elements of the human infrastructure. We integrate them into our economic activity, we integrate them into our planning activity, we integrate them into our political activity.

What is Kyoto? Kyoto is a process by which big chunks of the carbon cycle are brought into the human economic system and made human. What is biotechnology? Biotechnology is the commoditization of life itself. And go back to the world that is fully sensored and operated by NASA or DOE (pick what you want) and what have you really done? You've taken a lot of the information systems that existed in living biological communities that used to control the evolution of the planet and they have now become part of the infosphere where they are subject to human manipulation.

Human "control" is a little strong. Is this the case today? Of course not. But is it clearly foreseeable based on what we can see of the technologies that we are using now? Sure. So I start from that perspective and I just wanted to put out some thoughts about where that leads us. We can kick them around a little bit. I think that it leads us first to a very different relationship between ourselves and nature. Why does this matter? This matters because there are very few infrastructures that don't significantly impact natural systems more and more. That becomes part of the design problems of these systems. You start out with the worldview of, say the medieval period. You have a natural world. You have a human world that is completely within the natural world. You have a certain element of nature, the agriculture systems, which are integrated into the human. But by and large you have a pretty clean hierarchy.

But then you get to where we are now and you end up with a situation where we perceive ourselves to have a human sphere, which is relatively divorced from the natural sphere. Two hundred years ago, if you said natural and supernatural, people tended to think of supernatural as the really weird, mystical-type thing. Now what you get is technological society versus nature. Nature is the "Other." You can see this very powerfully in the environmental movement. But where are we? When I think about the world in engineering terms, we have integration and the human systems are becoming more and more dominant. Now don't mistake what I'm saying. I am not saying that humans control the world or that the world is human artifact, because that's not the case. Obviously, we don't *control* the world. If we did, hopefully we'd be doing a lot better. But the human impact becomes a significant element of the dynamics of most fundamental systems. We don't know enough yet to control it, we don't know enough yet to engineer it. What we do know is that the human impact is extremely powerful. If it weren't we wouldn't be worrying about the Kyoto process and global climate-change negotiations. We wouldn't be worrying about the perturbation of the nitrogen cycle and about the dead areas in the Gulf of Mexico or Long Island Sound. We wouldn't be worried about the hydrologic cycle like we are.

Now, I think there are a couple of ways to react to this development. The first, of course, is panic and denial. But it's too late. I don't think this is a world towards which we are moving as much as a world that we already are. Again, look at Kyoto. Kyoto is a belated recognition that, in fact, the accumulated activity of the past millennia or so has resulted in the situation where the human elements dominate the behavior of the climate cycle in certain important ways.

We're already in the human earth. What's frightening about it is that we don't know how to manage these issues at all. Kyoto, I think, is a very primitive first step. But in a sense, anybody who engineers important infrastructure activities runs up against these same issues. It's not just a technical world. There are cultural dimensions to these technical activities and one of the mistakes we make is that we're comfortable with the technological, but we're not comfortable with the cultural, so we take cultural issues that are extremely difficult and we push them into a technological silo. That's essentially what we've done with Kyoto, right? We've got serious questions about consumption and individual liberty, etcetera. And what are we doing? We're pushing it into a technological silo and it becomes an argument about technology. But it's a bogus argument.

I was at an RFF meeting about a year and a half ago and there was a representative from the American Petroleum Institute, debating someone from NRDC about global climate change. The language of that debate was exquisitely scientific. And it bothered me, and I couldn't understand why it bothered me. And finally I realized – you always realize things after you go to your room – what bothered me was that I had been listening to a theological discussion but it had been phrased in terms of science, and it was completely ineffectual. There was nothing the American Petroleum Institute representative could have said that would have changed the mind of the NRDC person and vice versa. It was not an argument about scientific data; it was an argument about religion, and unless we admit that and begin to deal with that as engineers and as technologists, I think that it's a significant communication problem.

So what's the world that these infrastructure projects exist in? I think that it's becoming more and more coupled in ways that are extremely difficult. Take the governance system. Not governments, but governance - the way things actually get done. Ten years ago when I had a problem as AT&T senior environmental counsel, I'd go down to Washington and talk to EPA or Congress. I knew where to go to. Now I haven't had a serious problem with the government in four or five years. With environmental NGOs? Sure. With human rights NGOs? Sure. And they're telling me that AT&T should begin managing its triple bottom line, which looks for social and environmental efficiencies. Whose social efficiencies should I manage to? Upper class America? Uganda? China? Well it's always the social agenda of the NGO that's involved; and if they are a strong NGO, they'll make you do it. If you think that a consumer-oriented firm is going to go against environmental NGOs, you're wrong, because the NGO will put them out of business. This is the kind of world that we live in, and this is the kind of world that our engineers need to be trained to operate in because that's what they're going to face.

The market. This is a biggie. Markets are very efficient, but what's going to happen when big chunks of the biosphere at all scales and the carbon cycle get incorporated into the market? What happens when the dynamics of the rainforest in Costa Rica are controlled not so much by what's happening on the ground in Costa Rica but on the market for rainforests in New York? I don't know, but it's a brave new world that few perceive, and no one's ready for.

Culture. Nobody wants to talk about culture. I mean we're all good post modernists, right: every culture is just as good as every other culture. But folks, it's there. You want to know why Kyoto failed? It didn't fail because there was a fundamental disagreement about the science, as much as that's pointed out. It failed because of culture. The more you ignore this, the more it's going to come out in ways that are dysfunctional. And it's the people that are working on the projects on the ground that are going to get hurt by it. And they're going to get especially hurt if they don't see it coming and haven't been trained how to think about it.

And then there's the world as human artifact. Again, think about me as an alien coming down and looking at the world. It's a monoculture. It's a monoculture with supporting systems. You got a rainforest in Brazil and it exists only so long as you let it. And if you decide it goes down, it goes down. Are we ready for that responsibility?

Moving from concepts to specifics, I started thinking about how you define a complex infrastructure like information technology. How do I think about it so that operating at various levels I don't get myself all confused? And this is sort of the first shot at it. I think that you can begin to break it down into different levels, and that what we know that each level is different and the ways that we know it are different. And I think that's one of the problems that we have. Listening to the conversations that we had today, I was kind of struck by the way different comments jumped to different levels of the system and it was very hard to kind of figure out the inter-relationships.

Every infrastructure that I'm aware of has some foundation on artifact – you've got to have switches to run a telephone number. And you can think artifacts in terms of their of manufacture, and in terms of the lifecycle of the artifact. This is not necessarily trivial.

What is the environmental and social impact of a jet airplane? If you do the traditional analysis you say "well it uses a certain amount of fuel and spits out a certain amount of exhaust and that's how I think about it, that's its main lifecycle impact." But in fact that technology has enabled the growth of a global tourism industry that has probably has more impact on the biosphere since anything perhaps since the European migrations during the enlightenment. So is that part of the jet airplane as a part of a piece of infrastructure? How do I bound that assessment? How do I research that? How do I conceptualize it? So it's not trivial even at this level, and let me point out that even at this level, the cultural content of the artifact is relatively low and our level of understanding is pretty good compared to what we know about the rest of it.

So lets say I take my switches and my routers and I put them all together and I get a network. A communications network. I can begin to break that down in to different kinds of operations. Construction; operation; impacts on ancillary networks. Does it matter where I put my communications network? Do I enable certain kinds of behavior if, for example, I create a wireless network in Argentina as opposed to a landed network in Argentina? Interesting questions, which have really not been researched, so I'm not going to try to give you an answer.

Then we get into the problem of integrated earth systems, which are complex and difficult to figure out. They a very high cultural content, and that makes them difficult. What kind of things do you run into? Well, let me give you a couple of examples. We all know that urbanization is proceeding extremely rapidly. What is it? Something like 80 million a year… And that's what? 8, 10 million person cities a year equivalent. All in the developing world. Now, this is being built on existing systems and structures. It's not like you just go out and build a Brasilia. You don't do that and when you do it doesn't work very well. But how do you think about cities as integrated systems, as integrated cultural, economic, natural, material flows, energy flows and infrastructure systems in such a way that we can begin to understand cities as a comprehensive system? So that we can better manage something that is already happening and that we know is going to happen in the future? Good question.

One of the problems at this level, I think, is that there are very profound changes that are liable to happen, that we know are going to happen, but that we tend to ignore because they are too complicated. Much of our certainty depends on cultural constructs, and at this scale they are contingent and not fixed. For example, 200 years ago, "wilderness" was satanic. It was a place of devils, and the purpose of the Europeans was to turn the satanic wilderness into farmland. "Wilderness" was thought of as where you went if you were bad and you died. OK? But what is wilderness now? Wilderness is where you go if you've been good your whole life. If you die and San Francisco is full. Right? So what do we know? We know that these cultural constructs power our responses, things "wilderness," like "environment," even "equity." We know that they have changed in the past, and we know that they are liable to change even more rapidly in the future as the internet rolls out.

Most of you remember reading in the papers, a couple of years ago, that rangers were having a lot of trouble in places like Yellowstone, because tourists would get out with a bag of food, walk up to a bear and stick the bag of food in front of the bear. The bear thought this was great right? Food and dessert. Why did they do this? They did it because their idea of nature was the television programs they saw. The bears are all big and fuzzy and friendly. When was the last time you saw a bear take a person out on TV? They just don't do that. So, if that's the impact of TV, what's going to happen with the internet, a much more powerful media? The internet is completely going to change the way we think about virtually all of the things we accept now as being definitive.

The Kyoto climate change negotiation process raises similar complex questions. The Kyoto process is, in one way, a mechanism for us to impose our contingent, specific views of what constitutes a good environment out for about two or three hundred years, because that's the timeframe that Kyoto operates in. By what right do we do that? I'm not saying it's wrong, by the way, because I have the same biases that everyone else does because that's my history. What I am saying is that there is a profound moral issue involved when we suppose that we can impose these culturally developed concepts on the future. And it becomes important again for infrastructure because the internet is going to change those types of constructs more rapidly than we ever have. And we're not ready for that. We don't even have the faintest idea what that means. I'm lucky to be able to talk to people about the environmental and social impacts of e-commerce, much less about what happens when the internet starts playing havoc with our cultural constructs that we all take as settled. So there are some very difficult issues in here that we've chosen to consistently duck.

Our policy system begins to get totally lost as we move this way. Artifact manufacture and lifecycle? We've got that and we can figure out ways to study that. Construction and maintenance of networks? We know how to do that; we're good at that. The services, the social practices based on the services and the knowledge economy and what it will do? At this level our understanding is much less robust, with the result that the policy system essentially breaks down.

Are we managing that level of complexity well? We're not. The integrative function that used to be performed by the government is missing in a lot of these cases. Who has managed the introduction of GMOs? Nobody. There are a lot of things that we have hidden from our vision because they are so complex and we are afraid to deal with them. I would be ok with that if it weren't for the fact that those things are what's going on in the world right now. What we have done as a species and as institutions and as individuals is build a world out there whose complexities and problems we're refusing to acknowledge.

Now, I want to close with something a little bit lighter. Most of you are too young to remember this, but there was a period back in the late 60s when America produced probably the most profound technology that any country has ever produced. I'm talking, of course, about muscle cars: 351 Mustangs, GTOs, 383 Semi Hemis. When I went into the army during the Vietnam conflict, half of the troops had girlfriends pinned up, the other half had their cars pinned up. And the people with cars pinned up cared a lot more. Now, what does that tell you? Let's look at what modern cars look like and let me suggest two things. First, the modern car is essentially an information artifact on wheels. Moreover, now they're putting them on the net. You'll be in your auto.com and you'll get your email and your net access in your car. It's going to make traffic jams really really pleasant because you can pull your email when you're in traffic jams. Think about whether that's a good idea or not and some of the unintended consequences of technology. But there are two information structures that you need to think about when you think about the automobile or you're going to blow the analysis. The first is the technical information structure that you have engineered into an automobile. The second is that the automobile as a symbol is the most powerful technology of independence, of psychological freedom that the world has ever developed. When Prague was free from the communists, the one thing they did for Prague was they left a good public transportation system. Within six months people in Prague had purchased something like 50,000 automobiles. Why? Because the automobile was not a way to get from point A to point B. The automobile was a way to say "you can't keep me at home any more. I'm free to go where I want." Why to you think Saudi Arabia, for example, doesn't let women drive? It's because they have a profound sense of what the automobile means for personal freedom. It's a way of maintaining control. That's what it is. So you're going to take this technology, with all the implications that are built into it and you're going to regulate it using technical means. I don't think so.

So, the serious point: there are at least two dimensions to any technology that is worth talking about. One is the technical dimension we're all used to and the other is the cultural dimension. And if you don't understand the later as well as you understand the former, in the future you're going to be making serious engineering mistakes, not to mention public policy mistakes.

But we can learn a lot more thinking about the automobile example. To begin with, the system is not just the car. There is a huge structure of roads, of gasoline refining and delivery, which have significant environmental and social impacts, which go into the support of the automotive system. This has a number of implications. Number one, if you don't understand the automobile as being the primary driver of demand for petroleum refining, then you're not getting it. Go back to the automobile as a source of perceived personal freedom, and think about the extent to which people are going to allow the environment to interfere with their ability to drive, and what happens when push comes to shove. The other thing is, because you already have these systems you significantly ameliorate the ability to evolve the artifact that may be giving you some concerns. So you say about the automobile "I want to change it. I want it to be a hydrogen based vehicle." Well, it's going to be difficult because it's coupled to other technological systems. So the automobile can become a model by which we understand our ability to evolve systems deliberately to be more environmental and socially friendly.

Now there are other issues that come in too. Lets talk about the interplay between infrastructures. One of the things that's happening with kids is that they're getting on the internet a lot more. The internet is beginning to become their source of perceived freedom, right? So, for example, this is aided by the fact that any kid can play around with the internet, but nobody can play around with a car anymore because the whole thing is so computerized. So what technology do teenagers play with now? They play with the internet. So what does this maybe begin to imply? It begins to imply that perceived freedom for that generation will come more and more from the internet than from automobiles. And if that is the case, does that mean that we can finally being to manage automobiles? Well, I don't know, but it's clearly an interesting infrastructure question, and as far as I know nobody's looking at it.

And I think, this, again, is a way to think about this. We tend to focus specifically on the artifactual level of these systems because we are comfortable with these artifacts. So we focus on the subsystem of the automobile. We focus on the automobile itself. We focus on the infrastructure technology that supports the automobile, the roads and the gasoline. But then there is a whole social structure that becomes associated with, coupled with the technology system that we have, and this can become extremely difficult to change.

So this structure begins, I think, to demonstrate that the simplicity that we sometimes assume practically in our policy approaches was probably misplaced. I'm going to close with a real low tech kind of evaluation that sums up some of these points.

Paper recycling. Ok, now who can be against paper recycling? We won't get into that, but I think it's useful to break it into three timeframes, and think about it in that sense. In the short timeframe paper recycling is pretty understood. As a technical matter we don't really know if paper recycling is better or not because it depends on where you get you energy source for running the paper mill; because if you recycle paper, then you use more fossil fuel energy than if you manufacture from virgin sources because when you manufacture from virgin sources then you can pull out what you call black liquor. The black liquor goes in and provides some of the energy for the process and you use less fossil fuel energy. So there are issues that come up but it's pretty simple. Moreover, the conceptual framework within which you need to think about this is fixed.

Now, the medium term gets a little more difficult. Why? Because you have economic development during that period. In this country we use about 150 kilograms of paper, in developing countries they use about 12 kilograms. China for example. What's going to happen when a billion plus people come on line at 150 kg? And how are we going to manage that with our current forest resources? Well, there's only one way that I can think of and it's major bioengineering. How happy are the greens going to be if that's the issue they're going to face? Alternatively, you can tell the developing countries not to develop. Good luck.

The long term becomes even more interesting. In the long term, you begin to ask questions like "how do I think about paper pulp agriculture and forestry as components of sustainable land use systems and what does it mean to have a sustainable land use system to begin with?" There are very few of the biological issues that don't become fluid in the long term. For example they're working now on trees that have low silicon, low lignin content. So you're going to end up, if they continue this research, with custom designed trees that give you maximum paper for minimum fertilization, at minimum environmental impact and minimum land use. Is that good or bad? A lot depends on how you feel about the quasi-religious question of biotechnology. But clearly everything becomes fluid.

Finally, when you think about it in these terms, you begin to ask questions not like "what does a paper recycling system look like?" but "what is the role of this system in global climate change, in carbon cycle management? In biotechnology management?"

So I think with that I'll close. I'm struck by the challenge that we face with dealing with the complexity that is in front of us. That challenge is going to appear in a lot of infrastructure issues, but I think that the infrastructure issues are broader than we've touched on. I think that the infrastructure issues are as broad as how do we structure the world now that we've dominated in ways that permit us to meet the values that we choose to impose on it. And that leads to perhaps the broadest quest of all, which I think will leave you with. But the real question, I think, that we have to ask ourselves is what kind of world we want, because we are building it right now. Every one of us. I submit it's high time we do it rationally and ethically, with our eyes open.

SECTION THREE

Real Time Intelligent Data Acquisition and Control Systems For Monitoring and Managing Infrastructure Networks

By

A. Emin Aktan[1] and Alexander Meystel[2]

[1]John Roebling Professor and Director of Intelligent Infrastructure Institute
[2]Professor of Electrical and Computer Engineering
Drexel University, Philadelphia, PA 19104

Abstract

Real-time intelligent control systems (RICS) are envisioned to serve as decision support systems for large-scale problems, on-line advisors for middle-scale problems, and rapid interference tools for a multiplicity of small-scale problems where no procrastination is allowed. RICS will serve as virtual shields protecting the functionality and health of regional transportation networks and other critical infrastructure systems.

RICS will provide network-level real-time management of incidents and emergencies, electronic tolling, real-time vehicle identification, behavior imaging, enforcement, in-vehicle guidance and optimum path selection, traffic conflict resolution and eventually even the remote control of unmanned vehicles in addition to maintenance management. Such functions require the collection of multi-modal, multi-bandwidth and multi-scale data throughout a regional transportation network and processing of the data to identify system components including traffic together with the environmental, constructed and organizational components of the meta-system. In addition, decisions about any real-time or delayed actions are required for safety and optimum functionality, and if so, various control loops at different resolutions should be activated to execute the appropriate decisions.

Data collection and processing, interpretation and decision-making, and executing multi-loop, multi-resolution control in real-time require learning-based, decision-theoretic intelligent agents. Authors and their students have been exploring health monitoring of infrastructure systems by taking advantage of intelligent systems with real-time control. They have recognized that there are three intellectual challenges that require resolution to construct RICS. These are:

(a) Development of the fundamentals of multi-modal, multi-scale data acquisition, processing and information design for real-time identification of complex dynamic systems with many different forms of uncertainty; (b) construction of learning-based, decision-theoretic intelligent agents that will in real-time interrogate the sensing systems, process and interpret the data, identify system elements including highly dynamic ones and decide on appropriate actions for safety and functionality; and, (c) real-time, multi-loop, multi-resolution control of large and complex hierarchic meta-systems for executing the decisions. These challenges and their possible resolutions will be discussed by taking advantage of a real-life application that is in progress on a long-span bridge over the Delaware River in Philadelphia.

IT Infrastructure and Energy Efficiency Markets
An Energy Practitioner's Perspective

Michael Bobker, CEM

Director of Strategic Planning, Association for Energy Affordability
Research Associate, Columbia University Program on Information and Resources

paper prepared for the Institute for Civil Infrastructure Systems of the Robert F. Wagner School of Public Services at New York University for the workshop "Bringing Information Technology to Infrastructure: a workshop to develop a research agenda"
June 25-27, 2001 Arlington, VA

Overview

Energy services are delivered through markets. In so far as markets are mechanisms for price discovery and transaction execution, they are informational in nature and can, therefore, be more fully integrated by the increasing application of information technology. One might view utility deregulation as replacement of information shared closely and fixed by a few parties with a widely shared, transparent, and dynamic set of information functions. Limitation of the market function (by constrained and distorted price signals) can be seen at the heart of the California debacle. The proper functioning of markets relies on adequate information across various levels along the electricity supply chain.

Energy efficiency resources are also purely informational in nature. They are the difference between a baseline -- what would have been used under some starting condition -- and what is actually used for the same outputs due to modified hardware and/or behavior. There is no delivery of a commodity and therefore no natural and ready fit into the traditional utility business model. Consequently, end-use energy efficiency has been delivered by a set of entrepreneurial firms (energy service companies or "esco's") working largely outside of the mainstream energy markets and, therefore, generally without the support of those markets.

IT evolution at the micro-level of the end-use (sensing and recording), the mid-level of system operation (monitoring and control), and the macro-level of market function offers an opportunity to integrate efficiency resources into the mainstream operation and market functions of the utility industry.

1. Some Background on End-Use Energy Efficiency Services

End-use infrastructure is a neglected step-child of the energy utility industry: a vast amount of relatively small pieces of equipment existing on "the other side of the meter". At some time some in the industry realized that "a kilowatt-hour saved is a kilowatt-hour generated" and, moreover, that end-use (demand-side) energy efficiency can generally be delivered at lower cost than supply-side resources. Yet such services are generally provided outside of the normal utility supply chain, by entrepreneurial firms acting in parallel for delivery to end users, introducing a variety of market discontinuities and barriers such as:

- higher ROI criteria and shorter time horizon than used for power system investment
- poor access to capital and/or higher costs of capital
- high transaction costs, poor economies of scale
- decision-makers without specific knowledge or mission with respect to energy, perception of energy as a cost center and a fixed cost

These barriers all reflect fragmentation of the market, with operating equipment owned individually by parties not involved in the energy market except as customers.

There was a brief period, just before deregulation, when the regulatory system addressed this problem. Through Integrated Resource Programs (IRP) and Least Cost Planning, utilities were told by regulators to treat energy efficiency as a source of capacity supply. The Electric Rate Adjustment Mechanism (ERAM) allowed profit to be earned on demand-side resources and this incentive turned utilities into eager DSM resource acquirers through a variety of programs such as rebates, standard offers, and integrated bidding. Energy service companies (esco's) suddenly found industry allies in utilities, "making the market" for projects. **The experience of selling into a market with liquidity and standard terms was eye-opening and business-model-shaking for esco veterans.**

However, the presence of market-makers disappeared with deregulation and has yet to re-appear. If a societal goal is to achieve optimal amounts of energy efficiency (as part of an optimal market-based allocation of resources to and within the utility sector), then considering the development path and application of IT to market design in order to incorporate end-use efficiency into the mainstream market deserves a place on the public research agenda.

2. IT Elements in today's end-use energy markets

IT-based elements and trends are finding their way into end-use energy markets through various channels. The introduction of solid-state devices into equipment and equipment controls is widespread but layered and with numerous gaps and discontinuities. The welter of activity can be examined in a tri-partite scheme reflecting that of the ICIS White Paper:

- local automation of equipment control and monitoring functions
- wide area networking with real-time communication
- electronic supply chain transactions

The point of this section is not to overwhelm with detail but to gain an overview of messy and disconnected evolutionary change. The hurried reader should consider going directly to sections 3 and 4.

2.1 Local Automation: processes, buildings, homes

Automation of industrial processes and facility/building functions has advanced quickly since the 1980's with major players (Honeywell, Johnson, Rockwell) promoting the extensive deployment of solid-state controls and computer-based systems replacing mechanical-electrical controls. There are many products, often incompatible, and various protocols, some of which (although decreasingly so) are proprietary. Legacy systems abound and patchwork is common as generation is laid over generation.

Automation for the home is less advanced. While chips have found their way into thermostats and air-conditions, they are still rare in refrigerators, the largest single electrical user in most homes, so that, for example, the energy intensive defrost cycle cannot be programmed for off-peak hours. The idea of wiring homes for intelligent routines and remote monitoring and control is still in its infancy (except for home security), being pioneered by several associations. Underdevelopment, however, also means few legacy issues and that progress can readily leapfrog to the latest capabilities.

At the other end of the supply chain, utility system monitoring has been widely automated by SCADA (supervisory control and data acquisition) systems. These systems do not normally cross the sacred boundary of the meter. Local transformers are typically the lowest level addressed, relating to system reliability rather than customer use (meter) data. The early advent of "advanced metering (integrated intelligence, memory, and communications) is handled separately from SCADA, as part of Customer Information Systems (CIS).

2.2 Real-Time (R/T) Communications over Wide Area Networks (WAN)

In the 1990's networking became familiar and then commonplace. Building automation systems (BAS) and energy management systems (EMS) are local area networks for equipment control. The availability of electronic signals and memory bits made the connection to digital telephony obvious and natural, opening the door to broader Wide Area Networks. Modem-based data logging has evolved to faster Internet communication. Custom-made data transfer and recording systems have become EIS and Enterprise Energy systems to provide standardized platforms for multiple site recording across varying equipment and control system softwares in real time with load profile graphics (skipping quickly over the evolution of BACnet, sponsored by the Association of Heating, Refrigeration,and Air Conditioning Engineers, ASHRAE, and its competition with the proprietary LONworks protocol for building equipment).

SCADA systems probably represent the first WAN application in the utility field. But in response to shrinking reserve margins, customer curtailment programs including residential pilots are being rolled out with only tangential connection to SCADA infrastructure. The idea that all electricity, since for the most part it cannot be effectively stored, should be subject to R/T pricing has enormous implications for the amount of information that must be captured, transferred, stored, and manipulated. Puget Energy in their residential load control pilot found interval data of 2 gigabytes per day for 100 customers, addressing only one point (a thermostat) per home.

With the exception of a few pilots, R/T systems do not yet extend to the level of the small end user (eg- single residential accounts, small businesses). But one can expect that the market structure will follow the availability of the technology, advanced metering, with the hardware transition financed by the elimination (and hopefully re-training) of expensive, unionized meter readers.

The idea of extending control from coordination center to end-usage points is truly staggering to the human mind. It is an impossible task without artificial intelligence routines and agents, which are presently at little more than the conceptual stage.

2.3 Electronic Marketplaces

When the gas industry was de-regulated in the 1980's, commodity and pipeline capacity were traded through electronic bulletin boards. These proprietary sites were the precursors of today's web sites for buying and selling electricity. There are many of these now, led by Enron with its trading and risk management infrastructure, but including pure auction sites which serve as trading locations rather than offering trading services. Most of these sites cater to large customers but a few are attempting to serve the mass (ie - residential) market.

Because the integrity of the electric grid requires critically close coordination of supply to demand, we also see electronic exchanges growing out of power pool coordination centers -- Cal PX, NY ISO, etc. -- which operate buy/sell spot markets and pass through bilateral transactions. Each local utility (now Distribution Company or DISCO) is also responsible for the integrity of its local system and thus operates a parallel control center coordinating supply and demand.

With R/T prices communicated to retailers, an end-user's load profile, in relation to its contracted purchasing terms, becomes a major cost factor and purchasing risk. **Here we see how the market makes demand side management critical**. The market cannot work without the metering data to dynamically monitor load profile and the end-user cannot accept the market terms without the parallel ability to see and shape its load profile to manage keeping within the bounds of its purchase contract terms. **The energy manager's job has just become much more complex and time-critical.**

Equally interesting is selling on-site load shedding and generation resources back into the system on a dispatchable basis. The NY ISO has established such a program in conjunction with a parallel Con Edison special rate established at the direction of the Public Service Commission. End-users become utility partners to meet peak system demands. The entire transaction from dispatch through capacity confirmation to payment is electronic.[1] From this, it is not hard to conceptualize a permanent and long-term market arrangement for the procurement of an efficiency resource to be sold back into the system. However, as of this date I know of no market that offers such a contract.[2]

3. Research Agenda for IT Application as Infrastructure for End-Use Energy Efficiency

Following the structure of IT elements and trends, the research agenda or "roadmap"[3] looks as follows:

- establish interoperability standards among the various levels and segments of controls and monitoring

[1] The precursor of this market mechanism is the Washington aluminum manufacturer that this year closed down its operations in order to sell it contracted electrical capacity into the California market.
[2] Although there may be no **market** buy-offers at present, there are in many states government programs established under "Systems Benefit Charges", structured similarly to the abandoned DSM / energy efficiency programs. In general, however, they are more bureaucratic and less aggressive than were the utility resource acquisition programs.
[3] The Department of Energy's Opportunities for Industry Collaboration (OIC) program uses the related term "Industry Roadmap"

- assess data density, architecture, and associated requirements which emerge from R/T WAN communication
- develop information architecture, protocols, and AI for conducting market transactions around efficiency resources.

3.1 Interoperability

Although it once looked appealing to use proprietary IT for competitive advantage, it is becoming increasingly clear that in networked industries fully isolated platforms benefit neither end-users or competitors and that conformance to an industry standard is preferable.

Interoperability is basic, virtually certain to be on the list for every sector. What is required here is an understanding of the scope of segments, platforms, and vendors across which integration is necessary. There is a convergence of building controls, home automation, utility SCADA, utility metering, and electronic marketplaces. This array of industry segment representation should be convened to create an effective working group and *a first research task would be to identify specific members of such a broad consortium.*

There may be critical junctures where interoperability is strictly essential but other areas where custom design and even proprietary formats may be acceptable. If full interoperability cannot be achieved, then alternatives need to be considered, such as industry-wide gateway libraries and translation formats. The widespread adoption of Internet Protocol may be establishing a de factor standard. *A second research task is to provide a comprehensive and subtle understanding of the juncture points between segments and platforms and specific interoperability modes at each.*

3.2 Data Density and Architecture

Data density for full market R/T integration from generator to end use will be.... significant. What will this infrastructure look like? How will it interface and coordinate with existing and emergent communication infrastructures?

3.2.1 Hardware and Data Management

A basic research need is to assess requirements for hardware and data management. There are pockets of existing information from early experience upon which extrapolations can be based, particularly with vendors and integrators of Energy Information Systems.

System architectures need to be developed on a conceptual and schematic basis.

The question of how this infrastructure will be owned and financed needs early address. From one perspective, this appears to be an opportunity for utilities (i.e. - local distribution companies, “discos”) to “build-out” their SCADA networks and add new functionality. Do the probable levels of investment and the multi-party needs for access provide reason enough to place this new aspect of the network under the remaining regulated monopolies? How this relates to orders for "competitive metering" is noteworthy.[4] If utilities are to be major owners, how should costs be allocated by regulators?

3.2.2 Power Supply

Computer equipment has entered the debate on sources of power demand and is thought to have become a significant component of electric load growth.[5] Even more important is the quality of power required for critical data protection. Any extensive IT system faces basic engineering questions of (a) what will electrical loads be? (b) how will they be distributed in physical space? (c) how will interface be made with existing power supply infrastructure? (d) what provisions will have to be made for Power Quality? Research on these questions represents a second phase of inquiry following upon determinations made under section 3.2.1.

3.2.3 Telecom Convergence

The system will place significant amount of additional traffic on the telecom system, whichever channel is chosen. What will this load be and what will the associated costs be? What are the criteria for choosing between the various different media and channels?

It's perhaps curious to note that while utilities at first have been tempted to move into the telecom business, in fact it may turn out that the telecoms have a greater interest in the energy sector as a heavy mover of networked information. Research should address the possibilities for partnerships between telecoms and utilities around this new infrastructure.

3.3 Constructing Information for Markets: Industry Best Practice Calculations, Protocols, Artificial Intelligence

The research focus here is determination of how to create uniform, reliable offers of energy efficiency which can be bid into markets. To offer reliable energy efficiency resources there must be a set of procedures to assure the quality of offers and to monitor and verify contract fulfillment. The system must protect against overstatement of projected savings or flawed designs which do not work as expected. Like any power contract, there will be penalties for failure to meet terms.

3.3.1 Baseline and Savings Calculations

The Energy Services industry has extensive experience and documentation in this area. The research task here then is not one of creating new tools or methodologies but of sorting through the array of procedures for specific applications with industry experts to find the best practices. Research should identify how the selected best practices and procedures can then be applied to database histories, load profiles, including the possibilities for aggregation of smaller customers. Uniformity of treatment can be enhanced by application of artificial intelligence tools.

3.3.2 Monitoring and Verification (M&V) Protocols

---

[4] See NYS Public Service Commission orders and documents on competitive metering and meter data management at http://www.nydps.gov.state.us under "documents".

[5] The debate, conducted largely on-line, has a consensus range of 3-11% of total electric demand, representing a phenomenal rate of load growth.

On-going feedback on project performance is now widely regarded as an essential part of any energy efficiency contract. Energy performance contracts require separate physical measurement to accomplish this. Data must be interpreted and agreed upon. The first and on-going costs can be significant. It is important, therefore, that the necessary level of data collection be built into the IT infrastructure so that this cost becomes a standardized system overhead rather than a custom-designed, project-specific cost.

Research on this topic should define how existing M&V protocols can be matched to and incorporated into the integrated IT system. As a massively repetitive function this would seem a logical candidate for automated data processing with graphical representation of actual to projected (contracted) performance.

3.3.3 Integration to Markets

Research for this section should be an exercise in understanding how data will flow through such a market, electronically and on web-based e-commerce platforms, in terms of general architecture, protocols for offer-making, acceptances, contracts, and recurrent payment settlements.

- Who will be the host markets and under whose auspices will they operate? What are the main platforms for existing marketplaces? What are the various IT and e-commerce interfaces and issues? How would the demand-side resources market relate to markets for supply-side resources? What are the geographical limits across which offers can be transacted?
- What rules would determine eligibility to place offers and how will registration be maintained? How would purchase offers be posted and sell-offers made in response? What are the necessary elements of an Offer? In what electronic format and with what supporting data?
- Can contracts be entered on-line? What are the necessary elements of contracts? What time frames should govern the life of contracts?
- What would procedures look like for on-going (monthly?) verification of fulfillment and payment settlement? Since this will involve data from the system-wide monitoring system, what form will this take and how can standardized processing be enhanced by artificial intelligence agents?

4. Conclusion: What an Efficiency Market Would Mean for End-Use Infrastructure

IT integration of the monitoring and control infrastructure for electricity down to the end-use level enables end-use efficiency resources to be part of a liquid and transparent market for electrical capacity. This changes the way energy services companies (esco's) and utilities (disco's) will operate, the offer and value-proposition which will be presented to end-user customers.

The ability to offer resources into a set market provides the channel to realize new value. The value of reduced energy use remains on site with the customer while the capacity value is splitoff to be realized in the capacity market.[6] Without access to a capacity market, this value remains unrealized (providing a positive externality to the utility industry).

Note also that the underlying transaction is quite similar to that proposed for carbon emission markets, where a credit is allowed for a demonstrated reduction from an accepted base case. Similarly, in so far as efficiency offsets other tradeable emissions from electricity generation (SO_2, NOx), it would appear feasible to trade in these markets as well.

The greater value so recognized will support greater focus and attention on the end-use infrastructure as a source of economic value. The economic potential will support esco's and related entities in playing an increasing role in managing end-use infrastructure. From the end-use customers point of view it will make increasing sense to outsource this management and move to a "chaufage" model[7] in which energy services (the outputs of conditioned air, hot water, lighting levels etc.) are purchased by the end-user rather than the energy or energy-using equipment (which are provided by the energy services provider). In this transition management of facility infrastructure moves from being solely a customer cost-center to also being a profit-center for those specialists who understand how to maximize its value. Specialized, profit-making opportunity will bring the following changes in the management and maintenance of the end-use infrastructure:

- willingness to accept higher risk (and consequent need for end-user protection against excessive risk)
- **accelerated adoption of innovative technology**
- detailed equipment monitoring as high priority for maintenance personnel, utilizing the IT infrastructure, with associated training
- a new residential customer relations function of providing energy management services, with associated staffing and training appropriate for former meter readers, young entry-level engineers, and perhaps neighborhood-based service centers.

Improving the energy performance and reducing emissions of our economy as whole requires both adjustment of operating practices and turnover of capital stock in the energy end-use infrastructure. It is now, hopefully, clear how the creation of viable markets for energy efficiency resources would push changes in this direction and how application of IT can help create such markets.

6 For an account of how this concept was used to create a secondary market in home mortgages see the picaresque Wall Street memoir Liar's Poker.
7 See S.Hansen and J.Weisman Performance Contracting: Expanding Horizons Fairmont Press 1998, p.8

IT and INFRASTRUCTURE

Professor Peter Brandon DSc, MSc, FRICS, ASAQS
Pro-Vice-Chancellor (Research and Graduate Studies)
University of Salford, Salford, M5 4WD, UK

Introduction

This short statement attempts to identify the key issues with regard to the contribution IT can make to Infrastructure development and the essence of the research agenda that might be required to fulfil the full potential of the technology.

Infrastructure

The term infrastructure is usually defined in the following way: -
"The basic facilities of a country or region, such as roads bridges, water delivery or sewage treatment" and in *Design Engineering* "broadly the underlying structure of any system". (The Academic Press Dictionary of Science and Technology 1992).

The lists below give some context to the 'market pull' which will be exercised on the IT industry when it addresses the research needs of those engaged in infrastructure development. However there is also the advance of technology itself which exposes new possibilities for the use of IT which in turn may well add to the market demand

The ***nature*** of many of these facilities in terms of their construction and for some their operation is that they are **d**angerous, **d**irty, **d**eteriorate fast and are often **d**istant from each other and spread over wide geographical areas.

The ***demands*** of the various stakeholders who are engaged with the facilities are that they should be **e**fficient, **e**ffective, **e**conomic and **e**nvironmentally friendly.

The ***support*** that can be given by IT systems is to make the transmission of information to man or machine **q**uicker, in greater **q**uantity, with better **q**uality. It is these benefits which need to be exploited for the good of the infrastructure.

To ***realise the potential*** and to ensure the confidence of the stakeholders the systems must be **p**eople based, **p**rotected and secure, and **p**lace independent.

Information Technology

This can be defined as: -
"The use of computers and telecommunications for the processing and distribution of information in digital, audio, video and other forms." (The Academic Press Dictionary of Science and Technology 1992). Most commentators today would place more emphasis on the information content and its structure and this says something about the changing nature of this fast moving field, If this is true it suggests that 'people issues' are critical to the success or otherwise of an application and that the 'hard' technology is in advance of the 'soft' technologies. In turn this would suggest that the hard technological advances are now

informing the market which has yet to realise the full potential of the technological advances being made. The definition of a decade ago seems curiously out of date!

Today the emphasis seems to be more on knowledge management within application areas rather than on the hard technology. However because of the nature of infrastructure projects it is likely that the two will be balanced. It will be necessary to pursue hard technologies particularly where there is an interface with machinery but knowledge management and the human computer interface will be important in the fields of management and soft systems involving the human exchange of information.

The Main Themes for Research

At the University of Salford (School of Construction and Property Management) we have identified four main themes under which we can explore various application areas for the construction industry which is also engaged in infrastructure development. These are: -

Visualisation – The ability to provide visual information in a way that corresponds to the equivalent of the human eye and brain and also to provide virtual environments which aid retrieval and use of information such as in data warehousing.
Intelligence – The ability of a machine to replicate human decision making and thought processes and to enhance human capability where relevant. In time this will also involve the 'jacking in' of machine parts into the human brain to compensate for human inadequacies.
Communications – The ability to transfer data and knowledge across spatial boundaries, man/machine boundaries, and machine/machine boundaries at optimum speed and perfect quality.
Integration – The ability to bring together all systems into a holistic 'organism' which can support all required applications, evolve towards new applications, call on the repository of universal knowledge when required and be accessible from a variety of appropriate devices.

The initials spell out the **VICI** program – a Latin word meaning "I conquered" and credited to Julius Caesar when he conquered Britain when legend has it he said "Vini, Vidi, Vici" translated "I came, I saw, I conquered!"

Each of these themes is critical to the development of the infrastructure and indeed most people would argue that information technology and particularly the communication networks are part of any advanced society's infrastructure. All four themes are developing in parallel but with different emphasis. The view among the Salford researchers is that *Visualisation* is active at the moment and is likely to remain so for another decade. *Intelligence* has had periods of rapid growth and interest such as the Japanese Fifth Generation project and the UK 'Alvey' initiative in the mid eighties and is likely to return to popularity in around ten years time. The area of *Communications* is largely in the hands of the Telecom companies and the mobile device manufacturers and these survive by being at the leading edge of the technology and are research sensitive. Rapid development will continue for some time to come and will influence all aspects of the infrastructure as well as being part of it. *Integration* is the major theme in research and application, driven by the improved communication networks and the view that the full potential of the information revolution will not be realised until the diversity of current systems are rationalised and brought together for mutual benefit. The whole is greater than the sum of its parts!

All are active at the present time and it is only the emphasis which will change. In developing a research agenda for infrastructure the nature and timing of these trends is important especially as the ability to apply technology and/or create the knowledge management systems, so often talked about, will depend extensively on the progress in industries outside of construction or civil engineering. If the research agenda is to address all these issues then the time span over which that agenda is operational is important. However ultimately all will be integrated together and the integrating mechanisms and their management will feature heavily in all programs. For example it is hard to imagine an advanced intelligent system without visualisation in the longer term but this will require management of the input and output of visual information which is of a different order to what we experience today. How do we sieve knowledge for example from all the information that we gather from sight?

The Priorities for Infrastructure Research

Assuming that the above set of assumptions are correct and the needs of stakeholders are as defined above then we can identify some key areas of focus for infrastructure research and IT development to work together. These are as follows: -

Knowledge Management
The ability to provide structured and meaningful information in such a way that it assists decision making by being pertinent, relevant and supportive of the decision making process at the time that the information is most usefully employed. This touches on intelligence and information management as well as those technologies which convey information and manage it within the computer system. For infrastructure research the key question is "How do I provide the right information at the right time and in the right format to aid decision making in management/design or the operation of devices?" Flowing from this is a whole series of research projects related to the storing, manipulating, presenting and managing information.

Remote Communication
The ability to operate machines or to supervise projects at a distance, usually to avoid dangerous or dirty conditions and/or to make the process more effective and economic. Within this area is the use of tele-presence and devices for visualisation, sensory feedback and remote control devices linked to information and management systems. The generic research questions relate to representation of real-life situations (particularly with regard to visual information), knowledge capture at a distance and quality of information transfer including the security of information. With new technology allowing 'location awareness' the networks need to know where you are, who you are, why you are there and how you are connected, for them to be able to support you in an efficient and effective manner. This is important within a spectrum of communications infrastructure which will encompass for the foreseeable future both cable and mobile transfer.

Control Systems
The ability to control devices or activities through controls operated automatically, usually at a distance, in order to improve the speed, effectiveness or cost of operation. The main areas here are the interface between human and machine and the degree to which intelligence can be imparted to the machine to ensure compliance with the human determined requirements. Coupling this area with communications the use of satellite positioning systems to link with PC and mobile systems to control machines and activities could lead to major changes to site control and methods of working.

Integration
The ability to bring together different systems in a harmonious way to create a seamless web of knowledge and technology which may in the longer term allow all systems to grow and develop in an 'organic' way with the possibility of a Darwinian model becoming operational within a technical infrastructure. The key questions here relate to the willingness of the stakeholders to collaborate for mutual advantage, the security systems to ensure confidentiality, the management systems to sift, control and organise both the knowledge itself and its transfer and in the longer term the 'jacking in' of computer systems into the brain so that neural functions are also integrated into these systems.

Barriers

It is easy to become highly speculative as to which direction the technology will take us in the future and science fiction is in the process of becoming science fact. However there are many barriers which stand in the way. In the short term these barriers seem to relate to legacy systems which firms adhere to in order to avoid the expense of retraining or because they have a lack of confidence (often based on unfortunate past experiences) in the progress that has been made. Perhaps even in research there is too much importance given to what exists already and allowing this to contextualise our work.

For many developments to reach their full potential then a culture change is required in the industry not dissimilar to that experienced in the financial and travel sectors but far more difficult because of the lack of coherence found in construction compared with these other sectors. There is also a requirement to raise the education of the industry to encompass both technology and management of the technology and the information systems within all technological infrastructures. In time education may become a downloading process into the brain and death may result in experience of the deceased being downloaded to another person or machine. Thank goodness this is a very long way off.

The reliability of systems, their security and their ability to interface with one another are major hindrances which require applied research to resolve them. There is a need for precision within data handling whether it be character, voice (the hardest!) and video if it is to be used in major infrastructure schemes where the penalty for failure can be catastrophe.
Finally the barriers raised by politics, economics, social issues and legal frameworks and regulation are probably far greater than those of the technology. These areas are under researched and require urgent attention.

Conclusion

If the infrastructure industries are to become world class in the sense that they can compete with the other major industries and harness information technology for the benefits of their clientele then there must be major incentives to change. Those will come from the market and the issues identified at the beginning of this paper will be the ones to enforce new developments in the democratic and free world. Research can often provide answers but it is only when the industry wants to adopt those answers will the results become effective.

IT and Transportation Infrastructure: Issues and Research Needs

Chris Cluett
Senior Research Scientist
Battelle Transportation Division
Seattle, WA
cluett@battelle.org

Discussion Paper Prepared for ICIS Workshop
Arlington, VA
June 25-27, 2001

Overview of the problem. Christine Johnson, the Director of the Federal Highway Administration's Joint Program Office, gave the keynote presentation at the Intelligent Transportation Society (ITS) America's annual meeting in Miami this past June 4th. She reported what everyone in this country already knows from personal experience -- America's transportation infrastructure is stressed to the extreme, and the underlying reason is that over the past two decades vehicle miles of travel have increased more than 70% while road capacity has increased little more than 1% during this same period. In some communities congestion is up over 300%. A Transportation Research Board study expanded upon this dilemma, suggesting that while "more people will be driving more miles annually, by 2020 there will be little fundamental change in the current network of highways."[1] What are some of the answers to this problem? Ms. Johnson suggests a combination of new construction (very expensive; raises environmental issues); bigger role for transit (but ridership has been declining, and it too is expensive); and managing better with technology. This is where ITS in general,[2] and IT in particular, is emerging as a major factor in the search for solutions to our nation's transportation dilemmas.

The Texas Transportation Institute in their widely publicized study on urban mobility patterns reports the following startling statistics:[3]

- The cost of traffic congestion nationwide totaled $78 billion, representing the cost of 4.5 billion hours of extra travel time and 6.8 billion gallons of fuel wasted while sitting in traffic.
- The average delay is 36 hours per person per year.
- The average rush hour trip takes 32 percent more time than the same trip taken during non-rush hour conditions.

[1] Transportation Research Board. 1997. *The Future Highway Transportation System and Society: Suggested Research on Impacts and Interactions.* Research and Technology Coordinating Committee (FHWA). Washington, DC: National Academy Press.

[2] The USDOT defines ITS as follows: Intelligent Transportation Systems represent the next step in the evolution of the nation's entire transportation system. As information technologies and advances in electronics continue to revolutionize all aspects of our modern-day world, from our homes and offices to our schools and even our recreation, they are also being applied to our transportation network. These technologies include the latest in computers, electronics, communications and safety systems. *[see "What's ITS" under http://www.its.dot.gov/]*

[3] Schrank, David and Tim Lomax. 2001. *2001 Urban Mobility Study.* Texas Transportation Institute.

The TTI authors suggest that there is no single solution to the worsening problem of traffic jams. "Widening roads is part of the solution, but it's only one of many elements we need to address the problem." They stress that other means, including demand management, operational efficiency improvements and better management of construction and maintenance projects, must also be employed as part of an overall mix of solutions. This is a conclusion on which most transportation professionals agree. There is also agreement that many of these desired efficiencies are going to come from the considered application of IT to improving the overall operational performance of the existing transportation infrastructure, and both the public and private sectors must partner in the search for solutions.

The FHWA conducted several public surveys in the year 2000 to better understand how the public perceives the performance of the transportation system infrastructure.[4] The public was asked to indicate preferred transportation improvements to overcome travel delay problems, and many of the leading suggestions included infrastructure and operations improvements, and IT-related solutions to the problems, as shown in Figure 1 below. As illustrated by the responses in this figure, many of the suggestions call for improvements in infrastructure and operations that can be facilitated by the greater efficiencies offered by IT/ITS.

The USDOT and ITS America are currently working on the development of a 10-year National ITS Program Plan and Research Agenda. Preliminary results of this effort suggest that "realizing the benefits of ITS does not require any fundamental breakthroughs of science or technology. ... Most of the challenges which transportation and ITS face relate far less to basic technology than to the need to change and update our institutions and to develop a far better understanding of the human factors of travel for drivers and other travelers in all modes. There is a need to eliminate communications barriers between people and between interrelated systems in order to provide seamless, end-to-end movement of people and freight."[5] This planning process has identified an extensive set of "outcome-oriented" and "facilitation" themes that will be used to guide the identification of future research. These theme topics are listed in an attachment to this paper. Full annotations for each topic are contained in the referenced *"Preliminary Results"* paper.

Battelle conducted two studies this past year that bear closely on the topic of IT and transportation infrastructure. The first was a synthesis study conducted for the Transportation Research Board that examined the impact of IT on transportation agencies,[6] and the second was a scanning report prepared for the TRB that examined some of the organizational impacts experienced by State Departments of Transportation as a result of new IT.[7] Both of these reports produced research recommendations that are outlined herein.

---

[4] U.S. Department of Transportation. Federal Highway Administration. 2000. *Moving Ahead: The American Public Speaks on Roadways and Transportation in Communities.* (February)

[5] USDOT and ITS America. 2001. *Preliminary Results: Ten-Year Program Plan and Research Agenda for Intelligent Transportation systems in the USA.* A "Work in Progress" released May 21, 2001 for further review and discussion. Available at: http://www.itsa.org/home.nsf

[6] Transportation Research Board. 2001. *Impact of New Information and Communication Technologies on Transportation Agencies. NCHRP Project 20-5; Synthesis Topic 31-08.*

[7] Transportation Research Board. 2001 (expected). *Innovations in Organization Development as a Result of Information Technology.* NCHRP 20-24(14) Task 6.

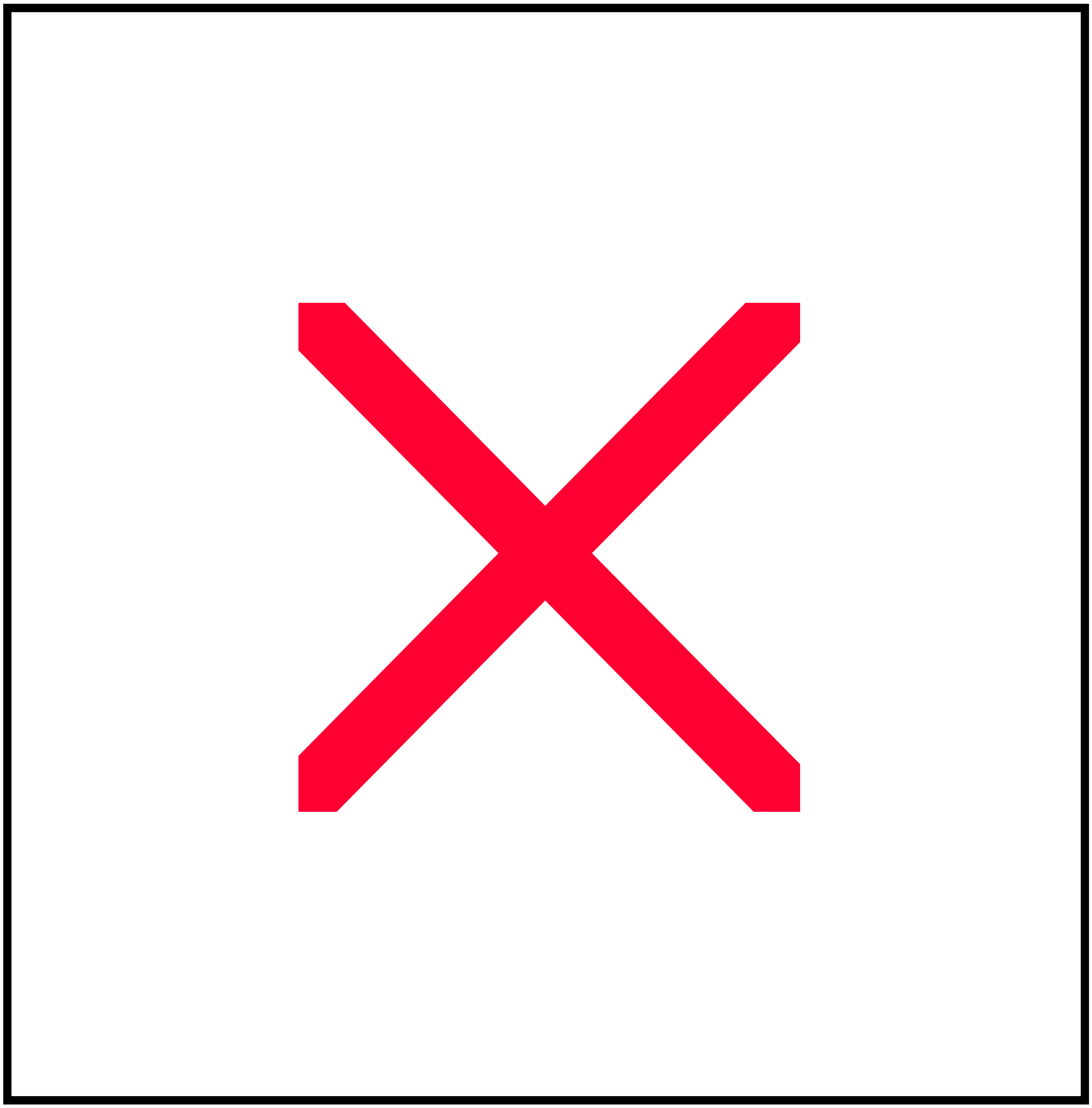


FIGURE 1. PREFERRED TRANSPORTATION IMPROVEMENTS

The second study conducted for the TRB had its origins in a workshop held in June 2000 sponsored by the TRB, the American Association of Highway and Transportation Officials (AASHTO), FHWA, and the Minnesota Transportation Department. This workshop also resulted in the identification of research needs, many of which are relevant to IT and infrastructure.[8]

Some Observations Based on How State DOTs are Using IT. Reviews of the literature, interviews with a variety of state DOT managers and engineers, and recent planning

---

[8] Transportation Research Board. 2000 (Issued in Draft). *Strategic Management Research Needs for State Departments of Transportation.* Developed by Participants in the CEO Workshop on Managing Change in State Departments of Transportation. June 25-27, 2000, Minneapolis, MN. Transportation Research Circular.

workshops have yielded a number of observations that may be helpful in the further consideration of research priorities.

The attached annotated table lists a range of Information Technologies and briefly describes some of their uses in the transportation arena. Findings from the TRB synthesis and scanning studies cited earlier indicate that many DOTs are already employing these technologies or are carefully considering using them to improve their operational performance and the performance of the transportation infrastructures for which they have oversight responsibilities. Many of these IT are central elements in ITS.

In considering how ITS may affect transportation infrastructure, the following issues seem relevant:

- It is instructive to look to the lead transportation adopters of ITS for examples of how IT is being used to address the underlying transportation problems noted earlier. As with any innovative product or technology, some transportation agencies are willing to take greater risks than others to see how effective these technologies might be and whether they can be fit within their existing programs. The successes and the failures in the implementation of these technologies help provide a roadmap for others to follow and to help avoid some of the early pitfalls experienced by some. Some have suggested turning to private industry to uncover lessons learned that can be applied in the public sector. How can public transportation agencies better utilize private sector resources? There is interest in convening state DOTs to review experiences and best practices. There are several active Internet-based dialogues that frequently touch on IT and infrastructure issues.
- In a recent survey of state transportation agencies and organizations, respondents were asked to rate the importance of various considerations in making decisions to purchase or deploy new IT. The top four decision criteria include the importance of adequate financial resources, evidence that the new technology is meeting customers' needs, evidence that the technology will have system-wide benefits, and having adequate staff to support and maintain the new technologies. The survey indicated that IT procurement and deployment decisions are complex, occur after extensive deliberation, and take account of everything from financial and staff resources, to the ability to identify and measure benefits, to having contingency plans in place in case the technology deployment fails to meet expectations.
- As some DOTs have discovered, it is important that IT procurement and implementation fit into a thoughtful planning process. Non-integrated technologies, or those purchased without the benefit of a long-range plan, can result in longer operator training times, poor operator performance, and errors in public information.
- A significant current issue in IT and transportation focuses on how to address the "data gap" problem. This includes the integration of new data sources and information with existing legacy databases, sharing data across organizational components (and all the institutional issues that derive from that effort), cross-platform data sharing, and coping with the more pervasive problem of insufficient data availability to support various transportation needs, such as the adequate provision of information to planners and travelers. Even in locations where good geographic coverage is available, the granularity and quality of the data do not meet the needs of services and systems that require a data stream. Ideally, public agencies would be deploying region-wide, full scale, detailed data collection systems, but the cost are prohibitive, so this is not likely to happen. While the consumer may eventually have to pay for some or all of these kinds of information services, today it is not possible to meet these requirements, even for a fee. What then

constitutes a reasonable, achievable outcome? How, for example, do we define a level of service for information, given the current data gap?

- The impact of IT in transportation agencies is likely to have far reaching ramifications well beyond their original intent. The move in the direction of e-government has implications for hardware and software improvements and skill training for the staff who will operate and maintain them. Agencies will need to look beyond immediate impacts to how changes in one IT area will affect other parts of their organization and operations.
- New IT is creating a competitive environment in which public transportation agencies find themselves competing with the private sector for scarce talent and seeking new ways to train and retain existing staff to fill new job roles and responsibilities. The adjustments required are not only technical but cultural and institutional as well. What will be the appropriate core staff competencies for transportation agencies in the coming years and how can they be best obtained (or retained)?
- DOTs and other transportation agencies are under increasing public scrutiny regarding their management of the transportation infrastructure. Increasing public expectations for performance in this area, along with new asset management requirements, is placing these agencies under a lot of pressure. IT has emerged as an essential tool in facilitating public interaction and the two-way flow of information between the public and the agency. More needs to be understood about best practices, both within and outside of transportation agencies, about how to facilitate citizen interaction and the engagement of the public in transportation infrastructure management and development, and project planning for the future, given the crisis conditions faced by transportation in many parts of the country.
- There is evidence that IT is contributing to a significant paradigm shift in many transportation agencies. The basic DOT mission is shifting from a focus on construction and infrastructure maintenance to a focus on more effective enterprise-wide asset management, enterprise information management, enterprise resource management, stakeholder and customer engagement and e-business. Because each of these agencies is different and operates in a different environment or context, each is interested in how best to customize existing IT developments to address their particular needs. How does a changing mission impact technology and information needs? How can transportation agencies develop quicker response methods for sharing management and technology innovations?

Some Research Directions. Recent discussions with representatives of State DOTs have identified a number of potential research directions related to IT and their role in a transportation context. While these serve as some examples of where some state DOTs would like to see new research headed that is related to the role of IT in their business, the "themes" mentioned earlier that are emerging from the comprehensive 10-year planning effort are suggestive of an even broader research scope that will be articulated over the coming months.

1. DOTs are operating their IT functions under a wide variety of different models across the country. A portion of the IT functions may be centralized, either within the DOT or at a higher state agency level, and others decentralized. There are tensions and tradeoffs, such as between conformity and flexibility, local control and central control, consistency and special needs, dependence and independence, procedural rigidity and responsive nimbleness, efficiency and redundancy, and complexity and ease of use. Research is needed to explore the relative advantages and disadvantages of the degree and types of centralization of the IT function in order to provide better guidance to state DOTs that are struggling to manage their IT functions with too few resources. This research should

describe the different approaches or models being used, explore their strengths and weaknesses, and provide clear guidance to DOTs and states about how to more efficiently and effectively manage the IT function.

2. Contracting out, or outsourcing, various functions of an organization is an increasingly common practice, and State DOTs are beginning to experiment with outsourcing elements of their IT function. In many DOTs outsourcing is a cost-effective alternative to trying to obtain scarce funding within the organization to provide various IT services, such as application development, database administration, or network services. Internal staffing constraints motivate some DOTs to outsource. But outsourcing comes with real costs. DOTs may have to give up a measure of control over their IT functions, and quality assurance becomes an important issue. Research is needed to identify and document the range of IT functions that can be outsourced, the experiences of DOTs with outsourcing, and the pros and cons of outsourcing. Recommendations should be offered to guide DOTs in understanding what to outsource, when to do it, and how to do it cost-effectively.

3. E-commerce or e-business uses IT to fundamentally change the way in which organizations operate. Some State DOTs are beginning to use e-business to communicate information about their activities and provide products and services over the Internet to customers, suppliers, and other DOTs. E-business also offers opportunities to support public-private partnering, contracting, procuring, and a variety of other DOT functions. But DOTs are generally slow to respond to these opportunities because of a lack of understanding about how to participate in this new way of conducting their organizations' business. IT requires a whole new business model. Research is needed to review how other organizations are using e-business approaches, to understand which of the many DOT functions can take most advantage of the potential benefits of e-business, to clarify the pros and cons of e-business particularly for State DOTs, and to recommend a step-by-step transition approach for DOTs to move in this new direction.

4. State DOTs are faced with complex and difficult choices when considering the acquisition of new IT. IT is mostly new to DOTs, it is changing and evolving rapidly, IT tends to be costly, and DOTs are under increasing pressure from their customers to get up to date with regard to IT. DOTs don't want to fall behind the curve in terms of their use of IT, but they also don't want to take undo risks with unproven technologies. DOT management tends to be conservative and the decision factors associated with IT procurement are typically new and uncomfortable. Research is needed to understand and organize the factors that are important for DOTs to consider as they move to adopt IT. The research should yield recommendations and clear guidance for identifying IT opportunities, prioritizing IT options, assessing the risks associated with IT acquisition, and tailoring new IT to best fit the needs of each DOT.

5. The rapid diffusion of IT presents state DOTs with pressing challenges of how to more effectively manage vast increases in information and data. This raises questions of what data are most important, how data are to be acquired and disseminated, how long does certain information and data need to be retained, who needs access to various information, and how information can be controlled and security maintained. E-mail and the Internet provide new ways for DOT employees and customers to gain access to information, but little is understood about the consequences. The costs associated with quantum increases in data volume and complexity are large. Managers are drowning in e-mail. Research is

needed to develop a set of recommended data management procedures for DOTs, and to describe the benefits of more careful attention to information flows both internally and externally.

6. The management and operation of IT requires a very different skill set compared with the traditional transportation engineer, operator or manager. In addition, these skills are in high demand in the marketplace today. When recruiting DOTs find themselves competing for scarce human resources with high salary demands, and when looking to upgrade existing staff, the training and staff retention costs are high as well. DOTs often are constrained with mandated salary caps, antiquated job classifications, and non-competitive benefits packages. IT staff turnover tends to be high, and the costs and challenges of addressing this problem are daunting. Research is needed to offer guidance to DOTs about how to address these problems and should include a recommended set of tools or strategies for managing their IT staffing needs. It should include an inventory of how DOTs are coping and should draw on organizational experiences and models outside of the DOT community for creative suggestions.

Information Technologies (IT)

Infrastructure-based sensors

Sensors imbedded in the road, on the road side, or overhead can detect and count vehicles, discriminate type or size of vehicle, extract information from the vehicle about the vehicle's condition or its contents if it carries a transponder device, weigh the vehicle in motion, and perform other such functions that provide traffic managers with information to help with operations and management. New detector technologies include laser, microwave radar, ultrasonic, acoustic, and video imaging. These are supplementing existing technologies such as telephone line, fiber optic, coaxial cable, satellite, and wireless. An example would be an Automated Vehicle Location (AVL) system that a transit agency uses to track and report on bus locations.

Vehicle-based sensors

Sensors in the vehicle can send information about the vehicle or its contents to external detectors along the roadway, to the driver of the vehicle, or to other vehicles. Information could include the presence of another vehicle in the blind spot (lateral collision avoidance), information about the vehicle in front or behind that could be used to regulate braking and acceleration (longitudinal collision avoidance), information about road hazards, night vision enhancement, and heads-up displays, and vehicle condition sensors that relay safety information to the driver, such as a tire failure warning system. Both infrastructure and vehicle-based sensors are being considered as components of an automated highway system (AHS). Sensors and signal devices can support capabilities such as signal preemption, allowing emergency vehicles or buses to alter traffic signal timing to facilitate efficient travel under certain authorized circumstances. Sensors on buses can count passengers, thereby facilitating the more efficient scheduling and management of a complex transit system.

Automated data collection systems

Examples included on-board electronic recorders used by some commercial vehicle operators (trucks, buses) to record hours-of-service in place of manual entries into logbooks as required under existing regulations, thereby facilitating data entry by operators and data administration by fleet managers.

IT in support of real-time traffic information

This information, also referred to as dynamic traffic information, provides drivers with actual up-to-the-minute traffic conditions on the roadway. This can include information on congestion, accidents, construction, or road weather. The information can be disseminated via radio, TV, the Internet, wireless technologies (PDAs, pagers, other), Kiosks, or in-vehicle devices (auto PC, IVN, etc.). Dynamic information can be integrated with static information, such as normal route guidance provided by an IVN, thereby providing optimal route guidance based on current conditions. This information can be provided to travelers pre-trip using television, the Internet, or the telephone, and also en-route using IVN devices, autoPC, wireless handheld devices, pagers, or cell phones.

In-vehicle Navigation Systems (IVN)

These IVN systems may be portable or permanently mounted in a vehicle. They are typically coupled with GIS and include up-to-date map databases to provide visual and/or auditory route guidance (turn-by-turn instructions) to the driver. They may include dynamic information on current road conditions and congestion.

Internet / Intranet

The Internet is becoming more widely used to disseminate various kinds of traveler and traffic information, including highway, transit, ferry, and other modal information. Typical applications offer real-time traffic conditions on a map-based display, with speeds, construction, and accident information. Video images are often components of these Internet sites. The Internet is at the heart of e-commerce and e-government. Transit web sites offer schedule, fares, route guidance, transfer information, and multi-jurisdiction integration. Information is made available on ride sharing plans, information for the disabled, micro road-weather information, and the like. The Intranet is used by DOTs to exchange operations and management information internally, and the Internet for external communications and information exchange, such as electronic dialogues. Information can be customized for the user and delivered via e-mail, wireless, or telephone. The Internet serves as an important conduit between DOTs and their customers, including Q&A, public notices, and customer satisfaction surveys. DOTs have web sites that they manage alone or in collaboration with ISPs. Private sector traveler information web sites typically access and add value to public traffic data. The Internet is accessible by DOT employees both at work and at home, thereby facilitating telecommuting.

Digital satellite photography

Images of large areas, with details on roadways and traffic conditions, offer traffic managers a tool for better understanding and managing traffic networks on a real-time basis.

<u>Voice-activated and voice-recognition systems</u> As IT proliferates in various in-vehicle devices, the ability of the driver to use these systems effectively without distraction becomes a critical safety issue. Voice-activated and voice-recognition systems provide a way for the driver to query the system and acquire needed information without taking his/her eyes off the road.
<u>Global Positioning System (GPS)</u> GPS has many applications in transportation associated with providing real-time location on map-based systems. Applications include IVN devices, arrival-departure information for transit buses displayed at transfer stations, ferry locations displayed on the Internet, assignment planning and tracking for snow plows, location and tracking of railroad cars, and many other related uses. By 2002 a Nationwide Differential Global Positioning System will be operational across the country, providing exceedingly accurate locational information, thereby facilitating a host of new transportation applications, including navigation and route guidance; the management of fleets of vehicles; emergency notification or mayday services; roadway maintenance; and intelligent vehicle infrastructure. Expected benefits include increased safety, mobility, and operations efficiency. AVL systems (notes earlier) are often GPS enabled.
<u>Automatic collision notification devices</u> When a vehicle is involved in an accident, the driver may either not know where he/she is located (at least not with precision), or may be injured and not able to call for help. These devices are automatically triggered by an impact and summon assistance without human intervention. They communicate exact location information, using GPS, to assist aid vehicles in quickly locating the accident site.
<u>Variable Message Signs (VMS)</u> These kinds of roadway message signs are variously called VMS, CMS (Changeable Message Signs), or DMS (Dynamic Message Signs). They are typically connected by landline or wireless communications to a Transportation Management Center (TMC). Standard message sets are displayed on these signs to alert drivers to potential dangers on the roadway, such as restricted lanes, construction, accidents, traffic congestion, weather, and the like. Messages can be posted and changed by central operators via telephone or other communication devices. VMS come in different sizes, depending on use and required length of message content. VMS can be fixed or mobile.
<u>Highway Advisory Radio (HAR)</u> HAR systems are based on short distance radio communication, typically from either permanently mounted or mobile transmitters. They are used to convey current traffic condition information over dedicated radio channels that are displayed to drivers on roadside signs. HAR is used for various types of traveler information, including weather, road conditions, accidents, construction, tourist information, ferry schedules and queue status, and other types of information. Messages can be posted and adjusted by traffic operators by phone, wireless communications, or manual replacement of message tapes.
<u>Closed-Circuit TV (CCTV)</u> CCTV is being used extensively by DOTs, for both metropolitan and rural applications, to display current conditions to travelers and system operators either over the Internet or on standard television monitors. Communications can be landline (typically fiber optic) or wireless. The cameras are often of the Pan-Tilt-Zoom variety that allow traffic centers to scan all segments of a roadway within the full field of view. They are useful for displaying traffic flow and congestion or focusing on accident scenes. The displays benefit both drivers and maintenance and emergency service providers.
<u>Wireless communication</u> Wireless communications are emerging rapidly with many transportation applications. Wireless has the advantage of allowing information exchange from remote locations that may not be easily or cost-effectively accessible by land lines. A good example is a road-weather information system (RWIS) that collects and transmits such information as road surface and sub-surface temperatures, wind speed and direction, precipitation, video images, and related data. RWIS facilities are placed in areas particularly vulnerable to icing, winter storms, flooding, and related environmental conditions that can impact safe travel, and these areas are often remote (such as a mountain pass). Wireless communications are often associated with VMS, HAR, CCTV and other data gathering sensors that feed data streams into TMCs to facilitate traffic operations. Individual travelers also have access to new wireless technologies for sending and receiving information that are used for trip planning, summoning emergency services, facilitating travel decision making, and the like.

Cell phones Cell phones are becoming almost ubiquitous, especially in urban areas where cell coverage is greatest. They are used extensively by travelers for trip planning and as a safety backup device. Some DOTs and private sector firms offer access to real-time traffic information via cell phone and even post toll-free highway information numbers on VMS. An emerging use for cell phones is as probe devices that allow traffic operators to track vehicles with cell phones anonymously and map traffic speeds, congestion, and flow patterns using automated computer software. These data can then be processed and disseminated to all travelers to offer system-wide real-time information that is not restricted to only those locations that have installed sensors. Cell phone technology also allows users to transfer text messages, thereby opening up additional transportation information exchange possibilities.
Pagers Pagers are as widely distributed in the population as cell phones. They are used as a way to wirelessly exchange information about travel conditions to travelers and can be customized by some vendors to provide only the information content and location specificity that the user desires. Implementations have included pager watches, which offer traffic information beamed to a users receptor watch in a package deal that might include other information such as sports scores, stock market data, or news headlines.
Personal digital assistants (PDAs) PDAs are becoming increasingly widespread in the population, and some of them have wireless connectivity, allowing Internet access to traffic updates, map-based route-finding capabilities, point-of-interest information, and other useful traveler information. PDAs are also being built into cell phones, though this is a leading edge application that is not yet widely in use.
E-commerce (E-government) E-commerce refers to business transactions conducted over the Internet. DOTs are increasingly adopting e-government strategies for the procurement of goods and services, for communicating with their customers, for managing construction bids, and for managing internal administrative processes such as payroll and travel. DOTs are providing their many types of forms over the Internet that used to be handled only in hard copy. Sharing of information over the Internet in this way requires significant efforts to standardize within and across agencies. A shift toward e-government requires the development and use of a variety of new computer software for financial management, timekeeping, literature search, database management, project management, construction management, and all the many other functions of a DOT.
Computer models, simulation and visualization, and database software Models and simulation offer DOTs an opportunity to better understand the characteristics of complex traffic networks under a variety of conditions and to test how interventions might impact or benefit system performance, such as changes in signal timing and coordination, the use of ramp meters, or changes in lane design. Modeling may be used in other aspects of the management and administration of DOT operations. Visualization software offers new capabilities in communicating complex concepts, understanding relationships underlying large data sets, and facilitating the modeling and analysis of transportation networks and traffic flow. In support of these information management and analysis capabilities is new database storage, retrieval, mining, and management software that facilitates handling large volumes of information more efficiently. Electronic data exchange software (EDI) also supports the more efficient exchange of information.
Geographic Information Systems (GIS) GIS incorporates location-based or mapped information into computer databases and provides software that allows the user to analyze a variety of data and information in terms of their locational attributes. DOTs, as users of GIS systems, would typically be responsible for the transportation "layer" in the GIS. This includes precisely digitized map information on roads, highways, points of interest, bicycle and pedestrian paths, and a variety of transportation facilities. Other agencies could contribute similar data on attributes of interest, such as the location of fiber optic cables, phone lines, power lines, and the like. Taken together, these data in a GIS, along with powerful analytic and display software, provide DOTs with a tool to plan new construction, system upgrades, and other modifications of the transportation infrastructure. In addition, geocoded data can be disseminated to travelers over devices such as IVNs to provide route guidance and other information that needs to be understood in its locational context. Mapped GIS applications in transportation require frequent updating in order to keep the information current with rapid changes in the transportation infrastructure and land use patterns.

<u>Portable pen-based systems</u> Pen-based technologies, which include PDAs, are typically used in the transportation field to allow easy remote access to data that reside on central transportation data base systems. They also allow field personnel to input and update data to the system, typically using pre-designed forms that are accessible in a portable handheld device. Pen-based systems are being used by DOTs in commercial vehicle programs for credential and weight verification at weigh stations and border crossings, and for tracking containers from ship to truck to rail.
<u>Remote access (e.g. Internet, Intranet, video conferencing, cellular, telecommuting)</u> IT is making it feasible for employees to work away from their main office, communicating by phone from remote locations, communications via the Internet and via dedicated access company computer networks, video conferencing in lieu of travel, etc.
<u>Electronic payment systems</u> DOTs are using electronic payment systems on passenger, commercial, and transit vehicles for toll, fare, and fee payment.
<u>CAD/CAM</u> New computer-aided design software (CAD) allows engineers to be more efficient and to communicate concepts to others more clearly and quickly.
<u>Decision Analysis Software</u> Software is available to aid managers and operators in analyzing complex sets of decision criteria and a wide array of information to aid in the decision making process.
<u>IT of the future</u> IT is changing and developing rapidly, so forecasting where IT is headed in the future is a highly uncertain business. Individuals working in transportation organizations are managing and exchanging ever increasing volumes of information. They can anticipate higher bandwidth computers that are even more portable. Advances in electronic information exchange hardware and software will facilitate interaction and communication among work groups and support the ability of employees to work offsite and on field assignments with greater access to company data. Individuals will be in constant touch with colleagues through portable communication and data exchange devices that can be easily connected through a single number for each individual. Automated systems will facilitate easy communication between company and customer. Voice recognition systems will be common, including automated language translators. Information and communication will cross national borders with increased transparency. Individuals, work groups, and entire businesses will be connected in cyberspace and supported with virtual reality capabilities. Portable, personal video-conferencing capabilities will increasing substitute for travel or the need to be located in central structures, and telecommuting will be more common than today. Of course, there will be developments in IT that we can’t foresee or anticipate that will further alter the way we do business.

Summary list of theme topics from the FHWA/ITS America ten-year program planning process:

Vision or outcome-oriented themes:

1. Seamless, End-to-End, Convenient and Affordable, Intermodal Travel for People, Regardless of Age or Disability
   - Door-to-Door Travel
   - Customer Based Traveler Information
   - Integrate real-time trip planning from all modes of transportation
   - Empower travelers by enabling multi-modal pre-trip planning and en-route flexibility
   - Personalize ITS
   - Special Services for Transportation Disadvantaged
   - New Transit Services (e.g., bus rapid transit; shared track rail)

2: Seamless, Efficient End-to-End Intermodal Freight Movement

3: Integrated Nationwide Network of Transportation Information
   - Integrated regional and national information
   - Better Operations and Planning Decisions Based on Data
   - Vehicles as Information Sources (e.g., probe vehicles)
   - Collection/Integration of real time multimodal information to make integrated system management and true multi-modal traveler information possible
   - Meteorological Data for Measuring Environmental Impact
   - Better Information for Reducing Environmental Impact

4: Advanced Driver Assistance and Active Safety Products in the Vehicle
   - Crash Prevention
   - Safety, Mobility, and Efficiency through In-Vehicle Electronics

5: Automatic Incident Detection, Notification and Emergency Response
   - Automatic incident detection and response
   - Emergency Response

6: Automated Enforcement

7: ITS Technology Reduces Environmental Impact

8: Universal Payment and Transaction System

9: Advanced Multimodal Control Systems

10: Qualified Operators

11: Cooperative Vehicle-Highway Automation

<u>Enabling, facilitation-oriented themes</u>:

1: Broaden the ITS Transportation Management Perspective

2: Refocusing Transportation Management on Customer Oriented, Performance-Driven Operations
- Organizational Efficiency
- Focus on Customer Service
- Policy Commitment to Customer-Driven Operations
- Program Opportunities (new coalitions, new workforce requirements, and new ways of doing business)

3: New Institutional and Organizational Roles and Relationships

4: New Approaches for Transportation/ITS Funding
- Funding Landscape
- Mainstreaming of ITS Planning with Conventional Planning and Programming
- Improved Public-Private Partnerships to Attract Capital Resources
- Create Special Resource Demands (see ITS as part of a balanced transportation program)

5: Mainstreaming ITS

6: New Public Sector / Private Sector Relationships

7: Privacy

8: Re-forming the Transportation Engineering and Management Professions
- Create new training opportunities
- Create professional interdisciplinary teams

9: Human Factors

10: Performance Measurement, Benefit Evaluation, and Market Research
- ITS will be most successfully sold where it meets marketplace needs, which must be investigated, defined, and better understood through effective market research.

11: Architecture and Standards
- The industry needs to explore whether traditional standards approaches are still appropriate for pursuing interoperability and lowering system lifecycle costs, changes that may be needed to the traditional process, and alternative approaches.

The Impact of Information Technology on Residential Location

Ingrid Gould Ellen
New York University

The rise in personal computer ownership, the growing use of email and the Internet, and the emergence of network-based computing are collectively changing how people work. The central question I am interested in is whether these technological advances are changing *where* people work, and ultimately, where people live. Some theorists have speculated that workers will soon choose to conduct all personal and professional activities from their individual homes, rendering the workplace obsolete (Toffler 1981; Negroponte 1995; Gilder 1995; Naisbitt 1995). Toffler predicts that "electronic cottages" will replace the office and that the home will become "the central unit in the society of tomorrow" (Toffler 1981). Without workplaces, Toffler and others argue further, the need for cities will cease. Gilder (1995) states bluntly that cities are simply "leftover baggage from an industrial age." Naisbitt believes that cities and countries will be replaced with millions of "hosts or networks that are all tied together" (Naisbitt 1995). Despite all these dire predictions, little is known about the relationship between telecommuting, cities, and residential location. My key interest is in examining the impact of information technology on residential patterns and urban form. More specifically, are advances in communications technology leading households to opt for more remote, less urban locales?

Reasons to Expect Decentralization

It is commonly believed that advances in transportation technology, such as the truck, the automobile, and the inter-state highway system facilitated the suburbanization of employment. During the 19^{th} century, when the cost of moving people and goods was high, urban areas were quite dense. As the streetcar, commuter railroads, and interstate highway system were developed, households could afford to move to outlying and lower density areas. Jobs followed too, as the development of trucks and extensive highways made transportation much cheaper and a central location less critical. Firms could now more easily move to the suburbs to take advantage of lower suburban land costs and to gain access to the new markets developing in the growing suburban communities (Mieskowski and Mills 1992).

Several theorists argue that advances in communications technology have similarly fostered suburbanization, especially of office jobs (Garreau 1991; O'Sullivan 1991). They argue that these new communication systems (telephone, fax machines, electronic mail) have effectively lowered the cost of transferring information. Office firms can now locate in more remote areas, reap the benefits of lower land and labor costs, and still communicate regularly with centrally located partners and clients, without incurring excessive costs. The extent to which this has in fact happened is unclear. Consider that high-tech firms are among the most concentrated of any in the United States, suggesting spatial dependence rather than independence (see below).

To the extent that businesses are suburbanizing, households are likely to follow suit. Moreover, many have speculated that technological advances will soon make telecommuting widespread, enabling workers to move to more remote locations, further from their workplaces. Given the high costs of urban living (traffic, crime, high taxes and rents), increasingly footloose households may then opt for outlying, dispersed residential environments (Salomon 1985; Pascal 1987; Castells 1989; Kumar 1990; Nilles 1991; Lund and Mokhtarian 1994; Gordon and Richardson 1997; Giuliano 1998; Shen 2000).

Shen (2000) models telecommuting as an increase in locational flexibility. Regardless of the location of workplaces, if people can substitute electronic communication for face-to-face interaction, then telecommuting should increase the number of feasible residential locations. This would predict a furthering of urban sprawl, a pattern that will be reinforced by the fact that workers living in more remote areas may see more to gain from telecommuting. It seems apparent, after all, that middle-class households in the United States have used the locational flexibility afforded by transportation improvements to move to outlying areas, either to seek larger homes and yards or to escape urban blight (Mieskowski and Mills 1992).

Reasons that Decentralization may not Occur

Despite the intuitive appeal of this hypothesis, there are reasons to believe that these technological advances will not in fact lead to such residential upheaval and decentralization (Gaspar and Glaeser 1998; Moss 1998). First, people may not telecommute on a regular and sustained basis, and thus commuting costs will not be so dramatically reduced. As of yet, relatively few workers have chosen to telecommute full-time (Mohktarian 1995; Wheaton 1999). Even armed with personal computers, fax machines, and high-speed cable-modems, most workers still apparently find it imperative to spend time at their office.

Second, workers may find electronic communications to be an imperfect substitute for face-to-face interaction (Thrift 1996; Gaspar and Glaeser 1998). As useful as email is, for instance, it is not ideal for exchanging complex ideas or transferring skills. As Moss (1999) puts it, “firms [still value] face-to-face activities as a means to generate new products and develop new services.” Indeed, trends in office design -- away from individual offices -- suggest a recognition that workplace interaction is, if anything, growing more critical as our economy grows more technologically sophisticated (Davis 1998; Barta 1999). In sum, although telecommuting may grow in popularity, workers are likely to telecommute only part-time, or for limited periods of time, and thus the option to telecommute may not radically shift people’s residential preferences.[9]

Third, while improvements in communications technology (e.g., cable modems or “DSL”) may lead people to telecommute more intensively in the future, workers may still prefer to locate in dense metropolitan regions. As workers use more technology, their networks may grow and they may find themselves *more* reliant on face-to-face interaction -- interaction that is naturally facilitated by dense, urban locations. (In other words, electronic and face-to-face communications may in fact be complements and not substitutes (Gaspar and Glaeser 1998).) Indeed, it is in precisely the information-intensive jobs that lend themselves to telecommuting that such face-to-face communication is likely to be critical. It is no coincidence that the high-technology industry is the most geographically concentrated in the United States (Schoonhoven and Eisenhardt 1992; Black and Henderson 1999). Despite their heavy reliance on up-to-date communications technology, high-tech firms find it critical to locate near to others in similar ventures to share workers, information, and ideas. Similarly, Audretsch and Feldman (1996) find that innovative activity tends to be more spatially concentrated in industries with higher levels of R&D expenditures.

[9] Workers in the U.S. also change jobs frequently, so they may resist moving too far away from future job opportunities and job networks.

Fourth, home workers may also choose to be centrally located to have easy access to airports and business services, such as video conference centers, office supply stores, and mail-related services. Finally, there is also something to be said for the importance of simple social interaction. Even if information sharing across workers is not so critical, workers may still feel the need for human contact. Some studies suggest that telecommuting is quite isolating for most workers (Moss and Carey 1994; Gillespie et al. 1995). Thus, even if workers do find it possible to telecommute full-time, they may choose to do so in urban settings, where they can easily interact with others.

Key Research Questions:

- Is technology changing business location decisions? If so, how, and are households following suit?
- How prevalent is telecommuting and how is it growing over time?
- Will more widespread availability of broadband technology increase the prevalence of telecommuting?
- Does telecommuting alter residential location decisions? In what ways? Do telecommuters tend to opt for more remote locations?
- Who tends to telecommute today? Do we see evidence of the digital divide? Might an increase in telecommuting alter residential segregation patterns?
- What variation do we see in the prevalence of telecommuting across areas? To what extent does the availability of telecommunications infrastructure drive these patterns?

Contributions to a Research Agenda on
Bringing Information Technology to Infrastructure

Steven J. Fenves, Senior Research Associate, NIST
University Professor Emeritus of Civil and Environmental Engineering,
Carnegie Mellon University

I certainly agree with the point in Peter Kissinger's *A Proposed Research Agenda* that the foremost issue in fostering the further adoption and expansion of IT is Issue 1: ***Developing value propositions that transcend the construction portion of the life cycle and bring compensation to the engineer-constructor for capabilities enabled in future portions of the life cycle.*** This, however, is not directly a research issue that calls for funding by NSF or any other potential research sponsor. It is an education and public relations issue that the A/E/C industry must address, so as to convince the clients of constructed facilities that IT investment in the design and construction phases is worthwhile.

The *Agenda*'s Issue 2 is: ***Knowledge consolidation and broadcasting about our industry, the diverse initiatives going on around the world, best practices, new value points, etc. to educate all involved. The work should build up CERF's cenet.org site and be done in a manner similar to the ASCE effort displayed at May meeting of the ad hoc committee.*** This, and the following issues on the *Agenda*'s list are perfectly appropriate for CERF which - the R in its name notwithstanding - is not a research agency in the sense used by NSF but an agency concerned with the dissemination, adaptation and adoption of already known research results.

Research, that is, the creation of new knowledge, whether that knowledge is embedded in theories, methods, concepts or devices, requires a different agenda. CERF's *Agenda* identifies a potential end state of that research, namely, that new devices resulting from the research may serve in turn as new input to CERF's adaptation process.

The starting state is also relatively clear to see, whether you subscribe to the "technology push" theory of the various IT technologies looking for another application area, or to the "demand pull" theory of the infrastructure, the public sector and the construction industry all looking for innovative solutions to important practical problems.

Between the start and end states is the research process itself, largely but by no means exclusively performed by the academic research community that looks to NSF for research support. As a member of that community for over 40 years, I offer a set of observations that may help to shape the research agenda. These observations are taken largely from [Fenves 1997]. If one asks the question what research, specifically academic research, has contributed to the evolution of IT and computing in practice, three trends appear to have taken place.

First, essentially every point tool that provides computational modeling of a physical or organizational phenomenon or process can directly trace its origin to academic research, whether it is matrix or finite element modeling of structural behavior, settlement or stability analysis of geotechnical materials, CPM or PERT modeling of projects, etc.. Furthermore, the tool capabilities mirror the progress of research. In fact, a good portion of the research in these areas is driven by practitioners' needs for greater scope and fidelity in computational modeling. The closer the computational modeling capability is to identifiable tasks in practice, the more rapid is the adoption of it. Just in terms of my own research, the structural analysis program and its associated problem-oriented language which my colleagues and I developed in the early 1960's was adopted very quickly and became the precursor of a large number of commercial programs [Fenves et al. 1964]. On the other hand, my work and that of my colleagues on standards representation and processing in the 1970's and on synthesis of conceptual designs in the 1980's and 1990's have seen only sporadic adoption [Fenves et al. 1995]. I attribute this discrepancy partly to the fact that neither standards processing nor synthesis are specific, identifiable tasks in the design process for which a point tool is sought.

A second trend is research leading to new disciplines that provide generic support capabilities, such as database management or geometric modeling. Here, research clearly arose out of the need to provide firmer, theoretical bases that could overcome shortcomings of practice. Witness the firm mathematical bases provided by the relational database model and by the constructive solid geometry and boundary representation geometric models over their empirical predecessors, the hierarchical and network data models and the wireframe geometric model, respectively. The fact that the relational database model is being overtaken by the object-oriented model and the two-manifold geometric models by the point-set (non-manifold) model does not detract from this argument. On the contrary, these changes have provided the research community with an impetus to extend their theoretical foundations.

These two trends vividly illustrate the interaction between practice and research in emerging fields: the role of research is to provide a scientific knowledge base so that empiricism can give way to rational, causal understanding, providing an explanation of observed behavior, a democratization of the field through education in fundamental principles and platform for building new capabilities. This is how in the nineteenth century structural mechanics evolved out of the empirical building craft that preceded it.

The third trend has not been nearly as encouraging. A substantial amount of research has been published on computer-aided engineering and IT in modeling and integrating civil and building engineering processes. Much of this research is motivated by the perceived shortcomings in practice. However, with very few exceptions, the vast effort by industry organizations and software vendors in intra- and inter-company integration has taken place with essentially no direct input from the research community. The best that can be said is that practice has benefited from some of the research explorations in areas such as objected-oriented representations, expert systems and other applications of artificial intelligence, product and process modeling, etc., that have produced awareness and illustrations of new approaches. On the other hand, this large body of research has not yet produced the formalizations, generalizations and explanations that constitute the scientific knowledge or conceptual framework on which new generations of practical capabilities can be founded. Thus, today, in many crucial areas of integration, practice is ahead of research, and the profession is still waiting for the emergence of a new knowledge base.

In summary, my 40 years of experience reduces to one observation about the unexpected synergy of research and practice: unless the research work is integral to an existing academic discipline or leads to a new academic discipline that is formal and teachable, the research results will not make much of a practical impact either. I trust that the above observations will assist the Workshop participants to define a research agenda.

References

Fenves, S. J., Logcher, R. D., Mauch, S. P. and Reinschmidt, K. F., (1964), *STRESS - A User's Manual*, MIT Press, Cambridge, MA.

Fenves, S. J., J. H. Garrett, Jr., H. Kiliccote, K.H. Law and K.A. Reed, (1995), Computer Representations of Design Standards and Building Codes: U.S. Perspective, *International Journal of Construction Information Technology*, 3(1):13-34.

Fenves, S. J., (1997), Computing in Civil and Building Engineering: Changes and Opportunities, In *Proceedings Seventh International Conference on Computing in Civil and Building Engineering*, pp. 11-18, Seoul, Korea.

IT Research Issues and Opportunities in Construction of Infrastructure

By
Carl Haas, Ph.D., P.E.
University of Texas

Submitted for discussion for the NSF Information Technology and Infrastructure Workshop hosted by the Institute for Civil Infrastructure Systems (ICIS) headquartered at New York University

At
Arlington, Virginia
June 25-27, 2001

Introduction

Construction has constituted on average about 9% of the US GDP for the last few decades. It represents probably the most significant component of an asset's life cycle cost, and its execution can impact operating and maintenance costs substantially. It is characterized by the intense mobilization of resources for a short period of time, in contrast with infrastructure systems operation and maintenance. Because of its highly fragmented, risk conscious, rugged, experience based, and dynamic nature it has historically resisted technological innovation. Nonetheless, it is beginning to experience a revolution much more significant than that of the introduction of heavy hydraulic equipment early in the last century.

Significant technological advances are just now beginning to emerge. For example, with the locating and positioning power of GPS and laser systems, the seamless communication of 3D design information, and the current computational power of computers, heavy equipment such as dozers, graders, and pavers have been roboticized, thus eliminating time consuming, critical path surveying operations and radically improving ease of use (re. Trimble, Topcon, and Caterpillar). Most successful firms are implementing 3D and 4D CAD to improve communications and coordination, eliminate design errors, and to anchor fully integrated and automated project management processes (e.g.s Fluor Daniel, Black and Veatch, and Bechtel). Project management software is beginning to be integrated. Hand held computers (or PDA's) have reached the work site and are being used at the foreman level. Over 30 PDA software applications for construction already exist. Because they are revolutionary, these technologies will disrupt conventional organizational structures, they will create tremendous value, and they will initially result in great waste in some circumstances. As a result, research needs abound.

The remainder of this working note attempts to follow the requested format for the workshop.

Use of IT in Construction

Categories of IT use in construction include:

- Project management
    - Needs analysis
    - Project definition
    - Modeling and simulation
    - Design
    - Procurement
    - Construction management
        - Cost control
        - Schedule control
        - Materials management
        - Quality control
        - Safety management
- Automation of field operations
    - Automation of heavy equipment control
    - Fleet management and logistics
    - Equipment condition monitoring
    - Rapid local area modeling
    - Smart tools
    - Smart chips on major components
- As-built data acquisition
- Communications
- Remote monitoring and inspection
- Etc.

Opportunities, Problems, Barriers, and other Issues

Much research has been conducted on barriers to technological innovation in construction, so they have been well documented (Stanford, NIST, UT Austin, etc.). Good research has also been conducted on methods to overcome such barriers, including an excellent effort and report by CERF. The ICIS white paper for this workshop also deals with some significant issues and problems concerning IT and the infrastructure in general. Some additional issues include:

1. understanding the impact of IT on the workforce

    Is information (or knowledge) power? While the access to all project information all the time may be enabling and empowering to workers, it may also bog them down. In addition, recent research suggests that mature automation technologies require less skill than traditional craft approaches, thus devaluing the workforce. So, will large investments in training be required for a new generation of super workers to deal with IT, or will IT in the form of equipment automation enable the deskilling of the construction workforce and the potential exploitation of low wage immigrant labor?

2. understanding the impact of IT on construction project organizational structure

    With web based project management tools emerging, will IT flatten and geographically disperse the project team, or is face to face time still critical?

3. integrating construction project IT elements

A myriad of software packages exist for construction management. Communication between the packages creates tremendous inefficiencies. One-time data entry and seamless integration are expected to create tremendous synergy. As Greenspan and others have noted, isolated desktop computers created little observable gains in productivity for the US economy until they were integrated via the internet. Such integration has been suggested as a key driver of productivity improvements in the US in the last few years, despite recent reverses. For these advantages to be realized in construction, data interchange standards and protocols have to be developed that are broadly accepted and that are flexible enough to link multiple generations of applications. Efforts to do so include PLANTSTEP, FIATECH, and various vendor initiatives.

4. managing the impact of an accelerating pace of change

   Assessing the value and optimal timing of IT based change to organizational and process structures is a tremendous challenge. For example, when should I upgrade my PC's operating system? Methods to improve this critical decision process would be valuable.

5. optimizing organizational memory, learning and knowledge in the face of frequent re-engineering and project mobilization

   Owner organizations felt the pressure to downsize their engineering operations in the 1990's. IT creates opportunities to address the loss of organizational memory due to downsizing as well as project demobilization. Concurrently, its introduction poses learning challenges.

6. handling information overload

   If all project information is available to all project participants all of the time, how will they handle it? How much information is optimal for each project participant? Will self-directed project teams become the norm, or will conventional rigid hierarchical structures prevail. A related question concerns the question of whether decision making for either project management or asset management should still be conducted in a hierarchical manner given the ubiquitous flow of information that may emerge, or whether distributed decision making based on general rules of behavior would be more effective. Put another way, is the value of all the information being generated with distributed sensing being severely limited by its aggregation and compression for traditional decision processes.

7. managing a high frequency feedback control loop

   Wild fluctuations and over-reactions in the stock markets have been attributed to computer based training programs and highly connected and informed traders. For project management, what is the optimal response time to fluctuations in project performance that can be observed when progress data is collected via IT daily or even hourly?

8. studying the behavior of highly connected systems of intelligent operatives

Related to the previous concern is the more general concern of the stability of systems such as traffic networks where each driver has real–time traffic flow information. In construction for example, will procurement of commodities such as aggregate or drywall via internet based market sites be made more efficient, or will prices fluctuate wildly due to short term shortages or perceived shortages?

9. exploiting information integration and fusion opportunities

   Fusing information made available by IT from different temporal and spatial perspectives can result in radically more robust observations and decision making. An example is recent research on the performance of fused traffic incident detection algorithms and logically integrated information for traffic management. Many additional opportunities for improved performance may exist in project performance tracking and infrastructure condition assessment. An obvious example is 3D laser scan based fusion of point clouds to create solid models of built facilities.

10. developing new information technologies

    Developing better, faster, more rugged technologies such as hand-held computers for site use will create real value. Improvements to the control systems and coordination of automated equipment based on IT will also result in significant benefits. The opportunities here are endless.

11. data mining

    Autonomous agents may be developed to find hidden, neglected, or unexpected relationships and correlations among the vast databases created by IT. This area is ripe for development.

How Improvements can be Made and by Whom

Industry, government, and academia should all have roles. In construction, its fragmentary nature should make consortia a more realistic strategy for improvement than efforts by individual firms. Some successful examples include CERF, CIFE at Stanford, CII at UT Austin, and groups at several other leading university construction engineering programs. However in practice, vendors of software and equipment have made the vast majority of technical advances in construction. Directing government ATP funds into construction IT R&D at leading vendor firms would thus probably accelerate developments.

NSF funded research has had a far greater impact than is often appreciated. For example, early research into integrated project databases and 4D project modeling at CMU, Stanford and a few other institutions inspired and broke ground for descendent commercial systems that are now emerging. A step change in NSF funding for construction IT research would no doubt result in even greater future results.

Good Research Topics

Addressing some of the questions posed in the earlier section on issues would likely result in some worthwhile research projects. Colleagues at other institutions and at UT as well as myself are trying to address some of these issues with many ongoing, small-scale research projects.

The Construction Industry Institute has a Research Committee and a Breakthrough Strategy Committee (BTSC). Each has developed prioritized lists of research topics. Examples from the Breakthrough Strategy Committee's list that are related to IT include:

1. "Smart" chips on all Materials and Equipment
2. Real-time Access Interactively for All Project Team Members to all Project Information and Data
3. Manipulable, 3D Holographic Images for Field Use
4. Field worthy computers
5. 24 Hour Construction
6. Voice Recognition for Field Computers
7. Automated Design
8. Completely Re-usable and Modular Facilities

The FIATECH consortium has several related initiatives, which are described on its web site at http://www.fiatech.org/.

The Role of IT is Real-time Infrastructure Systems Management: Challenges, Opportunities, Research Needs

Thomas A. Horan, Ph.D.
Executive Director
Claremont Information and Technology Institute
Associate Professor
School of Information Science
Claremont Graduate University

Overview

The typical connotations of infrastructure are as capital-intensive, "chunky", investments that provide the network grid for economies and communities to function. However, the performance of this infrastructure can vary widely. That is, it can be viewed as a dynamic system susceptible to fluctuations in demand, supply, price, etc. Information technology can play a critical role in enhancing the adaptability of infrastructures, yet these information systems require a level of implementation, coordination, and financing that may be quite different from traditional capital expenditures. I will use the case of Intelligent Transportation Systems (ITS) in Transportation to explore these issues. I will conclude with general observations about generalizability to other infrastructures and consequent research issues.

Surface Transportation Infrastructure

Surface transportation—the network of roads, streets, and transit systems have classic infrastructure characteristics—are very capital intensive and their provision is done through a public capital financing mechanism that typically favors building over operations (e.g. Highway Trust Fund). As a consequence, there are now institutions—such as Departments of Transportation—that are generally organized for building rather than operating. Historically, there has been little institutional motivation for the rapid deployment and use of information technology, though over the last decade the federal ITS program has provided over $1 billion in federal funding, and this has affected the overall posture of transportation toward the use of technology to improve infrastructure performance. The following section outlines some of the lessons from this decade-long experience.

Adequate Sensing. For information technology to perform its role, it needs to sense the demand that is being placed on the system relative to supply of the system. In surface transportation, it has been difficult to deploy a technology that has adequate sensing capabilities. While there is widespread deployment of in-road sensors, their reliability has been mixed. Moreover, there are varying budgetary commitments to their deployment and maintenance and this affects the confidence that can be placed in their availability as a core part of the IT management system. Conversely, the private sector is developing innovative new means for sensing (via wireless) yet the public sector may be hesitant to embrace a new technology with possible performance risk.

Timely Communication and Control. Even if the current conditions have been adequately determined, the ability to communicate that condition to the relevant parties to exert control is not assured. A further complicating factor is that the escalated nature of congestion once it is imbalance suggests rapidly deteriorating conditions that can take a while to regain stability. And while many systems are highly attuned to commute period congestion, an increasing percentage of trips are occurring off-peak. This creates new and different challenges for communication and control, as public and private communication systems (e.g. radio reports) are reporting infrequently during these time periods.

Pricing and Behavior. In the case of surface transportation, there is a long history of avoiding direct pricing of the cost for providing the service. There is an indirect price, the cost of delay and the gas tax, but with the exception of toll-facilities (and transit systems) very little direct price information is provider to the user of the infrastructure. Information technology has provided a new means by which to efficiently deliver price information: the electronic toll tag. This can serve as a leverage point to creating a real-time pricing delivery scheme that includes but is not limited to congestion pricing. While the perceived institutional and policy barriers to this solution are widely known, there are important pockets of deployments in major metropolitan areas that can serve as evolutionary system launching points. A better understanding of how to deploy pricing in an evolutionary sense, and taking advantage of wireless advances is needed.

Range of Options Available. The information system tends to highlight the predominate transportation mode. As such is often understates the role of alternative sources of mobility—transit, car-sharing, etc. At times this reflects the reality that there are not good alternatives to the dominant mode. And this can suggest the separate need to information systems about alternatives. While it is true that as an organization transit agencies are performance sensitive (e.g. on-time performance), there is still a strong capital orientation. While examined under previous initiatives as “jitneys” the role of real-time information in allowing for just in time delivery transportation system merits attention.

Trip Substitution as A Mode. While most examinations have focused on how ITS enables trips, an important part of overall system performance is as a substitute for travel. That is, under what conditions does information delay or substitute for travel. How can these energy and environmentally productive patterns be enhanced?

Institutional Roles. Because the transportation infrastructure has generally been provided by the public sector, there is a widely held view that the public sector should take a strong role in the provision of the IT(S) for the infrastructure. Yet it also widely perceived that the public sector budgeting, procurement and human resource systems are not well tuned to the production of new ITS systems. Consequently, there is a continuing need to create new relationships between the public and private sector where, for example, the public sector becomes more of a customer vis a vis a producer of information systems.

Generalizability and Research Issues

For the purposes of the NSF workshop, I would posit that several aspects of the ITS experience are generalizable to IT-infrastructure issues where the public sector plays a strong role. In these cases, the capital-intensive nature of the infrastructure finance and organization can lead to a conservative approach to infrastructure management and the use of IT therein. In part this is because the advent of IT as a sophisticated system may be relatively new as compared to this organizational history of infrastructure building. In part this may be because the procurement systems of the public sector do not easily lend themselves to technology intensive solutions. And in part this may be because the use of IT in infrastructure management may lead to a level of interaction with the user of a system that suggests "social engineering" through price or incentives.

However, as a general proposition it seems clear that the most efficient use of infrastructure systems will occur where there is a robust IT system that can be developed. The following research issues are aimed to examine the system, institutional, and user elements associated

Strategies for Emergent Networks. In the case of ITS, the National Systems Architecture provided an overall framework for the network to develop. However, the network has emerged under various formats. What is not understood is how the emergent network can suggest new forms of deployment strategies. For example, the institutional layer of the ITS architecture had originally envision a strong role for the public sector in providing data and a strong role for the private sector in managing and reselling the data. What if the private sector probes are more effective but the marketplace is very weak for traffic information. What does this do for the institutional architecture? How does this affect system design? The more general research issue is on models for infrastructure information provision, focused on varying roles of the public and private sector.

User Acceptance and User-driven services. The ability of users to interpret, respond to information, and otherwise behave in predictable ways is a central assumption of ITS systems, and probably for other systems as well. Understanding whether or not this in fact occurs is a critical element to a successful IT strategy for infrastructure. Moreover, the widespread dissemination of internet technologies is conceivable changing the role of the traveler and, more generally, infrastructure user. (For example, an increasing amount of travelers plan their own air travel) Research is needed on the behavior of information-enabled travelers or, more generally, information-rich infrastructure users.

Planning Methodologies. Infrastructure systems have developed tailored methodologies for planning their deployment. In the case of transportation, for example, there is a complex process for planning new transportation systems. Research is needed to assess the adequacy of this planning process with regard to the IT elements of the infrastructure. Moreover, there are a number of cases (such as energy and telecommunications) where infrastructures are converging. Understanding the promise and complications of planning converged technological systems is another area worthy of research.

Draft: June 16, 2001

A Proposed Research Agenda

Submitted by J. Peter Kissinger
Senior Vice President of CERF, on behalf of CERF and the CERF Ad Hoc Committee on Information Technology

For several years, the members of the Civil Engineering Research Foundation (CERF) Corporate Advisory Board and the Board of Directors have encouraged CERF to expand its information technology (IT)-related activities. IT is beginning to have a major impact on how members of the design and construction professions do their work, and even greater benefits are possible, including enhanced coordination, greater productivity, reduced operating costs, and better results for clients. This rapidly growing field is still relatively new and thus presents many opportunities for research and collaboration that will benefit the industry.

This "call for action" was consistent with the strategic-planning effort CERF had previously initiated in conjunction with the White House's National Science and Technology Council. That effort, which was designed to foster unprecedented collaboration among the various elements of our industry, established the following goals for the next decade:

·50 percent reduction in project delivery time
·50 percent reduction in operations, maintenance, and energy costs
·30 percent increase in occupant productivity and comfort
·50 percent fewer construction- and facility-related illnesses and injuries
·50 percent less waste and pollution
·50 percent greater durability and flexibility

In early 1999 CERF made a commitment to provide leadership and serve as a focal point for future collaboration on information technology. Specifically, CERF created an Ad Hoc Committee on Information Technology comprised of industry leaders to initiate a national dialogue in this area. Mr. John Voeller, Chief Technology Officer of Black & Veatch, agreed to chair the group. Subsequently, the Committee met twice and identified twenty-one high-priority IT-related issues and potential projects (see below).

CERF is now seeking organizations and individuals interested in transforming the issues into specific action plans and eventually collaborative projects that will address one or more of the needs identified. To that end, **this set of issues is provided to the participants in the Workshop on Information Technology and Infrastructure with the hope that many of the issues identified by CERF's work to date will be considered and integrated into the research agenda developed by this workshop.**

The following is a consolidated list of all the items from the Ad Hoc committee. They are arranged in the order of decreasing priority based on voting done by the attendees at the last meeting.

Issue 1. ***Developing value propositions that transcend the construction portion of the life cycle and bring compensation to the engineer-constructor for capabilities enabled in future portions of the life cycle.***

Perhaps the most difficult task to address, it is as compelling as any other in its implications for changing the profit margins of existing firms. Analyses of the impact of proper management of information assembled in design and construction on the future value opportunities in the operations and maintenance portion of the life cycle are unequivocal. Enormous benefit is facilitated by the E/P/C provider and constitutes an immense opportunity for new revenue. A national task force that establishes and documents these new value propositions, and leads an industry wide dialogue can ultimately change the industry.

Issue 2. ***Knowledge consolidation and broadcasting about our industry, the diverse initiatives going on around the world, best practices, new value points, etc. to educate all involved. The work should build up CERF's cenet.org site and be done in a manner similar to the ASCE effort displayed at May meeting of the ad hoc committee.***

CERF's parent organization, the American Society of Civil Engineers (ASCE) has established a new "Knowledge Management" unit in recognition of the importance of this issue not only to ASCE but to the entire design and construction industry. CERF and ASCE both agree that more emphasis in this area is essential and have vowed to collaborate on any future work. For example, discussions are underway to integrate the new ASCE "Communities of Practice" web site with CERF cerf.org and cenet.org sites.

However, to ensue these efforts go beyond the needs of CERF and ASCE and truly meet the industry wide requirements, it is vital that "the industry" must be intimately involved in these efforts. To that end, a national workshop of interested parties, where a detailed action plan and roadmap could be developed, is envisioned as an early next step.

Issue 3. ***Examining the applicability of advanced complex electronic commerce strategies of firms in other industries to construction. Many come from very surprising sectors and have dramatic similarities even though most would believe there could be none.***

CERF envisions benchmark discussions with key target firms from which to develop a better understanding of the modes of success and failure other firms have experienced in their e-commerce implementation. Targetted firms include Dell, Hewlett-Packard, Johnson Controls, Siemens, and Citadon.com. The initial effort would be a national workshop co-sponsored by CERF and Black & Veatch. Subsequent efforts could include benchmarking visits to the targeted firms.

Issue 4. ***Looking at the implications of genuine wireless connectivity in all forms to allow spontaneous collaboration of all participants with equal information access regardless of location.***

There are now six major high-speed (above 1 megabaud) players in the market and three will be available within the year. These should be carefully examined for impact on not only construction sites and vendor sites, but also multiple office environments.

Issue 5. ***Development of a "theory" of construction and a "theory of the business" of construction as opposed to continuing with the current perspective of using an evolved set of legacy processes.***

This would require bringing together highly experienced people from the CERF membership with people who have superb skills in extracting processes from experts and documenting and confirming it with their help. Black & Veatch has spent a year building this theory for our purposes, which should be a good strawman for accomplishing this. It was started with the specific purpose of re-inventing construction rather than just modifying its current processes.

Issue 6. ***Leveraging efforts in other industries that have intense similarity in process and purpose even though the implementation differences are significant.***

This effort could be combined with item one but a more compelling picture could be seen by visits to BP-Amoco, Chevron, and Statoil.

Issue 7. ***Mapping of value versus risk; a detailed analysis of the value propositions currently offered in this industry versus what could be done with major changes***.

This is a particularly critical exercise when the new and as yet uncertain risks of the various aspects of electronic commerce are factored into the discussion.

Issue 8. ***Industry needs an evolutionary vision that describes a stepwise picture of where we can expect things to go.***

Black & Veatch has written such a document and could make it available as a starting point for a workshop in which this could be refined.

Issue 9. ***Education of owners on the life cycle contribution, e-commerce**, **and other issues that change the roles and relationships between our industry and those we serve.***

This would be incorporated into and a natural follow on to the first item above.

Issue 10. ***Considering ideas such as a Construction Markup Language variant of XML designed to enable neutral drawing mark-up and review, state sensing and control on schedule control, progress reporting, crew management, materials configuration management**, **and other aspects of project life in an open format.***

There are three issues here:

- Education of the membership and exposure to the implications of this area.
- Presentation of go-forward plans by groups such as Bentley on where they are going and where they would go with stronger, broader support.
- Example scenarios that members can take back to their IT groups and assess readiness and probable implementation efforts

In addition, any work will need to be coordinated with other relevant efforts, such as the FIATECH program and the International Alliance for Interoperability (IAI).

Issue 11. ***Starting with no assumptions, develop new construction process without boundaries similar to what*** the ***automotive*** and ***aerospace*** industries***, and Frank Gehry**, **have done.***

Any work in this area should be coordinated and/or included in item four above.

Issue 12. ***Our roles, impacts**, **and consequence of electronic commerce**; **Understanding what these look like and how they will affect our members.***

This could be an associated output of item three above.

Issue 13. ***Examination of the cultural change impediment that seems to stifle many initiatives.***

This is a very general effort that would require behavioral psychologists to assist in the effort. The chair will initiate discussions with several universities to see if we can find a way to gain positive benefit for those we need to assist us. This actually has implications for almost every current and future automation effort in our industry.

Issue 14. ***Examining the powerful opportunity available to constructors by proper enabling of the owner's future asset management capabilities.***

An amalgam of the prior two items, this is a natural follow-on to items six and seven. One key is asset management enabling technologies which should therefore get priority attention.

Issue 15. ***Considering the consequences of electronic commerce applied to the recruitment and retention of craft labor.***

Both within their own labor force and those of contractors and support groups, a giant revolution is likely across our industry in the next ten years. The primary element of this will be the broadcast disclosure of details of skills, experience, and capabilities in a knowledge market from which resource consumers will shop for people. Each resource will have a Web site about their experiences, skills, desires, and needs, and consumers will assemble teams from this information regardless of affiliation. CERF envisions a workshop that will explore various models and visit the steps a member would need to consider to move forward.

Issue 16. ***Examination of implications of more work and greater scope of work moving offshore.***

This effort should start with a survey of all possible organizations about their current and planned efforts in this regard. This will establish intent, awareness of options, and market pressures to initiate. This could be done by a well-coordinated web survey.

Issue 17. ***Analyzing the impacts of human augmentation methods such as exoskeletal assistives site all-terrain tools, OrbComm style tracking systems, and other enhancement devices.***

This is being studied by Black & Veatch, which has agreed to provide the results to CERF for syndication and comment by the CERF membership.

Issue 18. ***Comprehensive risk mapping; a detailed examination of the topology of risk in our industry. This is not a static map, but one that changes over time and has different perspectives depending on the industry sectors.***

Unlike item seven above, this effort speaks more to the idea that the industry needs a tool to assemble, manage, monitor, and improve their risk profile over time. There are a number of similar efforts that came from combat strategic analysis as well as the NASA space program.

This is an effort that should be handed over to a construction-savvy academic to pursue in some detail. First step would be a literature search to surface both past efforts as well as strong researchers in this area.

Issue 19. ***Analyzing the massive changes that the coming introduction of intelligent devices will make on both the systems and tools the industry uses. The training and complexity issues go far beyond any recent transition the industry has experienced.***

With the very recent release of an ever-increasing number of both Fieldbus and Profibus devices, this situation will balloon into serious issues the CERF members and clients will need help in managing. The explosion of the 802.11 and 802.15 devices will compound this significantly and force EPC providers to acquire new resources they may not now have.

Issue 20. ***Considering the transplanting of parallel concepts such as Lean Manufacturing to the construction domain.***

Lean construction is taking root with some companies and there is a need to perform an object assessment for the benefit of companies in our industry.

Issue 21. ***In the manner of Nilsson, examining the ownership of construction innovations by labor as an augmentation of their adoption of new cost-reduction technologies.***

In all aspects of construction, there is a need to re-examine all structural business models of the industry, seeking new value propositions and illuminating where they might be and how to both find them and take advantage of them. This should take the form of a series of workshops.

Additional information on the above list, the work of the CERF Committee and updated information on each issue can be viewed at http://www.cenet.org/clearinghouse/

In summary, we are highly interested in your views and value your input and participation. If you are interested in finding out more or taking part, please contact John Voeller at 913-458-2000 or voellerjg@bvsg.com. Alternatively, please feel free to contact me, Peter Kissinger, at 202-785-6467 or pkissinger@cerf.org.

THE IMPACT OF INFORMATION TECHNOLOGY ON THE DEMAND FOR TRAVEL

Patricia L. Mokhtarian
University of California, Davis

A number of information technology (IT) advancements are improving the *supply* of transportation, through increasing the effective speed of travel and/or the effective capacity of the system. For example, Electronic Toll Collection (ETC) is speeding traffic through collection points, with passage of a vehicle through the collection point noted by means of a dashboard-mounted transponder sending a signal to a nearby receiver, and monthly bills (or electronic funds transfers) sent to the transponder subscriber. Real-time traffic information can be collected from vehicles sending similar signals to a traffic control center, and real-time optimal routes can be transmitted to individual vehicles equipped with in-vehicle information/navigation devices. Thus, traffic can be routed around congestion and incidents in a system-optimal manner. Electronic Data Interchange (EDI) and Global Positioning Satellite (GPS) technologies are reducing deadheading and down-time due to wayfinding activities, thereby improving the efficiency of goods movement as well as passenger transportation. Ultimately, engineers envision the implementation of sensing technology that will permit the platooning of multiple vehicles at close headways and high speeds; successful preliminary trials of such technology have already been conducted.

My interest is in the impacts of these and other innovations on the *demand* for travel. IT can affect the demand for travel in several different ways:

1. ***Indirectly, through its impact on supply.*** To the extent IT succeeds in improving the supply of transportation (e.g. by increasing speeds), demand is likely to be stimulated, just as previous technological improvements increasing the average speeds of travel have increased the total amount of travel.

2. ***Indirectly, through its impact on other activities***. To the extent that IT streamlines the conduct of various activities, time is freed for other activities. Some of those new activities may involve travel, and some of those activities may themselves *be* travel. The first case above is in some ways a special case of this one, in which IT streamlines the activity of traveling for previously-demanded purposes, thereby freeing time for new activities. However, improving the supply of transportation should have a stronger effect on travel demand than another improvement saving the same amount of time, precisely because it is *travel* that is being made easier.

3. ***Directly impacting demand***. The direct impact of IT on the demand for activities can take several forms:

a. *Substitution.* To the extent that the same or a similar activity can be conducted through the use of IT instead of in person, travel to the original activity is reduced or eliminated. There are numerous examples of this type of impact, including telecommuting, teleconferencing, distance learning, teleshopping, telemedicine, telejustice, remote provision of government services, and so on.

b. *Complementarity*. IT will also stimulate additional travel. In some cases, the use of IT *directly causes* or facilitates travel. For example, the contribution of the Internet to the widespread dissemination of information about people, activities, and travel opportunities of interest has inevitably generated travel to engage in some of those activities or meet some of those people. In other cases, travel is either a *necessary accompaniment to or a natural side effect of* the use of IT. The increased availability and lower costs of mobile phones reduce the disutility of travel and facilitate additional travel at the margin.

c. *Modification.* IT can modify something about a trip, such as its departure time, destination, route, or mode. The trip is still made (so it is not replaced by IT), and would have been made anyway (so it is not generated by IT), but there are system-level impacts. Depending on how travel demand is measured, a modification impact could be reclassified as one of the other two. For example, if demand is measured in vehicle-kilometers traveled (VKT), a change in route may either reduce VKT (a substitution effect) or increase it (a stimulation or complementarity effect).

4. ***Indirectly over the longer term, through its impacts on the location of activities.*** IT enables greater freedom in the location of residences and businesses. These location changes will entail changes in travel patterns.

It can be seen that Cases 1, 2, and 3b result in the demand for travel increasing or at best staying constant. Case 3a (by construction) is the only case in which the demand for travel decreases, while for Cases 3c and 4 the net impact is uncertain. The preponderance of evidence indicates that the combined impact of all these effects is in the direction of increasing travel.

The extent to which government should try to reverse that impact is debatable. Certainly, reducing congestion is an admirable public goal (up to a point – economists argue that a service with excess capacity is underpriced and wasteful). But it is acknowledged that mobility has benefits as well, and as a society we pay a certain price for curtailing mobility. Nevertheless, it can be agreed that providing more alternatives to travel – increasing people's freedom to choose non-travel alternatives – is a good thing, and so is using the transportation system more efficiently so that more travel can be accommodated within the existing capacity. IT has a clear role to play in both of these strategies, and public policies can be developed to support both.

Key research topics:

- Improve our understanding of the extent to which (and circumstances under which) travel-based alternatives are preferred to non-travel-based alternatives for the same or similar activities. This can involve a number of separate studies of different kinds of activities (e.g. business meetings, shopping, work), as well as more general studies of the positive utility of travel itself (beyond being a means to the end of engaging in spatially-separated activities).

- Improve our ability to model the net impact of IT on travel demand. This may involve aggregate time series analysis, and/or disaggregate panel studies.

- Improve our understanding of the location impacts of IT, and subsequent impacts on travel. For example, to what extent is teleworking affecting residential location? To what extent will e-commerce affect the location of distribution and retail centers?

- Improve our understanding of the travel impacts of e-commerce in particular, looking at the entire supply chain down to the end customer.

Information Technology, Data Communications and Automation Trends and Issues In the Modern Electric Utility

Charles W. Newton, President
Newton-Evans Research Company, Inc.

Overview

According to utility industry research programs conducted by Newton-Evans Research Company, electric utilities in the United States spend approximately $6.5 billion per year to support information technology systems, services and staff. Another 2 to 3 billion dollars are spent on data communications services. An additional several billion dollars is spent on automation products principally to smarten up the dumb equipment used to generate, transmit and distribute electricity.

The country's electric power production, transmission and delivery infrastructure consists of nearly 3,200 companies and public utilities. Fewer than 150 of these are investor-owned utility (IOU) companies, about 940 are electric cooperatives and about 2,000 are public power utilities. Most of the public power utilities are municipally operated, with others operated at federal, state and county levels of government.

The vast portion of the industry's revenue and spending for IT *(information technology)* and infrastructure equipment is accounted for by the investor-owned utilities. These 150 or so operating companies serve our largest cities, with a few exceptions *(such as Los Angeles, San Antonio, Nashville, etc.).* These same utilities account for about three quarters of total electric industry sales, which are now in excess of $250 billion per year. The IT budgets for this group of investor-owned power companies reflect nearly this same lion's share of total industry IT spending.

Unlike most industries, IT consists of two major and separate sets of activities and functions in electric utilities, at least in the IOU and cooperative segments of the industry. These are the computer data center, headed by the IS or MIS organization, similar to those found in all industrial and commercial enterprises. Secondly, and equally important, is the control center, responsible for the TIS – technical information systems, centering on operational control and monitoring of the utility's often far-flung field resources and assets.

Major IT Activities

The heart of the utility's MIS activities is the CIS – customer information system. The CIS commands the attention of at least 50% of the budget and staff available to the IS organization in most utilities. Rates software and planning applications are also vertically oriented. Mobile computing plays a large and ever-growing role in the IT mix used by utilities. Reliance on multiple communications paths and methods is also typical of today's utility.

Other key applications are “horizontal” in nature, similar to those operated by other commercial and industrial enterprises. These include work and asset management, accounting, financial and human resource management software, and the like.

In the operational control center, the heart of the IS activities is the energy management system in large utilities, and the supervisory control and data acquisition (SCADA) system is key to large, mid-size and smaller utilities. Substation integration and automation systems, and distribution network automation systems are newer additions to the growing portfolio of utility operations IT.

Today’s chaotic electricity industry, in the midst of deregulation on a state-by-state basis, desperately needs more and better coordinated IT and technology solutions to stave off further electricity infrastructure problems. IT can and will play a role in rescuing the industry in this time of great challenges, caused by fundamental changes in regulation, and increased demand for electricity. The Internet and related intranet technologies will play an ever-more important role in helping to improve the reliability of the nation’s electricity delivery system. Technology advances in time-of-use metering and related demand side management programs will help stabilize the country’s “power surge.”

Enabling Technologies for Project Supply Chain Collaboration

Dr. William O'Brien[1]
University of Florida

NSF/ICIS Infrastructure and Information Technology Workshop

June 25-27, 2001
Arlington, VA

Introduction

This paper describes a research agenda for enabling technologies to support supply chain collaboration in the construction industry. Its intention is not to provide a broad-based survey of research needs in construction for infrastructure applications; papers by others in this workshop perform that role admirably. Rather, the purpose of this paper is to set an agenda for technologies that will enable effective, computer supported sharing of knowledge among the many members of the project supply chain. It is the view of this author that improving the cost and time performance of infrastructure projects will necessarily come through improvements in supply chain performance. And while today there exist various tools and paradigms to effect performance improvements, implementation of these require data from the diverse members of the project supply chain. Obtaining this data is one of the most difficult challenges on projects due to dual challenges of heterogeneous information systems and knowledge that is not currently represented on-line. Thus this paper outlines enabling technologies including mechanisms to automate extraction of data and knowledge and mechanisms to enable local knowledge to be formalized and represented on-line so it can be shared. While specific in scope, the recommended research agenda is not narrow. Collectively, the technologies envisaged in this paper provide the basis to enable the next generation of supply chain collaboration tools.

Why the Supply Chain?

It is this author's view that performance improvements in the supply chain are central to making timely and cost effective investments in civil infrastructure. Projects must become less expensive, faster, and, just as important, more predictable in their schedule and scope. Figure 1 shows a conceptual model of a project supply chain. Several subcontractors work on a project. Each subcontractor is served by one or more suppliers. Suppliers in turn can be served by one or more sub-suppliers, and so on. While supply chain composition will vary from project-to-project, any given project may have hundreds of firms involved in the supply chain.

It is clear that much of the design and production knowledge on projects resides in the supply chain. Consider that on any given project, cost may break down as follows:

- Supply-chain operations and detailed design: 80%

[1] Assistant Professor, Dept. of Civil & Coastal Engineering, 345 Weil Hall/PO Box 116580, University of Florida, Gainesville, FL 32611-6580, 352-392-7213, wjob@ce.ufl.edu

- Traditional design and project management: 5%
- Insurance and related service costs: 15%

Of course, these numbers will vary across projects, but supply chain operations account for the largest share of project costs. It is through supply chain improvement that some of largest gains in construction cost and schedule are to be made. Examples of 25-50% reduction in time and cost are not uncommon in manufacturing supply chain applications, and the construction industry FIATECH initiative (www.fiatech.org) has similar goals of 30-40% reduction in cost and time through improved supply chain management and concurrent engineering.
In general, improved supply chain methods are dependent on leveraging knowledge resident in the firms that comprise the supply chain. Extracting this knowledge from potentially hundreds of firms is a fundamental problem in implementing supply chain improvements. A central issue for information technology research is: ***How do we share supply chain knowledge so it can be leveraged?***

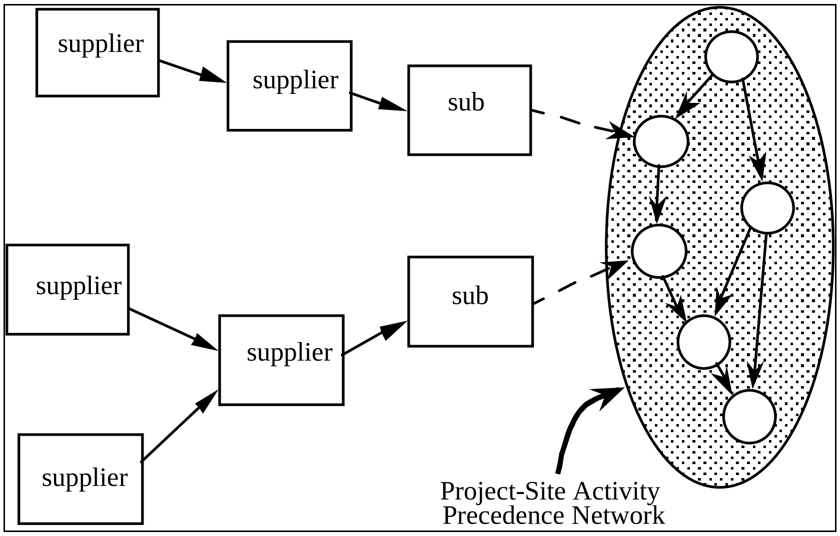


Figure 1: Conceptual representation of the construction project supply chain. Project supply chains are composed of hundreds of firms.

Ubiquitous Problems in Sharing Knowledge

With increasing use of computers in construction over the past few decades, we have become increasingly sophisticated in our understanding of the problems of sharing data and knowledge on project teams, including members of the supply chain. There appears to be an emerging consensus that the principal difficulties in sharing information are:

1. *Too many sources of information*: It is difficult for professionals to assemble information pertinent to business decisions. Information exists in many locations and is often in a raw form not useful for decision making. More time is expended gathering and transmitting information on projects than in evaluating it.
2. *Local knowledge is not formalized*: While increasing amounts of design and construction information is represented on-line, considerable local and tacit knowledge is not formalized. Information that is represented on-line is often in point solutions for individuals and is difficult to share and/or re-use. Much knowledge is in idiosyncratic mental models that are difficult to share with others involved in decision making. This leads to long meetings and miscommunication.

3. *Limited shared visualizations*: Partly due to points one and two, there exists little knowledge about how to visualize process-related information for individual tasks let alone tasks that require input from several professionals. It is all but impossible for professionals to visualize and understand the full magnitude of relationships and constraints in design and corresponding schedule alternatives, leading to unanticipated consequences such as errors and omissions, rework, and misallocated resources.

Limitations of Current Approaches

The principal research and practical approaches to overcome difficulties in sharing information have been based on the development of semantic data standards such as the IFC (iaiweb.lbl.org) and AECXML (www.aecxml.org). These standards facilitate automated sharing of data by applications designed to operate on those standards. Much of this effort has been directed to represent product data, i.e., the geometry and physical properties of construction products. These data standards have been extended to include process data such as cost, resources, productivity, etc. Data standards represent a significant advance, particularly in terms of providing a common language for product modeling. Applications build from data standards will probably usher in the first significant computer IT revolution in construction.

However, standards are not a panacea to all the problems of sharing data. Data standards may speed the collection of data across sources, at least partially addressing point one (above). It is less clear that data standards developed by a committee will be able to represent relevant local and tacit knowledge. And by themselves, data standards do not provide shared visualizations. Moreover, given the large number of firms on projects, and given differences in size and sophistication of those firms, it seems implausible that all the firms in a project supply chain will uniformly subscribe to a single data standard. It is more likely that there will be multiple standards developed for use by small groups of firms or trades, such as the CIMsteel standards (www.cis2.org). Moreover, as much process information in the supply chain relates to cost, time and production capabilities (i.e., much of firms' core operational and competitive information), it is likely that many firms will prefer to use legacy applications to manage this information, avoiding the expensive transition to new applications.

Research Agenda in Enabling Technologies

The challenges in sharing knowledge described above suggest three difficulties that must be overcome. First, extracting data resident in the supply chain. Second, enabling formalization of local and tacit knowledge. Third, development of shared visualizations of product/process knowledge. Existing technologies cannot adequately address any of these difficulties. Collectively, they suggest a research agenda in enabling technologies to support effective project supply chain collaboration.

Enabling technology one: Extracting supply chain data. Extracting data in the supply chain is a challenge as it will likely be stored in information systems with a high degree of semantic and physical heterogeneity. The only way to currently extract data from such systems is to write code for each link to each system. This is untenable given both the number of firms on projects and the transient nature of firms' participation on projects. We need to develop technology with the requisite intelligence to (semi-)automatically link to firms' information systems, discover knowledge resident in those systems, and translate it to a form needed for subsequent analysis. This is a difficult challenge that calls for research both in Computer Science and Civil Engineering. Fortunately, it is unlikely that general-purpose extraction tools are needed. Supply chain analysis generally calls for specific types of inputs, thus it is possible to generate specialized tools to discover specific and limited forms of knowledge.

Enabling technology two: Formalizing local knowledge. How can we help firms capture local knowledge so it can be represented in computer interpretable form? Construction research has a strong tradition of knowledge formalization by researchers. More broadly, computer science has a history of formalizing knowledge in expert systems. Neither approach has made significant impacts on practice outside of limited applications. We need a more general approach that allows practitioners to interact with the computer to develop useful formalisms. One such approach would be to provide graphical modeling tools of core firm processes. As these are customized, the formalisms would be developed almost in the background. In such an approach, core technologies to be developed are dynamic links between graphic models such as scene graphs and process models such as simulations.

Enabling technology three: Shared product/process visualizations. In many respects, the challenges here are similar to those of formalizing local knowledge. While it is likely that some standard shared visualizations will be developed, we must allow practitioners to customize these as needed. We must also provide them with the tools to generate new visualizations appropriate to the needs of individual projects. Visual modeling tools developed to enable formalization of local knowledge would be useful in the manipulation of shared models. However, shared models imply development and manipulation by multiple professionals. Enabling such sharing in computer interpretable form requires that the underlying languages of local formalisms be made compatible (in computer science terminology, we must provide mechanisms to develop shared ontologies). Shared models, if dynamic, must also be updated. The ability to continuously synchronize product and processes data based on events and changes requires extraction of data using technologies like those envisaged above.

Acknowledgements

The author would like to thank the NSF for funding under grant CMS-0075407 that has provided time and resources to develop research needs concerning extraction of supply chain knowledge.

Information Technology for Transportation Infrastructure

Kathleen E. Stein, Howard/Stein-Hudson Associates
ICIS Workshop on Information Technology
June 25-27, 2001

Information technology is increasingly seen as a central, critical component of the development and operation of transportation facilities and services. In this short paper, I will highlight six areas of interest and recent work:

- Intelligent transportation systems, particularly integrated electronic payments
- Traveler information services, including 511
- Multi-jurisdictional planning and implementation
- Customer-based transportation planning, decision-making and service delivery
- Transportation operations
- Data needs for place-based decision making

Electronic Payment Services

Efforts are underway to develop a multi-modal, integrated cross-jurisdictional electronic payment services (EPS) for transportation (and non-transportation) applications. Essentially, such systems would allow travelers to use one payment medium to pay for tolls, transit, parking, and non-transportation retail transactions. While the technical challenges are not insignificant, the institutional issues are seen by many observers as the most difficult and critical. Information technology is a key piece of the equation in several respects. In the early days of EPS in transportation, there was considerable concern about privacy issues associated with the data that transportation providers would have about the locations and movements of individuals. While concerns remain, they have not materialized to the extent feared, nor do they appear to have dampened the marketplace and growth potential of EPS. In fact, EPS use on the eastern seaboard has grown much faster than anticipated.

Two big issues have to do with managing the huge amounts of data in such systems; and carrying out clearinghouse functions for growing and potentially very large numbers of transportation service providers, many of them public agencies, and millions upon millions of transactions. Public agencies especially are struggling with issues such as these. How do we keep pace with information technology developments on the hardware side, given public procurement requirements (and extended schedules) and budget limitations? How do we avoid sinking huge amounts of public money into legacy hardware and software systems? How can we move toward interoperability, not just within a given mode, like highways, where interoperability across jurisdictions has advanced fastest, but across modes, with their very different operational foci and organizational cultures and information systems. How do we exchange funds among agencies, both to cover transactions and to allow one organization to "pay" another to carry out a clearinghouse function more cost effectively, given the historically rigid limits, controls, and public accountability for agency funds? How can we get users timely, accurate information about their "accounts" and assure user confidence in the security, quality, and accuracy of the information substantiating the accounts? What are good opportunities for public/private partnerships in EPS (the private sector has not stepped forward to the degree anticipated by public agencies)? How do we develop the multi-disciplinary workforce necessary to support EPS, particularly with civil service and pay limitations in the public sector?

511 and Other Traveler Information Services

In July 2000, the FCC set aside the 511 telephone exchange, with a five year mandate develop a nationwide system for traveler information, with state and local transportation agencies and telecommunications carriers being key players. Information technology issues are pervasive in this area of 511, indeed, in many aspects of the larger topic of traveler information systems and services.

At present, most traveler information services are highly disaggregated—a user must contact each service provider to gather relevant information and then piece a multi-step, multi-modal trip together herself. She might also have to gather the information in different ways: a phone call, a printed schedule, a kiosk at a train terminal, the internet, radio broadcasts of highway congestion in the car, television broadcasts, highway advisory radio. The nature and quality of available information is also highly varied: some information is static, other is real-time; some information is bare-bones, other is highly detailed; some is visual or graphic, other is printed; most is in English, much less in the other languages spoken and read by users; some is accurate and complete and up-to-date, other is inaccurate, incomplete, and out-of-date; some pertains to just transportation, other includes related travel services like accommodations and attractions; some is developed and provided by the public sector, other by private entities; much is free, some is provided for a fee (directly or indirectly).

Information technology is a central feature in developing any integrated traveler information services. Specifically with regard to 511, key issues have been identified in three areas: content, consistency, and cost. What should be the basic content and quality of information provided? What level of consistency is appropriate when considering such services across the country? Should 511 be free for users? How should it be financed?

More broadly, these issues have emerged. What are the costs and timeframes for instrumenting the nation's transportation systems in order to gather real-time data on system operations? (For example, only about 5% of Los Angeles roads and 20% of its freeways are instrumented; and this about the same situation nationwide.) How do we assemble and keep up-to-date the database necessary to give useful, reliable, credible information to travelers? How and who bears the cost of developing and maintaining these systems, given both the significant costs entailed and the value in the marketplace of the information derived? What scale and level of information integration is appropriate to the marketplace and to different types of users (commuters, visitors, truckers, etc.)? How do we develop and provide better integrated information related to the transit and highway systems (and aviation, rail, and marine)? Historical modal "stovepipes" are still strong and intact in most regions of the country. What aspects of providing traveler information services are most suitable for the public sector and the private sector? What enhancements are needed to the data? What is the value of publicly collected data, in itself and vis a vis value added resellers? What changes are needed in organizational structures and capacities, including workforce development, to support this new emphasis on integrated traveler information services? What new forms of interjurisdictional cooperation are necessary to support traveler information services?

Multi-Jurisdictional Transportation Planning and Implementation

Across the country, multi-jurisdictional coalitions, both formal and informal, have been coming together in recent years to address a variety of transportation issues that reach across large geographic areas. Some of these efforts have been spurred by legislation, such as NAFA, and the US DOT's borders and corridors program; some have been spurred by advancements in intelligent transportation systems and supporting priority corridor initiatives; some have been a result of public and private initiatives to fill perceived gaps in the nation's transportation system. Most of them are driven both by transportation considerations and by realization of the significance of transportation infrastructure to domestic economic health and global competitiveness. A related impetus is the realization that significant new capital transportation facilities are not going to be developed anywhere near the scale of the last several decades: we cannot build our way out of congestion, and need instead to develop new and better ways to better manage and utilize the capacity of the system in place. This cannot be done without sophisticated information technology and newly sophisticated transportation infrastructure owner/operators.

These considerations, along with recognition that travel patterns and operational coordination extend well beyond the boundaries of a given agency jurisdiction, have spurred the growth of coalitions. Half of the 40 largest metropolitan areas in the country span multiple states; many commuters travel across multiple jurisdictions, some using multiple modes of transport, and goods movement patterns span states and national boundaries. In response, public agencies have banded together into largely informal coalitions in order to coordinate transportation planning and operations and, sometimes, to develop integrated service systems (for example, with interoperable EPS systems discussed above).

Several key issues in information technology are apparent. Most data for planning and operations are gathered at the state or sub-state level; little data exist for multi-state regions. There are not good benefit/cost models that can inform and support decision making at a multi-jurisdictional regional scale. Better tools and decision support are sorely needed. For transportation planning and development purposes, most funding is at the state or sub-state level; how do we usefully and equitably fund improvements at the multi-jurisdiction level, and what information support is necessary to make and substantiate such funding decisions? Goods movement, in particular, is relevant at multi-state, national, and international scales. How can we develop better information for planning infrastructure investments with these large spheres of geographic relevance in mind? And where does private, proprietary information fit into this picture, when public/private cooperation is needed to develop and support such infrastructure? At the metropolitan level, much emphasis has been placed on metropolitan planning organizations in the recent surface transportation acts, yet MPOs are not strong players in these multi-jurisdiction issues. How can we foster stronger links at this level?

Customer-based Transportation Planning and Service Delivery

Transportation agencies have become much sensitive and committed to customer-based transportation planning, decision-making, and service delivery. However, there are significant gaps between these good intentions and the information agencies have available to them to make customer-based, customer-responsive decisions. The transit sector has historically been much more market sensitive than the highway side, and market based research has been used to develop service delivery plans. Still, there are huge gaps between what we would like to know about our customers' wants and needs, particularly for sub-sets of market segments, and the information at hand.

Some of the major issues are these. How can we foster the organizational culture changes that are needed to support customer-driven decisions and service? Some of this is happening, but all the information in the world won't help an agency make customer-focused decisions without a supportive culture at all levels of the agency. What are the most appropriate and necessary market research and decision support tools and how can they be brought into the agencies? What new workforce skills are necessary, and how can they be supported via education, training, and new job descriptions and classifications? What internal and external information and communications systems are needed? How can agencies share best practices in these areas, for mutual support and to increase the pace of change and the levels of performance? What are the implications of customer-based decision making for agency resource requirements and vis a vis the political decision process? Will public agencies develop new "vulnerabilities" by their very efforts to be more customer-driven?

We (Howard/Stein-Hudson Associates) are currently carrying out some research in this area for the National Cooperative Highway Research Program (NCHRP); and this research will likely uncover both new issues and new research needs in this area. We recently completed a scan for NCHRP on DOT Communications, Image, and Positioning, and the report on this effort, which reviews current practices and outlines six major areas for needed research, will be available very shortly. The research topics include: methods of conducting market research on image-building and positioning; methods of positioning agencies for public and legislative support; methods of keeping in constant contact with the community and others; methods of improving and maintaining internal communications; methods of comparing internal changes to external impacts on public perceptions; and methods of spreading information about best practices among the states

Other Areas

Two other areas I'd like to touch on briefly transportation operations and data needs for place-based decision-making. Major efforts are underway at the federal level, across the country, and within the major transportation infrastructure professional associations to develop and implement a new conception of transportation operations. This has been driven by some of the same points noted above: the transportation solutions for today and tomorrow will be more in operations than new capital construction. Operations are what impact customers and the quality of transportation services most directly day to day; and they can provide the basis for information to operators and customers about system conditions, along with the strategies to make best use of the existing system.   Many of the information and information technology issues raised above are relevant in the operations arena. What stands out to me as particularly critical is the need for agencies to recast themselves with such an operations focus. This implies dramatic changes in organizational structures, workforces, decision-making, accountability, and distribution of power and influence within and between transportation infrastructure owner/operators and other key players. The interstate highway system is often cited as the most significant change and challenge for departments of transportation. But, relative to this operations emphasis, that was just doing more and bigger on a dramatically larger scale. If successful, the transportation system operations emphasis will change the very nature of the organizations themselves. It's going to be a real challenge for them to bring about these transformations at the very time they also need to be doing the new operations job.

One final topic has to do with data needs for place-based decisions. The National Research Council is completing a report on this topic, in response to a request from the U.S. Department of Transportation's Bureau of Transportation Statistics. (I am serving as chair of the project panel.) Some of the major issues topics addressed in that effort are the following. In the last decade or so, considerable emphasis has been placed on the significance of "livability" of communities and the information needed to make decisions for sustainability. Data, especially geo-spatial data, and decision support tools are needed, as are cross-cutting indicators of livability and measures of performance. The project is focusing particular attention on transportation, land use, and economic development. We hope that effort will help focus thinking in this area and identify areas that are ripe for research and practice-based improvements in planning and decision-making.

COMMENTS ON IT AND INFRASTRUCTURE

Costis Toregas, President
Public Technology, Inc.
Washington, DC

1. Beyond the major IT functions of gathering and communicating information there is a third, much more difficult function and that is its power to ReEngineer the very function it is supporting. This BPR imperative that spontaneously arises from IT is eminently researchable and vitally important from a policy and management perspective.

2. Interoperability may be a better way of characterizing the relationship between IT and infrastructure than the term integration. Integration implies the necessity to shove competing and diverse systems together in a single box / platform while Interoperability is a bit more generous and flexible. Perhaps it forms another, or hybrid, dimension.

3. It is important to point out that urban physical infrastructure systems line up with local government (or at most regional governance) structures as well as being funded or motivated by State or Federal initiatives. It is critical to incorporate this local dimension.

4. An important research question is the alignment (or current mis-alignment) of IT investments between local, state and federal levels and the corresponding inefficiencies and problems. A classic example is the relationship of US DOT to State DOT funding patterns which ignore or run counter to local transportation initiatives.

5. In addition to the effect of IT in centralizing infrastructure functions, there is a new, net-centric future which follows non-hierarchical rules and which is beginning to influence Infrastructure IT systems.

6. Somewhere there should be a reference to the impetus that the new GASB34 standards will have on IT systems development in the infrastructure world, and perhaps a research initiative may emerge from this.

Information Technology Needs In Gas Distribution Infrastructure

Robert Torbin
Manager Business Development: Foster-Miller, Inc. Waltham, MA

Introduction

The distribution of natural gas downstream of the large interstate pipelines is based on an extensive network of buried pipes operated at intermediate pressures with minimum supervisory control required on a routine basis. Although the location of the pipelines is generally known, the local distribution companies usually lack the ability to consistently pinpoint their precise position. This has lead to a chronic problem associated with so-called "third party" damage to these underground assets. Daily incidents of third party damage have been chronicled in numerous gas industry trade journals and Office of Pipeline Safety accident reports. The application of information technology to this endemic situation would significantly improve the ability of the gas industry to reduce the number of accidents occurring annually to their infrastructure.

Technical Approach

The installation of most of the gas distribution infrastructure occurred prior to the advent of global positioning systems and automated facilities mapping software. New pipelines installed today can be accurately located utilizing these (and other) computerized software applications that systematically map the location of the underground facilities. However, older buried facilities are not well located as indicated by the number of hits on the piping occurring every year. The application of information technology to this issue raises three issues:

- Collection of mapping data on existing pipelines
- Transfer of this information to maps used by field crews and "dig safe" services
- Education of field crews to the proper use of this data

The collection of mapping data on existing pipelines must be performed using sophisticated inspection robots (known as smart pigs). Unfortunately, all smart pigs are designed for large diameter, high-pressure interstate pipelines. The piping networks associated with local distribution are by comparison operated at much lower pressures (30 to 60 PSI), are much smaller in diameter (4 to 12 inches) and with many more physical obstacles to the passage of the inspection robot (reducers, valves, tight elbows etc.). Many of these distribution networks are essentially non-piggable. A different platform is, therefore, needed to provide the basic carriage for conducting the piping surveys.

The national institution of a dig safe program has opened the door to the need for location data that is up-to-date and easily available to field crews and third party, construction contractors. The transfer of knowledge from the data collectors to the data distributors to the data users is of critical importance to the success of this process. Without timely access to this information, the contractor is operating blindly. Current practices have demonstrated the need for better accuracy and a more timely response from the utility marking providers.

The knowledge level associated with the typical field crew, while improving, is still low compared to other industrial knowledge workers. Familiarity with digital technologies is essential to the proper implementation and utilization of the mapping data. If the data is misapplied or misunderstood, the buried facility will be damage despite having the knowledge of its true location. Incorporation of location data into the digging methods and machines typically used by field crews must become part of the process. This can be accomplished either through hardware modifications and/or through training.

Research Needs

Extensive research has been conducted (in both the private and Government sectors) regarding the development of mapping and position location software. However, collecting that data for complex underground piping networks is still lacking. Adaptive and highly agile robotic platforms are needed to meet this challenging environment. Knowledge transfer and utilization is also lacking in this market sector. Downloading of current data right to the user and the construction equipment (possibly in real time over wireless communications) would greatly reduce the possibility of causing any physical damage to the underground pipelines.

Mobile Computing and Communications: New Interactions Between Information Architecture and Infrastructure Use

Anthony M. Townsend
Anthony.Townsend@nyu.edu
Research Scientist
Taub Urban Research Center, New York University

Position paper prepared for
Workshop on Bringing Information Technology to Infrastructure
Institute for Civil Infrastructure Systems
Washington, DC
June 25-27, 2001

Introduction

Three technological trends are converging to strengthen and reinforce the link between databases, computation, and the day-to-day management of cities and urban infrastructure.

The expansion of terrestrial wireless communications networks for voice and data
The widespread use of geographic data and geographic information systems
Advances in positioning technologies such as the Global Positioning System

This essay argues that the rapid growth of mobile communications and computing[1] in the first decade of the 21st century will present a series of challenges and opportunities to urban planners and managers. These challenges will come in the form of changes in the location of human activities in urban areas, changes in the character of these activities, and most importantly changes in the way such activities are organized and coordinated. It then suggests some possible topics of a new research agenda in this area.

Technological Trends Driving the Mobile Revolution

The new breed of mobile technologies is characterized by the integration powerful handheld or wearable computers with always-on, wireless, broadband data and voice telecommunications. In this scenario, mobile computing and communications will augment the user's ability to function in professional and social settings by providing supplemental information gathering, processing, and storage functions, which to a large extent will be cued to the user's geographic or locational context. While this vision is not yet a reality, three trends are working together to create this future:

---

[1] Geographer Nigel Thrift has argued that the mobile revolution is actually the real technological breakthrough of the massive worldwide investment in information technology research of the1990s.

Wireless growth. within cities, mobile technologies are quickly becoming more prevalent than the desktop Internet and the personal computer (PC). Furthermore, 490 million of the world's 1.3 billion telephones are now mobile. (ITU, 2000) Mobile terminals will overtake PCs as the most popular devices for Internet access by 2003. (IDC, 2000) Unlike the desktop Internet, voice-driven information portals can serve the billions who cannot read or write.[2] In short, the mobile handset is coming to define our global society in the way that television and the automobile defined earlier generations.

Growth of GIS and spatial databases. A mysteriously under-reported outgrowth of the 1990s revolution in information technology has been the explosion of computer-data that is spatially referenced. It has been estimated that 80 percent of the information on the web is or can easily be geographically encoded. (SRI, 1998) The worldwide market for GIS is estimated at several billion dollars, through the ultimate economic impact of the technology through efficiency gains is surely huge.

Advances in positioning technology. Regulatory initiatives aimed at improving emergency services responses (i.e. 911) to mobile telephone calls have pushed the development of positioning technologies for handsets. Additionally, the U.S. military, under executive order from President Clinton, stopped introducing errors into the Global Positioning System, which will greatly improve the accuracy of these signals in civilian positioning applications. Both developments are leading to miniaturization and reduction in power-consumption of positioning systems, making it practical to integrate them into an increasingly broad variety of devices.

These technologies are combining to create new information services that are *location-based*. That is, a wireless data link (tech #1) can be used to query a GIS (tech #2) for information that is relevant to the user's current position. (tech #3) The few demo applications emerging from computer science research labs offer hints at the types of uses these devices will ultimately be put to, such as posting virtual notes to places (Persson, et al, 2001) and searching for information (Youll, 2001)

Challenges

The rapid spread of mobile communications presents a number of challenges to urban planning and management with respect to the use of infrastructure. This essay does not specifically address the possibilities of using mobile technologies to manage infrastructure. Rather it focuses upon the strains that will be placed on static systems that must respond to an increasingly fickle population of computationally-enhanced cyborgs. These challenges fall into three main areas:

Changes in the location of human activities. Traditionally, urban scholars have addressed the issue of telecommunications from the perspective of its impact on economic geographies, land use, and travel patterns. (Graham and Marvin, 1996) Mobile communications, by freeing the need for many types of workers to remain at their desk, or check in periodically, is helping

---

[2] Services such as TellMe™ combine voice synthesis for the delivery of information on weather, traffic, and stocks via mobile telephone in response to spoken commands.

to move more work out into the field, where delivery persons, salespeople, and others can gain greater efficiency.

Changes in the character of activities. As Moss and Townsend (1999) and Mitchell (1999) note, it is not just the location but the character of urban activities that is changing through the use of new computing and telecommunications technologies. Public spaces in many European cities, once a venue for strolling, begging, or flirting are now primarily used as a place to talk on mobile phones. For those equipped with wearable computers, the parameter of place may become an important way to filter the vast variety of information available through computer networks like the World Wide Web. One can imagine a scenario in which people travel to certain places for the possibility of serendipitous encounters with interesting information, the way they travel now for the same types of chance encounters with people.

Changes in the way such activities are organized and coordinated. Most importantly, mobile technologies permit a new degree of freedom in both movement and scheduling that is unprecedented. Because information about status, ETA, etc. no longer flows from place to place, but from person to person, activities can be coordinated more loosely. Ling and Yttri (1999) call this phenomenon "hyper-coordination", while Townsend (2000) has argued that such changes represent a fundamentally decentralizing and accelerating force in urban dynamics and urban metabolism. Other possibilities include hot-spotting in physical locations, much like happens with popular websites. (Townsend, 2001)

Developing A Research Agenda

The evolution of mobile communications technologies have had a rich and fundamental connection to the shape and size of human settlements. There is a strong likelihood that the location-based services will continue and reinforce this connection between design and the built environment, yet will also extend this effect to the design of information architectures as well as that of physical infrastructure.

Crafting a research agenda at this early stage is fundamental to the future of urban planning and management. At present, it is clear that these mobile technologies will have a fundamental impact on the spatial organization of economic activities within metropolitan areas. However, while the effects of new technologies like the mobile telephone are beginning to be felt, we are still years or decades from the future city of ubiquitous computing. In the meantime, we have an opportunity to think about some of the opportunities and challenges outlined in this article.

Impacts on land use and travel. Where are mobile users? How do their usage patterns correlate with location, travel, and activity? We lack even sufficient *anecdotal* evidence to speculate in this area, let alone data to make reasonable generalizations. This is an area that needs to be explored in conjunction with the wireless carriers who have access to this kind of data. How do these technologies contribute to broad changes in settlement patterns, the location of economic activities, and land use?

Planning/Managing the real-time flexible city. How can long-range planning and construction of large, expensive, fixed infrastructure be effectively carried out in the flexible, and rapidly-changing urban environments that mobile communications and computing will support. However, as Humbad (2001) demonstrated, new masses of mobile users provide new opportunities for sensing and monitoring urban conditions in real-time.

Design and perception of urban landscape. Mobile technologies will act as intermediaries between users and environments, providing information about navigation, opportunities, etc. to urban dwellers. As such they will have significant impact on the *imageability* of cities. In turn, the need to provide supporting infrastructure for mobile users will have an impact on the design of buildings and neighborhoods. What location-based services and types of information can be developed to assist community and economic development in disadvantaged areas? As Abler (2000) notes, for the first time, these technologies will make it possible to assemble all the information about a place *in that place*.

Interactions between urban design and technological design. Mobile technologies will act as mediators between individuals, and between individuals and the built environment of cities. As primary points of distribution for information about places, localities, and transport networks, MCCTs can have dramatic impacts on the use of urban facilities and infrastructure. However, as illustrated by the backlash to the proliferation of mobile phone use in public places, the study of human environments has not been incorporated in the design and implementation of new mobile technologies and services. What are the interactions between the design of devices, interfaces, and built environment? How might changes in the design of one impact the design of others? How do information architectures for storing information about places impact the use and viability of neighborhoods and communities? How can open standards for geographically encoding information be tailored to reinforce the identity and importance of places and place-based communities?

References

ABLER R. 2000. “Mastering Inner Space: Telecommunications Technology and Geography in the 20th Century”, Address delivered at International Geographical Congress, Seoul, Korea, 16 August.

GRAHAM S AND MARVIN S. 1996. *Telecommunications and the City: Electronic Spaces, Urban Places.* (Routledge, New York)

HUMBAD S. 2001. “Suitability of Mobile Distributed Wireless Networks for Urban Traffic Congestion Mitigation” Master’s thesis, Department of Urban Studies and Planning, Massachusetts Institute of Technology. [http://www-personal.umich.edu/~humbads/thesis/]

INTERNATIONAL DATA CORPORATION (IDC). 2000. “Wireless Access to the Internet, 1999: Everybody's Doin' It”

INTERNATIONAL TELECOMMUNICATIONS UNION. 2000. *ITU Telecommunications Indicators Update*. Oct/Nov/Dec. p.1.

LING R AND YRRTI B. 1999. “Nobody sits at home and waits for the telephone to ring: Micro and hyper-coordination through the use of the mobile telephone.” Telenor Corporation Published Research Report. [http://www.telenor.no/fou/prosjekter /Fremtidens_Brukere/seminarer/mobilpresentasjoner /Hyper-coordination%20paper%20(FoU%20report).doc

MITCHELL W J. 1999. *E-Topia: Urban Life, Jim, But Not As We Know It.* (MIT Press, Cambridge, Massachusetts)

MOSS M L AND TOWNSEND A M. 1999. “How Telecommunications Systems are Transforming Urban Spaces” in *Fractured Geographies: Cities in the Telecommunications Age*, James O. Wheeler and Yuko Aoyama, eds. (Routledge, New York)

PERSSON P, ESPINOZA F & ELENOR C. (2001), "GeoNotes: Social Enhancement of Physical Space", Design-Expo at CHI 2001, Seattle, April, 2001. [http://www.sics.se/humle/projects/GeoNotes/]

SRI INTERNATIONAL. 1998. “The Role of NSF's Support of Engineering in Enabling Technological Innovation - Phase II Final Report” (Arlington, VA) [http://www.sri.com/policy/stp/techin2/]

TOWNSEND A M. 2000. “Life in the Real-Time City: Mobile Telephones and Urban Metabolism.” *Journal of Urban Technology*. (7)2:85-104

TOWNSEND A M. 2001. “The science of location: Why the wireless development communication needs geography, urban planning, and architecture.” Position paper given at CHI 2001, Seattle Washington, April 1.

YOULL J. 2001. *Wherehoo* server. [http://wherehoo.media.mit.edu]

Watchlist of 50 Technologies Likely To Affect The Engineering and Construction Industry

John Voeller
Black & Veatch

The following is an expanded description of the technologies presented by John Voeller that he believes will directly impact the engineering and construction industries and their clients in the next decade. Proactive organizations should examine this list and consider creating their own to ensure they are tracking those innovations that will impact them in knowledge, technology, skills, market offerings and internal improvement opportunities. They are presented in no particular order.

WebBook

With the huge volume of standards, guides, regulations, project requirements, decisions, pending actions, opinions and ongoing work product a professional needs to manage, each has a different perspective on how they organize information to support their efforts. Developed by Xerox PARC, this tool allows anyone to assemble all they need to support their efforts from any source, organize it the way they want it and yet the information never leaves its original source point. This means that if the source information changes, all information in all WebBooks that reference it are automatically aligned with zero effort and without disturbing the structure of the individual's information perspective.

Decision Conduit

Almost everything we do in business is designed to enable a decision or is a consequence of a decision. We bury decisions in a thousand places and cannot easily recover, reconstruct or reuse them and their associated information in the current computing forms. This makes the singularity we call a decision a perfect index around which all associated information can be organized. For example, all things that led to or supported the decision and well as all the consequences of the decisions can all be tied to it. This allows reconstruction of the decision path for learning, diagnosis if there is a problem, analysis by legal workers, and reuse in whole or as decision fragments in future efforts. A decision conduit provides a means of informing all of decisions pending, made, rescinded or closed that segregates and organizes them uniquely from all other information sources. This improves response time and eliminates confusion that leads to expense and risk.

Biometrics

This broad category of confirmation of identity using human physical traits is the key to future voting, licensing, permitting and other authorization systems. Fingerprints, retina scans, voice prints, and many new variants all are candidates. The EC industry has many facets of access and security that take too much time to manage using artificial identities. This will save time and money and manage risk.

Software Agents

These are autonomous goal-seeking software elements that often activate when certain information arrives, certain factors align, or certain conditions are met. They often work in teams and represent the most powerful new programming paradigm of the next five years. An example would be Audit Agent. As the speed of processing and approval are changed by everything from project website collaboration to digital signatures, the opportunity for inadvertent and cascading error will increase beyond the ability of human check and balance to control. We will need to utilize software agents to act as independent auditors of process and action to ensure quality and completeness in our activities and to eliminate risk where none appeared present. This is an area where intellectual property management and vending may be a significant opportunity.

Turing Branding

Branding is a well-known part of marketing and advertising. In the past, this has been directed at recognition of more than just a product when a name or symbol is presented. Sony for innovation; GE for well-run; GM for huge; Starbucks for time out; are all examples of branding. Turing branding involves convincing systems that you are a preferred provider or teammate. As automation increases and the use of agents grows, there is a new concern on how you make yourself attractive to a non-human entity. How does an agent come to "trust" your information over another's. The industry within it will need to plan for this and understand the consequences of one group failing in this area and potentially cascading mistrust into other groups.

Cisterna La Kansas

A $400 million project funded by the US and World Bank, this is directed at the creation of sustainable approaches to water, sewer, gas, electrical and telephone. Some of the ideas are well established and others are new, but the general concept of running cities well with lower cost, lower waste and higher livability is easily understood. This is a technology perspective the second and third world find much more attractive than the approaches used in the first world.

Moneyless Thinking

For centuries, civilization has used the value of money as a key if not singular metric on enterprise and personal achievement. However, it is a single metric that easily misleads decision-makers. An EC participant must step back from this and identify other metrics related to people, readiness to accept opportunity, ability to be proactive, and many others that are more meaningful. This is made more critical when those achieving things are not human. Moneyless thinking does not suppress or ignore the monetary component. Instead it embraces the traits of new participants that is more manageable and that they can influence.

Optical Cognition

With coming femto-second comparators, it is possible to examine items from documents to fingerprints to spectrographic output to weld x-rays and recognize them against giant data stores in seconds. This will change inspection, quality, materials management and many other areas.

Quantum Financials

Developing momentum at a significant pace, the important aspect of this innovation is a completely new model for management of funds by any institution. It does not change the rules of accounting, it changes the rules of valuation and risk management. It ensures that the entire chain of cause and effect of actions and decisions in work processes can be individually and collectively valued.

Opportunity Conduit

The ability to broadcast opportunity, solicit involvement, require attention or seek expertise is all hindered by current forms of communication. This technique is designed to create a consistent and flexible environment where opportunities and needs can be posted, bartered, auctioned or exchanged.

Broadband Wireless
Explanation: This is wireless connectivity available nation-wide with speeds running 1-10 megabaud. Early implementations of even lessor capability such as Metrocom's Ricochet at 128-256kb produce incredible productivity enhancements.. Serious changes in business process, decision-making, and support of the later stages of public works and political process life cycle will be first consequences. Once wireless achieves broadband performance and all access devices can be used without regard to which service is involved, there is immense opportunity to create organic, location-independent teaming with full information access for all.

Expert On Demand
In the EC community with such an enormous population of skilled people, each person can become an independent contractor/expert. Whether it is plastic molding or the history of the knuckle ball, there is likely to be an expert that cannot only use the electronic means to teach and help, they can actually meet and mentor those who are interested. This is directly in line with of Colin Powell's ideas, but ahead of his implementation. Today's communications technology and the coming bandwidth of broadband combine to create a fluid domain in which expertise can be found and brought to bear easily and rapidly.

Tabs & Pads
Developed by Xerox PARC years ago, this innovation family was never commercialized by them. However, they are replete in our world today and EC companies and those servicing them should be looking at every conceivable use. Tabs are actually RFID tags similar to those used in automated toll taking. However, new ones as small as a quarter with 50 foot read distances and some with unit costs of one-tenth of a cent could change the effort and accuracy of everything from asset management to timesheet verification.

Pads refers to tablets known as "impersonal" computers. With wireless links and a flat display surface, they change everything from office and field activities to how one uses a library.

Self-funded ITS
Intelligent transportation systems have a strong technology component, also may move in a direction not associated solely with roads. For example, Tokyo restaurants are now charging by the minute, not by entrée'. However, they are costly to build and maintain, especially if the economy is down. We have developed ways to utilize the information signage combined with cell or other technology to create a supplemental funding system that benefits the residents, city and merchants. Such ideas of e-commerce rolled into enterprise and facility planning must be a part of future EC offerings.

World Wand
Imagine a set of symbols on a TV screen, on a bill board, a store window or an ITS sign that is actually a reference point for a wireless receiver that is internet connected. On my cell phone, PDA or as a separate device, I touch A or 1 and that tells the otherwise inanimate display that I am interested in receiving information to my home of the offering. Punching B or 2 says send

the info to my e-mail. C or 3 suggests I want a phone call and D or 4 indicates I wish to buy. In each case, a cookie contain a number, address or credit card is sent and the transaction is confirmed. Besides the commerce potential, the hitting of keys could take the form of an opinion, a vote, a preference or a reaction to whatever is being displayed. This coupled with the time and whatever cookie information the user has allowed to be released creates a whole new kind of demographic and polling analysis environment. This same idea can be expanded to an onsite interaction device and environment to manage people, schedules, materials, tools, etc.

Holographic Storage

Such systems will create storage densities on the order of 10 Encyclopedia Britannica's in a pin head. With proper organization of our thoughts and records, they can capture, use, and mine an entire enterprise and its knowledge in an unprecedented way. The same technology used for display creates effects no other form of interface can provide. Without planning and much stronger organizational thinking, such technologies will become just another form of pile that we build but from which we cannot effectively retrieve our information and knowledge.

Micropayment/Microaudit

This entire area has significant implications on finance, banking, taxation, permitting and many other revenue and control areas. It can change the cash flow and latency rates in dramatic ways, lower administrative burden and balancing and create process efficiencies. Such activities as procurement, payment while in logistics, incremental credit, progress payments and many others will be impacted.

Lego Streets

The continued plowing of streets to modify infrastructure is an insane exercise given that we know if cannot end, whether in expansion or maintenance. Every street of importance should be redesigned once for future contingencies by using a chambered tunnel that runs underneath sidewalk caps. Much like the old steam tunnels on a college campus, this approach will not only minimize excavation and speed addition or modification, but it will also allow easy confirmation of adherence to key statutes. EC firms should encourage such efforts provide value instead of using old methods to increase manpower and equipment billings.

Lambda Sensors

In the form of software with a special hardware, such sensors will allow companies and owners to react and rearrange their direction, spending, focus and other factors based on subtle changes that are known to precede larger concerns but for which the patterns are not discernable by classical analysis or observation. This is a powerful component of a new risk management and future dynamic risk trading perspective.

Auto-Situation Awareness

Simulation is as old as computing, but simulation is done with postulation. A case is formed, then simulated and post-analyzed. True simulation must be seamless with existing circumstances and meld real-time information with forward scenarios to allow realistic alignment of circumstance with consequence. The key here is the melding of current information via the web from all participants including intelligent devices with well-formed predictive and experiential knowledge. The opportunity to simulate forward from any point in real time will allow better, faster and higher quality decision making and course correction in fast moving construction and procurement situations.

XML Variants
There are now almost 100,000 people working on variants of the XML information format with each directed at a specific type of business or human interaction. They all use the same basic methods, but each is directed at a different vocabulary and context. There are several that are growing quickly enough to become central points of attention in the EC industry. For details about all of them, interested firms should become members of Oasis, an organization that is coordinating several those of the industry efforts and archiving their schema and attribute plans.

Digital Signature/Seal
Now that the first Federal legislation has passed, the many interpretations of this technology will fall into the less informed ranks of the state bodies. This technology requires great care to be done well and right and not to create an inadvertent restructuring of risk that we have already outlined in planning scenarios. Firms should monitor these carefully and provide input where possible in your regions of business to ensure that dysfunctional interpretations of this key technology are not enacted. It is important to understand that independent of the significant implications for performing EC business, this innovation has the potential to create new avenues of fraud, misrepresentation, pirating and other problems.

Non-monolith Documents
Starting with the earliest notion of hypertext in the 1930's by Vannevar Bush, the idea of spontaneous inter-linking of information is now understood and being leveraged in a minimal way. The next big step is the situational assembly of information into spontaneous documents that do not otherwise exit in a discreet stored form. This is a critical mindset change with some attendant technology critical to the capture and packaging of knowledge critical to the effectiveness and productivity of any EC firm.

Pro-active Computing
All computing to date is reactive; that is it responds to us explicitly or by consequence of pre-programming. The next generation will be proactive. It will be given our goals and concerns and will watch how we satisfy these and will learn paths and processes by which to assist us without asking. The computer becomes a companion, not an automaton. For example, a site manager will receive notification from a freight forwarding firm that affects construction sequence, scheduling, resource management, etc. The proactive system would understand who else might be affected by such a change and will trigger agents to assess the situation and communicate it to those who can best analyze it and take appropriate action.

Genetic Schedulers
This technology will change everything from resource management to traffic management. A genetic algorithm based approach allows for observation, isolation and incorporation of key combinations of factors that may be counter-intuitive by conventional means. Non-intuitive relationships between factors can be captured and learned. As such systems learn and mature, the quality of their results improves and the ability to manage and adjust to situations not anticipated is enhanced. Such adjustments will ultimately incorporate nuances of subcontractor relationship and limitation or crew and personnel tendencies to allow for more accurate schedule creation.

Goal-based Search

Today's search technology is limited by our vocabulary, our language, our imagination and the mechanics of computing. Yet within our business tasks, our goals tend to be robust and continuous over time. The use of such goals to guide a search for finding supporting, conflicting or complementary information will bring more relevant and timely information to us. The only technology that can perform this is recursive persistent multi-agent communities. The first in the world was invented by John Voeller in 1991.

Multi-physics Analysis

After three centuries of analysis capabilities that paralleled our awareness of our physical world and our ability to model it mathematically, we now have tools that cross the lines between the separate branches of physical and financial thinking to perform multi-discipline simulation that will answer questions and anticipate problems. Such systems allow the solution of problems never before possible. In conventional analysis, the individual solution of a problem in one domain cannot account for the consequences introduced by the other systems' physics. There are branches of our business that can use these techniques to deal with situations previously considered unmanageable.

Virtual Proximity

The ability to view our projects in 3D is an old goal that better EC firms have realized. The addition of holography gives us virtual substance for our imagination to feast upon. However, the human disconnect in format and form with all the other information we need to make decisions must be closed. Just as multi-physics is transforming analysis, we must consider how we present all relevant information to a user in a conversation. This is a form of the Turing interface and it is long overdue for the EC industry.

Quantum Encryption

Current encryption techniques are poor and only using the higher order certificate and RSA technology can be considered safe. However, within two years, the next generation of security will be available and it will change our ability to organize and transmit information. Current encryption is file based which is clumsy and does not work with databases. The quantum approach allows encryption of individual pieces of information inside otherwise open information sources. This allows sharing of a kind not possible without forced reorganization of information just for viewing in shared situations. This will enable a new level of collaboration even between competitors not currently possible.

Tacit Knowledge Extraction

We bury extremely valuable information in a variety of places that are unorganized and cannot be retrieved in full context. E-mail is our largest repository of information and often knowledge and is our least well organized across the enterprise. There are techniques that will allow the organization of tacit information from such sources. We can extract information without overt action by users, organize, restructure, access and even mine information. This will also allow knowledge creation by incorporation of context and circumstance. There is perhaps no area richer in opportunity to gain value by a nearly fully automated means. The risk reduction impact of this technology in construction is significant and encompasses all sizes and types of firms.

Observation-based Training

The convergence of communications will allow interconnectivity and the continued increase in computing power will combined to allow co-worker observation of action and decision-making in a unique new training environment. OBT will allow the less experienced to learn from real world situations being handled by experienced people doing their best productive work. In normal form, the opportunity is anonymous and neutral. In Mentor Mode, the trainee will be allowed to interrogate the mentor about why they did things a certain way and how they concluded something from the collection of information they viewed. Both parties will learn about best practice and best process and it may also surface new ideas from the student that older eyes had never seen.

Non-medical Biotechnology

The vast array of biotechnology that will appear in the next decade will focus on the medical industry. However, the environmental and sensing applications of this domain are legion. The EC industry must proactively press for research in these uses as they can better society and provide new opportunities conventional approaches cannot.

Molecular mechanicals/molecular electronics

The general field of MEMS and nanotechnology will first impact the types of sensors and controls we will need to press for development and delivery. This field has a natural momentum in R&D, but EC needs to get involved NOW. We must imagine that a similar level of development of new kinds of facilities and infrastructure that took two decades to refine in chip fabrication will be required in this area as well. Imagine being the leader of MEMS facility design in 1970 and meeting Gordon Moore o Andy Grove.

Collaborative robots

Robotics has had a checkered adolescence as developers overshot the abilities repeatedly. A new branch of robots with appropriate expectations involves simple robots that collaborate to do more complex actions. Work at several universities and six companies is yielding a realistic set of deliverables seeking aggressive implementors. Several of these can have significant impact on construction methods and effectiveness.

Hidden Wearable Computing

Wearable computing as purveyed today is silly in a true field context. However, very limited involvement of EC to bring reality to the developers efforts will create a usable form of hidden wearable that does not encumber the worker or create a safety risk. The opportunity for better planning, coordination and reactivity are significant for EC.

Plastic Muscles

Already working in the lab, this technology will create a new kind of machinery for moving, placing and holding materials in both bulk and packaged form. It will also produce the opportunity for lightweight worker augmentation to limit injury and lengthen worker career span.

Multi-function System on a Chip Sensors

Already moving quickly in the computing domain and the “lab-on-a-chip”, this technology will produce new capabilities in integrated and complex sensors and control technology.

Intelligent Device spontaneous collaboration protocol

As devices become IP-addressable, the opportunity for spontaneous collaboration of elements in a system or even elements in different parts of the country is a powerful element of a new view to management of devices and facilities. The key is the creation of a protocol that is an extension of the DAML protocol developed at DARPA and input from EC is needed to move this in the right direction.

4D Optical Switching

The implications of this are stark, but many might believe it distant from the domain of EC which is true in a direct sense. However, this technology will create an entirely new control paradigm never before examined. The result will be a new complexity-based theory of control that will change the specification, construction and operation of facilities more than any prior change in the past.

Tri-ocular Multi-spectrum Imaging

The province of a new generation of sensors and operating aides, this technology is already available but its application in design, construction, operation and maintenance of complex facilities has not begun. EC must understand it now and plan for the future.

Affective Recognition

Encompassing voice and gesture, this area was first address by Brooks and is moving quickly. It will enable a completely new kind of human-machine interface in machines, tools and plants.

Commercial Artificial Life

Artificial life involves the creation, reproduction and selective mutation of complex algorithms for special purposes. AL will breed powerful, situation-specific software and control elements that will work optimally when installed and will mutate to remain optimal even as the plant and equipment age or change. Good breeding will yield algorithms that can be patented and sold as intellectual property along with the devices or systems or complete facilities.

ARIA (Automated Revision Implication Assessment)

One of the greatest sources of risk in the EC realm is misalignment between groups when changes occur in one and are not communicated to others. ARIA was developed in 1993 to ensure that the implications of change are evaluated automatically and the appropriate groups are at minimum notified and in sophisticated implementations, actions are taken directly.

Bi-Radial Neural Nets

Neural nets are proven technology in specialty domains, but are limited by the size of problem and number of variables they can address. BRNN provides a way around many of these limitations and will become a strong element of certain complex control as well as project management domains.

Muse Technology

Developed over the past decade, this technology creates entirely new and intuitive ways for people to visualize highly complex situations and quickly access them and take action. Such technology will be needed to complement the future increasing complexity in facilities.

Squids-In-Clothes

Based on medical work in the US and pioneering work in Japan, this technology uses squids, near-superconducting level hyper-magnets to sense brainwave functions and record them along with a variety of other physiological parameters. Taken in concert, these are assembled by monitoring someone particularly good at a task and recording the results. When the same sensory make-up is applied in reverse to a subject who has never attempted the task, their learning rate is markedly better. Originally thought only to apply to physical tasks, we are finding that it also affects intellectual efforts as well. Implications for not only training, by dynamic, in situ training and correction are significant.

Application of Chaos Theory to Multi-process, Multi-enterprise Processes

If we extrapolate the concept of integration across processes and enterprises and we harness complexity theory to understand the interdependencies, we can see opportunities
To optimize entire supply chains, complementary enterprises and life-cycle involvement. This is an area where collaboration between all participants in all facets of the EC business is paramount.

Exoskeletal Robotics

The average career span of a construction worker continues to fall and the ability to attract replacements continues to be more difficult. We must find ways to augment the physical component of such work with tools and techniques that mimic human motion while retaining agility and human guidance. An exoskeletal approach is critical to this as it combines human skills of thinking and observing with mechanisms that do not tire or become injured. Prototypes have been built, but the industry rebuffed them because of their simplistic view to man-hour implications.

Virtual Hall

The area of external labor management, whether union or not, is critical to the success of EC and requires new solutions. The tracking and management of all skill and experience types needs to consider a virtual hall concept. Such a national clearinghouse of construction knowledge, expertise and experience would raise the effectiveness of the industry and provide expanded opportunity for those wishing to have a career in EC. In discussion with the AGC, this was presented and they appear to be responding, but the rest of the industry needs to be involved.

Self-Repairing Systems

Though currently the province of integrated circuit research, the same concepts can be applied in discrete component regimes in facilities of many kinds. Instead of waiting for the manufacturers to wake up, EC firms should be applying these ideas in their designs which will accrue value for them and their clients.

Information Technology and Threats to the Infrastructure

By
William A. Wallace
Decision Sciences and Engineering Systems
Rensselaer Polytechnic Institute
Troy, New York 12180-3590
(wallaw@rpi.edu)

Prepared for ICIS Workshop,
Washington, D.C.
June 25-27, 2001

This paper is based upon remarks made at a planning meeting on the Role of the National Academies in Reducing the Vulnerabilities of Critical Infrastructures, National Academy of Sciences, Washington, D.C., April 1999.

Introduction

Human beings have always been beset by threats to their well-being. Yet, with each new deadline announcing earthquake, flooding, storm, terrorist attack or other crisis, it appears that the vulnerability of the infrastructure to catastrophic events is increasing. In fact, some studies have documented that losses and potential losses in the United States from various hazards are rising at an alarming rate.

Despite the headlines, many of these occurrences are perfectly "natural" events – some of which have been happening for millions of years, such as flooding river deltas. These events become catastrophic when we:

- move our activities in life, work, or play into high risk areas, and
- build complex, tightly coupled infrastructures to satisfy our needs and wants.

We are doing both. People are moving to suburban and exurban locations, many of which are in unpredicted flood plains, seismic risk areas, and exposed coastal locations. And we are building infrastructures to support their life, work and play. In addition, advances in communication and computing technologies are being employed to create both new infrastructures, e.g., cellular communications and the internet, and to make infrastructures safe and more productive, e.g., intelligent transportation systems.

Public posture with regard to managing hazards is interesting, yet, not particularly surprising. It is apparent to even the most casual observer that public, congressional, and research interest in emergency management peaks just after the occurrence of a hazardous event. At most other times, it has *appeared* that formulation of useful comprehensive emergency management plans and policies is a "back burner" item on local, state, and federal agency agendas. As testimony to this, it wasn't until 1979 that the federal government saw fit to consolidate its loosely connected disaster preparedness program by forming the Federal Emergency Management Agency.

For some time now, observers have also felt that research on threats to the infrastructure has been inadequate. Although we have had ongoing efforts, particularly in natural hazards, supported by agencies like the National Science Foundation, we see three new forces:

- attempts to extend the life of our aging infrastructures by using information technology,
- new information infrastructures, and
- the increase in (or new types of) willful actions that threaten critical infrastructures.

Risk Management

Managing threats to the infrastructures should be considered as a problem in managing risk – albeit an unusual type or risk. And, although the idea of "managing" risk may still seem novel to some, it actually is something public agencies have been doing for a long time in many areas.

To be more precise, "risk management" refers to the recognition and control of "perils of a fortuitous nature which, in their occurrences, can adversely affect…individuals." Though the term was probably coined in an insurance context, it also applies as a much broader approach to the control of undesirable events. Even in the private sector, the purpose of risk management is usually construed to mean the minimization of pure losses, i.e., it does not usually deal with risk taking for profit. Although the ideas of risk management have been traced back through thousands of years, the concept of inclusive control of risks did not formally develop in business organizations until the late 1940's, followed in a decade or so by public agencies.

In order to help ensure that we can inform and gather information from those effected by the threats to the infrastructure and the policies proposed to deal with these threats, we propose a systematic risk management approach that has three major steps: the accurate description of the threat, prescriptions of strategies to reduce or eliminate the threats, and providing the capability to monitor and control our efforts at ameliorating threatening situations. This framework will also be used to highlight areas for research.

Description

Description in risk management involves the detailing of the processes and outcomes germane to an unfavorable event. Such description can be given verbally as well as analytically in terms of an explicit model, an implicit model, or some combination of the two. In either case, the major task in such a procedure is to try to identify the event itself in some adequate manner as well as the possible set of outcomes resulting from it, i.e., the range of potential impacts upon individuals or society. Using either deductive or inductive means, one should also seek to attach probabilistic estimates of one sort or another to the outcomes. This may be done in various ways that extend through subjective or objective characterizations, through outcome/situation “enumerations” of historical data, or perhaps by cascading probabilities at the nodes of a network that represents the mechanics of the process.

Advances in computational theory and application have provided researchers with the capability to model and simulate the physical mechanisms and processes of both the infrastructure system itself and the environment surrounding it. Funding must be made available to support the research needed to capitalize upon these advances.

There exists a need for an equivalent effort to model the human activity the infrastructure is designed to support – both to assess the impact on society of an undesirable event, and to better understand those events caused by humans either by accident or willfully. Research in the cognitive and social sciences can provide insights and relationships that can be used to model these phenomena. Computational modeling is proving to be a valuable method for theory-building and virtual experimentation of cognitive, social and political processes.

Prescription

Logic dictates that once the probabilities and potential impacts of the events have been evaluated, we should then turn to the prescriptive component of risk management. Prescription is intended to integrate the outputs of the description process with strategies of policies that acknowledge resource limitations.

Essentially, prescription addresses the problem of marshalling and applying available resources in order to prevent, transfer, and/or reduce the probabilities and impacts estimated by the descriptive model(s). Various ways of classifying and delineating management strategies and policies are possible.

One possible framework is to first describe the hazard or threat process. Then to identify where in that process interventions can minimize or eliminate the impact of a potential threat to the infrastructure. The marine transport of hazardous materials is used to illustrate this process; Figure 1 presents the hazard chain for a marine accident.

The first stage, the CAUSE, is typified by such factors as inattentiveness, bad weather, and equipment failure. Next in the chain is the INCIDENT, such as collision, grounding, or ramming. In stage three, an EVENT occurs, e.g., oil or other deleterious cargo is discharged; and finally, the latter event promulgates some PHENOMENON such as loss of life, environmental damage, or revenue loss to the recreational industry.

Each stage of the process is connected to the succeeding stage; thus, we have three preliminary links in the entire process. These may be considered to be the “cause/incident” link, the “incident/event” link and the “event/phenomenon” link. In addition, there is an implied link between the “states of nature” and CAUSE.

In general, the linkages between stages in the process consist of probabilistic functions showing the frequency of accidents in which two stages are associated; and the strengths of a given link is best measured by this frequency with relation to the size of other frequencies. For example, we link navigation error (CAUSE) and grounding (INCIDENT) through obtaining the frequency of accidents in which groundings occurred due to navigation errors.

Public policies (regulations, SOP’s, training programs, etc.) can influence the process at all four linkage points as shown in Figure 2. First, they can influence the link between nature and CAUSE. For example, tighter rules on pilot qualifications might reduce the frequency of occurrence of personnel error. Second, actions can influence the frequency of incidents occurring, given the existence of a CAUSE (CAUSE/INCIDENT link). For example, a vessel traffic control system might reduce the amount of grounding, even though the on-board personnel have erred. Third, the actions can influence the process at the INCIDENT/EVENT link. Thus, mandatory double bottoms would reduce the incidence of spillage due to grounding of tank barges. Finally, the actions can influence the linkage between the EVENT and the PHENOMEN, such as in the case of improved containment and cleanup programs which can greatly reduce the impact of a spill given that it has occurred.

Assessing the effectiveness of present and proposed public policies can be readily accomplished using this construct. Policies will reduce some of the frequencies of occurrence represented by the links between successive stages in the process. By quantifying all of the linkages between the four stages, we can connect any type of action (once we know where it impacts) to its maximum potential effect on the stage four, PHENOMENON, of concern. This will enable officials to identify which current or proposed policies are most effective in mitigating the PHENOMENON.

An important observation to be made here is that there are *two stages* involved in the management of catastrophic events, the *pre-event* phase and the *post-event* stage. Management strategies are available to combat these events both before and after they occur. This characterization may appear to be trivial, but is also the crux of problem of managing threats to the infrastructure. The rare nature of these events has resulted in the formation of a public posture that is sensitive to such events "after-the-fact." That is, we have traditionally been content to "clean-up" after these events have occurred and have waited to pass legislation regarding these phenomena only after disaster has struck.

Monitoring and Control

When an appropriate management mix of strategies and policies is formed in the prescriptive mode, there then arises a need for a third component of risk management – monitoring and control. This generally entails the development and use of information technology for sensing and data fusion, for refining and improving the prescriptive models, and for providing indicators of performance in terms of prevention or reduction of the impact of the event.

Monitoring and control provides for one of the key elements of most effective program management processes: feedback. Feedback is necessary to provide emergency planners and policy makers' information on the results of the activities initiated by their programs as well as to permit the descriptive models to "learn" and the prescriptive models to be adapted to changing conditions. Initial analysis may prove to be incorrect in some sense or senses and, in any case, environmental, social, and political factors in decision making are subject to constant change.

Unfortunately, the state of the art is such that we really do not have much experience with the monitoring and control of disaster management and policies. There has been very limited knowledge gained from the multitude of preventative policies related to land use, building codes, warning systems, etc. We really do not know how effective these policies were or would be in the future.

Concluding Comments

Despite remarkable innovations in information technology, the user of IT systems often realizes that there is a gap between the tasks that need to be addressed and the commercially available technology. For example, take the case of emergency response to a threats to the infrastructure. Satellite tracking systems are built to provide a service that gives the user an economic advantage and are not designed for the safety and security of operations. Simulation environments provide high flexibility but little support for modeling safety and emergency response systems. Geographic information systems (GIS) are multi-purpose but do not integrate their displays with local and regional emergency plans in a way that permits dynamic revisions and development of new courses of action. Expert systems have been used in support of emergency management tasks, but are not incorporated into satellite systems. Finally, hypermedia environments provide very useful human-machine interfaces for decision support systems but there is still the need for the specification and development of the analytical procedures and models for strategic and operational risk management.

To close the gap between the decision tasks and the employment of these new technologies, appropriate decision support models must be developed. These models must aid the decision maker in both sensing the current state of the operations and reasoning about actions that need to be taken. Sensing is supported by data acquisition, positioning, and communications technologies. Examples are mobile sensors in the field that gather data about the status of operation, weather monitoring systems, satellite positioning systems to determine the coordinates of mobile units, satellite communications systems, and visualization systems such as GISs. Reasoning is supported by appropriate decision models. These models can include simulation models to study and display potential impacts on dispersion plumes, expert system modules to infer possible consequences, database systems to extract relevant facts about the operations, and symbolic and numerical models to compute new courses of action.

The issues that need to be addressed at the organizational level refer to investments into new technologies, changes of traditional work procedures, and definition of responsibilities for these new decision situations. Despite the many advantages that these new technologies seem to promise, there is a high degree of uncertainty about their benefits. Many organizations involved in managing the infrastructure do not have the resources to take substantial financial risks. In addition, traditional work approaches are difficult to change because they have worked in the past. Any new approach must provide enough benefits to overcome these obstacles.

In order to promote information technologies for managing the threats to the infrastructure, policies at the inter-organizational and at the political level should be established. These can consist of subsidies for certain technologies and decision models that include safety, economic and security criteria – measured in terms of costs, risks and benefits.

Applications of Information Technology in Electric Power Distribution Infrastructures

Richard M. Wiesman
Vice President, Foster-Miller, Inc., Waltham, Massachusetts, US
Aaron P. Coolidge
Senior Engineer, Foster-Miller, Inc., Waltham, Massachusetts, US

Introduction

New forms of automation in the electric power distribution industry are required to extend the service life of aging infrastructures; reduce operations and maintenance costs; and improve service. In addition, the power distribution industry is undergoing a fundamental change in market dynamics. Regulation has been diminished in some markets, energy supplies have been uncertain in some locations and competition between utilities for customers is intensifying. This is a time, at electric utilities, when cost-effectiveness, functionality, and quality are becoming the most important criteria for choosing a product, a process or a supplier rather than the reasons that arose from some forms of regulatory logic. Utilities need to invest in effective operations and maintenance technologies and services that can give them a competitive edge.

Information technology is presently employed in a number of areas related to the operation and maintenance of electric power distribution infrastructures. Sources of information include: historical maintenance and failure data; real-time infrastructure parameters measured at distribution substations; historical data on customer consumption; and real-time reports, from customers, on power delivery problems. The measurement and communication of real-time infrastructure conditions is probably the greatest limitation to the improvement of electric power distribution infrastructure operation and maintenance. Presently, direct measurement of infrastructure parameters is generally confined to substations and these measurements are processed through conventional SCADA systems. Barriers to the greater use of real-time measurements throughout distribution systems include: the cost of the sensors and the related necessary equipment; the cost of installation of sensors and associated equipment; and the cost of communications of sensed data including communications equipment, infrastructures and recurring communications costs.

The Need for Power Distribution Information

Present uses of electric power distribution sensors are generally confined to substations where the measurements are incorporated into conventional SCADA systems. At substations these sensors supply information on the utilization of individual feeders; the occurrence of electrical faults; and the operational status of feeders, switches and sectionalizers. Sensors can also be employed at switched capacitor banks to track the need for and the effects of "switching in" capacitance at a particular site. The traditional communications method of these sensors has been via radio telemetry, dial-up telephone, or leased-line telephone.

In safety related functions current and voltage sensors are used to verify switch status and line status to insure that lines are dead when service on lines and attached equipment is required.

In industrial applications, current and voltage sensors are employed in submetering, process control, and safety related applications. In submetering applications sensors are used to track the consumption of energy and to understand how various functions and processes account for the overall use of energy at a particular site. In process controls these sensors are used to directly regulate process parameters that may relate to functions like motor speeds (pumps, blowers, mixers, etc.), temperature (ovens, heaters, chillers, etc.), and actuator currents (motor torque, pressure, force, etc.). Traditionally, these sensors have been hard-wired into monitoring consoles.

The electric power distribution industry is facing a number of changes in both the condition and utilization of infrastructures for distribution and the markets that this industry serves. Demands for electric power are increasing at the same time most distribution companies are faced with aging and deteriorating infrastructures. The costs of large-scale infrastructure replacements are generally prohibitive. This is particularly true in denser population areas like urban and suburban environments. Many larger urban areas, throughout the world, utilize either partial or complete underground power distribution systems. In these situations, in particular, one can imagine the difficulty and expense in replacing a distribution infrastructure. New forms of automation and monitoring are required to extend the service life of these aging infrastructures; reduce operations and maintenance costs; and improve service.

In addition, the power distribution industry is undergoing a fundamental change in market dynamics, largely brought on by deregulation. Competition between utilities for customers is intensifying and this is driving utilities to incorporate effective operations technologies and services that can give them a competitive edge.

Present Sensing Technology and Limitations

For power distribution applications, current and voltage sensors have traditionally been current transformers and potential transformers. Potential transformers can be either capacitive or inductive. Since these devices supply proportional analog outputs of their respective waveform measurements, remote terminal units (RTU's) are generally installed in close proximity to the sensors to convert analog signals to digital measurements. Once digitized at the RTU's, the current and voltage measurements can be stored or transmitted to remote utility databases as "raw" measurements of the respective waveforms. Additionally, it may be desirable to process raw current and voltage measurements at the RTU. Such processing might typically consist of the calculation of root mean square (RMS) values and the detection of current and voltage values passing above or below alarm thresholds.

Current and voltage distribution sensors are commercially available for overhead applications, but the costs of these systems (including equipment, installation, and communications) generally prohibit their use beyond substations or special locations. Sensors for underground applications are just becoming available for limited beta testing. In addition to sensors intended for permanent "pole-top" installation there is portable, instantaneous measurement probes available for hot stick (insulated holding tools) use. These devices are useful for quick measurements at specific locations within a distribution network, but are not used for permanent installations.

There have been three significant barriers to the greater use of current, voltage and other types of sensors in electric power distribution. Those barriers are: the cost of the sensors and the related equipment necessary for use of the sensors; the cost of installation of sensors and associated equipment; and the cost of communications of sensed data including communications equipment, infrastructures and recurring communications costs. Additionally, the lack of commercially available sensors for underground distribution systems has been a barrier to sensing in these networks.

Developments in Power Distribution Infrastructure Monitoring

One approach to reducing the costs of operation of a monitoring system is to reduce the communications costs. Developing sensors that more fully process the data at the point of sensing and make critical decisions and observations on the infrastructure health can reduce communications bandwidth requirements. Most areas of power distribution systems are operating within normal limits most of the time. There is no need, nor is it desirable to transmit information from many different points describing a healthy system. A more desirable situation is to transmit only the data that may reveal an existing or developing problem, thus reducing communications densities and associated costs.

Another approach to reducing communications costs is through the use of available capacities within existing communications infrastructures. These may include wired or wireless systems that offer adequate bandwidth, security, availability and cost effectiveness. It may also be wise to consider less traditional communications methods when they offer particularly compelling cost or performance advantages in certain applications. One example of this is the use of power line carrier (PLC) communications from underground locations. In general, the costs are significant for installing communications conduits within existing underground power distribution structures, and wireless communications are usually not possible in these locations. PLC communications can utilize the existing power lines and may offer practical and cost effective communications solutions.

Foster-Miller and GridCom have developed a family of low cost and easily installed intelligent, communicating power line sensors for both underground and overhead medium and low voltage applications. The underground sensors were initially developed for Consolidated Edison Company of New York's Secondary Underground Network Distribution Automation System (SUNDAS) and are the result of five years of development and testing. The objective was to develop a comprehensive sensing system that would be relatively inexpensive to purchase, install, operate and maintain (inexpensive in quantities). Sensor data from this project has been delivered to the utility via the Internet, simplifying sensor system maintenance and facilitating upgrades.

The underground and the overhead systems each have hardware variations to accommodate the voltage category (low and medium voltage) in which the sensor will be applied. Responding to feedback and interest of the utilities, the present product developments are for overhead sensor systems for the 4 kV to 69 kV phase-to-phase range and multiphase underground sensor systems for low voltage (up to 600 Volts).

Consolidated Edison has tested versions of the Foster-Miller low voltage underground sensors in their Battery Park City and Harlem networks. These tests demonstrated the capabilities of the sensors to monitor, in real-time, power line conditions and to detect variations in line conditions associated with circuit limiter loss, arcing faults, changes in network protector relay status and unusual changes in power flow patterns. Based on the performance of the experimental sensors, Con Edison will install GridCom sensors throughout their Hunter network with installations having begun in winter 2000. Delivery of sensor data via the Internet continues to be used in this project phase. The use of an Internet WAN will enable true system scalability, as larger portions of Con Edison's underground distribution network are equipped with sensors.

Field tests of evaluation versions of the overhead sensors have also shown the sensors to accurately measure medium voltage distribution line currents and voltages; compute the desired power line quantities; and reliably communicate measured and computed quantities to monitoring facilities.

These power line sensor systems have demonstrated the importance of moving much of the data processing and system "intelligence" from traditional central processing stations out to the actual points of sensing. This approach can improve the overall sensing system reliability; greatly reduce communications requirements; and can allow a sensing system to utilize existing communications infrastructures. As described above, the use of existing communications infrastructures can be key in providing an overall cost effective sensing system. For the electric power distribution industry these low cost, intelligent, communicating power line sensors can enable widespread real-time monitoring of distribution system health and operation.

Several difficulties must be overcome to enable sensor data delivery via the Internet. The foremost is security, as utilities have protected their internal networks from most external data sources. To enable Internet based delivery of sensor data the utility IT system must allow external data sources onto its network in a protected manner. Obtaining this entry to the utility internal network can be extremely difficult and may require that alternative access methods be used. Additionally, the utility IT departments are most conservative, and may not allow monitoring software to be installed onto utility systems until that software has been tested and approved to their respective standards.

Key to the cost effectiveness of such systems is modularity and scalability. It is almost impossible to conceive of any software or hardware based information system, for monitoring power distribution infrastructures, which will not require some form of incremental installation to cover complete distribution networks. This means that, to be practical and cost effective, new information systems must be inherently modular and accommodate scaling to support incremental coverage of networks.

The development of more powerful, cheaper and lower energy microprocessors and digital signal processors has also enabled faster and more advanced data processing from less expensive equipment. Lower energy consumption from electronics has translated into the development of portable and sometimes battery-powered equipment for monitoring these infrastructures and diagnosing problems.

Better database structures can improve the effectiveness of information extraction from infrastructure data, and improve the efficiency of archiving data for event analysis and other activities. Databases like OSI's PI Historian offer flexibility and improved utility for tailoring database structures to the needs of power distribution infrastructure management.

Opportunities and Needs for Improvements

There are numerous areas offering opportunities for the improvement of power distribution infrastructure operation and maintenance. As discussed above, more capable and cheaper sensor systems offer one approach to cost effectively monitoring entire power distribution networks. Another need is for better data processing and analysis techniques that would provide better pictures of infrastructure conditions from fewer monitored points. This would essentially trade-off sensor density for smarter ways of using data. A specific example of this is the need for better methods of detecting and locating high impedance faults within power networks. High impedance faults are short circuits from one phase to another or from one phase to ground with a high enough resistance so that fuses or circuit breakers may not be tripped. These faults may produce significant damage over time and eventually result in outages.

Overhead networks in North America are generally radial type designs. In these designs, radial feeders branch out from substations, like tree structures, to supply wide areas. Feeders may be many miles long so that fine-grained coverage of such a feeder could require dozens of sensors. Coarser sensor coverage would mean that the location of faults or other problems would be less accurate and would require more manual investigation and inspection in the field. A technique for accurately locating faults and other problems between sensing points could permit the employment of a very coarse network of sensors while providing fast and accurate detection and location of problems.

Underground power distribution systems may present even greater challenges. In North America most underground systems are network type systems in which the feeders are connected in networks and power can flow to an end user through many different paths. These systems would have many potential connections between sensed points so it may be a more complex problem to detect and locate faults and other problems between sensors.

Along with better sensing, communications, data processing, and information extraction there is a need to shift existing operations and maintenance practices to more condition based practices. The improvements discussed will provide better and faster information reporting on the existing conditions within power distribution networks. This information will describe which areas are being most heavily utilized and which areas have greater margins of safety. Scheduled maintenance practices are generally not as cost effective as condition-based practices, however, condition based maintenance does require condition information. Similarly, the common industry practices of reactive maintenance must be replaced by better monitoring that can locate problems when they are small and more easily corrected. As infrastructures age and operate with lower safety margins small problems that continue undetected can result in both expensive system damage and extensive power outages.

An additional problem in implementing improvements in power distribution infrastructure monitoring is the relatively slow adoption of new technologies and techniques in this industry. The power distribution industry may be considered rather conservative because changes in equipment, practices, or techniques must be made carefully to insure that power delivery is maintained and infrastructures are not inadvertently damaged. IT operations in most power utilities are also conservative. The understandably conservative utility IT system may be reluctant to allow Internet-based delivery of sensor data onto their protected network or allow the installation of required monitoring software without lengthy testing and approval periods. Because a sensor system is only as effective as its interface will allow it to be, the usefulness of such a sensor system may be compromised because of a suboptimal interface needed to meet particular IT system requirements. All of this generally means that changes are adopted slowly within the industry and that the development and ramp-up of commercial products are very slow and expensive processes. This can have two negative effects. First, potential products and services are never commercialized because the developers seek projects in faster developing markets with faster project paybacks. Second, the higher costs of the lengthy and more conservative commercialization processes restrict product volumes and directly add to product cost. These higher costs may completely halt the commercialization of a valuable product or service that would be cost effective in an otherwise faster developing and higher volume market.

SECTION FOUR

BRINGING INFORMATION TECHNOLOGY TO INFRASTRUCTURE: A WHITE PAPER FOR A RESEARCH AGENDA[1]

by Rae Zimmerman[2] and Mara Cusker[3]

Draft, May 21, 2001 – For Review and Comment.
Do not cite or quote without permission of authors.

Introduction and Problem Statement

The dramatic growth in the development and use of information technology (IT) has had an untold impact upon the nature and performance of the fundamental infrastructure systems that support our economy and social environment. The use of IT is no doubt already pervasive in these infrastructure systems from design and planning through operations and maintenance. IT has the potential to address many of the quality issues that infrastructure has faced, by providing detection capability for infrastructure condition, coordination of complex operations, and integration of multi-modal and multi-locational facilities to provide seamless services to consumers. Still to be understood are not only the opportunities IT provides (for example, in terms of improved performance) but also the barriers to its use (for example, in terms of IT and infrastructure compatibility). Moreover, little is known about how IT influences infrastructure and the social systems it supports. This white paper provides a background for the development of a research agenda that addresses both interrelationships between IT and infrastructure and its impacts ranging from infrastructure operations to social systems.

Civil infrastructure systems – our roads, pipes, wires, and other public works – may often seem clunky, slow, and outdated in this age of tiny, high-speed gadgets and streamlined spaces. Yet they continue to provide the backdrop of essential services that allow us to live in relative comfort and stability in dense urban centers and remote rural havens alike. Just as other players in this new economy have found that effective use of IT is crucial to successful management of time and assets, those who own, plan, and manage our infrastructure systems are finding that IT can advance all levels of performance. IT can advance facility efficiency, customer service, and environmental compliance, as well as improve the management of our natural resources and built environment.

We are at the crossroads of change in our infrastructure whether it is roads, transit, air travel, electric power, water supply or wastewater treatment. Critical evaluations from professional societies, special councils and public opinion polls have rated the quality of infrastructure generally low across the board.[4] In order to meet public expectations, information technologies create the opportunity for aligning supply and demand, for example, through more immediate detection capabilities for infrastructure quality and capacity and the provision of consumer services.

At the same time, IT has been advancing at a pace that is generally much more rapid than the rate at which most infrastructure technologies change. By whatever measure – time to introduction of a technology, chip capacity, chip and data density, processing capabilities, internet capacity and usage, or investment – IT has proceeded at phenomenal rates.[5] The speed at which advances in IT have occurred poses an enormous challenge not only for IT and infrastructure systems integration but also for the way in which the infrastructure systems that depend on and are enhanced by IT potentially shape human settlements.

With respect to systems integration, the incorporation of IT into infrastructure often does not result in a single integrated system. The lack of integration occurs for a variety of reasons. These include immediate, short-term or marginal cost considerations that favor unintegrated IT systems that are external to the infrastructure systems, differences in the rate at which IT develops relative to in-place infrastructure, the lack of training of infrastructure professionals in IT, and other factors. As such IT is typically viewed as an add-on or external service, rather than being fully integrated with infrastructure. Potential adverse consequences range from temporary service disruptions to catastrophic system failures. This situation points to the need for a broad-based research agenda to address interface issues at all levels of management and planning.

With respect to the influence on human settlements, Allenby (2000) has underscored the need to adopt a systems perspective of global proportions that encompasses human and natural systems of which developments in IT and engineered infrastructure are a critical component. Debates are underway within a very large community of academicians on whether or not and how infrastructure and IT have influenced such settlements (Mohktarian, 1997; Moss and Townsend, 1999; Mitchell, 1999). The potential influence of infrastructure alone on urban growth patterns has been studied for decades. Studies of the role of IT and urban growth patterns as a separate area of inquiry have had a more recent history, primarily within the professions of geography and planning. The influence of the combination of these two elements on human settlements – infrastructure enhanced by IT (or alternatively, made less reliable because of a lack of system integration) – has typically not been addressed directly.

As a beginning for the development of a research agenda, the sections below address: 1) selected existing uses of IT in infrastructure; 2) some compatibility issues that have been raised in connection with the integration of IT and infrastructure; and 3) implications for urban development. Finally, examples of research questions are presented to begin the process of building a research agenda.

Selected Uses of IT in Infrastructure

Surveys of infrastructure industries indicate that the purposes of IT in infrastructure begin with two primary functions: (1) data collection, for example, for monitoring and detection and (2) the communication or sending of information to infrastructure users and managers. Overall, infrastructure systems have been integrating IT relatively slowly into their operations, given the large in-place nature of the components, the difficulty of making changes in those systems, and a traditional reliance upon mechanical and manual controls. Transportation has used IT more extensively in the form of intelligent transportation systems (ITS) that are becoming widespread in the industry, and which have been supported by strong government backing. Utilities use IT most commonly for measuring usage and supporting billing, however, the use of IT for operational controls has been a growing trend, primarily for condition detection in distribution systems. IT is used in water supply systems primarily for the detection of the condition of distribution systems, the quality of the water produced, and customer interfaces.

While transportation, water, and power systems vary by function, geographic, and physical scope, regulatory framework, political jurisdiction, ownership, and management, they often employ information technologies that are similar in terms of fundamental characteristics of design, construction, and operation. Table 1 (see Appendix, p.15 & 16) summarizes a number of the most prevalent infrastructure IT applications in transportation and utility infrastructure.

There are many ways to categorize information technologies for the purpose of describing them, and these categories often overlap or are interrelated. One means of classification is based on the use of IT in managing infrastructure. This yields the following categories: technologies that measure infrastructure characteristics and condition (such as sensors), support infrastructure users (such as communications technologies and payment systems), organize and manage information flow (including data storage and retrieval), and improve problem identification, analysis and resolution.[6]

Infrastructure Measurement (e.g., Sensing)

Remote sensing technologies provide the basis for the collection, communication, and processing, often in real-time, of infrastructure performance and operational data. Sensors are defined by NTIA (2001) as: "A device that responds to a physical stimulus, such as thermal energy, electromagnetic energy, acoustic energy, pressure, magnetism, or motion, by producing a signal, usually electrical." Sensors embedded in roads, pipes, vehicles, and other infrastructure facilities rely on a range of detection and communication technologies, including inductive loops, microwave radar, ultrasonic, infrared, and satellite and video imaging. Sensor-intensive infrastructure IT systems include Geographic Information Systems (GIS), Supervisory Control and Data Acquisition (SCADA) systems, Ramp Metering, Traffic Signal Control systems, and microprocessing chips imbedded or placed in materials, such as DNA chips.

The transportation sector uses sensing technology to measure traffic speed, volume, emissions, and other vehicle, road, and transit infrastructure characteristics, and to monitor congestion. Traffic and transit managers and transportation planners use this sensing data to improve mobility both in real-time by adjusting traffic signaling, metering, signage, and transit operations, and over the long-term by changing roadway design, transit scheduling, etc. Many of the primary applications of the national Intelligent Transportation Systems (ITS) Program, including Freeway and Arterial Management Systems, Transit Management Systems, and Multi-Modal Traveler Information Systems, rely on advanced roadside video sensing and sensors embedded in roads and vehicles (U.S. DOT/FHWA, 2000). These systems have been associated with significant improvements in highway incident response and congestion reduction (U.S. DOT, Bureau of Transportation Statistics, 2000). An advanced detection system of sensors combined with closed circuit TVs and data analysis software on the Gowanus Expressway in Brooklyn, NY, for example, is credited with reducing the average accident clearance time by 66%, from 1.5 hours to 31 minutes (U.S. DOT, 1999). The SCADA systems that are commonly used in rail infrastructure to enhance diagnostics and control are also dependent on sensing technologies.

Power and water utilities are also becoming heavily reliant on remote sensing technologies as they invest in SCADA, distributed control, and advanced outage management systems. Optical sensors are used to measure pressure, temperature, chemical concentrations, and other facility and environmental parameters to improve systems operations and maintenance. Sensors are also used in robotic and artificial intelligence systems for infrastructure testing and renewal in trenches and other subsurface or inaccessible locations (Gregory and Kangari, 2000). Closed circuit television (CCTV) cameras or neural networks of sensors can be mounted on robots or winched between manholes, for example, to scan the inner surface of sewer and water pipes and collect images and information to diagnose infrastructure conditions (Moselhi and Shehab-Eldeen, 2000). DNA chips are yet another, newer technology that increases the detection capabilities for a wider range of water supply contaminants at lower concentrations. The extent to which a particular contaminant can be identified depends on whether or not the contaminant is anticipated in advance and is included in the computer program. Thus, new and emerging pathogens might not be detected because their DNA signatures have not been included in the programming.

Sensor systems do not function in isolation from other kinds of systems described below. Sensors can provide data both to infrastructure operators and users and to computer software programs for analysis, archiving, and other operational applications. Digital satellite imagery, for example, provides highly accurate information for mapping, modeling, planning and designing infrastructure, and assessing environmental impacts. A generic type of sensing system that is intended to have wide-ranging capabilities in connecting with other information technologies is the Southern California Wireless Environmental Sensor Network and Information System [WESNIS] at the California Institute of Telecommunications and Information Technology (Cal(IT)2; http://www.calit2.net). This is a system of computing devices that links data sensing to computing to “adaptive actuators” that enable infrastructure to respond to stress.

Communications and Related Support Services

Advanced communications technologies are a second central component of infrastructure IT systems. Transportation and utility IT systems generally rely on a range of telemetry (data transmission) mediums, including fiber optics, cable, and wireless (e.g. satellite, radio) to link hardware to software systems, information to managers and operators, and services to customers. With growing demand among infrastructure users, owners, and managers for access to real-time information on conditions, pricing, consumption, etc., high-speed, reliable, and accessible telecommunications systems are becoming increasingly essential to a wide range of asset management and customer service systems. Recent advances in wireless and Internet-based communications technologies have enabled a number of infrastructure IT applications, from Web-based project management and customer information systems to mobile workforce management, and have allowed infrastructure providers to integrate once-disparate and isolated IT systems.

In transportation, ITS technologies depend on a variety of communications systems, from the extensive satellite-based Global Positioning System (GPS) for Automatic Vehicle Location (AVL) and Computer Aided Dispatching, to the radio-based dedicated short-range communications (DSRC) system for Electronic Toll Collection (ETC) systems, to broadband fiber systems for Internet-based Advanced Traveler Information Systems (ATIS). The integration of these advanced communications technologies with traditional transportation infrastructure is yielding significant improvements in operations and performance. The accuracy of GPS for use in fleet and freight management, for example, is credited with improving schedule adherence, service efficiency, safety, system control, and traveler information (U.S. DOT, "Automatic Vehicle Location," 2000). The short-range radio and "Smart Card"-based ETC systems have also saved costs and reduced delays and emissions at highway toll plazas. The EZ-Pass lanes on the Tappan Zee Bridge in New York, for example, accommodate about 1000 vehicles per hour compared to 400-450 vehicles in manual toll lanes (U.S. DOT, 1999). Telephone, cable, and fiber optic lines are providing travelers in over 35 of the nation's 75 largest cities with interactive, Internet-based information on real-time freeway traffic and transit conditions and have been shown to reduce uncertainty in trip planning and encourage off-peak and multimodal travel (U.S. DOT, Bureau of Transportation Statistics, 2000; U.S. DOT, 1999).

Water and power utilities are also expanding their telecommunications investments beyond the traditional and often separate corporate, financial, and billing systems by wiring and networking facilities and workers in both the plant and the field. Utilities are installing Automatic Meter Readers (AMR) and using radio, power line, and cellular communications systems to obtain remote, real-time readings of power and water consumption. AMR deployment and the replacement of manual readers is accelerating with advances in two-way communications technologies and with the increasing value of real-time metering information among deregulated utilities. According to a recent study by the Cambridge Energy Research Associates, communication devices are expected to be included in 25-66% of U.S. electric meters by 2015 (Taub, 2000). Utilities are also using the Internet to: 1) improve customer service by increasing payment options and providing real-time pricing and usage information; 2) improve market transactions among buyers and sellers of energy; 3) link utility SCADA, GIS, and other IT systems and provide for Web-based project management; and 4) create industry Internet "portals" that provide data bases, communication forums, virtual energy and equipment auctions, and other e-commerce applications (Causey, 2001; Makansi, 2000). Finally, wireless communications are enhancing the tools used by the utility sector's large mobile workforce to obtain and update field data and customer information and to communicate with dispatchers and central offices. From ruggedized laptops loaded with utility GIS software to personal digital assistants with intranet and/or Internet access, mobile computing devices are becoming increasingly sophisticated and useful as utilities invest in wireless and high bandwidth communications systems (Wilson, July/August 2000).

Organization and Management of Infrastructure Information

Computing systems, or data processing and storage technologies, are the third key component of infrastructure IT applications. In addition to increasingly fast and powerful personal computers (PCs), microprocessors (tiny computing and communication processing devices implemented on single computer chips or integrated circuits) are pervading traditional and new transportation and utility infrastructure systems (National Telecommunications and Information Administration, Telecom Glossary 2000, 2001). Preparations for the Y2K computing crises highlighted, for example, the ubiquity of embedded microprocessors in power generation and transmission and wastewater treatment infrastructure and illustrated the significance of this nearly invisible network of computing devices within massive infrastructure networks. These devices, usually in conjunction with software and some level of human interface, can process and store sensor data, automate infrastructure operations, signal and correct outages and failures, and perform a number of other tasks in infrastructure that would be manual, mechanical, or simply infeasible without computing technologies.

Computer hardware houses and integrates the sensing, communications, and software or algorithm technologies that make up the GIS, SCADA, Internet, and other IT systems that are becoming essential to infrastructure operations and management.

The transportation sector uses computing technology in all of its ITS applications. Traffic control centers, for example, are full of computers that receive data and images from roadside sensors and send response data to other computers in ramp metering or signaling systems. The "Smart Cards" and transponders used in Electronic Toll Collection (ETC) or Electronic Fare Payment systems contain microprocessors that store pricing or billing information that is then recognized by computerized readers in toll booths or buses. Internet-based traveler information systems are created and accessed on PCs and increasingly accessed via mobile phones and personal digital assistants (PDAs).

Similarly, power and water utilities depend on computer chips for storing input and output data for distributed control systems, workforce management, customer service, etc. Automatic Meter Readers (AMR), for example, contain microprocessors that obtain, store, and send meter data over a communications system. SCADA and other Computerized Maintenance and Management Systems (CMMS) involve networks of advanced facility instrumentation, such as digital valve controllers, that gather and process data on-line and PC-based automation systems at substations that provide real-time graphic monitoring and remote control of these facility components (Hoch, 2000; Swanekamp, 2000). Wireless computing devices like laptops and pen computers that provide digital and easily-modified replacements of bulky paper maps and customer files are becoming staples of the utility field workforce (Wilson, July/August 2000).

Problem Identification, Analysis and Resolution

The final and probably most integral component of infrastructure IT systems is problem solving technology. This encompasses programming, software, or algorithm technology that provides the data analysis, modeling, and instructional capabilities that integrate the other IT components (sensors, telemetry, and computer hardware) making them useful and compatible. Programming languages provide the medium for manipulating variables like data, text, and images and producing directions (or code) for execution by computer hardware and communications systems. In infrastructure planning, management, and operations, software applications are becoming indispensable for automation and decision-support. Computer Aided Design (CAD), GIS, variable pricing, Web-based customer service, and asset management systems are just a few of the infrastructure IT applications that require advanced database management, visualization, and accounting/pricing software. The transportation and utility sectors now provide a major market for software development of this kind and are benefiting from the growing assortment of off-the-shelf, interoperable, and often Web-based software products.

In transportation, transportation management centers rely on software programs for ramp metering, signaling and variable message sign control, vehicle tracking, and vehicle dispatching applications. According to U.S. DOT ITS deployment evaluations, these software applications are improving surface transportation systems around the country: for example, the implementation of ramp metering and signal timing optimization software is associated with increasing throughput and travel times and decreasing fuel consumption and vehicle emissions; and automated incident detection algorithms, now deployed in 10-30% of the nation's largest metropolitan areas, have achieved significant reductions in accident response times and congestion delays. (U.S. DOT/FHWA, 2000; U.S. DOT, 1999) On the other end of the ITS spectrum, Advanced Traveler Information Systems (ATIS) also require programs that process and display real-time traffic and transit information and can include programming for graphical user-interfaces and interactive mapping and itinerary creation.

Software is also central to utility IT investments, from pipeline design and engineering CAD programs to SCADA and plant diagnostics and optimization systems. Computer software is used to manage and interpret the data flowing from meters and sensors, create databases and graphic images of physical assets, load profiles, and power rate designs, and support demand management and variable pricing systems. While many utility IT systems remain proprietary and much utility data is competitively valuable, some software applications, including GIS basemaps and industry-wide Internet portals, promote the sharing of utility asset and market information. Real-Time Security Data Display software, developed by the Electric Power Research Institute (EPRI), for example, provides power utility operators with a graphical and statistical view of transmission reliability over a region as large as the North American grid and provides a tool for reducing the probability and impact of regional power disturbances (Douglas, 2000). Other utility software applications cater to water and energy customers and provide not only billing and pricing information and services but also consumption profiles and customized consumption recommendations, often via the user-friendly medium of the Internet. Large industrial Commonwealth Edison energy customers in Chicago use EnergyTracker, energy management software that can be customized to submeter and track the usage of individual machines (Smith, 2000). Kock (2000) has pointed out that Enterprise Asset Management (EAM) software is designed to streamline and integrate these diverse utility IT systems by using open-architecture and communication protocols. PSE&G in Newark, NJ, for example, uses an integrated computer management software system that combines outage management, computer-aided dispatch, GIS, SCADA, and customer information and business systems to serve over 2 million customers in a 2600 square mile service area (Kock, 2000).

IT and Infrastructure Compatibility

Characteristics of IT and Infrastructure System Interdependencies

Three aspects of the integration of IT into infrastructure systems are functional interference, differences in the rates of change of rapidly changing IT and relatively more stable infrastructure systems, and demand on energy and other infrastructure by IT production and use.

Functional Interference:

The rapid growth of information technology and its use in infrastructure has led to a dependency that has left many systems completely disabled when an IT error or mishap arises. This is often a function of the centralization of communications and control that increases vulnerability to outages. System disruptions range from computer operational problems to distribution system disruptions.

Computer Programming. Illustrative of the impact of computer programming errors is that Norway's national railroad company's new 16 airport express trains and 13 high-speed, long-distance Signatur trains would not start in the early hours of 2001, since the date on the trains' computers were not recognized (The Associated Press, January 1, 2001). Other examples are the computer system malfunctions that have disabled infrastructure systems ranging from air traffic control systems to the operation of nuclear power plants.

IT Distribution Systems. The mode of distribution of IT systems interfaces heavily with transportation, electrical, water and wastewater infrastructure distribution systems. Even wireless systems require some spatially located components. Fiber optic cable is typically co-located with electrical lines and roadways, a condition that has led to collaborations and even mergers within different infrastructure sectors and the emergence of innovative methods to coordinate distribution systems. The rate at which these cables are being installed is astounding, as noted earlier: "Every day installers lay enough new cable to circle the earth three times."[7] This has had dramatic effects on day-to-day life producing construction congestion that have led in some cases to periodic construction bans, e.g., in Washington, DC.

IT lines have often come into conflict with other activities. Schneider, ed. (1999), for example, pointed out that: "The single biggest cause of PTN [Public Telephone Network] outages is damage to buried cables (NRIC, 1997). And the single biggest cause of this damage is construction crews digging without proper clearance from telecommunications companies and other utilities. The phenomenon, jocularly known in the trade as 'backhoe fading,' is probably not amenable to a technological solution."[8]

Some unique methods for installing IT fiber optic cable are emerging in conjunction with other infrastructure distribution networks. Trenchless technologies, that involve stringing cable through conduits underground, have been well known. One of the newer applications to fiber-optic cable is the installation of fiber optics in sewer pipes, e.g., the Sewer Access Module being piloted in Albuquerque.[9] New York City is exploring that possibility also with unused water lines (Pristin, April 4, 2000). Cities all over the country are using rail and subway lines, transmission lines, and other conduits to co-locate fiber-optic cable, since the route that cable has to follow is similar to the route that these other conduits follow.

Many different utilities have entered or planned to enter the telecommunications business by virtue of owning the rights-of-way for their own facilities. Examples in the railroad industry include Norfolk Southern with its 21,600 miles of railroad rights-of-way and large microwave system with 400 towers (Caliri, October 19, 1999). Electric power companies have similarly taken advantage of their rights-of-way for the provision of optic fiber. Thus, having advantageous locations for those lines have given infrastructure utilities familiarity with and the potential to introduce IT into their systems in an immediately profitable way.

Wireless Technologies. Wireless technologies provide key linkages between field and centralized computer operations, and the use of this capability is expected to increase. Some forms in which interface issues appear in wireless systems is interference of signals among users at certain frequencies (Sandberg, January 8, 2001), interference with power utility operations and aircraft navigation systems (Kopp, 1998), and the lack of seamlessness of use or coverage geographically. Interactions with communities in the area of aesthetics are occurring with respect to some of the fixed facilities associated with wireless technologies, such as cell phone towers.

Differential Rates of Change in IT and Infrastructure Systems

One origin of the difficulty of integrating IT into infrastructure is differences in the rates of change of each of the underlying technologies described earlier. IT, as indicated above, changes dramatically every few years and the pace is expected to accelerate even further with the introduction of innovations in nanotechnology, optical switching, and other IT technologies. In contrast, the lifetime of even a single infrastructure facility is often decades, and in some cases hundreds of years, and as such, can be difficult to retrofit with new IT.

According to Strayer (May/June 2000) the problem of retrofitting SCADA systems with more powerful computing capability is very time sensitive, because “The average lifetime for most industrial SCADA equipment is over 10 years, but networking technology changes much faster than that.”

Short-term solutions to the problem of integrating IT into infrastructure operations often involve the use of off-the-shelf technologies that can be purchased and used quickly (Schneider, 1999). Inevitably, the subsequent generations of IT utilization in infrastructure will depend on the ability of these technologies to become an integral part of the infrastructure systems they serve where appropriate rather than continuing to be added on as separate systems.

Financing methods may be contributing to the inability to combine technologies with different rates of development. Some investment systems favor newer IT technologies, that may be difficult to incorporate into older systems. U.S. DOT, for example, has observed that “Traditional funding processes that facilitate initial capital investment but may complicate upgrades and system replacements create an attitude that promotes adoption of the latest technologies, encouraging changes to the system late in the implementation process.”[10]

IT Demand for Energy Infrastructure

IT depends upon other infrastructure systems in order to function. Electrical demand of IT systems is the most commonly cited of these dependencies. IT requires energy to operate, and demands a higher quality of energy than is typical of other uses. The impact of IT on energy utilization has been much debated, and estimates of the proportion of energy used by IT or its components ranges from 3% according to Lawrence Berkeley National Laboratory (Mulligan, December 18, 2000) to as high as 37% (Huber and Mills, 1999). Estimates of forecasted increases in energy usage are equally variable, and depend upon which technologies will be used. Wireless is considered to consume more electricity (Forbes, 1999), while optical switching technologies hold the promise of lowered energy usage. The MicroElectroMechanical Systems (MEMS) – a mechanical integrated circuit optical switching system is expected to reduce power consumption by 100-fold over electronic switches.[11]

Moreover, the concentration of information processing capability in data centers is estimated to generate a greater demand for energy, the bulk of the demand being from cooling requirements (Park, 2000). Blair (April 8, 2001), for example, cites a figure of 60-100 kilowatts of electricity per square foot as the consumption rate of an average data center compared with 6-8 kilowatts per square foot for the average commercial office building (citing Tom Uhl, a project manager at Con Edison on the telecom hotel team).[12]

In addition to the amount of energy required by IT, the type of energy is different as well. Highly reliable energy is needed in which variability is kept to a minimum.

IT depends upon other utilities as well. The manufacture of IT components consumes water. The transport of components from manufacture to assembly to ultimate use engages transportation systems in a complex way.

Some Solutions

Examples of some of the directions that are being taken to overcome barriers to IT and infrastructure integration were presented in the previous section. Some changes, however, are more extensive. These include the standardization of infrastructure and IT technologies and the development and use of standards to support such uniformity.

Standardization and Interoperability

Standardization has been suggested as one approach to promote integration to reduce problems at the interface between IT and infrastructure. In transportation, for example, this implies standardizing procedures for functions such as electronic toll collection systems, interregional traffic management and traveler information across different geographic areas. In the energy utility area, where IT systems were often considered proprietary and developed to meet the needs of a specific function, the sector has a tendency to create "islands of information/automation" that can not be easily integrated into a larger utility-wide or sector-wide network. The sector is working to promote standardization and interoperability of communications hardware and software. EPRI, together with the Gas Research Institute (GRI) and the American Water Works Association (AWWA), has developed the Utility Communications Architecture (UCA), a set of utility communications standards for the range of functional areas of electric, gas, and water utilities. UCA establishes models for real-time database SCADA and other data exchange models and end-devices like automated meters (EPRI. March 15, 1997. Utility Communications Architecture Version 2.0.).

Standards to Promote Seamlessness between IT and Infrastructure

Standards are used in some infrastructure sectors to promote uniformity, reliability, and simplification of communication, and to design information that enables users to transfer information from one system to another in the course of managing infrastructure. At the same time, standards do not necessarily imply standardization, that is, flexibility is still maintained for infrastructure managers in how to meet the standards.

Government agencies have in some cases taken the initiative to either require or encourage the development of electronic communication standards. The Federal Energy Regulatory Commission Order 636 of 1992, for example, requires pipeline electronic bulletin boards for the provision of information on transport capacity and transactions for releases (GISB, www.gisb.org).

The electric power industry illustrates the need for standards. Causey (1999) pointed out that problems with IT communication systems is in part due to differences in protocols and practices that are not governed by uniform standards. He pointed out that different versions of an electronic data interchange (EDI) platform that handles customer and energy data were adopted by California's three major investor owned utilities (Southern California Edison Co. (SCE), Pacific Gas & Electric Co. (PG&E), and San Diego Gas & Electric Co. (now Sempra Energy)). Subsequently, standards were developed. He further points out that incumbent utilities must maintain at least 14 different data communications relationships (with other incumbent utilities, ESPs, meter service providers, etc.) and when mismatched communications standards occur, the possibility for errors is huge: "California's EDI mapping and systems solutions don't match those in Pennsylvania, Massachusetts, or other states that are at or near open retail competition."

The UCA referenced above is an example of a standard for electric gas and water utilities across all of the functional areas of "customer interface, distribution, transmission power plant, control center, and corporate information systems," using the ISO/IEC 9506: Manufacturing Message Specifications (MMS) standard to provide a common message format (EPRI, 1997). In the 1999 EPRI Electricity Technology Roadmap use of the UCA for more complex and decentralized data management systems is mentioned.[13]

Similarly in transportation, the Transportation Equity Act (TEA-21) contains requirements for ITS, which are being implemented jointly by U.S. DOT and ITS America. This has been underscored in a national strategy.[14]

The standards are largely being developed and organized by the industry. The gas industry has created an organization – the Gas Industry Standards Board (GISB) – to develop electronic communication standards across the industry. The standards cover electronic communications, information exchange and business practices to promote seamlessness within the natural gas grid. Specifically, examples of standards are the announcement of transactions among shippers to sell capacity in order to allow for open bidding and notifications (called nominations) to service transport providers by shippers of the amount, origin (receipt point) and destination (delivery point) of gas deliveries. Information technologies are used to post the information, provide business services such as the routing of shipments, and ensure that communications and response times are standardized. According to GISB, one set of standards pertaining to business transactions follows a model developed by the Electronic Data Interchange (EDI) of the American National Standards Institute (ANSI Accredited Standards Committee X.12 in GISB, www.gisb.org; GISB, A Concise Guide to GISB, undated.).

Implications for Urban Development

There is an extensive and continually growing literature on how IT affects human settlements and how infrastructure affects human settlements. These include the dramatic changes underway in the design of buildings, neighborhoods and cities that Horan (2000) and Mitchell (1999) have described. Then there are statistics and studies on how cities and regions have become differentiated based upon IT deployment. Many focus on the spatial distribution of various IT components measured in terms of the use of information technology, in particular, Internet backbone capacity (Moss and Townsend, 2000), Internet domain names (Zook, 2000a), and Internet usage (Kelko, 1999), among other measures.[15] These have been analyzed with respect to location decisions and activities of businesses and residences that are associated with urban patterns (Zook, 2000b; Mohktarian, 2000). Many of these studies go further and address land use patterns as well as how place-based activities survive in the information age (Moss, 2000).

There is an equally large if not larger and older literature on how infrastructure influences urban patterns. This goes back several decades when large scale urban development models, land use and transportation planning models, the growth management literature, and the concept of carrying capacity in environmental planning tried to seek and apply relationships between the intensity and location of infrastructure and its influence upon land use.

Not as directly or intensively researched is how infrastructure, enabled and enhanced by IT affects human settlement patterns.[16] The extent and direction of the impacts on how people live depends upon how the use of IT in infrastructure is managed and the design choices that are made from local to global scales.

Conclusions

This paper has identified a very broad range of issues associated with the interface between IT and infrastructure and some of the implications of these processes for urban areas and social systems in general.

IT has been showing signs of improving transportation and utility infrastructure performance in terms of speed of delivery of services to consumers as a result of tighter operational controls for the production systems and communication systems for customer interfaces. The major challenge will be whether or not infrastructure can keep up with the rate of change of IT and solve a number of the adverse effects of spatial and functional interactions that have been arising between the two systems. A few suggested issues that will require further research include the following:

- The next generation of connectivity is expected to involve networks that electronically integrate across systems, namely, from measurement to data processing, analysis and control systems and, in addition, often incorporate a system capable of adaptations based on the findings of the analyses. The extent to which this type of integration improves overall system operation is an important area for research.

- The increased use of IT in infrastructure has been accompanied by a growing dependency on it and centralization of IT control centers. An open question is whether or not such centralization has the potential for counteracting the performance improvements attributed to IT if the vulnerability of the overall system to disruptions is increased.

- The highly localized or immediate social implications associated with the spatial interaction of multiple distribution systems encompassing IT and infrastructure is a research question that could influence the manner in which these distribution systems are co-located and constructed especially in urban areas and along frequently used utility corridors.

- The growing dependency of infrastructure services on IT have implications for equity, and research is needed to understand the extent of this problem and mechanisms that provide access to those who cannot afford such services and training for those requiring education in their use.

- Research is needed to begin to address uncertainties about how the growing dependency of infrastructure services on IT is changing human settlement patterns from the level of the individual building through the differentiation of cities and regions based on IT enhanced infrastructure.

Appendix: Definitions

Computer: "1. A device that accepts data, processes the data in accordance with a stored program, generates results, and usually consists of input, output, storage, arithmetic, logic, and control units. 2. A functional unit that can perform substantial computation, including numerous arithmetic operations or logic operations, without human intervention during a run. Note 1: This definition, approved by the Customs Council, distinguishes a computer from similar devices, such as hand-held calculators and certain types of control devices. Note 2: Computers have been loosely classified into microcomputers, minicomputers, and main-frame computers, based on their size. These distinctions are rapidly disappearing as the capabilities of even the smaller units have increased. Microcomputers now are usually more powerful and versatile than the minicomputers and the main-frame computers were a few years ago."

Computer System: "A functional unit, consisting of one or more computers and associated software, that (a) uses common storage for all or part of a program and also for all or part of the data necessary for the execution of the program, (b) executes user-written or user-designated programs, and (c) performs user-designated data manipulation, including arithmetic and logic operations. Note: A computer system may be a stand-alone system or may consist of several interconnected systems. Synonyms ADP system, computing system."

Information Technology: "The branch of technology devoted to (a) the study and application of data and the processing thereof; i.e., the automatic acquisition, storage, manipulation (including transformation), management, movement, control, display, switching, interchange, transmission or reception of data, and (b) the development and use of the hardware, software, firmware, and procedures associated with this processing."

Telecommunication: "1. Any transmission, emission, or reception of signs, signals, writing, images and sounds or intelligence of any nature by wire, radio, optical or other electromagnetic systems. [NTIA] [RR] 2. Any transmission, emission, or reception of signs, signals, writings, images, sounds, or information of any nature by wire, radio, visual, or other electromagnetic systems."

Source: National Telecommunications and Information Administration's Institute for Telecommunication Sciences (NTIA/ITS), Standards Committee T1, Telecommunications. 2001. Telecom Glossary 2000. U.S. Department of Commerce, Washington, D.C., http://www.ntia.doc.gov/
http://www.its.bldrdoc.gov/projects/t1glossary2000/t1g2k.html

Appendix: Table 1

Summary of the Use of IT in Selected Infrastructure Systems

TECHNOLOGY (alphabetically)	SURFACE TRANSPORTATION INFRASTRUCTURE APPLICATIONS	UTILITY INFRASTRUCTURE (Water, Wastewater, and Power) APPLICATIONS
Automatic Meter Reading	Not currently applicable	▪ remote and continuous online data reading ▪ real-time load profiling ▪ power-quality and distribution-system monitoring ▪ demand forecasting and management ▪ outage, leak, and theft detection ▪ remote connection and disconnection ▪ itemized billing and variable rate structures
Computer Aided Design (CAD)	▪ systems planning, siting, engineering, and design	▪ systems planning, siting, engineering, and design
Computer Aided Dispatching, Routing, and Scheduling	▪ fleet and freight management ▪ traveler information systems ▪ emergency response	▪ workforce, fleet, and outage management ▪ emergency response
Computerized Maintenance and Management Systems, including Supervisory Control and Data Acquisition (SCADA), Enterprise Asset Management (EAM)	transit and rail management, including: ▪ automatic vehicle location (AVL) ▪ real-time monitoring of operations and equipment condition and performance ▪ failure location and diagnostics ▪ signaling control ▪ power load control ▪ data archiving and analysis	asset management, including: ▪ automated operations ▪ distributed control ▪ real-time monitoring of operations and equipment condition and performance ▪ failure location and diagnostics ▪ data archiving and analysis ▪ workforce and outage management
Geographic Information Systems (GIS)	▪ systems mapping, planning, and modeling ▪ public information systems ▪ asset and data management	▪ systems mapping, planning, and modeling ▪ public information systems ▪ workforce and outage management ▪ asset and data management
Global Positioning Systems (GPS)	▪ in-vehicle navigation ▪ automatic vehicle location (AVL) for fleet and freight management ▪ emergency response management	▪ in-vehicle navigation ▪ automatic vehicle location (AVL) for workforce management ▪ facility and data mapping and modeling ▪ incident/outage location

Appendix: Table 1(continued)

TECHNOLOGY (alphabetically)	SURFACE TRANSPORTATION INFRASTRUCTURE APPLICATIONS	UTILITY INFRASTRUCTURE (Water, Wastewater, and Power) APPLICATIONS
Internet-Based Information and Communication Systems	▪ IT systems integration ▪ multi-modal traveler information systems: real-time traffic conditions, transit information, scheduling, billing, point-to-point itineraries for highway and multi-modal trips, real-time weather information, parking information ▪ freight management ▪ e-commerce: equipment/service procurement, contracting ▪ knowledge management and sharing: virtual industry consortia, electronic newsletters, information libraries ▪ web-enabled project management	▪ IT systems integration ▪ customer information and billing systems: real-time pricing, consumption monitoring, bill payment, outage reporting and response ▪ e-commerce: utility market transactions, e-market places for equipment/service procurement, contracting, utility information ▪ knowledge management and sharing: virtual industry consortia, electronic newsletters, information libraries ▪ web-enabled project management
Mobile/Field Communications Devices	▪ variable message signs for traveler information, traffic and incident management ▪ data collection and systems planning, mapping, maintenance ▪ fleet and freight management ▪ incident reporting and response	▪ workforce and asset management ▪ data collection and systems planning, mapping, maintenance ▪ recording customer information ▪ incident/outage reporting and response
Ramp Metering Systems	▪ traffic and incident management	Not applicable
Remote Sensing and Imaging	▪ traffic surveillance and management ▪ incident detection and management ▪ data collection and systems planning, mapping, maintenance ▪ real-time traveler information systems ▪ road surface, transit infrastructure, and vehicle performance measurement and diagnostics ▪ emissions monitoring and environmental impact assessment ▪ commercial vehicle operations systems (e.g. weigh-in-motion truck clearance) ▪ advanced vehicle control and safety systems	▪ surveillance and data collection of operational and environmental parameters (temperature, pressure, water quality, emissions) ▪ facility and equipment performance measurement and diagnostics ▪ facilities mapping and planning ▪ environmental impact assessment
"Smart" Card Technologies	▪ automatic electronic payment for highway tolls, transit fare, parking fees ▪ real-time/congestion pricing ▪ automated vehicle/passenger counts ▪ freight management and tracking	Not currently developed (see Automated Meter Reading)

References

Allenby, Brad R. Spring 2000. "Earth Systems Engineering: The World as Human Artifact," The Bridge, pp. 5-13.

Bishop, David J., Giles, Randy C., and Das, Saswato R. January 2001. "The Rise of Optical Switching," Scientific American, Volume 284, No. 1, pp. 88-94.

Blair, Jayson. April 8, 2001. "There's Money in Housing All Those Internet Servers, but There's a Power Drain, Too," New York Times (April 8, 2001), p. 40, L+.

Caliri, Lois. October 19, 1999. "Norfolk, Va., Rail Company Plans to Lease Network for Telecommunications," The Roanoke Times.

Causey, Warren. January/February 2001. "GIT unites WMS and OMS," Energy IT, Special Section on Geospatial Information Technology.

Douglas, John. Winter 2000. "Power for a Digital Society," Electric Power Research Institute (EPRI) Journal, http://www.epri.com/Journal.asp?issueid=245906

Electric Power Research Institute (EPRI). April 2000. "EPRI's On-Line Performance-Monitoring Workstation," http://www.epri.com

Graham, Stephen and Simon Marvin. 2001 (forthcoming). Splintering Urbanism. UK, Routledge.

Gregory, Rita A. and Kangari, Roozbeth. March 2000. "Cost/Benefits of Robotics in Infrastructure and Environmental Renewal," Journal of Infrastructure Systems, ASCE, Vol. 6, No. 1.

Hoch, G. Jeffrey. May 2000. "With the flip of a switch," Utility Business, Overland Park.

Horan, Thomas A. 2000. Digital Places. Building Our City of Bits. Washington, DC, The Urban Land Institute.

Huber, P. and Mills, M. 1999. "The PowerChip Paradigm," The Power Report, pp. 1-8.

ITS America. July 2, 1999. National ITS Deployment Strategy: Saving Lives, Time and Money Using Intelligent Transportation Systems: Opportunities and Actions for Deployment, Interim Final Draft.

Koch, Bill. July/August 2000. "Automation—Tame unplanned outages," Electrical World T&D.

Kolko, Jed. November 1999. "The Death of Cities? The Death of Distance? Evidence from the Geography of Commercial Internet Usage," Paper presented at the Cities in the Global Information Society Conference, Newcastle-upon-Tyne, England.

Kopp, Alan. August 1998. Get mobile—with today's handheld, wireless devices. Power magazine. http://www.powermag.com/search.vts?

Makansi, Jason. September/October 2000. "Information technology: Portals for powerplants," Power Magazine.

Mitchell, William J. 1999. E-topia, Cambridge, MA, MIT Press.

Mokhtarian, Patricia L. October 1997. "Now That Travel Can Be Virtual, Will Congestion Virtually Disappear?" Scientific American.

Mokhtarian, Patricia L. c.2000. "Telecommunications and Travel," A1C08: TRB Committee on Telecommunications and Travel Behavior," TRB, Washington, DC.

Moselhi, Osama and Shehab-Eldeen, Tariq. September 2000. "Classification of Defects in Sewer Pipes Using Neural Networks," Journal of Infrastructure Systems.

Moss, Mitchell L. 2000. "Why Cities Will Thrive in the Information Age." ULI on the Future: Cities in the 21st Century, Urban Land Institute, Washington, DC, pp. 24-31.

Moss, Mitchell and Anthony Townsend. 2000. "The Internet Backbone and the American Metropolis," The Information Society Journal, 16(1):35-47.

Moss, Mitchell and Anthony Townsend. April 1999. "How Telecommunications Systems are Transforming Urban Spaces," Taub Urban Research Center, New York University.

Mulligan, Thomas S. December 18, 2000. "Energy: Electricity demand in Silicon Valley has grown at four times overall U.S. rate, experts estimate," LA Times.

National Telecommunications and Information Administration's Institute for Telecommunication Sciences (NTIA/ITS), Standards Committee T1, Telecommunications. 2001. Telecom Glossary 2000. U.S. Department of Commerce, Washington, D.C., http://www.ntia.doc.gov/
http://www.its.bldrdoc.gov/projects/t1glossary2000/t1g2k.html

Pristin, Terry. April 4, 2000. "City Finds a Fiber-Optic Solution Underfoot, in Old Pipes," New York Times, L edition, p. B7.

Sanberg, Jared. January 8, 2001. "Raft of new wireless technologies could lead to airwave gridlock," The Wall Street Journal.

Schneider, Fred B., editor. 1999. Trust in Cyberspace, Washington, DC, National Academy Press.

Schwartz, John. March 8, 2001. Wiring the City: Humans Won't Do, New York Times, G1.

Smith, Dennis L. September/October 2000. "The meter: Heart of competition," Energy IT.

Stix, Gary. January 2001. "The Triumph of the Light," Scientific American, pp. 80-86. Also see: http://www.lightreading.com

Straayer, Russell. May/June 2000. "Scada: The need for speed," Electrical World, Vol. 214, Issue 3.

Swanekamp, Robert. September/October 2000. "Finding the right IT tool for the right IT job," Power Magazine.

Taub, Steven. September/October 2000. "The information engine," Electric Perspectives.

The Associated Press. January 1, 2001. "Millennium bug belatedly bites Norway trains." http://www.nandotimes.com.

U.S. DOT. 2000. "Automatic Vehicle Location."

U.S. DOT. 1999. ITS Benefits: 1999 Update. Washington, DC, U.S. DOT.

U.S. DOT, Bureau of Transportation Statistics. 2000. The Changing Face of Transportation, Washington, DC, U.S. DOT.

U.S. DOT/FHWA. December 2000. What Have We Learned About Intelligent Transportation Systems? Washington, DC, U.S. DOT.

Wilson, J.D. July/August 2000. "The mobilizing of utilities." Energy IT.

Zook, Matthew. 2000a. "Internet metrics: using host and domain counts to map the internet," Telecommunications Policy, Vol. 24, pp. 613-620.

Zook, Matthew. 2000b. "The web of production: the economic geography of commercial Internet content production in the United States," Environment and Planning A, Vol. 32, pp. 411-426.

ENDNOTES

[1] Portions of this paper are drawn from a monograph entitled, "Information Technology and Infrastructure" prepared under a grant funded by the National Science Foundation entitled "Information Technologies and the Future of Urban Environments" (Grant Number 9817778) to New York University, and is also supported by the Institute for Civil Infrastructure Systems (ICIS) (Cooperative Agreement No. CMS-9728805), supported by a grant from the National Science Foundation. Any opinions, findings, and conclusions or recommendations expressed in this document are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

[2] Professor of Planning and Public Administration and Director of Institute for Civil Infrastructure Systems (ICIS). E-mail address for correspondences about this paper: rae.zimmerman@nyu.edu. ICIS is a partnership of NYU, Cornell, Polytechnic University of NY, and the University of Southern California, and is located at New York University's Robert F. Wagner Graduate School of Public Service.

[3] Graduate Research Assistant at the Institute for Civil Infrastructure Systems located at NYU.

[4] See, for example, the 2001 American Society for Civil Engineers (ASCE) infrastructure scorecard at www.asce.org/reportcard/.

[5] For some of these measures, see: Webopedia. 2001. http://webopedia.internet.com.

[6] Categories similar to these have been suggested in U.S. DOT/FHWA, What Have We Learned About Intelligent Transportation Systems? 2000.

[7] Stix, January 2001, p. 81.

[8] Schneider, ed., 1999, p. 37.

[9] Schwartz, March 8, 2001, p. G1.

[10] U.S. DOT/FHWA, What Have We Learned About Intelligent Transportation Systems? 2000.

[11] Bishop, Giles, and Das, 2001, p. 91.

[12] Blair, April 8, 2001, p. 40.

[13] EPRI, 1999, p. 45.

[14] ITS America, July 1999, pp. 113, 116.

[15] These are summarized in Moss, 2000, pp. 25-26.

[16] Graham and Marvin, forthcoming, 2001, address some of the IT and infrastructure linkages and urban condition.