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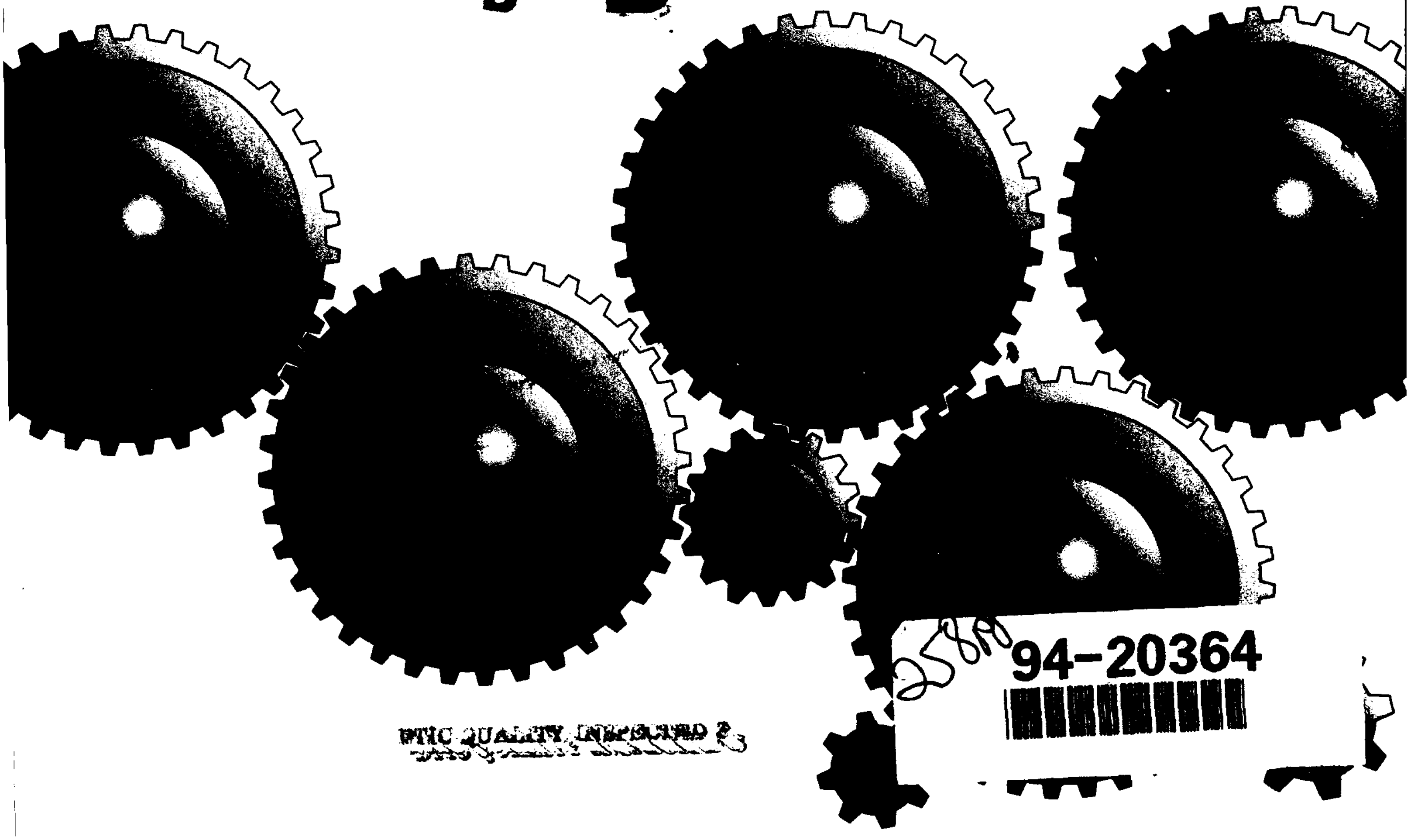
U.S. Army Corps of Engineers
Construction Engineering
Research Laboratories

Challenges and Opportunities for Innovation in the Public Works Infrastructure - Volume II



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94-20364

Federal Infrastructure Strategy Program

June 1993

IWR Report 93-FIS-3

Federal Infrastructure Strategy Reports

This is the third in a series of interim reports prepared to support the Federal Infrastructure Strategy Initiative, a 3-year program to explore the development of an integrated multi-agency Federal infrastructure strategy.

The Federal Infrastructure Strategy is a dynamic program involving many Government departments and agencies. The series of reports which chronicle the strategy's development reflect the desire to publish interim documentation as results become available. Theses documents will be used to facilitate the dialogue within the Federal and non-Federal infrastructure communities as policy deliberations continue.

The program will culminate with a final report to be published at the end of 1993. The interim documentation contained herein is not intended to foreclose or preclude the program's final conclusions and recommendations. Within this context, comments are welcome on any of these reports.

This report documents the results of an in-depth study and workshop which developed methods which could be applied to overcome barriers to innovation and the use of innovative technology within the nation's public works infrastructure.

The first report published as part of the Federal Infrastructure Strategy Program was:

> The Federal Infrastructure Strategy Program: Framing the Dialogue - Strategies, Issues and Opportunities (IWR Report 93-FIS-1).

The next three reports planned for publication as part of the program are:

> Challenges and Opportunities for Innovation in the Public Works Infrastructure, Volume I (IWR Report 93-FIS-2), and
>
> Infrastructure in the 21st Century Economy: A Review of the Issues and Outline of a Study of the Impacts of Federal Infrastructure Investments (IWR Report 93-FIS-4).
>
> Federal Public Works Infrastructure R&D: A New Perspective (IWR Report 93-FIS-5)

For further information on the Federal Infrastructure Strategy, please contact Robert A. Pietrowsky, Program Manager at:

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The Federal Infrastructure Strategy study team includes Cameron E. Gordon, Economic Studies Manager and James F. Thompson, Jr., Engineering Studies Manager. The program is overseen by Dr. Eugene Z. Stakhiv, Chief, Policy and Special Studies Division, and Kyle Schilling, Director of the Institute. Reports may be ordered by writing (above address) or calling Arlene Nurthen, IWR Publications, at (703) 355-3042.

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS, WATER RESOURCES SUPPORT CENTER
INSTITUTE FOR WATER RESOURCES
7701 TELEGRAPH ROAD
ALEXANDRIA, VA 22315-3868

REPLY TO
ATTENTION OF

June 24, 1994

CEWRC-IWR

MEMORANDUM FOR COMMANDER, Defense Technical Information Center,
Cameron Station, Alexandria, VA 22314

SUBJECT: Transmittal of IWR Report 93-FIS-3

1. Reference AR 70-31.

2. Two copies of IWR Report 93-FIS-3, "Challenges and Opportunities for Innovation in the Public Works Infrastructure - Volume II", has hereby been submitted

3. Initial distribution of this report has been made to appropriate Corps of Engineers agencies. It is recommended that copies of this report be forwarded to the National Technical Information Center.

4. Request for the DTIC Form 50 (Incl 2) be completed and returned to WRSC-IWR.

FOR THE DIRECTOR:

Enclosure

Kyle E. Schilling
Director

THE FEDERAL INFRASTRUCTURE STRATEGY PROGRAM

CHALLENGES AND OPPORTUNITIES FOR INNOVATION IN THE PUBLIC WORKS INFRASTRUCTURE

VOLUME II

Directorate of Civil Works
Office of Interagency and International Activities
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June 1993

IWR Report 93-FSI-3

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CHALLENGES AND OPPORTUNITIES FOR INNOVATION IN THE PUBLIC WORKS INFRASTRUCTURE:
VOLUME II – WORKSHOP PROCEEDINGS

INTRODUCTION

This report is Volume II of a two-volume set. Volume I includes a survey of professional and technical literature on innovation, infrastructure, and technology transfer issues, and summarizes the contributions of a group of experts to a national workshop on the topic. The current report, Volume II, comprises the proceedings of the workshop.

That workshop, "Challenges and Opportunities for Innovation in the Public Works Infrastructure," convened a group of nationally recognized experts to discuss barriers to innovation in the public works infrastructure, share insights, and suggest ways innovation could be promoted to benefit the condition of the nation's public works infrastructure.

The workshop was sponsored by the U.S. Army Corps of Engineers Federal Infrastructure Strategy Program. It was hosted by the U.S. Army Construction Engineering Research Laboratories, in Champaign, Illinois. The program included sessions for presentation of papers and group discussions to develop recommendations for overcoming barriers and taking advantage of opportunities to innovate in the public works infrastructure. Participants were strongly encouraged to make recommendations for enhancing the role of innovation.

The program was organized into three separate topic sections: (1) opportunities for innovation, (2) barriers to innovation, and (3) enhancing technology transfer. For the group discussions, participants were divided into three groups corresponding to these topics. At the end of the workshop, there was a plenary session for reporting on each group discussion. A chairman and a recorder were assigned to each discussion group and were responsible for producing the final group discussion summary. Three group discussion agendas were sent to all participants to be used as a starting point for their discussions.

Contents of this volume include the following: a reproduction of the workshop agenda, the text of all the workshop papers, reports on the three workshop group discussions (as submitted by the recorders), summaries of the workshop presentations and group discussions, and biographical sketches of all workshop participants.

The authors would like to express their deep sense of gratitude to all who participated in the workshop: Prof. Arthur Baskin, University of Illinois; Dr. James A. Broaddus, Construction Industry Institute (CII); Mr. Joel Catlin, American Water Works Association; Prof. J.M. De La Garza, Civil Engineering Dept., Virginia Polytechnic Institute and State University; Prof. John P. Eberhard, Carnegie-Mellon University; Mr. Michael B. Goldstein, Dow, Lohnes & Albertson; Dr. Francois Grobler, U.S. Army Construction Engineering Research Laboratories (USACERL); Prof. Neil Hawkins, University of Illinois; Dr. Andrew. C. Lemer, Building Research Board; Prof. Stephen Lu, University of Illinois; Mr. Carl Magnell, Civil Engineering Research Foundation (CERF); Mr. Benjamin Mays, Government Finance Officers Association; Mr. William D.

of Water Resources (IWR); Mr. Jesse Story, Federal Highway Administration; Mr. Richard A. Sullivan, American Public Works Association (APWA); Mr. Jim Thompson, IWR; Mr. Jeff Walaszek, USACERL; Prof. Michael Walton, Transportation Research Board (TRB); Prof. Thomas D. White, Purdue University; Mr. Ronald Zabilski, Stone & Webster Engineering Corporation.

Many people at USACERL helped provide important logistical support for the workshop. Although it would be difficult to name all who contributed, it is important to acknowledge the efforts of Dr. Francois Grobler and Mr. Thomas Napier to help prepare, conduct, and report the discussion sessions.

WORKSHOP PRESENTATIONS

PERFORMANCE CHALLENGES TO INFRASTRUCTURE DESIGN
Enhancing the Role of Innovation in Public Works

John P. Eberhard
Head, Department of Architecture
Carnegie Mellon University

To make significant advancement in the urban networks of movement, information, metabolism, and shelter required by new challenges and opportunities calls for a new perspective on the nature of infrastructure problems and new goals for the performance of such systems.

Functional Performance:

Every populated area requires four basic infrastructure systems:

1. A means of movement for persons and goods between locations within the area, and a method of connecting to movement systems outside the area. In most situations there is a requirement for both horizontal and vertical movement.
2. A means of communicating between persons and between organizations, and for providing information for governance and management. This includes both written and aural modes, as well as instances of tactile requirements.
3. A "metabolic" process providing energy for work to be done, materials for building and repairs, and methods for disposing of resulting wastes.
4. The "skin and skeleton" of the city which shelter the functions of individuals and organizations. These places provide protection from the elements and enemies; create visual, acoustical and tactile spaces for living and working; and should adapt to changing functions over time.

Over thousands of years the infrastructure of cities changed slowly. Ways of harnessing animals for transport gradually were supplemented by steam and water-borne modes of movement within cities. Communications methods moved from town-criers and messengers to written documents as more and more people learned to read. The energy of coal, whale oil, and steam was harnessed to do work. Waste was transported further and further from city centers for disposal or dumped into rivers, lakes and streams which flowed through the city. Buildings became designed and crafted objects of large size (compared to primitive shelters) and often of some elegance.

However, towards the end of the 19th century the growth of large urban centers (beginning to approach one million inhabitants), spurred on by the Industrial Revolution, made this slow evolution unsatisfactory. Especially in the congested city centers, the prevalence of epidemics, the growing threat from major fires, and the economic pressure from speculative increases in the price of land, became the "necessity" for which invention was a dramatic response. Large numbers of people capable of technological inventions, protection afforded by a patent system promising nineteen years of no competition, and the corporate form of business enabling thousands of persons to make small investments to capitalize a new venture, all helped stimulate a period of rapid changes in the infrastructure of cities. The resulting quantum leaps towards the end of the 19th century can be termed a "second generation of urban infrastructure".

The second generation was based essentially on eight innovations introduced before 1900:

1. The steel structural system, separating structure from the exterior walls, thus making tall buildings possible.
2. The elevator making vertical movement within buildings taller than five or six floors practical.
3. Electrical systems, including generators, distribution methods, motors and the electric light.
4. Central heating which removed the danger of fire and the logistics problems of fireplaces and stoves;
5. Indoor plumbing, including water supplies, sewers, bathtubs and toilets.
6. The telephone, including switching centers and wires for distribution.
7. The automobile (more importantly the internal combustion engine) easing trips to the suburbs.
8. The subway, making movement patterns in dense urban areas more effective.

Since the turn of the century, with the possible exception of radio and television, there has been no major invention capable of displacing these one hundred year old systems. All civilian infrastructure investments and creativity have gone into modest improvements in performance and/or appearance of these eight innovations, or into the diffusion and maintenance of existing systems.

It seems clear that major new infrastructure inventions and innovations are possible. One of the requirements for advancing new concepts and introducing innovations is to have a set of performance requirements, e.g., goals and objectives for infrastructure stated in language which is independent of existing solutions. A preliminary set of such performance requirements follows:

Attributes Required of All Systems Independent of Function:

1. Systems should be financed in a way which makes them economically viable and socially just for all citizens.
2. Systems should be operable whenever needed to sustain a safe and effective supporting network for the community, including periods of darkness and/or inclement weather.

3. Systems should be ecologically benign and supportive of the natural environment in which they are located. This includes the long term impact on resource depletion as well short term maintenance of air and water quality.
4. Systems should be safe to use and equally accessible to all citizens, including those impaired by age or disabilities (The American with Disabilities Act provides for the civil rights of more than 900 categories of disabilities. On July 26, 1990 the ADA was signed into law by President Bush. This is civil rights legislation designed to improve access to jobs and workplaces for people with disabilities. A key phrase is to provide "full and fair enjoyment" to all citizens.)
5. Systems should be easily repairable and have adequate back-up support to be operable at all times.

Performance Criteria Specific to the Four Basic Systems;

1) **Methods of movement** within an area must:
   - facilitate movement between all geographic sectors of the area including three dimensional changes in topography or building levels;
   - facilitate movement of loads of any reasonable size and weight and provide sufficient flexibility to accommodate additional sizes and weights under special conditions;
   - accomplish such tasks within a time frame responsive to the functional needs of the community (but always within safe limits);
   - be capable of growth and adaptation to both short-term demands, such as daily commuter patterns, and long term changes, such as population increases and changes in functions; and
   - be responsive to emergencies to facilitate rescue operations, fire fighting, police calls, and medical care.

2) **Information-management systems** of the community must:

   - be sufficiently reliable and have adequate redundancy to assure continuous operation at all times, especially in emergencies;
   - enable the management of the operations of all other infrastructure, including the interactions between each system;
   - provide effective connections to all other infrastructure;
   - be capable of use by large and small assemblies of citizens, as well as by individuals, regardless of their language skills;
   - be capable of expansion to meet growing long-term demands or rapid short-term surges, and

- provide the highest technological level of service to the largest number of citizens possible, commensurate with economic conditions.

3) **"Metabolic"** systems must:
- facilitate the supply and distribution of energy, goods, food and other resources to support life and growth in the community;
- provide for the effective removal and disposition of all wastes created both inside and outside the system;
- be flexible and adaptable to short-term changes in demand; and
- make provisions for those times when extraordinary demands may be placed on the system by the community or by natural events.

4) The surrounding shells and interior divisions of the **shelter system** must:
- facilitate privacy for individuals and groups under all reasonable circumstances;
- protect all citizens from harm and danger, whether caused by failures in the shelter system, natural events, or intruders;
- enable all users to find their way within the shelter enclosure and to identify places (such as parking spaces) with sufficient clarity to recall their location;
- provide an esthetic context which responds to community values and is harmonious with other adjacent places.

If the standards making bodies of this country would further develop performance requirements of this type, and if government programs for funding infrastructure research and development were to be tied to these requirements, we might begin to see a third generation of urban systems early in the next century.

SEARCHING FOR THE INFRASTRUCTURE OF TOMORROW:

NATIONAL RESEARCH COUNCIL ACTIVITIES, FEDERAL INTERESTS AND FEDERAL ROLES

An Issues Paper Prepared for the

Workshop on Challenges and Opportunities for Innovation in the Public Works Infrastructure

Construction Engineering Research Laboratory
Champaign, Illinois
3-4 March, 1992

Prepared by

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Director, Building Research Board
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February 12, 1992

SEARCHING FOR THE INFRASTRUCTURE OF TOMORROW:

NATIONAL RESEARCH COUNCIL, FEDERAL INTERESTS AND FEDERAL ROLES

by

Andrew C. Lemer[1]
Director, Building Research Board
February 12, 1992

INTRODUCTION

Today, the products of technological innovation in many fields are all around us: Organ transplants have become almost commonplace in hospitals around the country. A daunting array of new food products with long shelf lives entice us at supermarkets. Computers that now fit comfortably on one's lap pack more power than the room-sized machines commonly available just two decades ago.

In contrast, our infrastructure relies for the most part on technologies that emerged initially in the 19th century. Brooklyn's (New York) was the first modern urban sewerage treatment system, built in 1857 (Herman and Ausubel, 1988). The first concrete roads followed within two decades the 1824 invention of Portland cement, and the Place de la Concorde in Paris was paved with asphalt as early as 1835 (Hamilton, 1975). Modern water supply was born in London in the middle of the century. Alexander Graham Bell invented his telephone in 1876, and Edison his electric light in 1880.

Some observers argue that technological innovation in infrastructure is lagging, and that government action is needed to remedy the situation. Others note that with the exception of occasional newsworthy events—burst water mains, ruptured steam lines, failed cables and switches—most of the U. S. infrastructure continues to work well, and that other demands for public resources merit higher priority. Does the United States face particular problems of opportunities lost or higher costs for infrastructure innovation? Is the United States falling behind other nations in providing infrastructure's services, with consequences for our future quality of life and international competitiveness? If so, can we agree on an effective course of action? The Building Research Board (BRB), a unit of the National Academy of Sciences, is working to help answer such questions.

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[1] The views contained herein are the author's and do not necessarily reflect those of the Building Research Board or the National Research Council.

This paper reviews some of the BRB's current work that sheds light on these and related questions. We are finding that there are indeed problems and, while these problems are frequently subtle and resistant to analysis, there appear to be effective ways to deal with them. However, much remains to be done.

DEFINING INFRASTRUCTURE

Speaking at subcommittee hearings in 1987, during which the results of one NRC study were being discussed (NRC, 1987), former Sen. Stafford commented that "probably the word infrastructure means different things to different people."[2] One cannot take for granted that people know what "infrastructure" is.

Physical infrastructure is a system of users interacting with a diverse collection of constructed facilities and associated services, ranging from airports to energy supply to landfills to water treatment. While facilities—infrastructures, as some term them—comprise the hard core of the concept, to discuss infrastructure only in terms of facilities neglects the important services provided by both private enterprise and public agencies, that are enabled by these facilities. The success of such corporations as Federal Express and DHL in air parcel delivery, for example, reflects the development of new infrastructure services based on existing infrastructures.

The system of infrastructure is constructed and managed primarily at the level of states and localities, but has crucial importance for the nation's economy and quality of life. Yet there is no federal center of responsibility for infrastructure policy, nor are there mechanisms in government at any level for addressing issues of infrastructure as a whole. Despite more than a decade of debate regarding problems the nation's infrastructure suffers—underinvestment, inadequate maintenance, lagging technological progress—a variety of institutional and social barriers block effective action.

SLOW CHANGE OF INFRASTRUCTURE

A study sponsored by the National Academy of Engineering noted that a decisive characteristic of infrastructure is the generally long physical lifetime of the facilities and the persistence of development and use patterns that make infrastructures difficult to remove or retire. (Marland and Weinberg, 1988) Infrastructure facilities are routinely designed to meet demands projected for three decades or more into the future, and despite some early failures, most dams, bridges, and highways endure for many decades, and sometimes for centuries[3]. Maintenance and occasional refurbishment are required, but the underlying structure often remains little changed.

Infrastructure facilities are in many instances taken out of service only when a competing device can perform the service more effectively or because the service is no longer particularly valuable—for example, a bridge is too narrow for increased traffic loads. However, the design of facilities often reflects the expectations of the designers, and so U. S. highway pavements have been designed for 20-year lives, while the German autobahns designed to serve Hitler's 1000-year reich still are serviceable, 50 years later. Power plants have typically been expected to last 25 to 30 years because history has shown them to become noncompetitive by then, although that perception is said to be changing—and lifetimes lengthening—as designers reach the ceiling of thermodynamic efficiency in conventional generation technology.

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[2] Subcommittee on Water Resources, Transportation, and Infrastructure; Committee on Environment and Public Works; October 21, 1987.

[3] The Takoma Narrows Bridge, famous for its dynamic response to winds, collapsed four months after its opening. In contrast, the Brooklyn Bridge still serves after 100 years.

Because of the large investment embodied in infrastructures, new technologies that might require replacement or substantial reconstruction of existing facilities must offer much greater benefits than might otherwise be the case. The evidence shows that there is a relatively long time period, on the order of 100 years in the case of rail and road, in the transition from one infrastructure technology to the next. The rapid advance of computers and consumer electronics is due in no small measure to the short service lifetime (e. g., less than four years for desktop computers) expected of these devices. Shorter-lived or more flexible facilities would provide an incentive to innovation in infrastructure technologies but this approach raises questions of risk and reliability, and flies in the face of several centuries of engineering tradition of designing for the long term.

New technologies that can be put into practice through incremental alteration of existing infrastructures stand a much greater chance of success than those that require major new construction. For example, a quantum leap in road transport became possible only after introduction of the internal combustion engine. Before that, even ambitious road construction programs could not significantly improve the slow transport speeds of horse-drawn carriages and wagons.

The sites occupied by infrastructure facilities may live longer than the facilities themselves. Urb [illegible] nd regional development patterns respond to infrastructure's availability and thereby create demand [illegible] continuation of infrastructure's services. Public resistance to location of new facilities enhances the [illegible] f continuing operations at existing locations. These effects give substantial impetus to efforts to enhance productivity of infrastructure technology, relative to its uses of land.

TECHNOLOGY RESEARCH AND INNOVATION

Evidence is strong that declining research efforts and a continuing focus on incremental project-by-project advances underlie a lagging rate of technological innovation, felt throughout the construction sector but especially serious in applications to physical infrastructure. Accurate statistics are stubbornly elusive, but estimates by the Building Research Board (BRB) placed aggregate spending on research by the U. S. design and construction industries at roughly $1.2 billion in 1984, about 0.4 percent of sales in the industry (BRB,1988). In comparison to other mature industries such as appliances (at 1.4 percent), automobiles (1.7 percent), or textiles (0.8 percent), this spending rate is low.

In comparison to the construction industry in other countries, the spending is low as well. Estimates assembled by the Conseil International du Batiment pour la Recherche l'Etude et la Documentation (CIB) place the rate of building research and development (R&D) spending in the United States at well below half the rate in Japan, and a role for just over 20 percent of the spending rates in Sweden and Denmark, the nations seemingly most committed to building research within their national economies (Sebestyen, 1983).

New programs in the United States, such as the U. S. Army Corps of Engineers' Construction Productivity Advancement Research (CPAR), the several research foundations associated with professional societies and industry associations, and the Construction Industry Institute have been started since these statistics were assembled, but there is no indication that the aggregate levels of R&D activity have increased significantly. According to the National Science Foundation, total annual nondefense R&D expenditures in the United States have stayed nearly level at about 1.8 percent of gross national product (GNP) since 1981 (Jankowski, 1989). In West Germany and Japan, the 1988 spending rates were approximately 2.6 percent and 2.9 percent of GNP respectively, up some 30 to 40 percent over the past decade.

A currently ongoing BRB study on innovation has noted that some of the spending on construction research—perhaps most of it, in the United States and elsewhere—is devoted to solving problems on particular projects. Such effort goes unreported in the standard economic statistics and yields benefits initially restricted to the single project (although more generally applicable improvements in technique typically are used again on other projects, spread to other firms in the region and eventually to other regions). Also, in contrast to many other nations, there is no U. S. central government department of construction or other agency responsible for policy in the building industry, so under-reporting of R&D may be marginally more severe in the United States.

Nevertheless, many people have suggested that the U. S. construction industry is lagging, and some go so far as to argue that U.S. construction and related industries are antiquated and have little real potential for innovation. It is instructive, however, to recall Charles H. Duell, director of the U. S. Patent Office a century ago, who advised President McKinley that the agency should be closed down because "everything that can be invented already has been."

INSTITUTIONAL FORCES FOR NEGLECT

Several characteristics of U.S. society and government are basically ill-suited to effective infrastructure development and management. The most frequent result of these characteristics is that we underspend and underinvest in infrastructure.

U. S. per capita demand for water supplies, the automobile, and disposable materials are extremely high by global standards, even when corrections are made for relative income levels. These high demands require high capacity facilities, which then entail more burdensome maintenance and repair requirements. Yet our political system makes it difficult to assure that funding will be available, so there is a tendency to spend from capital by allowing facilities to deteriorate more rapidly and then having to refurbish or replace them sooner.

In addition, infrastructures are intrinsically poorly suited to yielding the short term results, particularly in financial terms, that U. S. business and elected officials favor. Hence, we tend to underinvest. While financial instruments such as revenue bonds and corporate stocks are available to bridge the gap between long term and short term interests, they expose the technical concerns of infrastructure to the vagaries of financial markets and further discourage investment.

A free market system works effectively in principle only when the prices are right for the goods and services exchanged in that market, and the pricing of infrastructure is notoriously faulty. Infrastructure draws on natural resources——treatable water, clean air, pristine landscapes——that traditionally have been viewed as free to all who would capture them, despite early recognition that the herds of a few may overgraze the public common. Government's role as the primary provider (or at least the regulator) of infrastructure having direct impact on public welfare has a long-accepted tradition, carrying with it the expectation that general taxes should offset some or all of the costs. Hence, the direct beneficiaries, users or others, seldom pay the full costs of infrastructure. In the absence of strong political forces to build infrastructure, this under-pricing also encourages underinvestment.

Because infrastructure facilities are typically big, geographically extensive, and used by many people, infrastructure development and operations often have substantial environmental and social impacts. These impacts have frequently in the past been poorly estimated or neglected in planning and design, and often are poorly managed within the context of traditional governmental, economic, and institutional relationships. The rapid expansion of U. S. environmental legislation in recent years has resulted in an "uncoordinated patchwork" of control requirements that has grown, by one count, from only seven environmental laws enacted in the entire history of the United States to 1955, to more than 40 by 1986 (Balzhiser, 1989).

These laws, enacted to effect important changes in public priorities, have slowed and sometimes stopped investments in infrastructure that would have been easily accomplished in prior decades. However, a valuable consequence is the emerging shift toward environmentally beneficial technologies, more supportive of "sustainable" economic and social activity.

Finally, the substantial public works aspect of infrastructure collides with a distrust of government that is deeply imbedded in American ideology but especially active in the final decades of the 20th century. Major infrastructure projects that displace individuals and disrupt communities raise this distrust to a level much broader than the self-interested resistance of the NIMBY response, further discouraging investment and innovation.

THE BRB'S STRATEGIC PROGRAM IN INFRASTRUCTURE

Reflecting past and current studies, the BRB concluded, first, that there are indeed obstacles to innovation inherent in the technology of infrastructure. These obstacles cause innovation to lag behind that being experienced in other technological fields. Further, these obstacles may be no greater in the United States than elsewhere, but evidence suggests that U. S. efforts to search for and willingness to invest in new infrastructure technology lag behind those of other industrialized nations.

To foster broader vision within the nation's leadership regarding the problems of infrastructure and prospects for enhancing the system's contribution to future wellbeing, the BRB has undertaken a program to encourage research, changes in government policy, education, and cooperative action by private and public decision-makers. The BRB program is founded on a premise that the traditional emphasis of research and policy initiatives——addressed primarily to particular modes of infrastructure——should be linked with broad cross-cutting initiatives that take an integrative and synoptic view of infrastructure as an organic system. These cross-cutting initiatives should focus attention on a core of political concerns, institutional structures, and scientific and technical knowledge common to all infrastructure:

- Complex facilities and multiple users linked through geographically extensive networks
- Common materials such as concrete, steel, and ceramics
- Facilities and services valued not for their own sake, but rather as support for other social and economic activities
- Long service lifetimes requiring long-term financial commitments to assure reliable and safe service
- Diverse and often unforeseen environmental and social impacts that are felt unequally by the various users and neighbors of infrastructure.

Advances in these cross-cutting core areas will ultimately provide broadly useful lessons for more effective infrastructure development and management. The pursuit of such cross-cutting concerns——and their effective integration into national policy——is the central element of the BRB's strategic program in infrastructure.

LOOKING AT LOCAL SOLUTIONS

The initiating activity under this program, approved by Executive Committee of the Governing Board of the National Research Council in December 1989, has been a series of colloquia designed to address topics of immediate interest, substantial payoff in terms of motivating improvements in the nation's infrastructure, and long term relevance. Recognizing that infrastructure problems have national strategic consequences but their character and solutions are essentially local, the BRB concluded that a major obstacle to effective national action in infrastructure is bridging the gap between national policy and diverse local and state-level concerns. Studies to date have largely neglected infrastructure's local users and neighbors, including those who may view particular infrastructures as a burden out of proportion to their local benefit. This neglect is manifest in the increasingly widespread NIMBY response to infrastructure projects, now sometimes being supplemented by NOTE (not over there either) and NIMTOO (not in my term of office)!

Yet there have been notable successes in which local communities have been united and mobilized to come to grips with their infrastructure problems. Identifying the common elements of these successes will give infrastructure planners, administrators, designers, builders, and operators better understanding and guidance in formulating development and management strategies. This guidance will in turn enhance—at the national level—the performance and efficiency of our aggregate investments in infrastructure.

Three colloquia are being held to define these common elements of success, in Phoenix, Arizona, Cincinnati, Ohio, and Boston, Massachusetts. These three regions were selected from among a long list of proposals, based on eight principal criteria:

- Uses of innovative technology
- Transferability of technology
- Demonstrated overcoming of barriers to use of new technology
- Demonstration of constituency building and community support
- Demonstration of effective citizen involvement
- Effective improvement of existing infrastructure (vs. new-build)
- Demonstration of unique institutional approaches
- Effective application of life cycle cost/benefit analysis as a management tool, particularly in the context of political decision-making

Each colloquium will serve as a reconnaissance or "fact finding" workshop involving local professionals familiar with how infrastructure issues were raised and resolved in their communities. Following the third colloquium, scheduled for August, 1992, the BRB will prepare a report on the common lessons learned and how these lessons may be more widely applied.

Partial support for these symposia has been received from the Office of the Assistant Secretary for Civil Works, Department of the Army, and the Program for Structures and Building Systems, National Science Foundation. Additional support is being solicited.

NATIONAL INFRASTRUCTURE RESEARCH AGENDA

A second element of the BRB's strategic program will be a study to define the state-of-the-art, basic research needs and priorities related to the structures, geomechanics, and building systems of infrastructure. This study is being undertaken by the BRB at the request of the National Science Foundation's Division of Mechanical and Structural Systems of the Directorate of Engineering, in cooperation with the NRC's Geotechnical Board. The resulting research agenda will present high-priority opportunities that may be used by the National Science Foundation and the research community to guide basic infrastructure core research, targeted ultimately to provide lessons of cross-cutting value for effective infrastructure development and management.

The study will be focused on fundamental underpinnings of physical infrastructure technology, but will be shaped by the broad national policy debate reflected in such reports as those by the National Council on Public Works Improvement and others, and work by committees of the NRC and National Academy of Engineering. The study will also build on other infrastructure research agenda-setting efforts, including work by the Building Research Board and the Geotechnical Board, and the recent work of other organizations such as the Civil Engineering Research Foundation's "National Civil Engineering Research Needs Forum" and the International Society for Arboriculture's "National Research Agenda for Urban Forestry in the 1990s."

COST-EFFECTIVE INFRASTRUCTURE PERFORMANCE

In developing their 1988 report, Fragile Foundations, the National Council on Public Works Improvement found that none of the various measures available gives a clear, comprehensive, and convincing picture of the status of the nation's infrastructure. In this, the Council echoed the concerns of an earlier body whose 1984 report, Hard Choices, had questioned at length the widely used concept of measurable "need" for infrastructure. These studies exemplify a growing awareness among professionals and policy-makers that the ways performance of infrastructures is characterized and the standards used to judge whether performance is acceptable have far-reaching but poorly understood consequences for how problems are perceived and what solutions appear reasonable.

As a part of their efforts to explore future federal government roles in infrastructure development and management, the Army Corps of Engineers, Institute for Water Resources, has undertaken to identify and address key issues of infrastructure performance and its cost-effective achievement. Institute staff have asked the BRB to undertake a study to delineate and address key issues related to the definition, measurement, and achievement of cost-effective infrastructure performance. Such issues include data needs, problems of measurement, problems of institutional structure, and others. The study, subject to approval by the Governing Board of the National Research Council, will focus primarily on infrastructure within urban areas.

OTHER STRATEGIC PROGRAM ACTIVITIES

In addition to these major initiatives, the BRB is working to extend the strategic program. For example, the BRB's Federal Construction Council and the National Institute of Standards and Technology jointly hosted a symposium on Addressing Infrastructure Problems on Government Installations. The symposium, held in February 1992, explored the problems of infrastructure on military bases and other campus-style multi-building installations, what some refer to as the "mesoscale" of infrastructure. The Federal Construction Council has requested the BRB to undertake a study of how to assess needs and priorities for infrastructure renewal at this mesoscale, but budget limitations may delay this study.

Development of joint international research and development for new infrastructure technology is being explored with Japanese local governments and private companies. If feasible, the idea might be extended to the European Community and other areas. For example, a joint international program might be initiated as a multi-year activity of partnering and exchange, undertaken with financial support and professional participation balanced between the United States and Japan or other nations, with participation of both private and public sectors in these nations. Some coordinating body might be established (perhaps a Joint Infrastructure Research and Demonstration Institute——JIRDI) to act as sponsor or broker for specific research and demonstration activities. The specific activities could address both new technologies responding to needs in one or more modes, and major new systems providing substantially different services from those now available. Selection of specific topics will depend on the program's specific private and public participants, sources of sponsorship and funding, and other institutional arrangements. A variety of mechanisms might be considered for setting priorities and financing the work.

Attention is being given to the relationship of infrastructure to environmentally and socially sustainable development. "Sustainable development" is, to quote the President of the National Academy of Engineering, "an imprecisely defined concept that seeks to capture what many regard as the central problem of humanity: how to sustain the life-supporting environment of the planet while providing for the economic development that will ensure civilized standards of living for its inhabitants." Development and diffusion of environmentally advantageous technology is crucial to the solution of this problem, but there is at present no mechanism for mobilizing the nation's vast technical resources to address these needs.

The BRB's work is intended to produce new policy initiatives and functioning programs to address issues of physical infrastructure. The work and recommendations that motivate such action are embodied in reports issued by the National Research Council. The target audience for reports prepared under this program includes federal agencies and the Congress, state and local governments and their representative institutions such as the National Governors' Association, the American Public Works Association, and the U.S. Conference of Mayors, academic and research communities. These reports are prepared and issued according to the NRC's stringent report review procedures intended to assure balance and objective analysis of the issues at hand. Dissemination of the information developed in these activities will be supported by public events and media presentations as well as broad distribution of reports.

DEFINING THE FEDERAL ROLE

While such activities under the BRB's strategic program in infrastructure are addressing a variety of specific obstacles to innovation, these activities and other BRB studies of technological innovation in the building industry are making clear the need for some overarching central force for infrastructure innovation. This implies a possible federal government role. However, defining this role is a complex problem.

In contrast to many other countries, there is no U. S. government agency with explicit responsibility for representing or encouraging enhancement of either public works or the nation's construction industry as a whole. The Department of Commerce and the Office of Science and Technology Policy share executive branch concern for the nation's technology and industrial competitiveness, but seldom address issues of construction and public facilities.[4] There is an effective gap between the interests of the agencies that undertake construction or manage facilities as accessories to their primary missions—e. g. the Corps of Engineers or the Public Health Service—and the policy-oriented agencies that may include construction, building products and equipment, or facilities themselves (i. e., housing or highways) within their broader purview.

Analogies have from time to time been drawn between the U. S. farm and construction industries, both characterized by many small producers spread across the country, and proposals have been made that there should be a construction equivalent to the Department of Agriculture or a U. S. government equivalent of other nations' ministries of construction. In an historic example, the national crisis of the Great Depression of the 1930s (during which the total annual rate of construction in the United States dropped to one third of its average in the late 1920s) fostered creation of the Public Works Administration (PWA). However, the diversity of interests among federal construction agencies and the many organizations active in the private sector have been generally unresponsive or antagonistic to such proposals. Although the PWA survived for some years, its role as builder was largely relinquished to local government or supplanted by special purpose agencies. (Craig, 1984) Other centralized building programs of the era, such as the WPA (Works Projects—originally Progress—Administration) were dismantled as the nation went to war in the 1940s.

Despite such past reluctance, there are sound reasons why the federal government should play a significant role in the search for infrastructure innovation:

- Infrastructure innovation will help government agencies to achieve better cost, quality, and performance in their own facilities.
- Infrastructure innovation will enhance quality of life in the United States.

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[4] A major exception is the focus on the construction industries of Japan and the United States in trade negotiations of the late 1980s and early 1990s.

- **Infrastructure innovation will support growth in U. S. industry's productivity and thereby enhance competitiveness in international markets.**

While no comprehensive evaluation or recommendations have yet been made, the BRB's studies of innovation suggest several promising components that might be incorporated in the federal role: (1) federal agencies encouraging applications of new infrastructure technology for their own projects, (2) support for world-wide infrastructure technology intelligence-gathering to increase domestic awareness of international technological progress, (3) development of standard testing procedures and evaluation criteria that would enhance the acceptance and effective transfer of new technology to U. S. local communities and the private sector, and (4) increased support for targeted research efforts to develop new technologies in specific areas, perhaps through existing and new university- and industry-based "centers of excellence."

A SPECIFIC PROPOSAL

No specific form for the federal role has yet been considered in the BRB work. These four components might be distributed among agencies or concentrated in one existing or new institutional location. However, the author's own analyses suggest strongly that the search for new infrastructure technology (and policy) should be pursued initially with strongly unified and focused effort. The reasons are several:

(1) In any society, there is an inevitable limit on the resources available to deal with any particular issue, problem, or goal. When these limited resources are spread too thinly, little is likely to be accomplished, and that has been a problem with infrastructure.

(2) The institutional framework is complex, and with the notable exception of transportation—and highways especially—there is no historical focal point for infrastructure issues in the United States, although professional organizations and trade groups (e.g., the American Public Works Association, the American Water Works Association, the American Society of Civil Engineers, and others) do provide some focus. What is needed is some institutional and intellectual coordination of effort to address the common, crosscutting opportunities and problems of infrastructure.

(3) Stronger linkages between the national level and state and local bodies active in development and application of infrastructure technology are needed. The existing modal and disciplinary professional organizations are vital channels for forging these linkages, but additional efforts are needed to mobilize and guide the university-based research and education programs that will be expected to yield new technology and the personnel trained to apply this new technology to practical problems.

The new focus would provide leadership in the national discussion of infrastructure policy, a point of contact for international exchange on issues related to global infrastructure and impacts, an effective clearinghouse for research and development information exchange, and perhaps limited funding for policy-related research. The Council on Environmental Quality, the Advisory Council on Historic Preservation, or the Office of Science and Technology Policy might be domestic models for a new agency. The International Institute for Applied Systems Analysis, in Austria, and the International Rice Research Institute, based in the Philippines but with projects in other countries, are possibly applicable international examples.

An effective focus might be established within an existing institution. The role of the Surgeon General of the United States and the 19th-century office of the "Supervising Architect" responsible for federal building design are models of what might be done within existing agencies. The current joint work of the Army Corps of Engineers and the Department of Transportation on possible federal support of high-speed magnetic levitation (maglev) transportation suggests that other forms may also work. However, there is no clearly defined responsibility for this activity within any single currently active federal body, and the specific form should be crafted to assure the institutional linkages needed for research results to enter practice quickly and effectively.

The greatest proportion of work on infrastructure research and policy concerns issues specific to one or another of the modes of infrastructure, but perhaps ten to twenty percent of concerns span modes and warrant this focused interest. A research-funding agency, such as the National Science Foundation, could undertake to establish one or more "Centers of Excellence" in infrastructure technology and modal agencies such as the Department of Transportation, the U. S. Army Corps of Engineers, the Environmental Protection Agency, and others could be directed to channel some portion of their research spending——perhaps one to two percent initially——into topics of cross-cutting significance, for which university and agency researchers would compete.

The loose confederation of university transportation centers, some of which competed successfully for funding under the Department of Transportation's Congressionally mandated system of ten designated "centers of excellence" (grown to fifteen under the new 1991 transportation legislation), is possibly a target model of an effective system of university-based infrastructure research and training, and might provide the seed organization from which a broader infrastructure research program could be grown.

Supplementing this government-sponsored, there should be tax credits or other federal incentive to private sector participation in infrastructure research and development activities. The benefits of this broader participation would be felt not only within the U. S. infrastructure system, but also in the export potential of new U. S. infrastructure products and services and in the generally enhanced productivity of a nation better-served by infrastructure.

The core of this incentive might be preferential tax treatments for private expenditures on infrastructure research and development, public-private partnerships for new technology demonstration programs, and privately financed programs of insurance and other mechanisms for sharing the unavoidable risks of new technology. However, formation of a national infrastructure development bank, modeled perhaps on operations of the World Bank, would establish a "lender of last resort" for demonstration projects that appear to offer high economic returns but with institutional challenges that exceed what private financial markets are willing to accept. Capital for this bank could be raised initially by small commitments from existing federal infrastructure trust funds——perhaps two to five percent of current highway, airport and interstate energy transmission funds——and private market underwritings. In addition, all state and local jurisdictions hoping to participate in projects funded by this bank would be required to commit some fraction of their property tax and infrastructure use tax revenues (e.g., licensing fees and sewer rates)——again, perhaps two to five percent——to the institution's capitalization.

CONCLUSION

As with any technological field, innovation in infrastructure faces many challenges but offers opportunities as well. The challenges in infrastructure may, for many reasons, be greater than in other fields, and the finding ways to encourage innovation has been especially difficult. The BRB is working to build understanding of whether actions can and should be taken to meet these challenges and, in particular, what role national policy and the federal government can play in this very locally oriented field.

Baseball star Yogi Berra is said to have opined "No matter where you go, there you are." In discussions of infrastructure innovation, we are still at the stage of determining where we are, and where we want to go. The BRB is working to help us find the way.

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HOW EFFECTIVE IS OUR INVESTMENT IN ROADS, STREETS AND HIGHWAYS?

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Introduction

States are making a significant annual investment maintaining, rehabilitating, and constructing or reconstructing the highway and bridge infrastructure. However, there is still concern about the overall level of serviceability and condition of these facilities. Similarly, large cities have deteriorating roadway/street networks. These cities are population centers and public service demands are taking a larger portion of available financial resources and as a result reducing the resources available for the roadway/street network as well as other important infrastructure components. Small cities and towns have generally not had the tax base and do not now have taxpayer support to increase taxes to fund major construction or rehabilitation. In many cases they do not have resources for effective pavement maintenance programs.

Real improvement in the serviceability and condition of the highway transportation infrastructure will require an innovative and long term perspective. A large part of the problem lies with legislation, agency philosophy, and industry. In turn a large part of the solution will come from these same parties.

Transportation Significance

By any measure, the impact that transportation has on the Nation's economy is significant. Table 1 gives the relative percent that can be attributed to transportation for several components of the nation's economy. This includes gross national product, federal taxes, capital outlay and civilian employment.

The estimated freight bill for transportation of products produced by the economy are shown in Table 2. The highway component of freight transportation, obviously is the most significant of those listed. The total government expenditures at the federal, state and local levels for transportation facilities are given in Table 3. The highway share of these expenditures is the largest.

A measure of the innovation that might be applied to the transportation system would be the U.S government R&D outlays for transportation that are shown in Table 4. The interesting statistic from this table is that the outlay for highways is about 14 percent of the total federal R&D outlay as compared to 66 percent for air transportation. Another interesting fact from this table is that the federal R&D outlay for transportation as compared to total government R&D outlay is 3.3 percent. The outlay for highways based on this total government R&D would be about 4 tenths of one percent.

Enabling System for Transportation Infrastructure

As shown in Figure 1, an attempt has been made to consider the institutions that make up the system for legislating, overseeing, designing, building, advising, advocating and researching aspects of the infrastructure in general and the transportation infrastructure specifically.

Figure 1 shows these various interests as legislatures, industry, academia and agency. Of course, the philosophies, concepts, and actions of these interests all impinge upon society (John and Jane Q. Public). In fact, the health of society, as supported by the strength of the economy, is guided and determined by the action of the other components. These components of the system impact the transportation infrastructure in a number of ways.

Legislators

Legislation or rules that affect transportation infrastructure occur at various levels of government. However, the primary legislation is enacted at the federal and state level. Local policies and rules are generally adopted under the guidelines set at the state and federal level.

Because of the impact that transportation has on society and the amount of resources necessary to built and maintain transportation systems, the transportation departments of government become a focus of politics and legislation. The complexity and technical aspects of transportation departments should dictate that a high degree of technical ability and professionalism would be employed in the leadership of transportation departments. In some states, this is the situation, however, in a number of states it is not. In those states that this is not the situation the leadership is provided by political appointees, often times with little experience and leadership for such a position. In one midwestern state, with a change of administration, the job description for district engineers was rewritten as a district managers position. This creates the possibility the position could be filled by an appointee without an engineering background. The situation that this creates is that the engineering activities of the transportation department in that district would not be directed and managed by a professionally trained engineer. If this should happen the responsibility and the liability of engineering activities undertaken within districts then would be passed to the central office and the chief engineer. Supervising these dispersed engineering activities from the central office would be a significant responsibility for the chief engineer.

Politics also play a role in the organizational structure of transportation departments, restructuring for efficiency is desirable and may actually be one of the options for dealing with a structured civil service system. Unfortunately, in todays tight financial resource situation restructuring is associated with making do with less money. Salaries in transportation departments are traditionally low, although there may be a few exceptions. In many cases the low salaries are making it difficult to replace professional staff in a timely manner. State administrators and legislators are reluctant to raise salaries because it is considered poor politics. The lack of professionally trained leadership and administration of transportation departments is ultimately a loss to society.

There is an opportunity for comprehensive long-term legislation to impact the transportation infrastructure. Perhaps an omnibus legislation at the federal level could provide a framework for an integrated transportation system and guidelines for growth of that transportation system. It is time for new comprehensive transportation development that would include integration of air, automobile, rail, truck and bus modes of travel and movement of goods. In a recent newspaper article Boeing Aircraft Corporation was quoted as having estimated that air traffic will triple by the year 2020. There are a number of factors, particularly the national and international economy, that will affect the actual rate of growth. Whether air travel triples or not, it will grow significantly within that time frame. It is easy to suggest that the number of airports will not triple within that period of time. Only a modest increase in physical facilities is likely to occur. That means that there is going to have to be a significant latent elasticity for handling increased demand with current airport facilities.

A large portion of the major airports in the United States are concentrated in urban areas. The increase in air traffic and an associated increase in passengers will impact on ground transportation. Attention paid to developing an integrated transportation system would pay benefits by establishing a structure for ground transportation that would not only be more efficient for handling an increase in the number of air passengers but would benefit the other modes of transportation. It is recommended that the existing transportation system be integrated as soon as possible.

There should be an extended time horizon with which legislation and policy is established. This may be difficult when many legislators view their position on a time horizon of two to four years which is based on the political expediency of being reelected. A distant time horizon for many institutions in U.S society would be beneficial. It is particularly true of the transportation infrastructure. A significant reason for adoption of the legislation establishing the current interstate highway system was predicated on the need for a direct high speed road network for national defence. The interstate system as a means of public transportation was also stated and the benefits to the public were considered. However, once established and construction undertaken, the national defense aspect became less important. During the 1970s and 80s as the initial construction began wearing out, the cost of maintaining and rehabilitating the highway system became a prime issue at the state and federal level. The twenty to thirty year time frame for planning and design of the initial interstate system obviously was not adequate. It would have been more appropriate to have adopted a time horizon of a 100 years or more. That a national policy for such an important aspect of a nations infrastructure could be established for 100 year has an interesting example in the current development of a national high speed rail network in France.

Plans already implemented in France call for the development of high speed rail (TGV) segments to serve four quadrants of the nation. These segments will hub at Paris where a central facility has been built. The right-of-way leading into Paris for the high speed rail will follow a right-of-way that was set aside for rail purposes in 1900. That right-of-way is being developed as a multi use corridor that will blend the rail service with a green belt that will provide recreational opportunity and blend well with the neighborhoods through which the right-of-way passes.

There is an opportunity for legislators and political leaders to establish long term policies that would insure timely and logical development of the nations transportation infrastructure and foster innovation. This would require non-partisanship and vision on the part of our leadership. It appears that the public sees a need for leadership and is becoming increasingly sensitized to such issues. The presidential primary of 1992 has been a very enlightening experience in this respect. For example, the news media in a surprised way reported in the South Dakota primary that the voters of that state were exhibiting a deep-seated anger at the business as usual attitude and lack of leadership from legislators and administration.

On the political landscape, legislators are having to face the fact that society is going through a period of activism. The activism comes from individuals, groups and businesses and their associations. This activism has significant impact on transportation infrastructure development. For example, in San Diego, California a light rail mass transportation system is being developed. The development of that rail system is being focused upon by individuals and groups that are divided by the definitive positions of yes and no. It is difficult to work at developing this transportation facility on a timely and cost effective basis in this type of an environment. However, in spite of this focus of attention, the development of the light rail system is proceeding.

Industry

A large part of our economy produces, transports or sells goods. There is also a part of the economy that provides services. The transportation system that supports these business as well as personal travel demands is itself supported by a large component of industry that includes contractors, consultants, material suppliers, equipment suppliers, and industry associations and research centers. Users such as the driving public, truckers, and airlines can also be considered to have an impact on the transportation system. These parties are considered in this paper as the transportation industry. This industry affects the transportation system through demand, support for legislation, and materials and equipment for construction and maintenance.

The transportation system and society would be better served by balancing demand. Trucking interests lobby for bigger vehicles. However, bigger vehicles are not necessarily compatible with small vehicles or with the transportation infrastructure. Construction material interests compete for market share and there needs to be an equable process of comparing material choices and pavement types. Standard materials and pavement types would be better applied and innovative materials and processes could be better evaluated.

There are a number of opportunities to enhance the effectiveness of resources that are expended on the transportation infrastructure. Professional engineering experience and knowledge could be expanded by certification in specialties. Certification would create a demand for continuing education to prepare engineers for certification and to maintain that certification. Another enhancement would be a means of evaluating new technology that would reduce the time for approval and adoption by industry. Accelerated pavement testing that is being pursued by several agencies is an example of how materials, pavement features and loading can be evaluated. Figure 2 shows a schematic of an accelerated pavement testing system being put into service by the Indiana Department of Transportation and Purdue University in West Lafayette, In.

Traditionally design and construction research in civil engineering has been done in the public sector. The transportation infrastructure would benefit from industry taking a more active role in funding research in-house, at universities or in research centers. The National Asphalt Pavement Association and National Stone Association have recently established research centers in their respective areas of interest.

Agency

Transportation agencies establish the scope, design criteria, material specifications, construction methods and quality control/acceptance method for transportation infrastructure projects. In some agencies this system is historical and well entrenched and provides barriers to innovation. A new perspective of this system would create opportunities to apply innovation to the transportation infrastructure. The concept of a warranty for construction is used in Europe but not in the US. Additional benefit might be gained by combining warranties with the concept of design/build. This combination would encourage innovation from the design/build team. There is also the potential for private industry to own and maintain transportation infrastructure facilities.

Agencies can benefit from innovation and are faced with implementing a number of new technologies. Productivity incentives have been evaluated in Oregon for Department of Transportation maintenance workers. Productivity is measured by amount and quality. Agencies are on the threshold of an information explosion. This is coming about because of development of hardware, software and the means of collecting data.

Research can be a source of innovation for agencies. The Strategic Highway Research Program is producing a number of innovative products and agencies are developing plans for their evaluation. However, there are constraints on research that inhibit innovation. The constraints come from the fact that major research funding organizations solicit research based on defining the tasks, products, schedule and funds. The National Cooperative Highway Research Program is an example of this approach to funding research.

Universities

Universities face challenges in hiring faculty, incorporating infrastructure technology in course work, and teaching and research resources. Infrastructure technology is evolving rapidly. There is a shortfall of knowledgeable, experienced faculty and a number of universities are having difficulty filling vacant positions. Another trend that may impact the nations infrastructure is that a number of major universities have deemphasized Civil Engineering which is the major discipline for infrastructure engineering staff.

The shortfall of financial support to maintain and equip laboratories for teaching and research is growing. Many university laboratories are not equipped to demonstrate current test procedures. As innovative materials and tests are adopted this limited capability will not be adequate. As an example, the Strategic Highway Research Program is proposing asphalt and asphalt mixture tests that will require equipment that has been estimated will cost $320,000. If these tests are adopted only three or four universities in the country are likely to be able to purchase the equipment. Research will be further inhibited.

Summary

Transportation and its infrastructure represents a significant portion of the nations economy. Continued health of the transportation infrastructure will benefit from long range planning to include a time horizon of 100 years or more and integration of transportation modes. Innovation is needed and is possible both from industry as well as transportation agencies. Universities need support if key infrastructure technology is to be effectively taught and meaningful research conducted.

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Table 1. Impact of Transportation on Economy - 1981 (Germane 1983).

Gross National Product	About 21%
Federal Taxes	About 15%
Capital Outlay	Over 15%
Civilian Employment	About 10%

Table 2. The Nation's Estimated Freight Bill (Germane 1983).

	1980
Total in Millions	$204,698
Percent of GNP	7.79%
Carrier Shares	
Air	1.6%
Highway	72.7%
Oil Pipelines	3.3%
Rail	13.6%
Water	7.2%
Other (Forwarder & REA Exp.)	0.4%
Shipper Internal Costs	1.2%
	100.0%

Table 3. Federal, State & Local - for Transportation Facilities (millions of dollars) (Germane 1983).

	1978	Shares
Airways & Airports	4,106	11.2%
Highways	30,831	84.4%
Railroads*	---	---
Rivers & Harbors	1,588	4.4%
Total	36,525	100.0%

* Does not include government guaranteed loans or AMTRAK, or urban and high speed ground transport federal expenditures.

Table 4. U.S. Government Transportation R&D Outlays (% of total federal R&D) (Germane 1983).

	1980
General	2.6%
Air	66.2%
Highway	13.6%
Railroad	5.2%
Urban Mass Transit	6.9%
Water	5.5%
Total Transportation	100.0%
Total Transportation R&D (millions of $)	$ 1,020
Total U.S. Gov't Outlays for R&D (millions of $)	$30,477
Transportation R&D as a % of Total U.S. Government R&D	3.3%

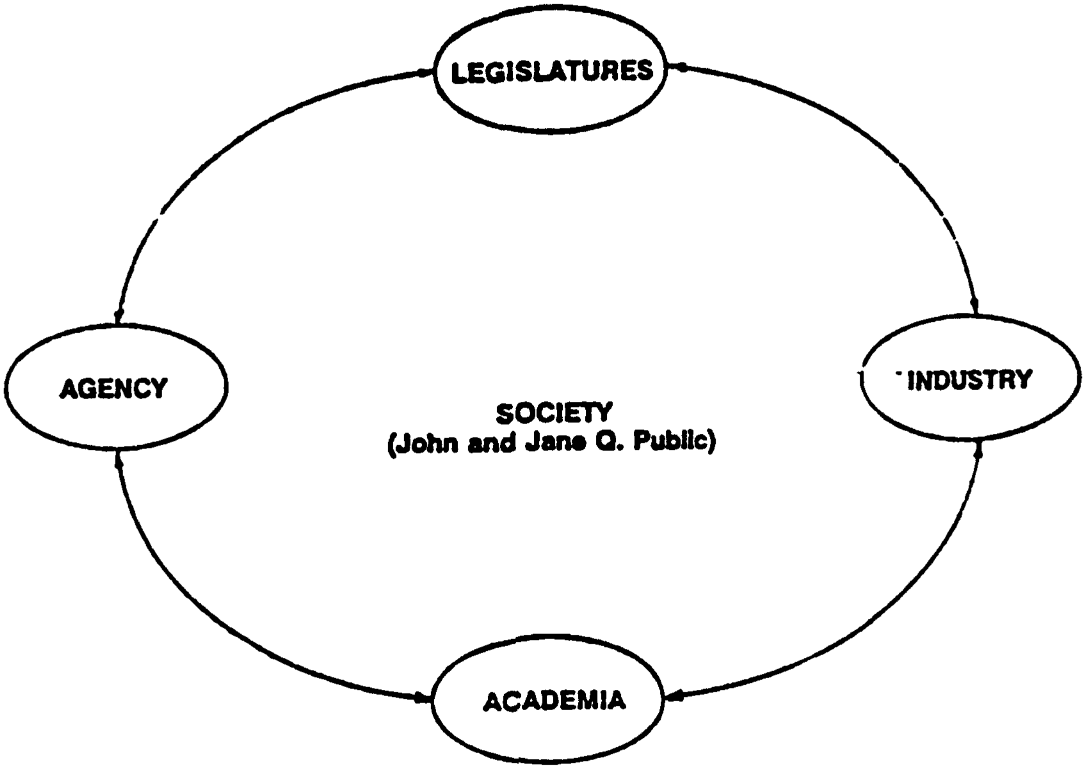

Figure 1. How Does the System Work.

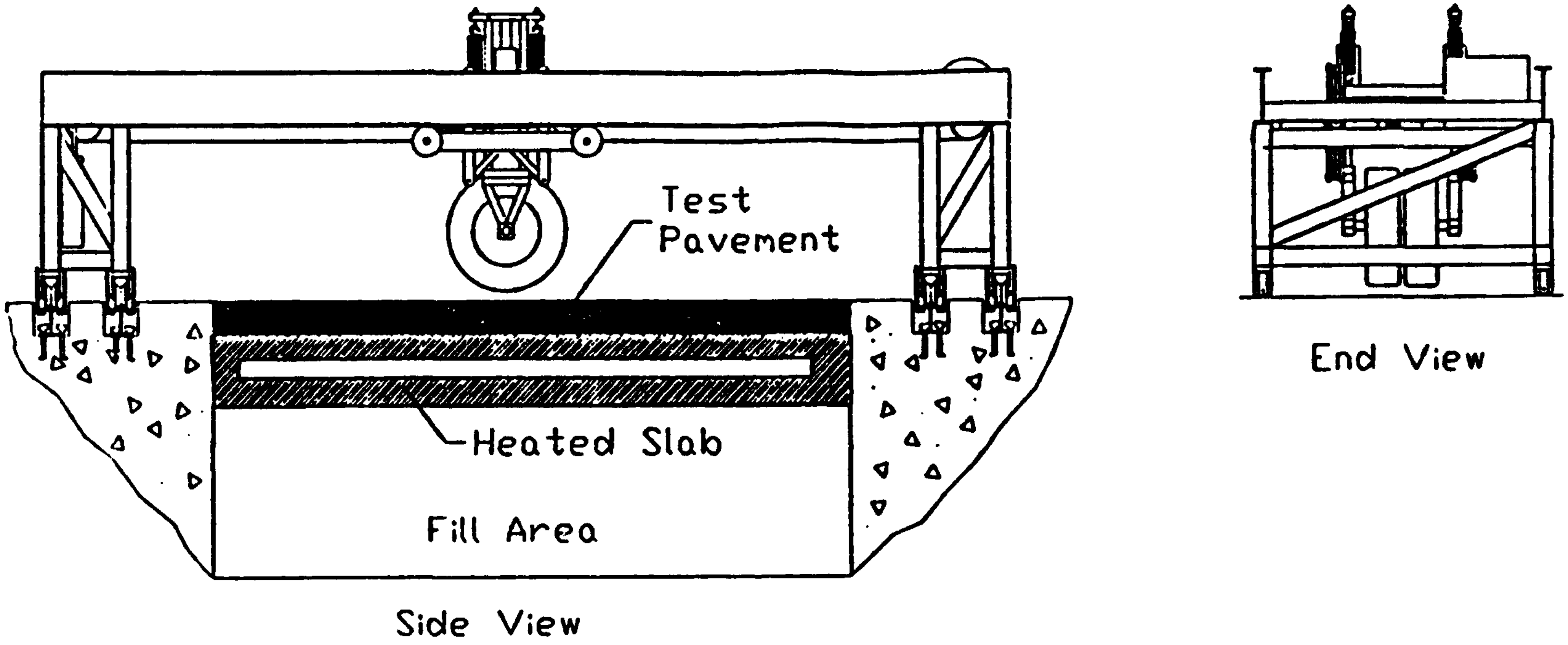

Figure 2. Accelerated Pavement Tester.

CHALLENGES AND OPPORTUNITIES FOR INNOVATION IN THE PUBLIC WORKS INFRASTRUCTURE WORKSHOP

UNITED STATES ARMY CORP
OF ENGINEERS
CONSTRUCTION ENGINEERING RESEARCH LABORATORY

AN EXAMPLE OF SUCCESSFUL INNOVATION: THREE-DIMENSIONAL GRAPHICS ON CONSTRUCTION PROJECTS

Ronald J. Zabilski[1]

ABSTRACT

Stone & Webster Engineering Corporation is using a Computer Aided Construction System that integrates construction planning with estimate development, schedule generation, and project management tools. Integration is achieved by linking IBM's DB2 relational database with the CATIA three-dimensional (3-D) solids modeling application. The relational database is the central repository for all plant information and documents of a project over the life cycle of the entire facility. The 3-D model is the plant design and the window to the database information.

Construction planning is conducted with the 3-D construction sequence model. The model provides the construction engineer with a tool that helps clarify the scope of the project. The design model is disassembled into its base components, pipe spools, concrete pours, and equipment. A project team then assembles the model, simulating the sequence of field construction activities. The sequence model can be played back for verification of the logic and can be easily modified to account for problems, such as material and equipment access, delays in equipment delivery, and craft loading. Quantities are developed from the physical characteristics of the 3-D model. Labor-hours are generated by multiplying historical installation rates by the modeled quantities. Material and labor costs are then extended. The graphics sequence model is then used to generate the project network schedule. Construction progress is reported by selecting modeled components that have been completed in the field; labor-hours are loaded from the project's accounting system. The system then updates the schedule and reports using performance measuring techniques.

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INTRODUCTION

Stone & Webster Engineering Corporation has implemented a project development and management system that integrates all plant information into a single Integrated Plant Database. Information is developed in three-dimensional (3-D) graphic format for plant layout and as text data that describe and document the project. The graphical and textual information is linked together in the database by unique identifiers, which permits the development of applications for design and construction of new plants, backfit and life extension of existing facilities, and operation and maintenance of operating plants.

The IPD was developed using commercially available IBM products, including DB2, a relational database, and CATIA, a 3-D solids modeling application. Stone & Webster created interfaces that allow these programs to communicate. The IPD operates in a mainframe environment.

CONSTRUCTION

With the advent of 3-D computer modeling, construction personnel have become more interested in the capabilities of computer graphics. The 3-D computer solids model has enabled the construction engineer to benefit from information that was previously unavailable to him. He can view a design from any desired view. He can choose the information and the format in which the information is to be displayed. With prior systems, information was displayed in a form that was chosen by the designer.

Leveraging the capabilities of the CATIA 3-D modeling application and the benefits of the DB2 relational database, Stone & Webster has developed an advanced construction management system. The **CO**nstruction **MAN**agement **D**isplay **S**ystem (COMANDS) enables automated quantity development of project estimates linked to the modeled quantities, automated development of construction schedules based on the construction sequence model, identification of bulk materials for procurement, and construction progress reporting by pointing to completed elements in the model.

CATIA supports true full-scale 3-D solids modeling, which means that each element in the model has full-sized physical dimensions and properties. The software can automatically calculate length, area, and volume. If element densities are provided, weight and center of gravity are also calculated. When element descriptors are added to each component, quantities, such as cubic yards of concrete, tons of structural steel, and square feet of painted surface area, can be generated automatically from the model. This information is stored in the database and is used to create an estimate of the material and equipment that will be needed during construction. Total craft labor-hours and costs are also calculated in the database by multiplying material quantities by historical craft installation labor rates and craft hourly wage rates.

Stone & Webster uses COMANDS in two modes: on Stone & Webster designed projects and projects designed by other engineering companies.

In the first mode, projects are designed and engineered in CATIA 3-D graphics. The project database is developed simultaneously. Drawings are generated by projecting a solid geometry image into a 2-D window. Notes and dimensions are then added. Construction personnel then use this information to develop the COMANDS database.

In the second mode, the project is designed by others. Three-dimensional models and the database are then developed from the design drawings. The drawings are loaded into CATIA by construction, estimating, and scheduling engineers. Experience has shown that information can be modeled from 2-D drawings very rapidly. The boiler building of a 150 MW pulverized coal power plant was modeled in three weeks by two engineers. The model included the structural steel columns and beams, the boiler, all major equipment, piping, HVAC duct, cable tray, and platforms. The modeling effort simulates construction in the field and familiarizes the participants with the project's scope of work. Since all components have to fit together in the 3-D model, the design is verified prior to start of actual construction activities, with constructibility analysis, value engineering, and interference identification being conducted concurrently.

Since COMANDS is used as a construction tool, the level of detail that is required in the 3-D model need only be at the level that project management chooses to monitor the construction activities. Modeling to the nuts and bolts level would be extremely time consuming, whereas a building block model would not provide sufficient detail to be useful. Stone & Webster models to the level of detail that is identified in the project's work breakdown structure (WBS). The WBS account/activity list identifies this level of detail. An activity can be tracked at a system level; for example, "Install Feedwater Piping and Testing." It can also be tracked at a component level where each account is identified in the installation process; for example, 10 inch carbon steel pipe, pipe supports, welding, valves, painting, insulation, testing, and turnover. As a rule all civil and structural activities are modeled to the level of detail in the design. This includes excavation, backfill, foundations, slabs, walls, and structural steel. Mechanical equipment has been modeled as it physically exists and as volumetric blockouts. Pipe has been modeled with and without valves and fittings. Electrical equipment is modeled as equipment blockouts, and cable tray is routed dimensionally correct. Conduit is not usually modeled since it is normally run to suit existing field conditions.

A compromise needs to be made between the initial cost of the detailed 3-D model and the downstream savings of having this information available for estimating, purchasing, and project control. This does not preclude specific areas of the design being modeled in a high level of detail for study purposes.

APPLICATIONS

Duct Removal Project

After the model has been developed, planning is the first step in the use of COMANDS. Planning starts with the development of a construction sequence model. The model is disassembled into its base components. Concrete slabs and walls are split at the construction joints, piping by spool section. The model is then assembled by a project team, simulating the sequence of construction activities as they would be conducted in the field. The sequence model can be played back for verification of the logic and can be changed easily to account for problems such as material and equipment access, confined work spaces, and craft personnel-loading. An example of this is demonstrated by the demolition of an exhaust duct section which was part of a precipitator backfit at an operating plant (Figure 1). The precipitator was designed to be installed in the location of an existing duct section. The project was designed in 2-D. The design was manually loaded into CATIA in three weeks. The model consisted of the exhaust duct section, chimney and breaching, precipitator foundations, structural support steel, and hydraulic jacks. The installation duration spanned 18 months and included two planned outages, one at the start and one at the end of the project.

During the initial two-day outage, a pipe sleeve was installed through the existing exhaust duct. After the sleeve was installed, the exhaust duct was put back into service. This enabled the installation of the foundations, structural steel, and precipitator without impacting the plant operations. The second outage took place at the end of the schedule when the duct section was cut out of the exhaust duct. The 105 ton duct section was lowered to the ground with four 27.5 ton hydraulic jacks. Once on the ground, the duct was cut up and removed. Also, the precipitator tie-in was performed simultaneously.

The modeling effort identified three construction problems that were not readily apparent from the 2-D design. The first problem was identified after the assembly of the model and interferences were investigated. A second interior structural steel column was occupying the same space as a portion of the duct and stiffeners. A second concern was raised during the sequence study of lowering

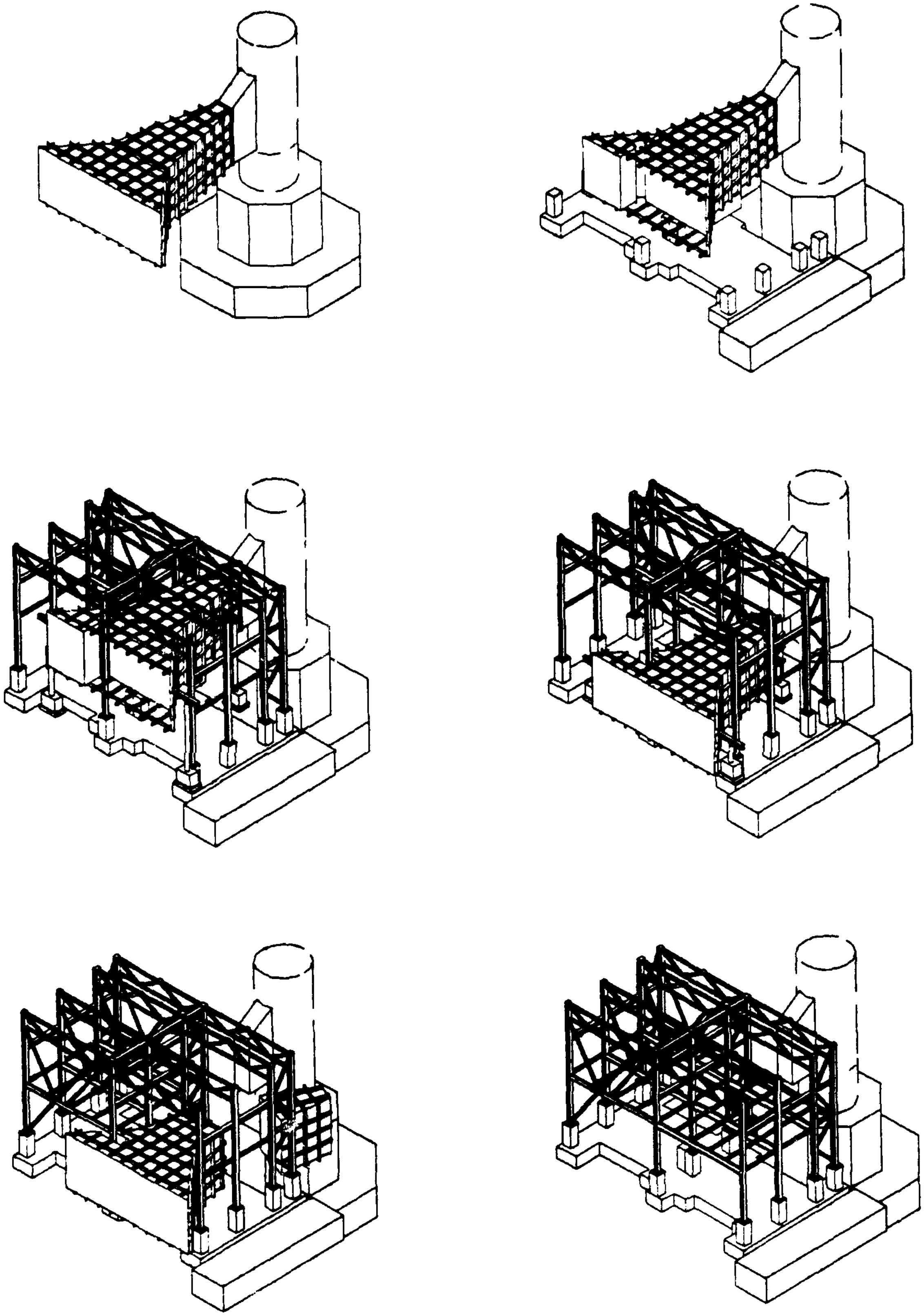


Figure 1. Exhaust Duct Demolition Sequence Planning

the duct section. The design of the foundations caused the duct to hang up on the concrete prior to contact with grade. The last restraint was identified when the remaining structural steel was installed between grade and top of the structure. The bottom of this steel interfered with the top of the duct. This would require that the duct section be removed prior to installation of this steel, thereby increasing the duration of the schedule.

The first problem with the structural column was solved by cutting out the portion of the duct stiffeners that was interfering. The second and third problems was solved by modifying the foundation design, eliminating the hang up and enabling the top of the duct to be 18 inches lower than the bottom of steel when lowered to grade.

The 3-D construction model identified these deficiencies early enough in the project to permit effective constructibility analysis and value engineering. If the problems of the duct hanging up on the foundation and the structural steel interference were not identified until the outage commenced, the impact on the schedule could have been severe.

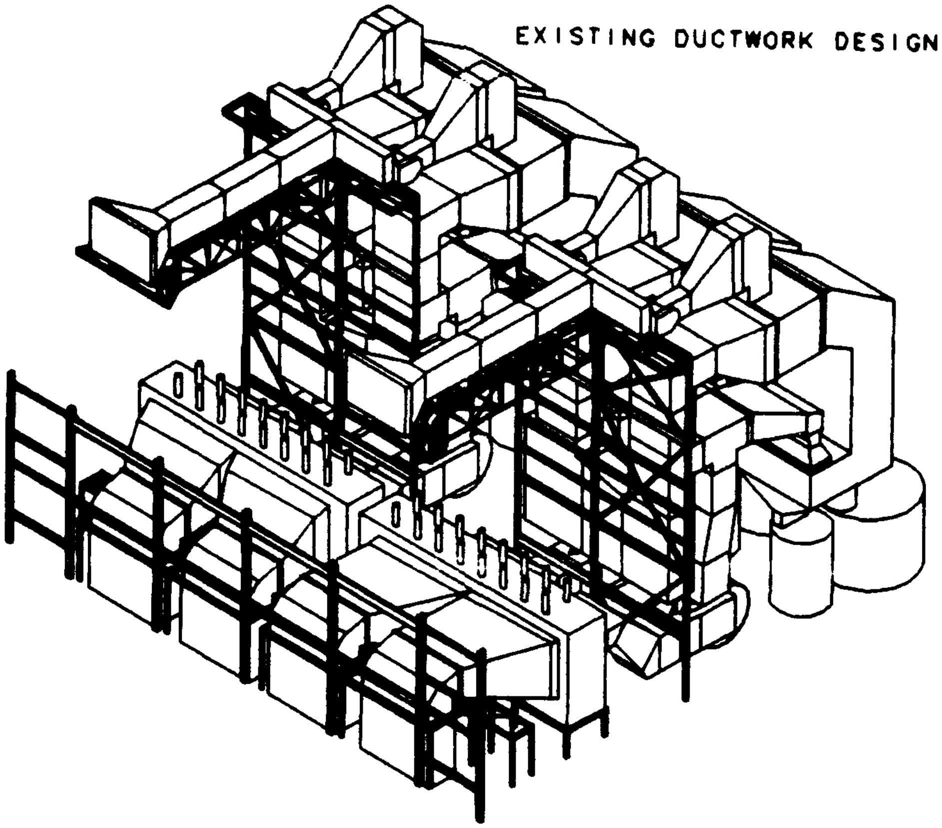
Power Plant Environmental Systems Retrofit

Stone & Webster's 3-D modeling system has also been used on a 550 Megawatt pulverized coal fossil power plant. The project consisted of retrofitting the existing scrubber units, removing precipitator units, and replacing 800 tons of exhaust duct during a twelve week outage.

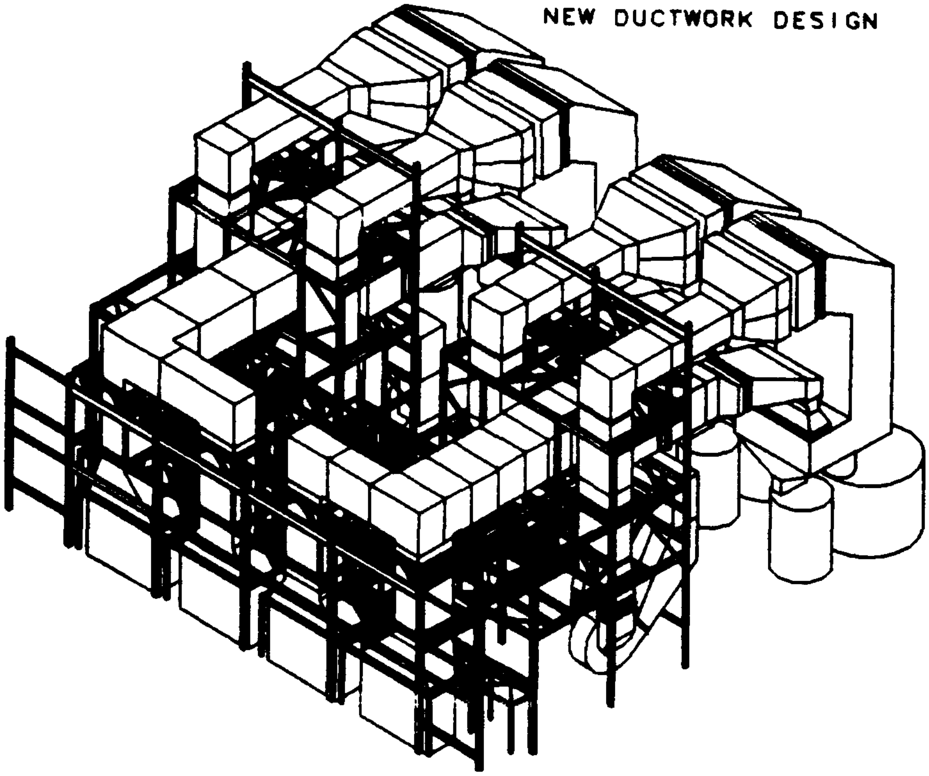
During the proposal, 3-D computer models were developed of the existing plant configuration and the owner's conceptual new duct design. The models were developed from the existing plant drawings and a preliminary walkdown of the plant. The models were completed by two construction personnel in three weeks and included all facilities and equipment associated with the plant's flue gas desulfurization area (Figure 2).

The models initially were used to help Stone & Webster personnel understand the scope of the outage work and facility layout for the project. They were also used to quickly determine quantities of duct work, structural materials that were to be restored, removed, or installed, and the surface area of the structural steel for sandblasting and painting. However, the main use of the models was to develop a construction sequence to visually verify that the project could be completed on schedule. This approach was used to convince Stone & Webster's management, as well as the owner, that the tight schedule could be met with minimal risks.

After the contract award, Stone & Webster conducted the detail design of the plant building upon the model developed in the proposal. Three-dimensional modeling was used for all new



EXISTING DUCTWORK DESIGN



NEW DUCTWORK DESIGN

Figure 2. Existing and New Environmental Systems Configurations

mechanical and structural design. This included footings and foundations, structural steel, mechanical equipment, duct work, pipe, and pipe components. Design drawings were made from the 3-D geometry using the system's 2-D capabilities.

Using 3-D design, the design engineer translates the 3-D image in his mind to create that same image on the screen of the workstation. Structures and systems are continuous and complete. They are not regulated or designed on separate sheets. Structural bays are developed; general arrangements of equipment are fitted into the bays; and pipe, HVAC, and electrical systems are routed between equipment, avoiding interferences. When the model has been completed, checked, and verified, drawings are then created. In this fashion the design is represented in the model; drawings are used to communicate that design. Most 3-D systems have been developed to enable the geometry of the drawing to be created by projecting the image of the model into a 2-D window where clipping and dressing-up of the image can be conducted. Notes and dimensions are then added.

A duct work configuration different from the original conceptual design was developed in 3-D. The new design could have been conducted in the 2-D mode; however, communicating that design with the 3-D model among the project participants proved to be very effective.

The Construction Industry Institute (CII) estimates that the cost of rework on industrial projects exceeds 12 percent of the total project cost. Design deviations, changes, errors, and omissions account for 80 percent of the increased costs. Construction deviations account for 20 percent. The CII cost influence curve also shows that the earlier construction experience, methods, and knowledge are introduced to a project's design, the higher the probability that these factors will influence the design and reduce cost and schedule. With this philosophy in mind, two full time construction supervisors were assigned to implement constructibility issues early in the design of the project. Construction worked closely with the engineers and designers during the design process. Areas of concern included labor and material access, scheduling, and construction equipment placement.

During the design process, Construction Specialists are reviewing the models for constructibility. In the past these specialists reviewed completed drawings which did not allow a great deal of flexibility to make changes. Now copies of the model are used starting in the conceptual stages of the project continuing through detailed design to assess site layout, craft and equipment access, and ease of construction; implement modularization; size pipe spools and locate field welds; plan the construction process; select and size construction equipment; and create the construction schedule. The 3-D design model provides the project with a powerful communication tool utilized among all levels of the project team, including project management, the owner, engineering, and construction.

Computerized modeling also provides the capability to more fully integrate both design and construction with the facility's operations and maintenance requirements. This can be achieved by passing the as-built model to the owner for future use and linking the model to the owner's customized plant database.

Construction used the proposal model to refine the demolition sequence of the existing precipitators and duct work. Crane studies were conducted with a library of premodeled cranes to analyze access, placement, capacity, and boom reach. A 4600 Manitowoc luffing tower crane was selected based on capacity, reach, and the minimal number of setups required. After the crane was chosen, sizes of the existing duct-work sections were then identified for removal. The 3-D modeling system enables densities to be applied to each modeled solid and the corresponding weights to be determined. Cuts in the duct work were identified that maximized the size of the sections to the capacity of the crane. Centers of gravity were also calculated for each duct section to identify rigging pick points. Using this quantitative information obtained from the model, in conjunction with 3-D graphic images as a guide, a preliminary outage demolition schedule was developed using Primavera's Finest Hour scheduling package. The demolition sequence model was then refined based on the critical path and manloading capabilities shown on the schedule.

When the design reached the final stages, construction made copies of the models and began to take them apart to experiment with different construction scenarios. Duct work was again sized to the capacity of the crane at the placement boom length. The new duct work installation sections were analyzed and scheduled similarly to the duct work removal sections. The demolition and installation sequence models were integrated to facilitate a complete outage construction sequence. This sequence model revealed that modifications needed to be made to the corresponding duct work construction schedule where original assumptions did not hold. Isometric piece mark sketches were then created that identified the duct mark number, weight, and sequence of installation. These sketches were sent to the duct vendor, at their request, to assist in the duct work fabrication and delivery schedule (Figure 3).

Using the 3-D system, construction personnel developed their own erection drawings from the engineering models. Pipe spool sizes and field weld locations were identified on the model, based upon construction requirements. Isometric sketches were then developed with each spool piece, hanger, and field weld identified. Welding procedures and test information were included for each weld. The materials management module provided an automatically generated materials list, by spool piece, for each pipeline, which was fed into the purchasing system. The isometric sketches and bills of

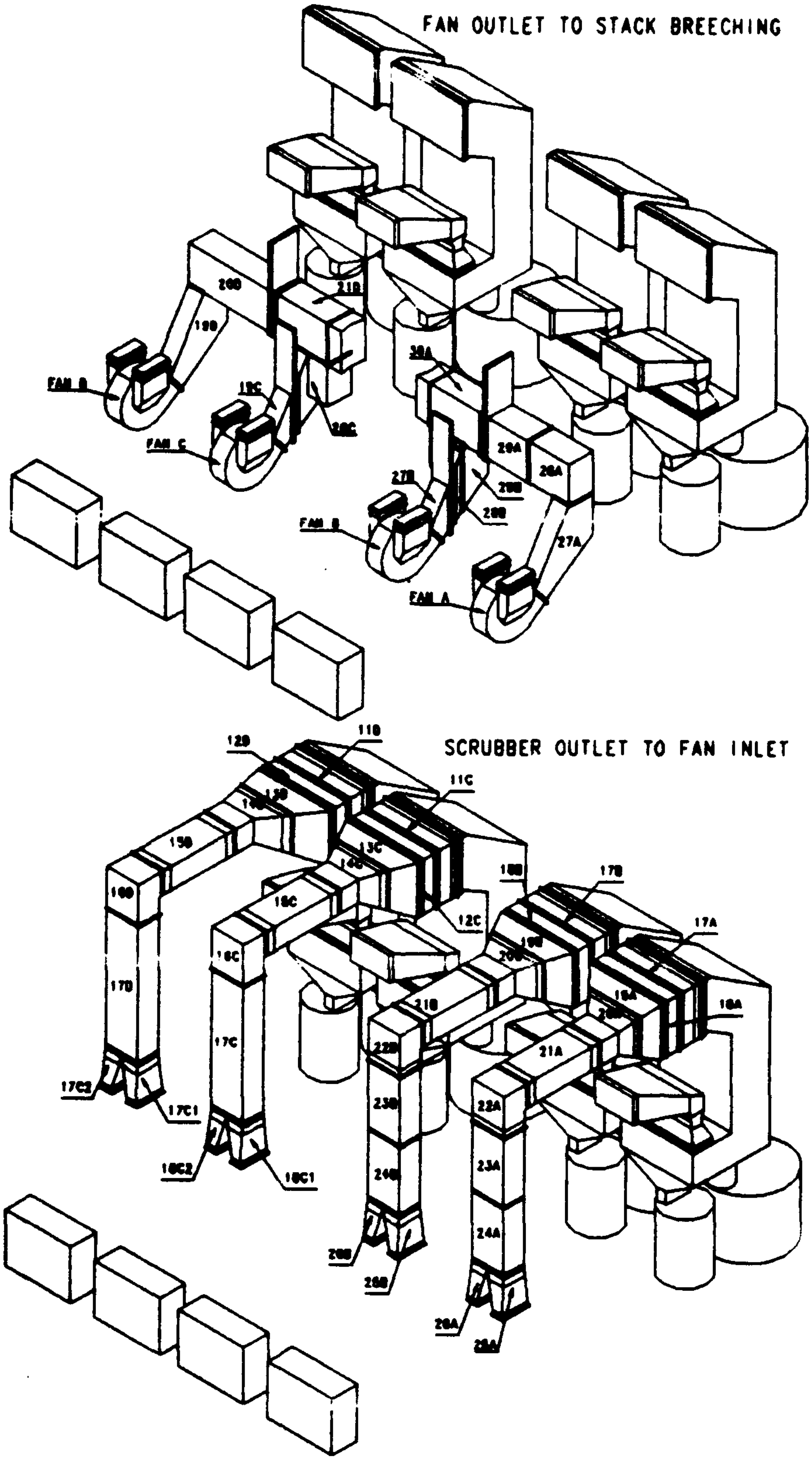


Figure 3. Duct Piece Mark Sketch

materials were included in the bid packages to the prospective pipe fabricators, along with the orthographic drawings.

When the Finest Hour construction schedule was completed, it was downloaded to DXF format and uploaded into the modeling package. The sequence model steps were placed around the schedule, matching time frame and logic. The result is a document that provides all of the logic and detail of the schedule and a 3-D graphic representation of the project (Figure 4).

Three months prior to the start of the outage, the client delayed the duct and scrubber modifications for approximately 18 months. Business reasons were cited for the postponement, as well as extensive boiler modifications scheduled during the same time period and labor shortages in the area.

Prior to this announcement, Stone & Webster was awarded the boiler modification construction work. This consisted of boiler water wall panel replacement, asbestos removal, hot reheat pipeline replacement, coal pulverizer refurbishment, and the replacement of six feedwater heat exchangers.

Construction Specialists responded to this sudden change in scope by again utilizing the 3-D modeling system. Facilities included in the new contract were fully modeled using the owner's design drawings, clarifying the scope of work and verifying preliminary installation scenarios.

The model also proved to be invaluable when 3 weeks prior to the start of the boiler modification outage, the owner requested that the two existing precipitators be removed and replaced with duct work. Using the design model, Stone & Webster's engineers were able to select newly fabricated duct sections, previously designed for use in the modified duct work arrangement, as transition pieces in the precipitator area. Supports were designed as a combination of the existing precipitator support steel and temporary support modules. The ends of the transition pieces were modified to connect the assembly to the existing boiler duct and the scrubber duct. The temporary modification design was completed in only 4 weeks after notification.

These models also proved valuable on the jobsite in familiarizing new construction personnel with the project. In the Spring of 1992, duct and scrubber outage planning and scheduling will begin again.

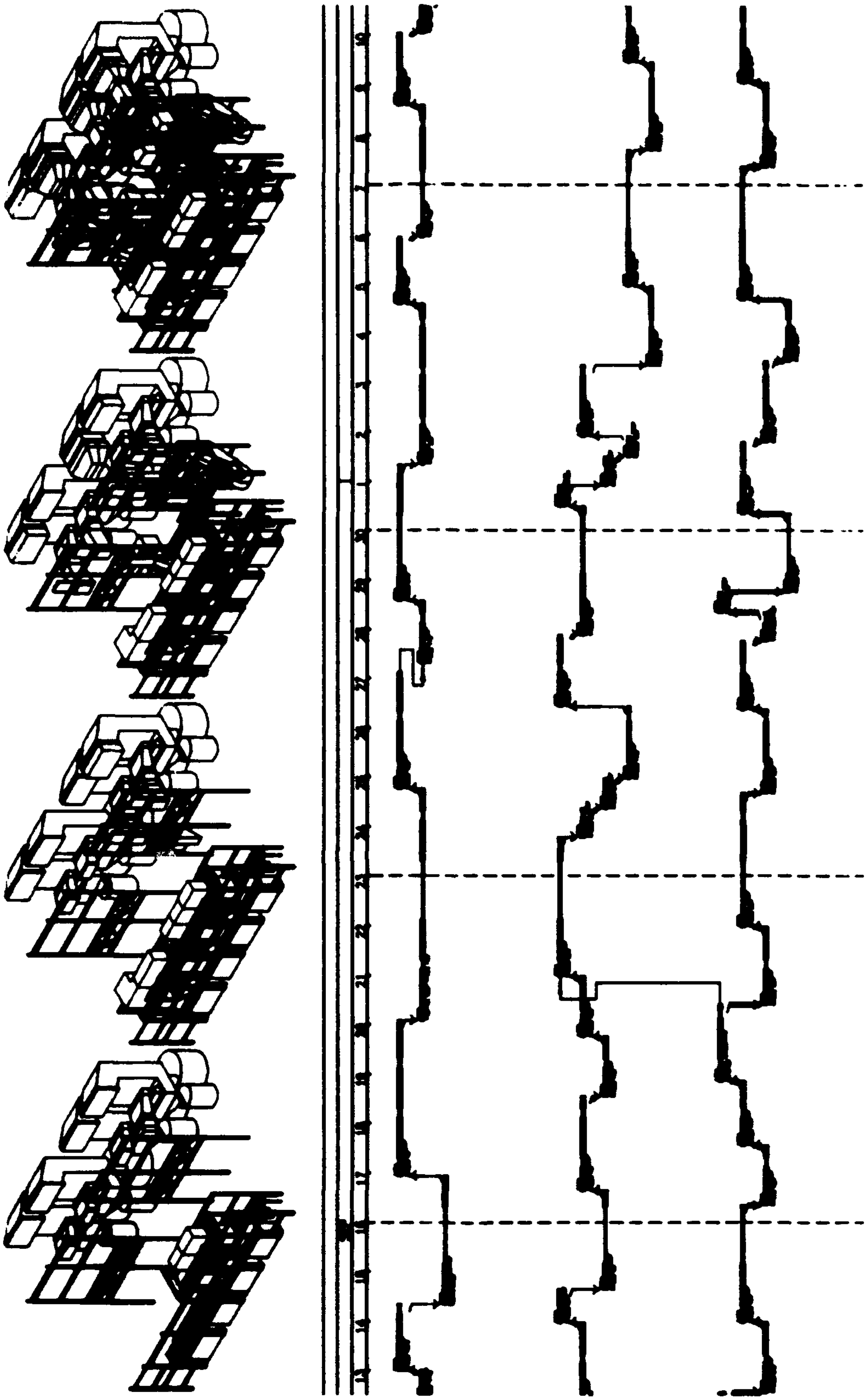


Figure 4. Construction Sequence Model Linked to Schedule

Issues in Technology Transfer: Sharing Experience Between Manufacturing and Construction

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In manufacturing, construction, and infrastructure maintenance, there is an increasing premium on solving large system-level problems in shorter times, with fewer resources, and without compromising the quality of the result. In the manufacturing arena, the increasing complexity of engineering products and the intense competition of the world market have combined to force a change from the centralized methods of the past toward a more decentralized approach. This decentralized approach deals with complexities by dispersing different product development functions to a team of engineers, where each team member contributes special expertise to the overall solution.

For complex construction projects or in situations where materials and/or building techniques call for specialized expertise, the same sort of group coordination is required. In the best case, solving the problem of coordinating the various sets of expertise leads to a shorter construction process with an attendant cost decrease. In the worst case, the integrity of the structure can be compromised when design or construction changes are made without adequate review by the appropriate construction team members.

The condition of the national infrastructure will have a profound effect on the competitiveness of U.S. industry in the emerging era of global competition (1). Here again, multiple interacting constraints must be brought together to balance the competing costs of deferred maintenance with present day outlays for repair or rebuilding. In much the same way that materials knowledge must be brought to bear on developing useful, reliable, and economical manufactured products, engineering life-cycle knowledge must be used to allocate limited resources for infrastructure repair or replacement.

Manufacturing, construction, and infrastructure maintenance all involve complex system-level problems which, at best, can only be decomposed into multiple interacting sub-problems. These sub-problems require cooperative conflict resolution among differing areas of required expertise. While this approach allows more complex problems to be solved than more traditional methods, it is more difficult to manage than previous approaches. Fortunately, computer tools for cooperative work, such as those being developed for concurrent engineering, are beginning to become available (2,3). While this emerging technology is still in its infancy, there is every reason to expect that it will produce an impact on group or team productivity as profound as that of the personal productivity systems on individual workers.

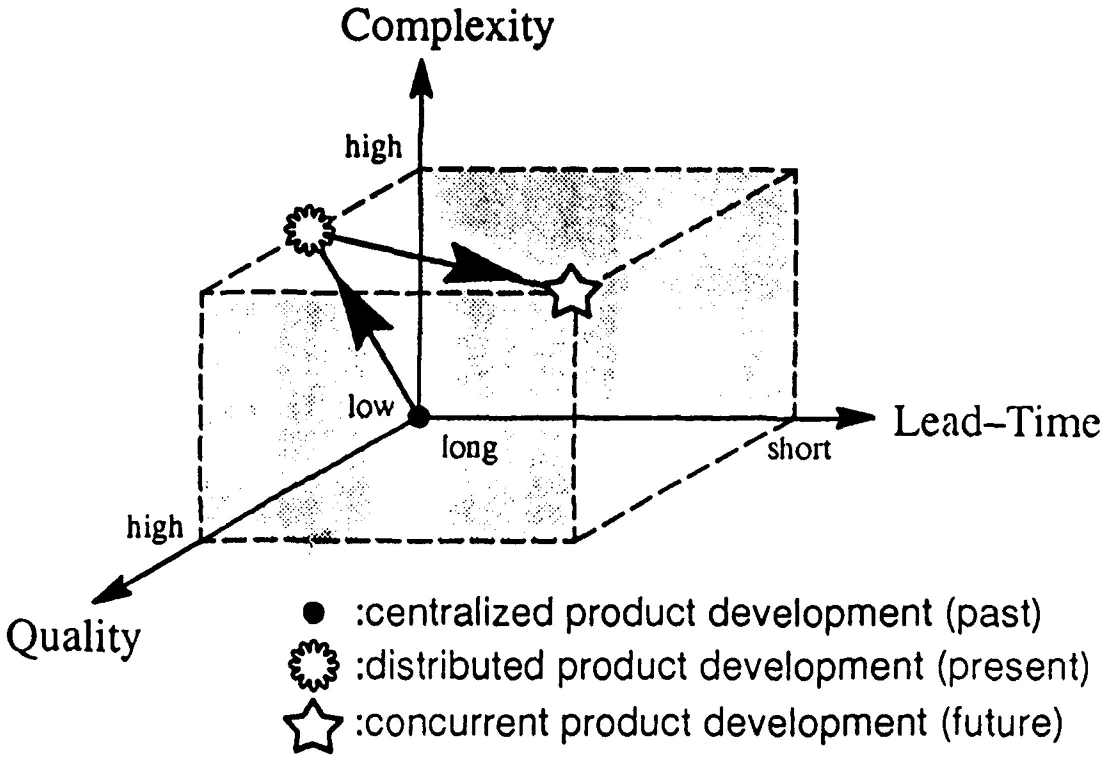
1. The Two Meanings of Technology Transfer

In all three of the areas discussed in this paper, technology transfer can mean either the transfer from researchers to practitioners or the adaptation of tools from one discipline to another. In preparing this paper, we have used both definitions of technology transfer. After discussing the need for cultural change in the next section, we discuss issues which arise when information systems are used as agents for transferring new decision making technologies from researchers to practitioners. We illustrate these issues with examples drawn from our experience in manufacturing and engineering logistics management. In later sections, we generalize currently active areas of research in concurrent engineering to problems in construction and infrastructure maintenance. By looking at the challenges, requirements, and solutions being developed for system-level engineering problems, we may be able to benefit from work done in one area by transferring techniques, if not actual tools, from one discipline to another.

2. The Need for Cultural Change

As we briefly outlined above, there is a need for a change in the traditional decision making culture in manufacturing, construction, and infrastructure maintenance. In each case, separate (and usually serial) decision making needs to be replaced by a more parallel process emphasizing cooperative conflict resolution. Traditional manufacturing design was a serial process in which communication was frequently in the form of specifications and drawings. In this approach, conflicts lead to expensive backtracking in order to revise early design commitments in light of downstream factors. The current emphasis on concurrent engineering represents a change in culture away from this serial approach.

Figure 1 illustrates the evolution of product development practice with its increasing emphasis on concurrent engineering. As we shall discuss in greater detail in the remainder of this section, manufacturing has evolved from centralized product development to distributed product development on its way toward true concurrent development. Construction and public works infrastructure management are already highly decentralized and will need to converge on a more concurrent planning process in order to improve.



The concurrent product development practice (also called Concurrent Engineering) strives to:

- Shorten product development lead-time (better manage life-cycle concerns)
- Manage high product complexity (through tightly integrated functions)
- Increase product competitiveness (keep high quality with low costs)

in order to maximize the overall product *value.*

Figure 1. Competitiveness of Product Development and Its Evolution

2.1 The Need for Increased Communication and Coordination

In large construction projects in the U.S., there is frequently a separation between the architectural designer and the construction team. Again, there is a relatively low bandwidth communication channel between these two groups (e.g. architectural drawings and associated specifications). As in the manufacturing case, design rationale is rarely captured in such documents making it difficult to make the inevitable modifications due to the arrival of downstream considerations. Based on the experience with manufacturing design, it seems clear that a change will be required in this arm's length relationship between the necessary components of expertise. Indeed, this change has already begun in Europe where it is not unusual for an engineering design firm to receive a separate contract to oversee construction according to its design.

As much of the U.S. infrastructure ages, it will become progressively more important to use fiscal resources wisely. In such areas as maintenance of the nations navigable waterways, it is only now becoming possible to adequately inventory the state of this component of the infrastructure. In many cases, construction and repair materials and techniques have changed radically since original construction. In addition, the experience with existing structures now provides life-cycle models that can be used to predict the future course of maintenance activity. Unfortunately, these three sets of information are rarely found in a single individual or even a single group. As in the two cases above, a change of culture is required to break down the barriers between existing groups of experts in order to improve the quality of decision making, and thereby, the infrastructure itself.

2.2 The Need to Reward Innovation and Its Attendant Risks

In addition to the need to change from a serial information flow and decision making process to a more parallel process, there also needs to be a qualitative change in the character of the decision making. In the manufacturing arena, this change is usually described as a need for innovation. In construction and infrastructure management, this change is usually described as a need to promote more experimentation and, thus, risk taking behavior. In each case, a change in the nature of the decision making process will be required. Although not apparent on the surface, these two qualitative changes are really aspects of the same underlying mechanism. Promoting design innovation is not possible without making it sufficiently safe to try new materials or new product definitions. Promoting innovation in construction also requires making it sufficiently safe to try new materials or construction methods. As long as it remains impossible to wave a magic wand and remove risk, the only way to reduce individual risk will be through risk sharing. Whether by bringing downstream design considerations to bear on early manufacturing designs or melding architectural design rationale with construction and life-cycle expertise, it will be essential to change the current serial and adversarial conflict resolution into a more parallel and cooperative process.

2.3 The Need for the Right Amount of Decentralization

In manufacturing, concurrent engineering will mean a more decentralized process in which relatively independent agents coordinate their activities to achieve a common goal. In construction and infrastructure management, the problem is that the process is currently too decentralized. In these cases a more centralized process will be required. Judging from the recent experience with manufacturing design, the challenge will be to avoid over shooting the desired equilibrium point where the currently adversarial independent agents engage in cooperative conflict resolution.

3. Information Systems as Agents of Cultural Change

In working with engineering field offices at U.S. Army installations in the continental United States and Europe, we have noted, and occasionally exploited, the role of computer-based information systems as agents of change. A new information system can either reinforce existing patterns of communication and problem solving or it can disrupt existing patterns. In working with Directorate of Engineering and Housing (DEH) offices, we routinely suggest that a conscious decision be made about which role new technology is to play. When the decision is made to introduce new patterns of communication, it is also necessary to provide administrative support for the new system (which is not usually required for automating existing patterns).

Implementing the cultural changes outlined in the previous section will be facilitated by using information systems as an agent for change. As at the DEH, this change will require additional administrative support. By implementing information processing systems that foster a new pattern of information sharing and decision making, we can build an information processing infrastructure that will positively reinforce the desired changes. Having now resolved to build *computer-based information systems to foster a change in decision making culture*, we will discuss some of the constraints on such development in the remainder of this section before discussing the importance of timing in the next section.

3.1 Information Systems Should Support Evolution Not Revolution

As appealing as a revolutionary change in information processing might appear, revolutionary change is almost never possible. Even such apparently revolutionary technologies as local area networks and CAD work stations are actually well grounded in previously existing patterns of information sharing and design document presentation.

As an example of the need for evolution, consider our experience developing tools for capturing design rationale. In our early tool development, we produced a computer-based system which debriefed an engineer to capture a detailed statement of overall and component design rationales. While the system worked as we intended, it required the engineer to separate out a component of activity which is not naturally separated from the process of designing an artifact. Even though the potential benefits for design reuse could be quite large in the future, engineers preferred not to use the separate design rationale system because it actually interfered with current practice. Based on these reactions, we are now developing techniques to embed design rationale capture in more traditional design tools in order to provide a more natural method of capturing design rationale.

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3.2 Information Systems Should be Grounded in Current Practice

Even when using new information systems to promote cultural change, we have found it wise to conduct empirical studies of human problem solving in order to better match our tools to patterns of human information sharing and problem solving (4,5). New tools which conform to existing patterns of human cognition and problem solving will be more readily assimilated than tools which require users to adapt to inefficient patterns.

As the design rationale example above indicates, it is possible to evaluate tools by developing them and metering their effectiveness with actual users. Unfortunately, this generate and test approach is terribly inefficient and is part of the reason why only a small fraction of developed software systems are actually put into widespread use. In our work with engineering design, we have used a different approach. We have conducted empirical studies of architectural design and aircraft design in which we have analyzed the actions of interactive design teams. We have looked both at expert and novice behavior. In these situations, we have concentrated on routine design problems and identified the types of problem solving behavior found. Surprisingly, even in routine design where one might expect that use of previous patterns might dominate, we have seen a preponderance of conflict detection and resolution behavior. Thus, even in cooperative (i.e. non-adversarial) groups, communication of mutually interacting constraints on the solution plays a dominant role. This rapid folding together of constraints on the solution from different perspectives leads to better decisions in shorter times.

As part of our development effort, we analyzed transcripts of problem solving activity and formed a basic theory conflict management for cooperative conflict resolution. Figure 2 shows a portion of the conflict hierarchy which we developed. In our complete conflict hierarchy, we were able to identify types of conflicts associated with resource management design and routine design. Figure 3 shows a schematic diagram of a computer-based system which we developed to provide conflict management advice to a group of cooperating experts (human and/or machine). These two figures, taken together, illustrate the pattern of deriving functionality requirement from studying human performance and then building tools that match the human performance requirements.

As another example of the importance of grounding new systems in a knowledge of current practice, consider the development of branching questionnaires to collect medical histories. These systems were developed in the early 1970s to meet a perceived need for collecting more complete histories than is possible in a normal office visit. Apart from some managed care systems in California which used the systems as screening devices, the systems were a failure. In an effort to be comprehensive, these systems generated so many false positive responses that their reports were too lengthy to be digested by a physician before an office visit. For this reason, the systems have not been incorporated into medical practice despite studies that clearly demonstrate their effectiveness at information gathering. They simply do not fit current practice and do not provide a sufficiently great benefit to offset their perceived cost.

- conflict instances (~60) and resolutions (~200) were collected and analyzed to build hierarchy of conflict classes with resolution strategies

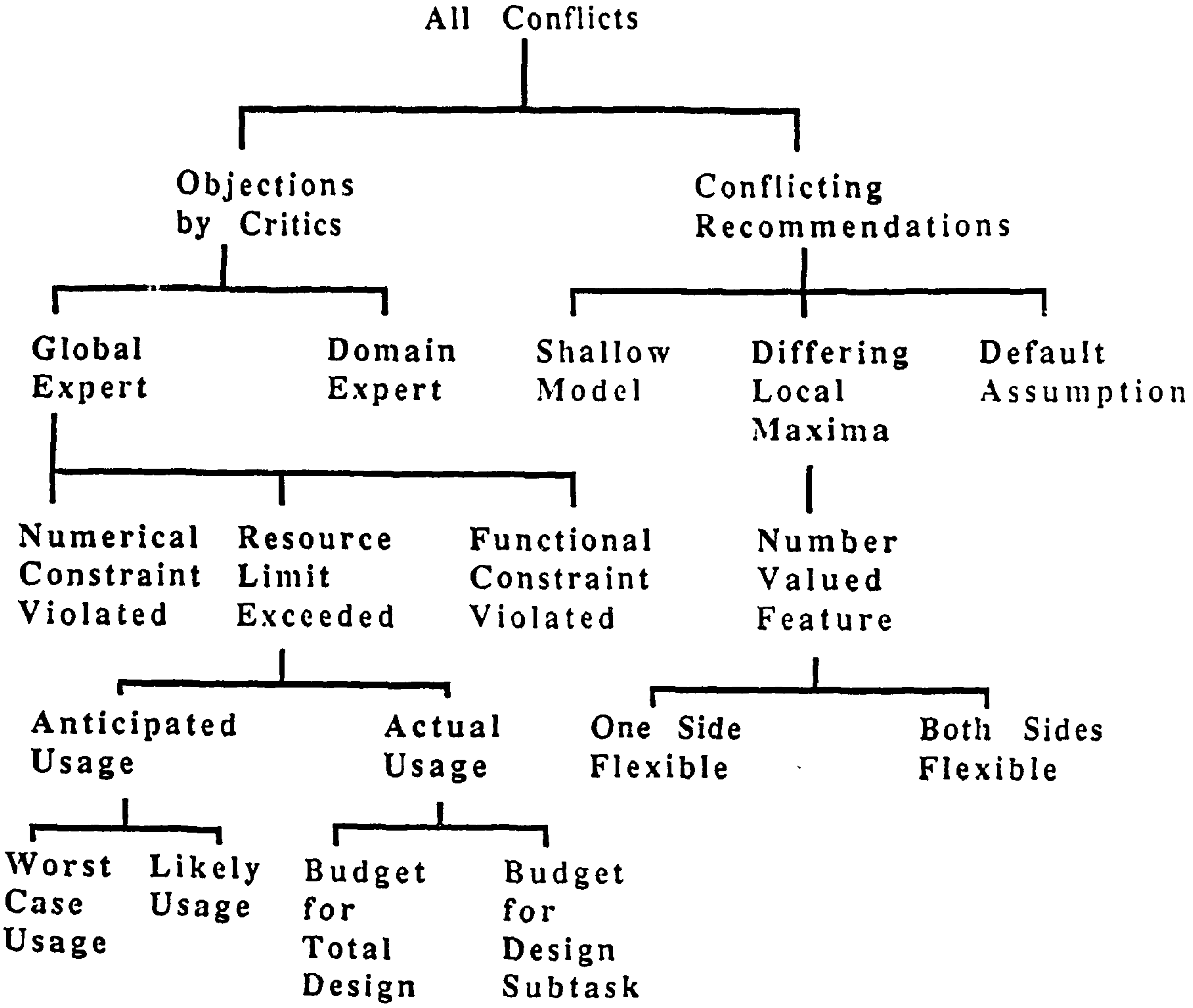
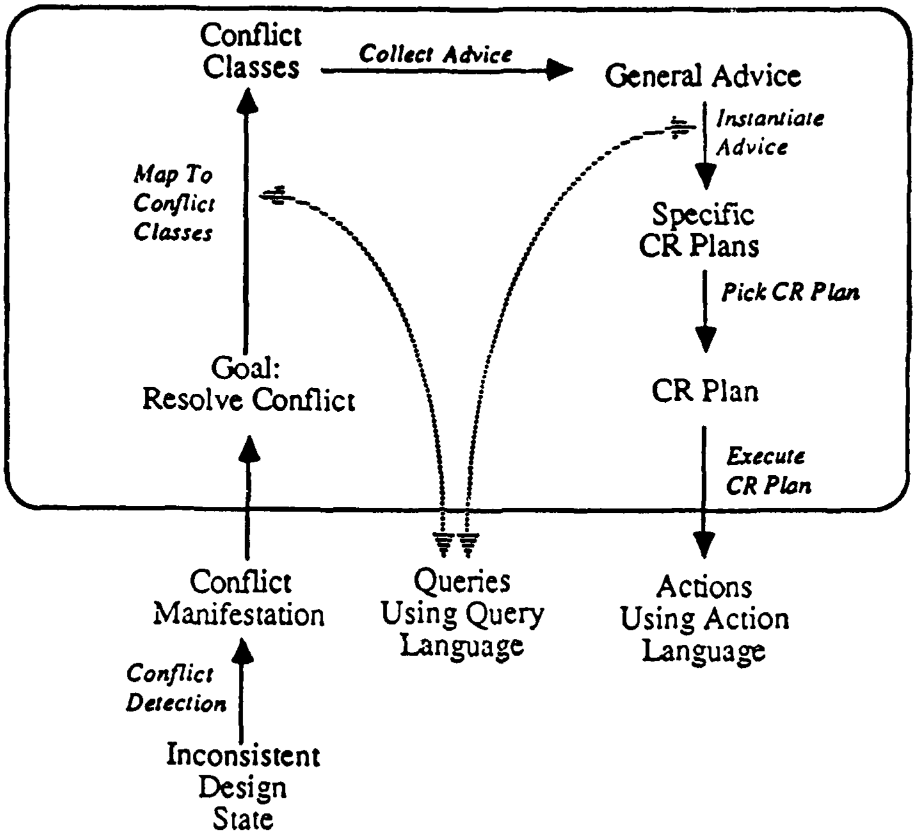


Figure 2. A portion of a conflict hierarchy obtained by analyzing a the problem solving behavior of human experts involved in architectural design and local area network design.

- **design agents consist of distinct domain design and conflict resolution components**

- **CR component maps conflicts to conflict classes to specific suggestions via dialogue with design agents involved in conflict**



Δ search taxonomy for classes whose abstract preconditions subsume conflict - use abstract "query" language, e.g.

conflict involves critique?
component isa resource-conduit?
untried plans for goal?

Δ fill in "slots" in associated strategies with context-specific values to produce specific advice expressed using action language

Figure 3. A computational model for conflict resolution based derived from the study of cooperative conflict resolution by groups of human experts.

3.3 Exploit the Natural Evolution of System Level Problems

While it would be possible to blindly apply concurrent engineering tools to problems in manufacturing, construction and infrastructure management, such an approach ignores much of what has been learned in the last ten years. Improving the quality of decision making in these areas requires more fundamental considerations than just simply implementing better procedures for cost controls or managing change requests. We must examine the complexity of concurrent engineering from the perspective that this approach is intrinsically a system-level problem. In general, there are three required levels of understanding, namely event, process, and methodology which must be understood before sound solutions to a system problem are possible. The event level focuses on individual results (or cases) and experiences gained from these results. The process level involves underlying reasons (e.g. physics, mechanisms, rationales) upon which the events were based. At the methodology level, various paradigms and theories, either empirical or analytical, are proposed to explain and guide event occurrences based on the understanding of their respective processes. It is important to note that one can only arrive at a sound system solution through a gradual evolution through these consecutive levels of understanding.

Table 1 summarizes research and development challenges in manufacturing, design, concurrent engineering, and infrastructure management. In manufacturing, different operations (i.e. events) were treated as black boxes and experience-based knowledge dominated the community before 1950. The work of Dr. M. E. Merchant in 1950 marked significant turning point with the introduction of the notion of *manufacturing systems* (6a). Unfortunately, early research attempted to leap directly to a systems approach without a sound understanding of manufacturing processes and methodologies. As a result, even though discussion of manufacturing systems continued from the 1960s through the 1980s, the significant research results in this era were reported from the studies of the physics involved in various manufacturing processes. Results from these studies gave us a clear understanding of detailed mechanisms and enabled us to propose different methodologies to control manufacturing operations for improved results. Only after this long journey through event, process, and methodology, are we now able to produce useful results for manufacturing systems, 30 years after Merchant's initial proposal (6b).

Although not thought of as a system-level problem yet, recent research on engineering maintenance and repair (REMR) has begun to exhibit many of these properties (7). Early field work emphasized the need to inventory and, later, inspect the condition of such large civil works structures as locks and other structures within navigable waterways. During the past six years, a number of computer-based systems have been developed to automate the maintenance of inspection data for these structures (8). These programs have recently grown to emphasize the reporting of status for groups of structures and attempts to use life-cycle process knowledge to assign a condition index (CI). The condition index along with its underlying rationale is comparable to the physics of manufacturing discussed above. Surely, system level integration and coordination of activity was an implicit goal of the REMR effort. Unfortunately, the data from inspections and validation of CI calculation mechanisms is not yet assembled into methodologies for infrastructure management. Based on the experience with manufacturing, results becoming available from the use of REMR tools over the next few years should spur the development of new paradigms and theories of managing large infrastructure systems. These new paradigms will need to be embodied in information systems in order to be most effective.

Exploit Natural Evolution of System Problems

Levels				
	Event	Process	Methodology	System
Focus	results experience	physics mechanisms	paradigms theories	integration cooperation
Manufacturing	1950	early 1980s	mid 1980s	late 1980s
Design	mid 1980s	(?)	late 1980s (?)	(?)
Concurrent Engineering	(?)	(?)	(?)	late 1980s (?)
Maintenance and Repair	late 1970s	Mid 1980s	Early 1990s	(?)
Examples	Financial Tracking and Inventory	Materials Research	REMR Life Cycle Condition Index	

Table 1. System-level problems naturally evolve from events through process and methodology before a true system solution is possible. This table shows history and status of the movement toward concurrent engineering as well as the analogous situation for maintenance and repair.

4. Decisions Have an Optimal Time to be Made

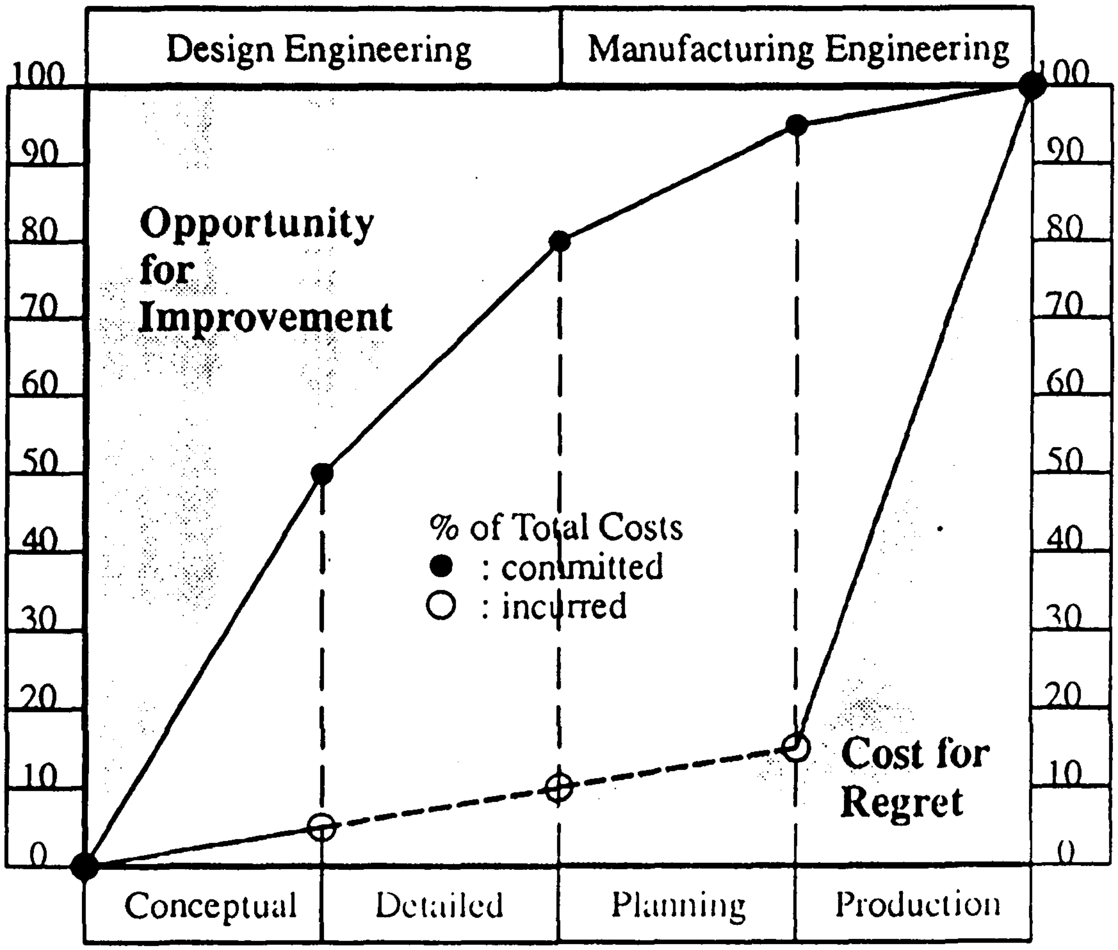
The case for the importance of decision timing is very strong. Figure 4 shows a typical cost break-down for a product development process involving conceptual design, detailed design, manufacturing planning, and production stages (9). These stages could just as readily be design, planning and construction stages for a large construction or civil works project. There are two types of costs, one for the committed cost (i.e., the % of final product market cost that is being determined at that stage) and the other for the incurred cost (i.e., the actual expenses of product development activities at that stage) indicated for each stage in the figure. It is clear that a majority (about 80%) of the final product cost has already been determined at the end of the detailed design stage. This leaves only very small opportunities for cost improvement at the production phase where a majority of actual expenses are incurred. It is interesting to note that the area above the upper line can be seen as the opportunity for improvement, and the area under the lower line can be viewed as the cost for regret. In this way, the challenge of concurrent engineering can be defined as "how to make sound decisions at early stages of product development where committed costs are high (or how to maximize the opportunity for improvement by increasing the area above the upper line)?". Similarly, it can also be defined as "how to avoid changes at later stages where incurred costs are high (or how to minimize the cost for regret by reducing the area under the lower line)?".

The key message from Figure 4 is that sound decisions must be made at early stages to avoid (or minimize) subsequent engineering changes. This is because that engineering changes are the main "cost-driver" in product development. For example, engineering changes have been a main factor in determining the product competitiveness between U.S. and Japanese manufacturers as illustrated in Figure 5. The figure compares the pattern and amount of engineering changes in a typical U.S. (dotted line) and Japanese (solid line) company in the automotive industry (10). As can be seen from this figure, most engineering changes in a Japanese company occur between 36 to 24 months "before" the date when product is introduced to the market (the D day), and there are almost no changes afterwards. In contrast, engineering changes in a U.S. company occur much later during the process, reaching a peak during the production stage, and continuing on even after products are on the market.

The significance of this comparison is not only on the number of engineering changes processed (the Y axis) but, more importantly, the time when those changes occurred (i.e., the pattern distribution along the X axis). Again, engineering changes at early stages of product development have lower costs and can help to minimize future changes. This is a very important point and must be incorporated into concurrent engineering computer tools.

In both of the cases above, the most important observation is that the value of decisions at different point in the development process is not uniform. In general, design decisions which include downstream considerations at earlier times will be more valuable than those which serialize the process.

Different Costs for Product Development

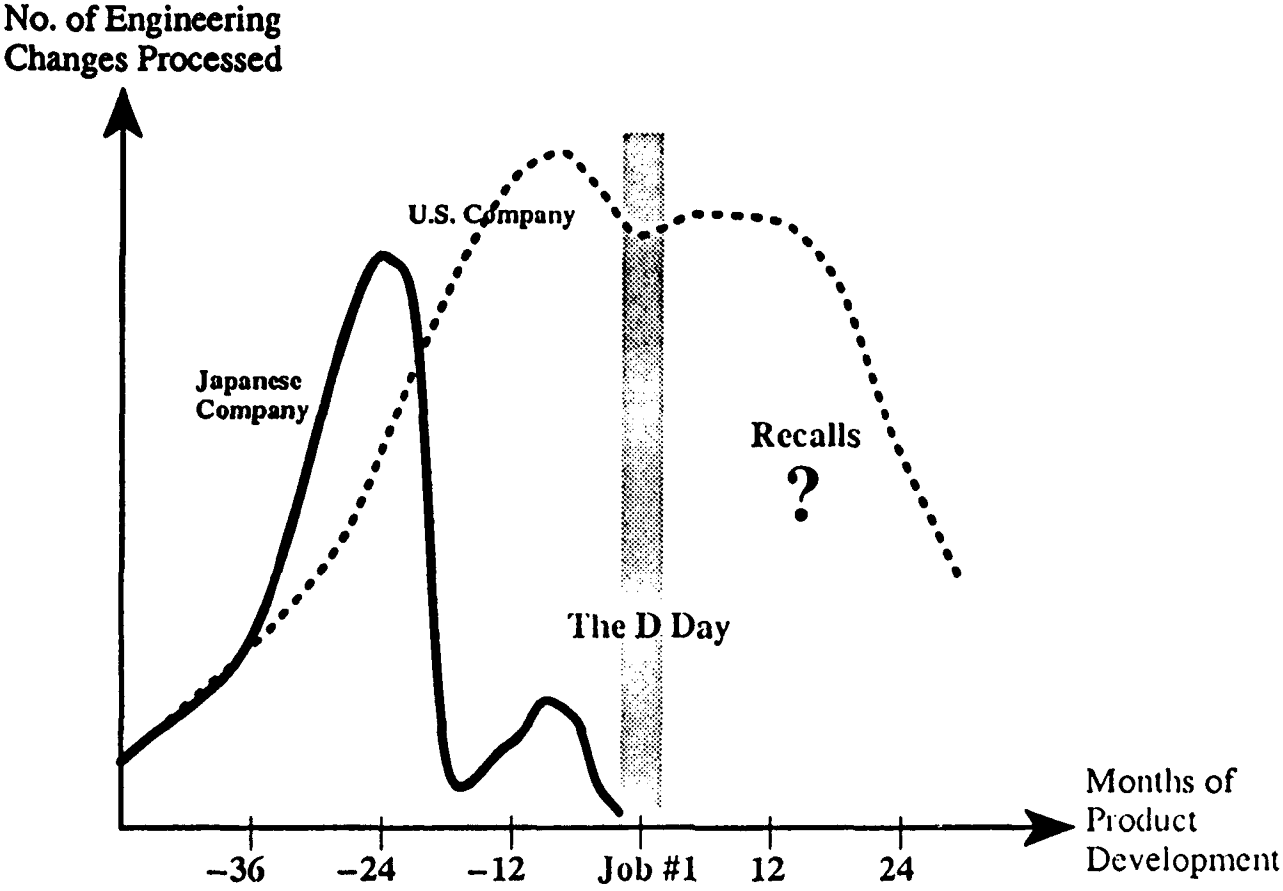


Concurrent Engineering Challenges:

- How to make sound decisions at early stages?
  - (i.e., to maximize the opportunity for improvement)
- How to minimize changes at later stages?
  - (i.e., to minimize the cost for regret)

Figure 4. Different Costs During Product Development Stages

Benchmark Comparison of Engineering Changes



Concurrent Engineering Challenges:

- How to reduce the total number of engineering changes?
- How to minimize engineering changes at later stages?
- How to best manage and support engineeering changes? (if they are not avoidable!)

Figure 5. Benchmark Comparison of Engineering Changes

5. General Requirements for Concurrent Engineering Tools

In order to transfer technology between disciplines we should understand how the challenges, current techniques, and future requirements of the disciplines relate. Technology transfer between disciplines based on such a foundation is more likely to be effective than the use of isolated techniques. In this section we explore requirements originally developed for concurrent engineering in manufacturing settings which should also apply to construction and civil works.

To develop a new design, engineers use their specific domain knowledge to generate geometrical shapes and relationships which, in term, result in a set of *data* defining the product specifications. For mechanical products, knowledge, geometry, and data are the three basic entities that engineers must effectively deal with in order to make good decisions. At the beginning of the computer-aided engineering era, many tools were developed to support data-intensive tasks such as engineering data bases and simulation programs. Those tools are useful mainly for the later stages of product development (e.g., analysis of product performance) where product knowledge and geometry have already been decided. The development of various computer-aided drafting and design programs (e.g., CAD) over the past two decades have produced computer tools for geometry-intensive tasks. Those tools are useful during intermediate stages of development to represent product knowledge in geometric forms to be converted into engineering data for downstream activities. Recently, artificial intelligence (AI) techniques have been used to build expert systems to support various engineering decision-making tasks (11). Although their full potential is yet to be seen, AI-based tools should be more suitable for knowledge-intensive tasks at earlier stages of product development than those traditional geometry- or data-oriented tools.

As engineers go through the early, intermediate, and late stages of product development, the challenges of their tasks shift from being knowledge, geometry, and data intensive accordingly. Therefore, as more computer tools are being developed to support early activities, the foci of these software developments are being extended from data and geometry to knowledge about the product. Unfortunately, current computer tools for supporting data, geometry, and knowledge intensive tasks are often developed in isolation from each other. As a result, they are only useful at a particular stage of the development process. To move from one stage to another, it is common for engineers to change to different computer tools (e.g., data-based, CAD-based, or AI-based) to cope with the changing requirements of different product development tasks. This results in many wasted efforts and prevents the integration of various product development concerns required by concurrent engineering. To overcome these difficulties, more intelligent software must be developed to support knowledge-intensive tasks and integrate with existing geometry- and data-oriented tools (12). This section will examine some functional requirements of computer tools that are useful for knowledge-intensive, decision-making tasks in concurrent engineering. Specifically, we will discuss these requirements (denoted as **R**) according to their roles in the following activities needed for concurrent engineering:

- *integration* of complementary engineering expertise (**R-a-**),
- *cooperation* of multiple competing perspectives (**R-b-**),
- *communication* of upstream and downstream concerns (**R-c-**), and
- *coordination* of group problem-solving activities (**R-d-**).

5.1 Integration of Complementary Engineering Expertise

In order to effectively incorporate life-cycle considerations, different engineering expertise must be "integrated" during the product development process, rather than "interfaced" afterwards. Knowledge representing complementary expertise must be shared among product engineers before they reach their individual solutions (13). The following four functions are required to support the knowledge sharing and expertise integration during product development:

(R-a-1) Combine numerical/symbolic representations: Some of the product development expertise, such as performance analysis, will have numerical representation while others, such as manufacturability checking, may be more suitable for symbolic representation. A useful concurrent engineering tool must be able to treat numbers and symbols indifferently with a uniform representation to facilitate the true integration of different complementary expertise.

(R-a-2) Break the synthesis/analysis barriers: With traditional practice, synthesis and analysis are done separately and iteratively through the product development process. To minimize engineering changes, the barriers between these two tasks must be broken so that they can be done simultaneously. In order to do this, computer tools must be able to effectively reason (or calculate) from inputs to outputs and vice versa. This requires multi-directional data propagation among problem attributes within the tool.

(R-a-3) Adapt to standard data definitions: One major difficulty of integration in the current practice is that computer tools for different engineering tasks, such as design, planning, and scheduling, all use different data definitions. Data incompatibility prevents sharing of expertise and makes cross-functional consistency checking impossible. Efforts in developing standards for data definitions, such as PDES/STEPP and IGES, are important to the realization of concurrent engineering.

(R-a-4) Integrate with CAD and database tools: As explained before, any decision support tool at the knowledge level must be integrated with software for representing geometries and storing data. This integration is more than just creating file links or software pointers between different programs. It requires the ability for decision support tools to truly "reason about" knowledge implicitly available from geometry and data programs.

5.2 Cooperation of Multiple Competing Perspectives

Product development practice is not a pure scientific activity, and product decisions are always perspective-driven. A major challenge in concurrent engineering is to effectively manage competing perspectives to maximize the values of differences during the product development process (14,15). The followings are desired functional requirements for managing competing perspectives:

(R-b-1) Record decision histories and rationale: Since product development is a "process" of making decisions, records of how different decisions evolve (i.e., history) and why they evolve in a particular way (i.e., rationale) are useful for the management of various perspectives. Most current computer tools, such as CAD and databases, only document "results" of product decisions without keeping track of their heritage. They act as "static cameras" taking snap shots of product development results. Concurrent engineering tools must be able to record histories, assumptions, rationale of various decisions. Such records can minimize the risk of making changes which violate early assumptions, provide bases for systematic conflict resolutions, and facilitate communication and coordination among product development team members (see R-c- and R-d-).

(R-b-2) Automate consistency maintenance: Most existing tools are "inactive" in the sense that they allow inconsistent specifications to exist in the product model before its execution. A way to minimize changes at later stages is to have computer tools that can immediately "complain about" (or detect) inconsistent decisions at the time when they occur. Such *reactive* tools are very useful for supporting individual and group "what-if" analyses to ensure that innovations do not violate the global states of consistency. Since the burden of maintaining consistency is shifted from human to computers, engineers will be more willing to try new alternatives, consider different opinions, and accept "better" ideas from others.

(R-b-3) Facilitate conflict management: Competing perspectives lead to conflicts which must be detected and resolved before the product development process can proceed. In a typical product development team, a significant portion of engineers' time and resources are spent detecting and resolving conflicts. Therefore, computer tools that support conflict management activities will be of great value to concurrent engineering. Methods must be developed to automatically identify the sources of conflicts, suggest possible resolution strategies, and summarize consequences of proposed changes. Once certain changes are decided to be necessary (by either engineers or computers with human consent), the tools should automatically carry out these changes (with human supervision) and detect any side-effects. Decision histories and rationale play an important role in automatic conflict management as previously explained.

(R-b-4) Provide comprehensible explanations: The ability to explain ones decisions to other concerned parties in a comprehensible manner is crucial to integration, cooperation, and coordination among product development team members. Computer tools which can provide understandable explanations of decisions will be beneficial to engineers who often need to explain what they did, how and why they did it to their colleagues. This requires more than just printing out pre-stored textual information. The explanations must be automatically tailored to particular viewpoints with proper levels of details for those concerned engineers. Graphical representations of explanations (e.g., graphs of dependency networks) are often useful for easy comprehension. Again, good records of decision histories and rationale play an important role in these explanation activities.

5.3 Communication of Upstream and Downstream Concerns

Iterations and changes at later stages can be minimized if downstream product development concerns can be communicated upstream to those who make decisions at early stages. Therefore, computer tools must be developed to promote and support early communications among product engineers to avoid iterations and changes (16). These tools must also provide representations of decisions in a manner suitable for communication. The following functional requirements must be considered:

(R-c-1) Support the least commitment approach: A way to facilitate upstream and downstream communications is not to make premature commitments or specifications, leaving room for others to express their concerns later on. This is called the *least commitment* approach to problem solving in AI, and is a very useful concept to promote communications in concurrent engineering. For example, one way to support the least commitment approach is to develop computer tools that allow *interval* value specifications. In the early stages of product development, few details may be explicitly known. Engineers can use intervals to specify acceptable ranges of values based on upstream concerns, leaving these intervals to be further refined by others at later stages where downstream concerns become apparent. Traditional tools only support atomic value specifications (e.g., single numbers or symbols) and, hence, force engineers to commit to specific values unnecessarily. In contrast, interval values, much like the tolerance concept in design and manufacturing integration, can make product decisions more "communicable" to promote concurrent engineering.

(R-c-2) Adaptive focus at multiple abstraction levels: Upstream and downstream product concerns are often expressed with different levels of abstraction. Therefore, computer tools must be able to support reasoning with adaptive focus for concurrent engineering communication. Given a specification of "interests" based on engineers' different roles in the product development team, such tools must be able to automatically mine out relevant information from generic product specifications. As engineers change their interests at different stages, these tools must adapt their focus of information mining accordingly. Without such tools to support adaptive focus, engineers will be overwhelmed by the amount of information, most of which is not directly relevant to their current interests, and unable to communicate effectively at the proper time.

(R-c-3) Facilitate early evaluation of decisions: Early evaluations are important because they can eliminate unpromising choices before major resources are consumed. However, upstream evaluations are difficult because most traditional analysis tools require very detailed decision specifications and, therefore, can only be used for downstream analyses. Methods must be developed to form analysis models based on downstream detailed knowledge to support early evaluations of upstream decisions. With these early evaluation models extracted from downstream knowledge, product decisions can be gradually refined at optimized at various stages.

(R-c-4) Provide hypothetical reasoning: Since not all the concerns are explicitly known at upstream, engineers often need to hypothesize downstream conditions to generate several different product scenarios. Hypothetical reasoning is an important activity in product development, and good computer support for this activity can greatly assist concurrent engineering. There are several software techniques from AI, such as multiple worlds and truth maintenance systems, which can be used to support multi-scenario reasoning based on different hypotheses and can automatically merge different scenarios when necessary. These techniques must be further developed and integrated to support hypothetical reasoning at different abstraction levels for concurrent engineering.

5.4 Coordination of Group Problem-Solving Activities

Concurrent engineering is inherently a group activity and, therefore, ``group productivity'' is a main concern. To date, most computer tools are design for enhancing individual productivity. New tools must be developed to support group interaction of engineering teams with different technical backgrounds and geographical locations (17). These interactions could be centralized or distributed, synchronous or asynchronous, technical or administrative, and involving both people and machines. For the concurrent engineering purpose, these group productivity tools must meet the following requirements:

(R-d-1) Deal with homogeneous and heterogeneous tools: Unlike small groups where members are likely to use similar tools in problem solving, heterogeneity of computer tools always exists when dealing with large engineering groups or a collection of small groups. Group productivity tools must be able to accommodate small and large groups with similar and different tools. These group tools should act as a common platform for group work, allowing results generated from different tools to be integrated. The issues related to unified representations, standard data definitions, and automatic consistency management discussed above play important roles in supporting this group-work platform.

(R-d-2) Manage ownerships among group members: Although engineers are encouraged to share ideas and work cooperatively in concurrent engineering, they must declare and control ownership of some product decisions in order for the product development team to be effective. Without some technical authority of decisions, it is impossible to assign and evaluate the responsibilities of engineers in the team. Computer tools must automatically manage these ownerships and responsibilities of decisions as they are declared and agreed by the group members. These tools should also allow sharing and changing of ownerships as necessary and manage these situations accordingly.

(R-d-3) Support synchronous and asynchronous interaction: Depending on the nature and stages of product development, the required interactions in a product team can be either synchronous or asynchronous. Supporting synchronous interaction is important because it allows implications and feedback of one engineer's decisions to be immediately known by the group members. However, such instantaneous interactions could sometime cause instability of the overall team development efforts and discourage innovation by team members who might wish to try out some new ideas without being publicized right away. Since good ideas take time to mature before they can be seriously shared, engineers may sometime prefer asynchronous interaction with large time delay. Group productivity tools for concurrent engineering should be able to support both types of interactions.

(R-d-4) Promote local and remote interaction: Engineers who have required product development expertise may not come from the same location, and yet still need to interact during the product development process. Computer tools which can create ``virtual co-location' among engineers regardless of their actual geographic locations are needed for concurrent engineering. New hardware and software technologies, such as local and global area networking, multimedium information systems, and distributed databases supporting consistent and persistent data storage, are all important to this activity.

5.5 Three Fundamental Requirements

Among the above 16 functional requirements of concurrent engineering tools, three are most fundamental (12,18) to software development as indicated by the axes of Figure 6. The X axis represents "perspectives" which refer to different life-cycle concerns such as function, structure, manufacturing, and maintenance. On the Y axis, "stages" indicate the current stage of decision-making activities, ranging from the early stage of conceptualization to the final stage of detailed analyses and production. The Z axis represents "participants" and refers to the number of engineers required for developing a competitive product. It is interesting to note that most conventional, computer-aided engineering tools available to date only support a single perspective, are biased toward a particular stage, and are only suitable for an individual user. These tools are represented as a single point at [0,0,0] in Figure 6. In contrast, computer tools for concurrent engineering must ideally be able to incorporate multiple perspectives, support multiple stages, and work with multiple participants. They are represented by the volume of the [1,1,1] cube in Figure 6. Basic research efforts are needed to extend current computer-aided automation technologies from zero-dimension (a single point at [0,0,0]) to three-dimension (the volume of [1,1,1] cube) to support concurrent product development (19).

6. Some Recent Results

There are many different approaches available for developing concurrent engineering computer tools. Good examples are the Taguchi method (20) and the Axiomatic design principle which have been explored as ways to support design and manufacturing integration (21). In fact, since concurrent engineering is a system-level problem, any approach that can improve on system solutions is useful. In this section, we will introduce some recent results from an extended AI-based approach, called the *Knowledge Processing Technology* (KPT).

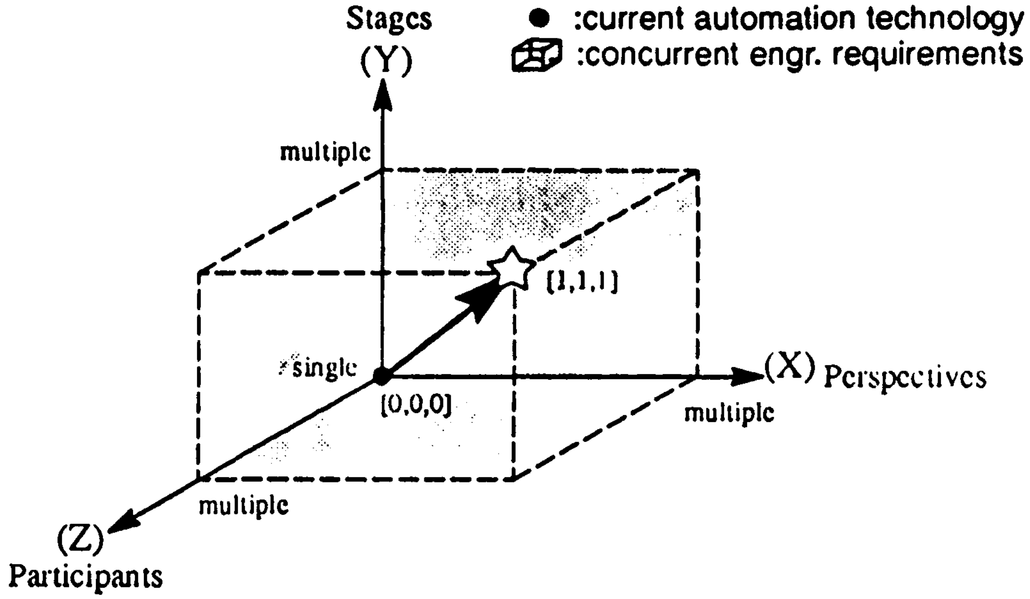
6.1 The Basic Concept of Knowledge Processing

The need for developing computer tools that can handle multiple perspectives, stages, and participants calls for a new automation foundation beyond the current foundation which is based on the data processing technology (DPT). We developed KPT as a new foundation which allowed us to build computer tools that could manipulate higher level information contents than what was possible with DPT. In a generic sense, KPT can be defined as a logical set of software techniques, from both AI research and traditional engineering methods, that can increase the utility of engineering knowledge to support complex decision making tasks (22). An important concept of KPT is the distinction between data and knowledge. Both knowledge and data are problem-solving information with different representations and utilities. Knowledge represents the structure, meaning, usage, justifications, interpretations, and other high-level concepts of data. In contrast to data, knowledge is more flexible, comprehensible, and can be dynamically inferenced (rather than statically retrieved). While data keeps records of past events, knowledge lies within the models that give proper meaning to data for future applications.

Due to the above differences, processing data is sufficient for *interfacing* of mass-production automation tasks while processing knowledge is required for *integration* of highly flexible production systems. Interfacing and integration differ in the method and degree by which

Tool Requirements for Concurrent Engineering

Computer tools that are useful for cooperative team support in concurrent engineering must have the following characteristics:



The ability of modeling engineering know-how, know-why, and know-what intelligence by KPT makes the development of these computer tools possible.

Figure 6. Three Fundamental Requirements for Concurrent Engineering Tools

sub-tasks communicate with each other during problem solving. If no problem-solving knowledge is shared between sub-tasks during the formation of their respective solutions, and sub-solutions are only pieced together at their result level, it is considered an interfaced approach. On the other hand, if problem-solving knowledge is communicated among sub-tasks *before* arriving at their respective solutions, it is an integrated approach. Essentially, interfacing can occur at the result level via data communication, but integration must occur at the task level through knowledge exchange. Based on this definition, traditional product development is an *interfacing approach* (and hence DPT is sufficient) while concurrent product development calls for an *integrated approach* (and hence requires KPT).

KPT utilizes modern computers' extensive processing power to process knowledge directly, thereby elevating the current focus of automation in industry from data to knowledge. KPT consists of five basic knowledge processing operations, namely *Knowledge Acquisition, Knowledge Representation, Knowledge Integration, Knowledge Coordination, Knowledge Utilization.* The two KPT operations which have not been widely recognized in traditional approaches (e.g., expert systems) are knowledge integration and knowledge coordination, both of which are important in concurrent engineering. Existing techniques for knowledge acquisition, representation, and utilization, although widely recognized as important aspects in traditional approaches, are not sufficient and are being extended in KPT research.

6.2 The Impact of KPT on Concurrent Engineering

Generally speaking, KPT offers the following two fundamental advantages over DPT as a basis for developing computer tools to support concurrent engineering (23):

- Because knowledge contains high-level meanings and justifications of data, processing knowledge directly can expand the types of intelligence that can be explicitly modeled on computers. This expanded set of intelligence includes *know-how* knowledge which specifies *how* domain knowledge can (and should) be used to solve a particular problem, *know-why* knowledge which explains *why* a know-how knowledge is being applied in a particular way, and *know-what* knowledge which indicates *what* are important aspects to focus on (or adapt to) at a particular stage of decision making. To be effective, concurrent engineering tools must be able to capture these three types of product development intelligence.

- Because knowledge captures the concepts, usages, and structures of data, KPT is useful for integration of complex engineering and software systems. For software integration, KPT provides opportunities of integrating computer tools, such as CAD packages and data bases, which are built upon DPT. In fact, KPT can serve as an integration platform upon which knowledge-, geometry-, and data-intensive tools can be unified and coordinated. As previously explained, such an integrated computer environment that can process engineering knowledge, geometry, and data seamlessly is very critical to the realization of concurrent engineering.

The combined effect of the above two advantages allows KPT to be used to explicitly model different competing concerns to support a group of engineers cooperatively working on a product development task at different levels of detail. This makes KPT a very suitable foundation for building intelligent computer tools that can handle multiple perspectives at different stages for multiple users, meeting the fundamental requirements of concurrent engineering as specified in Figure 6.

6.3 Core KPT Tools for Concurrent Engineering

Based on the generic concept of knowledge processing, various KPT tools (see Figure 7) have been developed at the Knowledge-Based Engineering Systems Research Laboratory (KBESRL) to support different aspects of concurrent engineering (24). In Figure 7, the bottom layer shows basic software techniques used in the development of our KPT tools. As can be seen, there are many AI-based techniques integrated with traditional engineering methods. The middle layer indicates the three generic software environments which form the core KPT technologies: IDEEA for know-how knowledge, AIDEMS for know-why knowledge, and AIMS for know-what knowledge. The upper layer presents those application-specific systems and prototypes resulted from the above three generic environments, as well as general software systems that extend the functions of the generic environments. These extended environments integrate the basic capabilities from the generic ones and provide more robust supports within different engineering domains. The following discussions briefly review the CORE KPT software developments and functions (in reference to the requirements identified in Section 3), and then introduce current efforts to apply, enhance, and integrate these core KPTs for real-world concurrent engineering problems (see the upper layer of Figure 7).

6.4 Processing Know-How Knowledge for Concurrent Engineering

We developed an Intelligent Decision Environment for Engineering Applications (IDEEA) (see Figure 5) as our core KPT for know-how knowledge for concurrent engineering (25). Several software techniques from AI are employed in IDEEA to form an integrated, domain-independent problem-solving environment. Within this environment, a *frame-based* scheme is used to represent domain objects and *composite values* (i.e., numbers, symbols, sets, and intervals) are employed to represent data (R-c-1). A *constraint-based language* and the *rule-based system* serve as the primary and the secondary modes of computation. A *truth maintenance system* is used to record dependencies for all domain objects and values (R-b-2). The constraint system allows multi-directional propagation of composite values and, hence, supports the *least commitment approach* to problem-solving (R-c-1).

The IDEEA know-how modeling tool is particularly useful for domains containing multiple objects (either physical or conceptual, macro or micro) with known relationships among them. It is interesting to note the similarity of these types of problems with concurrent engineering tasks which require many interacting nodes of knowledge. The complexity of these types of problems results from interrelated interactions among large numbers of objects, rather than from local relationships between any particular two objects. The constraint language used in IDEEA provides a uniform representation for both numerical and symbolic knowledge (R-a-1) and, hence, helps to integrate different engineering expertise. The bi-directional characteristics of

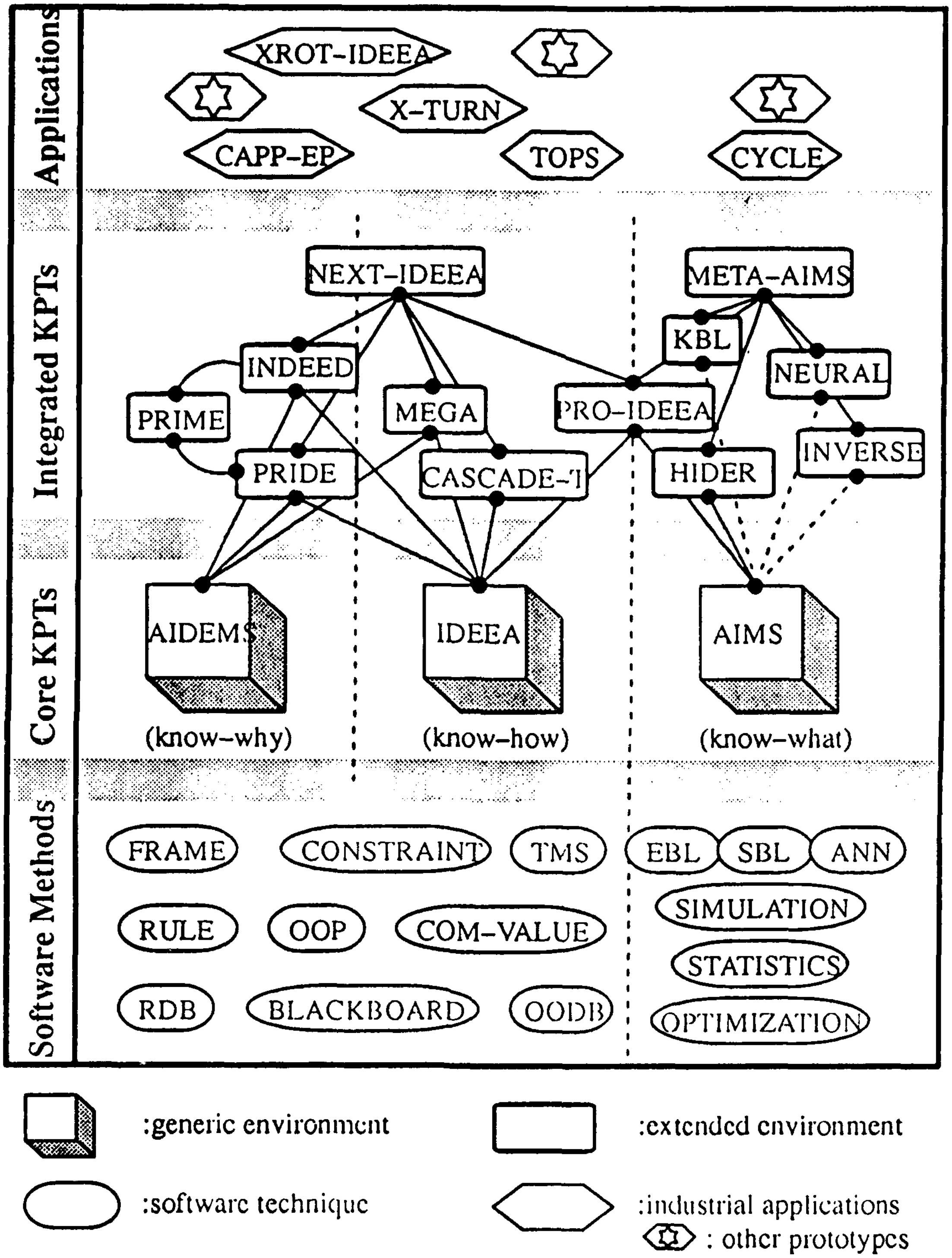


Figure 7. Various KPT Tools to Suport Concurrent Engineering

constraint relationships between known and unknown attributes eliminates the need to pre-specify input and output parameters in IDEEA-based models (R-a-2). This makes IDEEA suitable for multi-participant problem solving, where each participant may provide different inputs and seek different outputs. The interval value specifications provided by IDEEA's composite values remove the need for users to select a single value in order to use the model. This enables IDEEA to be used during both early and later stages of decisions where interval and atomic values are desirable (R-c-1). The explanation facility in IDEEA provides the ability to examine the constraint networks in either a graphic or text-based manner with multiple levels of abstraction (R-b-4). This makes the knowledge in the model more understandable by other human or machine-based knowledge sources (KSs) which may have different perspectives.

6.5 Processing Know-Why Knowledge for Concurrent Engineering

To support concurrent engineering, it is necessary to include several know-how KSs which can contribute their different expertise to the product being developed. There will be many instances where these know-how KSs suggest competing ideas during a product development process which evolves over a period of time. It is necessary to manage those competing suggestions systematically to maximize the values of differences. A critical issue here is the ability to keep track of *why* a particular decision was made by a particular know-how KS at a particular time. In other words, it is necessary to explicitly model engineers' product development *know-why* knowledge on computers. Here, know-why knowledge represents the *rationale* of decisions made by know-how KSs, and the *history* of a decision-making process involving one or several know-how KSs over a period of time. Processing decision rationale supports better coordination of competing perspectives provided by multiple participants, while tracing the decision history facilities explicit management of multiple decision stages.

A design evolution management (DEM) methodology (26) was developed which supports the acquisition, representation, and utilization of decision rationale and processes (R-b-1). This methodology was implemented in a prototype system, called AIDEMS (An Interactive Design Evolution Management System) (see Figure 5). Know-why knowledge is represented and utilized in AIDEMS at both *strategic* and *tactical* levels. Decision strategies are explicitly modeled in the form of plans whose structures consist of a *refinement hierarchy*, parallel *view-paths* for each refinement, and sequential *views* within a view-path. View-paths represent the different life-cycle perspectives considered and views record the incremental, increasingly detailed stages of product development activity. This representation enables the establishment of a strategic context based on different perspectives, which is critical to the proper management of later design tactics. Design tactics are captured as *decision procedures* whose execution results are represented as *connections.* Connections record the interdependent relationships which exist among decisions made in a product description (R-b-2). These explicitly recorded connections can be used to explain attributes of a product description and automatically (R-b-4) modify them when changes in design strategies or tactics occur at the later stages (R-b-3). This is an important feature for supporting decision making at multiple stages during product development (R-c-4).

6.6 Processing Know-What Knowledge for Concurrent Engineering

When solving complex system problems, such as the concurrent engineering task, engineers are often faced with large amounts of information obtained from simulations, experiments, and past solutions. Given this information, they must construct know-how models which are optimal with respect to the specific problems at hand. The knowledge required for constructing optimal models and refining them to enhance performance is called *know-what* knowledge. This knowledge is necessary to support the various stages of the decisions, and to cope with the changing perspectives in concurrent engineering. A new modeling methodology for interactive model formation and utilization to support know-what knowledge processing was developed (27). The methodology integrates simulation, learning, and optimization to form an Adaptive and Interactive Modeling System (AIMS) to support multiple perspectives (R-b-) at different stages (R-c-). Given a database of examples collected from simulations or experiments (R-d-1), and a set of modeling objectives and design objectives, AIMS performs multi-objective optimization at both the model formation and utilization phases. During model formation, layered models with explicit trade-offs between modeling objectives are induced from the example database. These models are then used during model utilization to find optimal solutions with explicit trade-offs between design objectives. By varying modeling objectives, such as speed, accuracy, and comprehensibility, AIMS can produce layered models to meet the changing needs at different stages of design (R-c-2). By treating different life-cycle concerns as competing design objectives, AIMS can support systematic incorporation of multiple perspectives for concurrent engineering. Furthermore, a layered set of models built by AIMS offers several distinct advantages over traditional analysis models which can only provide evaluations at very detailed stages of product development. These advantages include early evaluation to avoid costly iterations (R-c-3), fast execution for interactive decision making, enhanced comprehensibility for human inspection (R-b-4), and deep roots in domain physics for higher accuracy. AIMS represents an intelligent integration between AI and traditional engineering methods to form the needed know-what KPT.

6.7 Integration and Application of KPTs for Concurrent Engineering

The above core KPT tools offer a set of desirable functions which have been integrated and applied to provide concurrent engineering solutions. Some of these application and integration efforts performed at KBESRL (see Figure 7) are briefly summarized below. It should be noted that although not all the current applications are in the specific context of product development, all systems demonstrate some functions required by concurrent engineering. Also, due to the space limitation, only one reference paper is cited for each system. Those readers who are interested in more details of these systems should refer to (19).

TOPS *Turning Operation Planning System*: a domain specific application system built by IDEEA for process planning of lathe-turned parts (28). Although not directly used in the concurrent engineering context, TOPS serves as a critical link for design and manufacturing integration (R-a-1). The system is linked with a solid modeler for design and a relational database for tooling (R-a-4).

CAPP-EP *Computer-aided Process Planning Enabling Platform*: IDEEA is used to implement a set of generic function modules, called the enabling platform, for developing different process planning systems (29). The system adapts to the current PDES standards (R-a-3), and has links to CAD tools and databases (R-a-4). In addition to functional supports to CAPP systems, our CAPP-EP can record plan intents (R-b-1) and maintain consistency for planning activities (R-b-2).

XROT-IDEEA *Manufacturability Advisory System for Rotational Parts*: another application of IDEEA for manufacturability checking of rotational parts during various design stages (30). The system integrates CADROT, a CAD tool (R-a-4), with an AI based process planning knowledge base (R-d-1), uses multiple representations (R-a-1), and conforms with PDES/STEP standards (R-a-3). The CAD and CAPP knowledge are implemented on two separate computers, and the interaction modes between designers and planners can be both local and remote (R-d-4).

CASCADE-T *Computer-aided Synthesis and Computer-aided Design of Engineering Tolerances*: an extended IDEEA environment for the domain of tolerance synthesis for mechanical design (R-a-2) (31). Tolerance is an important subject in concurrent engineering, serving as a communication window between design and manufacturing. The CASCADE-T system can simultaneously consider function and geometry requirements in designing consistent tolerance specifications (R-b-2 and R-b-3), and provide domain-dependent explanations (R-b-4) at multiple levels of abstractions (R-c-2).

INDEED *Intelligent and Distributed Environment for Engineering Design*: a major extension of IDEEA which supports remote and local interactions for group design (R-d-3 and R-d-4) (32). INDEED provides extended capabilities from object-oriented database technology (R-b-2) which allow consistent and persistent data storage (R-a-4) by multiple engineers. It also support recording of design rationale (R-b-1), managing conflict situations (R-b-3) and ownerships (R-d-2). It allows hypothetical reasoning by individual engineers in a group design setting (R-c-4).

PRIDE *Providing Rationale in Engineering Design*: an application of AIDEMS in the domain of frictional clutch design for transmissions used in heavy vehicles (33). Different design assumptions and rationale at both strategic and tactical levels during clutch design are captured in the system (R-b-1).

PRIME *Providing Rationale in a Multi-agent Environment*: an integrated know-how and know-why environment which combines the functions and methods from IDEEA and AIDEMS. It supports the recording of design histories (R-b-1) in an interactive mode, helps the management of design plans, and controls the sharing of design decisions and rationale with other engineers in the same design group (R-d-2, R-d-4). PRIME is currently being tested in the domain of transmission design.

MEGA *Managing Engineering Group Activities*: an integrated know-how and know-why environment to support team design based on the discourse design model (34). The system supports adaptive focus with different viewpoints and abstractions (R-R-c-2), recording of rationale (R-b-1), detecting and resolving conflicts (R-b-3), and integrates with different CAD tools (R-a-4, and R-d-1). It can be used for synchronous and asynchronous interactions (R-d-3) with local and remote design teams (R-d-4).

PRO-IDEEA *Probabilistically Valued IDEEA Environment*: a system that support acquisition, representation, and manipulation of probabilistically valued attributes (35). It uses objects from IDEEA for representation (R-a-1), constraints from IDEEA for manipulation (R-c-1), and machine learning from AIMS for acquisition of probabilistic values to support design and manufacturing integration. The system supports what-if analysis (R-c-4) and the learning tasks can be distributed across networked computers (R-d-4).

NEXT-IDEEA *Advanced Versions of IDEEA*: many major extensions are being developed for IDEEA to enhance its basic capabilities as a more robust and useful tool for concurrent product development. These extensions include integration with CAD tool for geometry processing (R-a-4), recording of decision rationale (R-b-1), domain dependent explanations (R-b-4) at multiple levels of details (R-c-2), hypothetical reasoning (R-c-4), and a blackboard architecture for group problem solving (R-d-).

CYCLE *Classification and Sorting of Recyclable Containers*: an application of AIMS for the control of continuous operations based on on-line sensory information (36). Although not directly related to concurrent engineering, the system demonstrates the abilities to integrate sensors with learning algorithms (R-d-1) to produce classification models with varying details (R-c-2), both are required functions for concurrent engineering.

NEURAL *Neural Networks for Complex Control*: an application of neural network learning algorithms to open-loop controls of complex mechanical systems (e.g., a combine harvester) (37). The system is able to integrate various sources of knowledge (R-a-1) about the process and adjust machine control parameters to adapt to varying operation conditions (R-c-2).

HIDER *Hierarchical and Interactive Design Refinement*: a domain-independent system which supports hierarchical refinement of decision spaces through successive optimizations with layered models induced by AIMS (38). This methodology bridges the synthesis and analysis gaps (R-a-2), supports decisions with varying abstractions (R-c-2), and facilitates early evaluations of designs (R-c-3). HIDER is being applied to the domains of concurrent engine design and quality control of semiconductor production.

META-AIMS *Meta Learning System for AIMS*: a meta-learning system which learns how to optimally control and select various learning algorithms in AIMS with different application domains (39). Such a system can enhance the performance and operation of AIMS in concurrent engineering applications.

INVERSE *Inverse Engineering Methodology*: a machine learning system that can automatically induce knowledge to support design synthesis from those analytical models of the domain (R-a-2) (40). The models produced are "invertible" and can be at various levels of details (R-c-2) including those required for early stages (R-c-3).

KBL *Knowledge-Based Learning*: an integrated machine learning system that combines the strengths of inductive and deductive algorithms (r-d-1) for real-world problems which are data-intensive and knowledge-sparse (41). The system can work with various representations of domain knowledge (R-a-1).

7. Summary and Conclusion

In this paper, concurrent engineering was defined as a system approach to cooperative team work in product development. The technological challenges of concurrent engineering were explained by comparing product development costs at different stages and examining the impact of engineering changes. Using a system perspective of concurrent engineering the research and development needs were presented. Based on these challenges, a set of functional requirements of concurrent engineering computer tools were identified. These requirements were explained with respect to their roles in integration of complementary engineering expertise, cooperation of multiple competing perspectives, communication of upstream and downstream concerns, and coordination of group problem-solving activities. The knowledge processing technology was defined and introduced as a foundation for developing intelligent software that can meet these requirements. Some recent results of various KPT tools to support concurrent engineering were briefly reported.

As noted in this paper, concurrent engineering is a complex system problem which requires technological, organizational, and, perhaps, cultural solutions. Although computers are not the final solution, they certainly play a very critical role in the realization of concurrent engineering. Developing intelligent computer tools for concurrent engineering tasks can not only help our product development practice but also result in new software paradigms which are more suitable for integration of complex system problems, meeting one of the most challenging tasks in engineering automation.

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ADVANCING INNOVATION IN TRANSPORTATION THROUGH RESEARCH

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Perhaps at no other time in our history as a nation, and industry, or a profession, has the outlook been so bright for those interested in advancing transportation technology and innovative practice. It is little short of amazing that there is such a consensus and so little opposition to the large expenditures for research that are now being contemplated for materials, methods, IVHS, transit, and various University research programs in transportation.

To put this phenomenon in perspective we should consider the factors influencing the changing U. S. transportation environment:

* Regulatory Reform
* Federal Budget Deficit
* Globalization of the Market Place
* Changing roles of Federal/State/Local Government
* Environmental Concerns
* Tort Liability and Insurance costs
* Demand for Efficiency and Productivity
* Private Sector Involvement

These factors helped to focus on the identification of critical issues confronting the transportation environment. These critical issues are:

* Economic Competitiveness & Productivity
* Congestion
* New Investment
* Maintenance
* Environmental Protection
* Energy
* Intergovernmental and Public-Private cooperation
* Safety
* Human Resources

From this list of critical issues a number of projects and programs have been structured to assist in evolving an effective agenda for the Transportation Research Board and the Transportation Community.

In our euphoria over this increased interest, we must begin to consider that our increased visibility will also increase the need for producing results and insuring that the various research initiatives are properly coordinated. One of the reasons that research is currently favored, is because of the strong impression that the strategic highway research program (SHRP) activity has been successfully organized, managed, and carried out, without significant questions about its objectivity and fairness to all concerned.

But SHRP's success further underscores the absolute necessity for us to organize these new research efforts effectively, and work hard to insure coordination of the various pieces. I am happy to be able to report that TRB has established the new high level-what we've called the Tier One Group-Research and Technology Coordinating Committee (RTCC). The committee is now appointed and has had its first meeting. AASHTO and the States have been rather insistent that the new build-up in the Highway Research Program should be accompanied by the establishment of a high level Oversight Group, which can review the entire federal effort in Highway Research including SHRP, IVHS, Turner Fairbanks, HPR, NCHRP, and the University Research Program , to insure that the program remains on target: is responsive to real needs; is clear of duplication of effort, is coordinated with related research efforts technology, and doesn't develop gaps. Dr. Norman Abramson, former Executive vice President of the Southwest Research Institute, a member of the National Academy of Engineering, and a person with an outstanding record in organizing and managing large research efforts has agreed to be the chairman of this panel. Dr. Ray Chamberlain, Executive Director of the Colorado Department of Transportation, has agreed to be the Vice Chairman. The Committee has members from the private sector, Academia, and State and Local Government.

I wish I could tell you exactly how this group is going to function. Our nearest model is the Strategic Transportation research Study (STRS) Committee, which did the STRS report that in turn recommended SHRP. This group also looked at our overall highway research programs and compared them to how we were spending our research funds. In some respects the new research and technology coordinating committee will be in effect, a continuing STRS. Tom Larson and Charlie Miller of FHWA are providing adequate funding for this committee to do more than just react to their proposals; it is expected that the panel will be proactive and will make recommendations of its own. But all of us recognize that we've experimental mode. All are committed to making it work however, and I'm optimistic that it will. It must if we are to keep this large decentralized research effort on track as we move ahead towards the year 2000.

I'm happy to report that progress is also being made in organizing for Post-SHRP Activities. SHRP is scheduled to terminate in June 1993, but that the long term pavement project-LTPP-is scheduled to transfer from SHRP to FHWA in June 1993. But because of the big role that States are playing in LTPP, it is important that we organize so that the States can have a major voice in how LTPP is run over the next 15 years. Unusual efforts are being made to insure that this transfer of activities from SHRP to FHWA is seamless--that is, that there is no disruption to this vital experiment. This requires that provisions be made for many of the staff to transfer to other agencies, and that responsibilities be moved in an organized and planned way. Agreement has been reached between all parties on how this is to be done. In addition, a smart panel (smarts stands for SHRP Monitoring and Research Transfer Committee) will be established within the TRB beginning next Spring with its own staff and a schedule of activities and responsibilities, which will grow until June 1993, when it will assume full responsibility as SHRP Terminates. Initially the panel will begin work by assisting SHRP in planning for implementation activities, and providing review and critique of the LTPP program with recommendations to the FHWA and AASHTO. By June 1993, it will take over any residual SHRP activities that remain undone. The smart panel will look much like the state people augmented with some industry and academic experts. Again, Tom Larson and Charlie Miller have been implacable in their insistence that this activity move ahead in a timely fashion. TRB is currently in contract negotiations with FHWA to obtain the funds to begin this work.

LTPP is an enormous effort devoted to an enormous cause. Because the whole world spends countless billions on pavements every year, and because this amount continues to increase annually, our need to know more about how pavements perform is self evident. On the other hand, because we operate in such a decentralized fashion, suffer such turnover in our leadership, and are subject to such jolts in our funding patterns, the difficulties of sustaining this effort over the 20 year required period is formidable. The first five years have been devoted to getting the effort organized and beginning data collection. During the next five years, we will begin to see some major new findings as serious analysis of these data begin. Some of the results may jolt previous notions of some very controversial issues about pavement materials, the effects of environment versus loadings, and the relative effects of heavy versus light loads. It is essential that we be organized so that appropriate unbiased assessments of these findings can be made on a timely basis. It's also interesting to note that the data base will have cost us about 250 million dollars as we approach the 20th year of data collection. It will be an asset requiring serious management efforts. The smart panel should give us the ability to handle all these matters, and we're proud that you have seen fit to allow TRB to serve in this way.

Now let me shift to the subject of Transit Research. There is growing interest in the U. S. in transit. The States as a group have been spending more money towards transit assistance than the Federal Government for several years now. It's also clear that in many areas of the country, we are going to be seeing more money spent on transit than we have in the past, considering concerns about mobility, air quality and energy conservation. The problem is that we may not know how to use the additional monies very effectively. Whether we are talking about maintenance of deteriorating transit infrastructure, or studying new service delivery methods, we have spent little to learn how to improve Transit effectively in recent years. If there is an area in transportation where research has been neglected over the past decade it is Public Transit.

Fortunately, Former Secretary Skinner and Bryan Clymer, FTA Administrator, are committed to developing an effective Transit Research Program, and are using TRB Special report 213-The Transit STRS Report completed in 1988, as the guidebook for this revitalization. The TRB report argues that one of the most pressing transit research, the Transit operators, and further argues that the way to meet this need is to model a transit research program after the National Cooperative Highway Research Program (NCHRP). Thus, the Transit Cooperative Research Program (TCRP) is being organized, as authorized by the ISTEA Legislation, and TRB is being asked to play a role similar to its role in NCHRP. The American Public Project Selection Committee. TCRP will be funded at about $12M annually, which makes it about the same size as current projections for the NCHRP. The existence of these two programs side-by-side in TRB, with responsive links to the using industries, provides some brand new opportunities for the carrying out of multimodal studies that would have been impossible in the past. With the tremendous problems we are having in planning and implementing urban transportation strategies that effectively deal with air quality, energy concerns and mobility, this joint research resource should, if effectively used, provide a real opportunity to advance our knowledge in this whole field. We must learn how to take advantage of these new resources and use them in effective ways.

For all this new Research Activity, there is one area that remains essentially neglected, and I now refer to our inability, as yet, to effectively engage the private sector in research and innovation. Whenever we talk about research, we usually at some point acknowledge that we must get the private sector more heavily involved if we are to really effect innovation. And we have made some progress. IVHS America is having success in developing a public - private partnership to develop and deploy IVHS technology. Our asphalt contractors have progressed in sponsoring European study tours, setting up a national center for asphalt technology, developing a text book, and jointly sponsoring a TRB prepared hot-mix asphalt handbook, which is being jointly endorsed by AASHTO, FHWA, FAA, U. S. Corps of Engineers, National Asphalt Pavement Institute, American Public Works Association and the National Association of County Engineers. But much remains to be done.

TRB set-up a task force two years ago to work on innovative contracting methods, looking for ways to contract for roads other than the "Low First-Cost Bid" method. This group included people from both the public and private sector and is about to release their report, which advocates large scale experimentation with a variety of contracting instruments, all of which are designed to require the contractor to be responsible from the performance of some or all aspects of the performance for the road- and not just to follow the owner's recipe for the materials and methods. FHWA is much interested in funding demonstrations to see whether this is possible and what contracting instruments work well in our cultural and legal environment.

But there are much greater issues where we can engage the private sector if we can but identify them and find ways to move ahead. Another TRB task force under the chairmanship of John Gray, NAPA, has been working for about a year on some of these other issues. While it's too early to know where they will end up, they are examining ways to develop product testing centers, way of funding private sector sponsored research, and ways of conducting joint training. One result of this task force, is that TRB will hold a major seminar during CONEXPO at Las Vegas in March 1993, displaying SHRP products that the private sector should know about. One may be critical of public sector activities at Las Vegas, but more than 100,000 private sector contractors will be there, and if we want to communicate with them, then we must go where they are. This meeting may also be an opportunity for some public sector types to see the greatest collection of high-tech construction and maintenance equipment that can be found anywhere, while attending a TRB meeting.

During my tenure as chairman of TRB, I have had the opportunity to preside over the development of the first TRB Strategic Plan. Some of the items I have discussed are part of that plan, but there is much more, including a stronger international outreach-something that we must all do as part of the research build-up, since a lot of the technology we need exists in other countries.

In Conclusion, let me list the points I believe make a difference in promoting opportunities for innovation in public works Infrastructure:

* Leveraging Advanced Technology
* Multidisciplinary Teaming
* Public-Private or government-Industry (& Academia) Partnering
* International Networking

- Creative Engineering Degree Programs
- Influencing Change in Institutional Arrangements
- Promote Risk Taking or Those who Embrace Risk
- Commitment to Productivity
- Leadership at all Levels

Thank you

Technological Advances and Public Works: A Synergistic or Antagonistic Relationship

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ABSTRACT

Barriers to the use of public works as a vehicle for making technical advances are discussed with particular emphasis on identification of the policy issues that must be addressed in order to make such implementation a synergistic rather than an antagonistic relationship. The political process systematically introduces societal factors into the formulation of policies for the creation of public works. But as more people and organizations become involved in translating those policies into realities the issues that must be addressed become increasingly technical and recognition of the importance of societal factors in the process diminishes. Societal considerations are supplanted by permitting processes with gatekeepers, and prescriptive codes and standards with rigid interpreters. Ostensibly the aim of those gatekeepers and interpreters is to achieve a quality product but in actuality the result is a stifling of innovation and the creation of adversarial relationships. Continued commitment to societal rather than individual goals, with the gatekeepers and interpreters converted to leaders, is essential to the nurturing of innovation in public works. The need for government, private industry, and academia partnerships for the development of an effective construction technology advancement program is demonstrated by comparing similar construction technology advancement programs in Japan and the U.S.A.

INTRODUCTION

The ability to utilize public works as a vehicle for making technological advances is closely linked to both the policy makers', and the experts', experience with such a process. Such experience is almost totally lacking in the public works sector in this country. Contracting and permitting practices, ostensibly established in the public's best interests to hold down costs and insure a quality product, mitigate against technological advances during public works. Existing processes frequently penalize innovation and create adversarial relationships. By contrast, in the public works sector in Japan, and for military procurement purposes in this country, there has long been a practice of successfully using key projects as a vehicle for technological advances. Not every project is used in this manner. Usually only "visionary" or high risk projects are used and even then the extent of innovation attempted and who pays for the cost of that attempt, varies from project to project through mutual agreement of all participating parties.

This paper stresses the need for public policy visions to orchestrate our actions. Societal, technological and administrative considerations resulting from examination of that vision should guide the type of research that is conducted, the technology for which proof of concept is sought, the public policies that are implemented. To illustrate the views expressed in this paper, Japanese government policies used to guide the practices of the

Ministry of International Trade and Industry (MITI) and the Ministry of Construction (MOC) are examined. Two case histories of MOC practices are presented, one for development of an automated compaction measuring robot, and the other for precast concrete seismic structural systems (PRESSS). The Japanese policy practices for PRESSS are contrasted directly with the US policy practices for the coordinated US PRESSS program. The expected differences in outcomes are highlighted in order to suggest the changes in US attitudes and practices needed to develop a synergistic relationship between public works programs and construction technology advances.

To achieve technical innovations risks must be taken and the basic issues are who should pay if the innovation is not successful and who should benefit if the innovation is successful. A synergistic relationship for public works activities and innovation requires a commitment to the innovation vision and process, and not to their own self interests, by all who are part of the process or stand to benefit from that process: government, academia, consultants, contractors and society.

THE CIVIL ENGINEERING PROCESS

Technology advances are essential to economic growth and current thinking ties growth primarily to manufacturing output. Yet, effective and efficient constructed facilities are essential for quality manufacturing and are, in essence, the foundation on which the technology of our society is built. The importance of the quality and efficiency of constructed facilities is clearly illustrated by their loss as a result of a natural disaster. That loss disrupts society and requires an expensive emergency response. The quality and efficiency of such facilities affects directly the way society does its business and consequently that quality and efficiency contributes directly to society's long term well being.

The achievement of technological advances requires simultaneous investment in both research and development (R&D) activities and in education, and success stimulates increased investments in R&D activities and education. Thus, the involvement of higher education professionals in technology advancement activities is essential to the achievement of such advances. However, in the short term, technological advances are more dependent on proof of the technological concept and its implementation in a few key cases in practice than on a healthy basic research program. In science improvements come primarily from breakthroughs, but for technology improvements are usually incremental with as much knowledge often gained from field failures as from field successes. The systematic collection, analysis, and interpretation of the consequences of attempting to implement technological advances is fundamental to the development of both successful technological advances and to the development of relevant public policies that facilitate technological advances.

Shown in Fig. 1 is an idealization of the civil engineering process for a typical public works project. The project starts with a societal need which in itself must be clearly identified. Certain public works concepts that are responsive to that society need are then suggested by public authorities. From that stage onwards the public policy issues diminish in significance and the technical issues, along with administrative (permitting) and budgetary issues, increase in significance. Predictably any technical constraints are dictated by the limits of existing technologies and those limits can be changes only by developing a new technology. Conceivably, that is possible if there is a reservoir of basic research that can be tapped to develop that new technology and thus alter the original concept, within the time period when the concept is translated into actual design documents. Clearly, the most effective concept improvements and the greatest cost savings are reaped from technical advances when those advances, as indicated by route A in Fig. 1, are made an integral part of the initial design concept. The judgement of the effectiveness of those advances should not be made solely in terms of their impact on the initial concept but in terms of their impact on the totality of the civil engineering process which should include not only design and construction considerations but also operation, maintenance and repair considerations. Further the evaluation should not be made simply in terms of budgetary considerations but also in terms of the degree to which the societal need has been satisfied and the technology of society advanced.

From Fig. 1 it is apparent that while introduction of a gatekeeper operation between the design and construction phases may be able to hold down costs is also effectively prohibits technology development, if as illustrated by route B, that technology development requires certain actions during construction that no bidder on the project is qualified to perform. Further the same can be said for other gatekeeper operations introduced between the construction, operation, etc., phases of the project if certain technology development practices, as illustrated by route C, are essential to the success of that operation. The extreme fragmentation of processes in the construction industry, as currently exists in the U.S.A., in general lowers initial costs and develops firms with great depths of knowledge in a given specialty. However, society is also paying an additional long term price for those short term gains. The process stifles technological advances which society must pay for separately if it is to maintain a technologically competitive construction industry. The long term price to society is least if the industrial participants have operations vertically integrated throughout the whole cycle of Fig. 1 since that participant can then reap the greatest benefits from any investments made in basic research and technology development.

THE IMPACT OF SOCIETAL ENVIRONMENT ON TECHNOLOGICAL CHANGE

The problems of today are often the result of yesterday's solutions. One obvious example is the need to develop new technologies to clean up the hazardous wastes created by the development of the nation's nuclear arsenal. Unless society attempts continuously to improve its economic well-being through the creation of new wealth it can do little to correct the problems caused by yesterday's solutions.

Shown in Table 1 is a simplistic listing of determinants of a nation's economic well-being(1). In the old system, land mass and its associated natural resources, population size, military prowess, and available capital were considered the determinants. By contrast, for the current global economy the determinants seem to have become the society's level of technology, the skills of its population, the capital investment choices it has made and is willing to make, the stability of its political environment and the societal infrastructure. The latter is best described as the way society gets its business done socially and physically. Obviously the civil works infrastructure of the nation is a major determinant of economic well being in the new system.

Technological innovation is a key factor in wealth creation and therefore the establishment of policies that successfully encourage technological innovation should be the aim of government. The factors that drive technological innovation are many and complex and include, in addition to technical factors: economic and financial; political and legal; and cultural, educational and societal factors. The incentive to invest in a different construction procedure depends on the cost of resources and the probability of return. Public policies strongly influence both those factors. Technological change brings with it uncertainty and investors in changes which are deemed to be in the public interest must have an opportunity to profit from them if there is to be wealth creation.

The cultural, educational and social foundations of a nation are intangible assets that can be catalyzed by industry or government to either spur or retard technological innovation. In Japan, the government's technology innovation process for all ministries is built on that premise. As shown in Fig. 2 the Ministry of International Trade and Industry (MITI) assumes for its technology development policy that there is a cyclical relationship between external factors, internal factors, and technological innovation(2),(4). When appropriate external circumstances threaten the community, then as shown in Fig. 3, the proper policy systems can make that relationship self-fermenting.

In Fig. 2, the external factors include the social and cultural environment, the economic environment, and the physical and natural environment, (which to the Japanese way of thinking includes energy). Internal factors refer to the R&D environment within a given company with the government providing qualitative input through its judgment of whether the company has met certain technological qualification standards, and the company providing quantitative input by means of their R&D expenditures and the technologies they import. With that input the proper machinery, (the government's R&D policy systems), can generate significant output that can be measured in terms of the improvement in the technological level, patents, etc. That improvement in the technological level then changes the external environment, and the cycle continues.

In Fig. 3 the same process is represented differently with the external factors decompossed into two parts, a social and cultural foundation, and an economic environment. The factors considered important in the foundation are: the level of education and diligence of the workers; and the systems and customs of society and management. The economic environment includes the severity of competition in the private sector, in terms of the quality demands of the consumer, the extent of interactions between different industries, and the relation between investments in R&D and structural changes within the industry.

It is MITI's experience that appropriate government policies and administrative measures, combined with relatively small governmental financial investments, can spur major R&D efforts and technology innovation by industry in response to a clearly identifiable social need or society threat. Typical government policies are the selection of goals through the development of white papers that define the critical technologies on which efforts should be concentrated, clarification of the appropriate building blocks for those technologies through the formulation of visions utilizing those technologies, and the implementation of a series of administrative measures that stimulate R&D activities in the directions indicated by those visions. The administrative measures include governmental guidance in the form of laws, regulations, tax incentives, etc.; coordination among the different planning divisions of the Ministry of the activities associated with that vision; and the development of specific programs to stimulate the diffusion of knowledge to all working on the vision. Success of the policy measures requires close cooperation with, and consistency with other government agency industry related policies; a flexible approach to organizing R&D activities; catalytic use of governmental, including academic, research laboratories; and the establishment of partnership activities between industry, academia, and government.

For the model of Fig. 3 there are two elements that have little significance for the current Japanese economic environment but strong influences in the current U.S. economic environment. Those elements are shown in boxes in the economic environment box of Fig. 3 and are liability costs, and capital investment incentives expressed as the cost of capital and the probability of return.

In Japan, the Ministry of Construction uses the model of Fig. 3 to provide leadership for technology innovation in construction by coupling innovation and regulatory policy, thus reducing the liability of the contractor authorized to use an innovative technology. By contrast, the current U.S. situation discourages innovation. Liability is a major consideration and the regulatory requirement common in public works of mandatory acceptance of the lowest responsible bid has lead to increasing separation of the design and construction processes on both public and private works, and, often, the preordaining for public works of a confrontational relationship between contractor and owner.

THE IMPORTANCE OF INVOLVING THE CONTRACTOR

The organization of a society, and particularly the role of the major contractors in that society, affects strongly the transfer of research into practice for constructed facilities. The major current concerns of the construction industry, in the U.S., Japan, and Europe are the same: the increasing age of skilled workers in construction, compared to workers in others industries; and a stagnant or decreasing productivity per worker. Construction is dirty, difficult and dangerous. The construction industry could benefit markedly from advances in robotics; in aesthetically acceptable automation-oriented structural and cladding systems; and in computer integrated procedures.

The profiles of the construction industry in Japan and the U.S. are very similar with the six largest firms in both countries handling about 10 percent of the total market, and the top 0.3 percent of the total number of contractors holding about 35 percent of the total market. Yet in Japan the six largest contractors spend an average of 1 percent of sales, about 60 percent of their net profits, on R&D. The six largest U.S. contractors spend only about 0.04 percent of sales on R&D. The amount spent on construction R&D in Japan by contractors is more than double that spent by their government. The amount spent on construction R&D in the U.S.A. by contractors is about one seventh of that spent by the government. Lack of capital and appropriate human resources, competing business priorities, conflicting government policies, a lack of incentives and particularly liability issues, are major factors causing this low level of R&D expenditures in the U.S.A. The amount U.S. contractors spend on liability is a magnitude greater than the amount they spend on R&D, and they confine their R&D activities to actions that do not increase their liability exposure.

For the large Japanese contractor investment in R&D is necessary for three reasons: (1) for the firm to be judged socially responsible, otherwise it cannot survive financially; (2) for design-build activities, since major clients choose contractors, and the government pre-qualifies contractors for public works, based on demonstrated expertise in new technologies; and (3) for improvements in job site activities. Essentially for U.S. firms only the last incentive exists currently.

The introduction of new technologies into construction practice in Japan is very difficult with the government using that difficulty to spur R&D expenditures. The situation is equivalent to a U.S. Government Department, such as Labor or Commerce, controlling what appears in the Uniform Building Code (UBC)(3); delaying revisions to UBC until the technology has been widely proven for some time in practice; selecting contractors for public works based on their level of technological achievement; and routinely requiring extensive laboratory and field tests, and participation in collaborative research activities with other contractors of similar technological achievement, if they wish to introduce a new technology. In Japan before a new technology can be used in practice, a recommendation for approval must be received from an independent technical committee that oversees that testing. The Japanese government uses essentially the same process, catalyzed by varying degrees of government financial and technical assistance, to foster the development of desirable new construction technologies. The research is planned and executed so that there is a direct transfer of the technology into construction practice, with participating industry partners being assured of one of more government construction projects that use that technology as part of the reward for their participation.

The Japanese Ministry of Construction (MOC) uses MITI's vision system, combined with a complex new technology approval system, to steer construction research in directions it desires while simultaneously accomplishing technology transfer. The approval system for introducing new technologies into public works projects is illustrated in Fig. 4 and an example of its use for the development of a compaction measuring robot by Mitsui Construction Company in shown in Table 2.

In 1983 the MOC established a goal of developing measures to increase both construction productivity and quality. Its vision for such increases involved the use of electronics based automated systems. The MOC issued a request for proposals, step 1 of Fig. 4, for such systems. To evaluate the resulting proposals, step 3 of Fig. 4, the MOC had the Public Works Research Center (PWRC) form a proposal Evaluation Committee. The PWRC is a neutral professional organization which in the U.S. would be analogous to the American Society of Civil Engineers (ASCE). Evaluation committees have an almost equal balance of academics and industry professionals and both must have appropriate experience in the area of the submission. In the example, the private enterprise, (Mitsui Construction), proposed that it develop a soil compaction measuring robot. In its application Mitsui identified the technology advances needed for the robot's development and the solutions it proposed to achieve those advances. In 1984 the PWRC Evaluation Committee recommended to the MOC, step 4, limited approval of Mitsui proposal. The PWRC committee identified specifically the solutions for which it recommended research funding. The Public Works Research Institute, located in Tsukuba, contains the principal laboratories, and public works researchers, of the MOC. Within that Institute the MOC formed an Examination committee for the Mitsui project. Typically some MOC researchers are members of both the Evaluation and Examination committees. The MOC Examination Committee agreed that research support was appropriate for four study areas: travel control; position identification; measurement of the degree of compaction; and communication and display. The Examination Committee conveyed its findings, step 5, to the PWRC asking it to form a Project Evaluation Committee and inform Mitsui that it would provide funding for the project stages of step 5 in Table 2. The MOC and Mitsui then signed a research agreement and Mitsui, and its sub-contractors, commenced work.

The features and function of the robot developed by Mitsui are summarized in Table 3. By 1987 Mitsui had satisfied all the concerns of the PWRC Evaluation Committee with regard to the reliability and specified features of the robot and therefore that Committee forwarded a final examination report recommending approval of use of the robot to MOC. Before issuing a certificate for use of a new technology the MOC must demonstrate publicly the reliability of that system. Typically that demonstration is through the letting to the applicant of a contract for a specific job using that system. In 1988 MOC let a contract to Mitsui for a public works project during which Mitsui demonstrated that the robot had features satisfying the initial objectives of the project. The MOC then issued a certificate, step 11 of Fig. 4, for use of the robot.

The construction research community has three major constituencies: private industry, including both contractors and consultants; government; and academia. The Japanese experience suggests that technology advancement works best, and the benefits to society are greatest, when all three constituencies are active contributors to an R&D program with specific objectives. When the three major constituencies work alone, private industry does research for profit and therefore their research activities become minimal. The government bifurcates with the legislative arm trying to exercise leadership by passing laws, and the executive arm, typified in the U.S.A. by the National Institute of Standards and Technology (NIST), conducting research to protect the safety of the public and prove the societal value of the new technology. The government products become dictums and reports. Academia retreats to its ivory tower and does research in a search for truth with their findings eventually published in papers. The feedback to academia from practice is minimal and the potential for using academia's idealism to improve the level of technology is seriously impeded. All three constituencies of the Japanese construction community participate in joint technology advancement research activities. The advancement achieved by that team effort is considerably more than that resulting from each constituency acting alone. The Japanese contractor is a partner in such efforts because: 1) partnering is necessary for prequalification on government jobs, such as the Kansai airport; 2) the public then judges them socially responsible and the private sector provides them with the more profitable design-build jobs; and 3) participation reduces their liability in using that technology. Because of partnerships, government agencies frequently have contractor employees assisting in their institutes, such as the PWRI. The government agencies role in the partnership then becomes threefold: 1) to decide fundamental research policies including the subjects that should be addressed; 2) the degree of assistance, financial and technical to be provided from government sources; and 3) the administrative guidance appropriate for insuring public safety in the transfer of research into practice. Through this leadership the government's strategic planning and program quality management abilities are enhanced. Academia's role in the partnership is twofold: 1) the undertaking of the basic research needed to achieve the partnership's objective; and 2) participation in, and also leadership of, the technical committees steering the research and appraising its quality for government approval. Thus, academia obtains real life experience relevant to its understanding of the construction and management of a process from its conceptual planning through design, execution and maintenance. The result is more effective, and more society and construction community relevant, education at universities.

A COMPARISON OF JAPANESE AND U.S. CONSTRUCTION TECHNOLOGY ADVANCEMENT MEASURES

The effectiveness and efficiency of the Japanese partnering process for the transfer of R&D into practice, compared with the situation in the U.S.A., can be demonstrated by a comparison of the advances in the two nations resulting from 12 years of cooperative research into the seismic resistance of buildings. In 1978, as part of the U.S.-Japan government program on natural resources (UJNR), collaborative research was initiated on the large scale testing of buildings. The program is funded on the Japanese side by the MOC. On the U.S. side funding is provided by the National Science Foundation (NSF) and administrative oversight is by NIST. Originally this program was a joint activity with sub-assemblage testing and analysis performed both in the U.S. and Japan, and five story large scale structures tested at the Building Research Institute (BRI) in Japan. The first two programs were on reinforced concrete and steel buildings. After evaluating the return on its investment for those first two projects, and particularly the degree to which results were implemented in practice, the U.S. government concluded that the benefits to the U.S.A. of this joint program were inadequate and subsequent work on masonry and precast concrete structures has involved collaborative, parallel programs, rather than joint programs. However, the difficulty lies not in the basic research content of the U.S. work, since the Japanese continue to look to the U.S. side for technical innovation even in the parallel programs, but in who is in the research partnership on the two sides. The results show that participation of contractors is essential for the rapid transfer of any technology developed into practice.

Case History - U.S.-Japan Program on Precast Structural Seismic Systems

The UJNR project on precast/prestressed concrete seismic structural systems was initiated in Fall 1990. Figure 5 summarizes the parallel Japanese and U.S. plans, including the reasons reported by each side for undertaking the research, the immediate objectives of each side, the time for completion and the cash funding. The U.S. plan is only the first phase of a multi-phase program. It involves more basic work than the Japanese plan, has as an objective a major increment in technology, and after three years and a cash expenditure of about 45 percent of that of the Japanese side, anticipates having as a product a plan recommending an extensive test program to validate the technology concepts it has developed. By contrast, the Japanese plan is technology transfer oriented from objectives through to report recipient. After four years and a cash expenditure by the Japanese government of only about 40 percent more than that of the U.S. government the Japanese will have an incremental advance in technology in place that is widely accepted, and probably that advance in technology will foster increased construction productivity.

The financing and management of Japan PRESSS is shown in detail in Fig. 6. The Japanese plan involves almost equal partnering and effort by government, contractors, and others. The "vision" for the project is MOC's 1988-92 emphasis on increased construction productivity and automation of which Japan PRESSS is part. Challenge funding is provided by MOC with the Building Research Institute (BRI), the equivalent for buildings of the PWRI, contributing effort to the basic research and management of the project. The academy group, (academia), performs basic research using the general project funding and participates in, and provides leadership to, the technical coordinating committee and the research promotion panel, organized by a neutral agency, the Building Center of Japan (BCJ), the equivalent for buildings of the PWRC. A total of 35 contractors with engineering organizations, and most with their own R&D laboratories, have joined the effort. For that privilege they each provide ¥1 million per year to the Building Contractors Society of Japan, which retains ¥5 million per year and contributes the rest to the project. In addition the contractors have formed groups to test specific details that will meet the generic conditions established by the technical coordinating committee. Representatives from each contractor group participate in the two working groups. The precast concrete industry, PCa, as in the U.S.A., is independent of the engineering contractors and is contributing independently to the Japanese activities. They also participate in the working groups and in test activities. The structural consultants, JCSA, are making trial design consistent with the working groups' recommendations, and their contributions are in-kind efforts only.

The outcome of the Japanese plan is that there will be, by 1993, MOC approved manuals for use by consultants and engineering contractors that should insure adequate earthquake resistance for precast concrete structures. Designs conforming to those manuals and using one of the certified systems of the 35 contractors contributing to the program will be automatically approved for construction by every city and prefecture in Japan. Contractors who have not participated in this program will not be able to gain approval to erect systems satisfying the guidelines in those manuals until they have done equivalent testing for their own systems or those design guidelines have been incorporated into standards. Such standards are revised only after a delay of several years.

For contrast the Phase I situation in the U.S.A. is shown in Fig. 7. The U.S. project has five sub-projects, one with a structural consultant and four with universities. Funding is provided primarily by NSF, with limited contributions by the Precast Concrete Institute, PCI, (which represents precast concrete suppliers), the Precast Manufacturers Association of California (PMAC), and varying degrees of in-kind contributions. The project is managed by an Executive Committee consisting of two professors and a consultant. There is advisory input from a Research Panel and an Industry Panel. However, the funding does not permit face to face meetings of those panels. The cash contribution of the precast concrete manufacturers to the project in the U.S.A., relative to the government contribution, is about the same as that in Japan. However, in the U.S. plan there is no active contribution by engineering contractors except in an advisory panel and the structural consultant work is primarily the contribution of one firm. There is no assurance that the results will be acceptable to the American Concrete Institute (ACI), the Structural Engineers Association (SEA), or the International Conference of Building Officials (ICBO), committees that must endorse those findings before they can be accepted into model building codes. Further, even if those results were acceptable there has been little input by which to judge if contractors would find designs in accordance with those results cost-effective to build. Certainly contractors are less likely to take the risk of being the first to use such systems than in Japan, and owners are less likely to want to have their facility constructed from such "unproven" systems.

Participatory cooperation of all sectors of the construction community is necessary for effective research and for its transfer into practice. Participatory cooperation means allocation of funding, personnel and time to the research and its implementation. Participatory cooperation creates a sense of community. It confers on its members an identity, a sense of belonging, a measure of security, and is the ground-level generator of value systems and new skills. Cooperative work on a significant new task strengthens the sense of community, builds commitment, and gives meaning to an individual's life. Participatory cooperation of all sectors of the construction community in research is needed for effective public policies for construction technology advancement.

CONCLUSIONS

If this nation is to develop a dynamic construction technology advancement program greater cooperation is needed between three major construction industry constituencies: government, contractors, and academia.

Greater leadership is needed from all levels of government, federal, state and local, in support of R&D activities for construction. Greater leadership requires the formulation and articulation of constructed facility visions consistent with government's societal goals; identification of the technologies whose development is needed to achieve those visions; development of incentives to reward R&D investments by the private sector in those technologies; fostering of participatory, rather than adversarial, relations between government, academia, and industry; and a willingness to use construction projects for proof of concept demonstrations of new technologies.

Much greater contractor participation is needed in the selection and conduct of R&D activities and in partnering the transfer of outcomes into practice. Such participation requires communication as well as commitment by all constituencies; hardware and human resource involvements as well as a willingness to permit flexibility in their use; a compensation structure that not only rewards contractor participation but also rewards annual increments in contractor commitments; and a research and technology transfer structure that minimizes legal and economic risks for the contractor.

Academia needs to provide greater leadership in the process of achieving consensus on the research directions required for developing new technologies appropriate for the construction, or reconstruction, of facilities. Academia needs also to participate more in construction industry proof of concept and technology transfer activities.

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COMPACTION MEASURING ROBOT

FEATURES:	• No field workers required for robot • Real time analysis and display increases quality of work and productivity of compacting crew
FUNCTIONS:	• Travelling Capacity: Forward, Reverse at 66 ft/min and up to 1 in 10 slope. Left and right steering, spin turn and contact stop. Battery Powered and Computer Controlled. • Dual Position Identification Systems * Automatic navigation system (distance meter, magnetic position, and vibration gyro sensors) mounted on robot that detect distance travelled and direction * Information mats at boundary of work for robot to define boundary and position • Contact Free Compaction Measuring System Determines compaction density from back scatter emissions of gamma ray radiation source, (Co-60), and moisture content from measurement of heat neutrons created by emissions from a fast neutron radiation source, (Cf-252), colliding with the hydrogen of water

TABLE 3 CHARACTERISTICS OF MITSUI SOIL COMPACTION MEASURING ROBOT

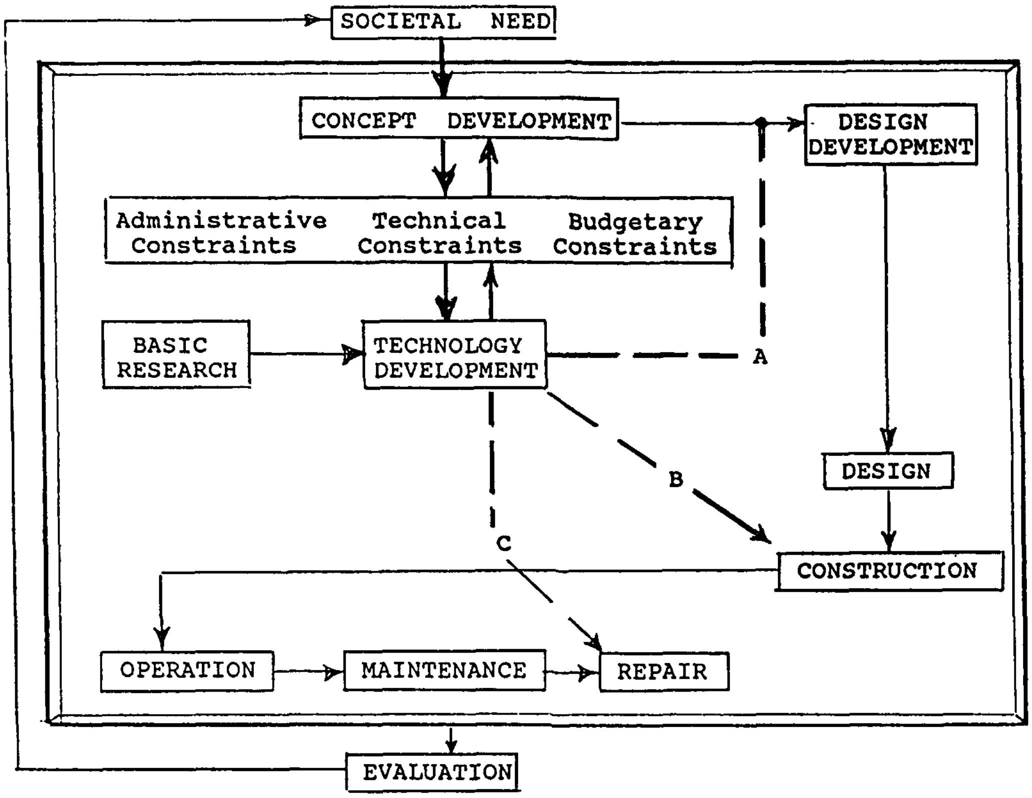
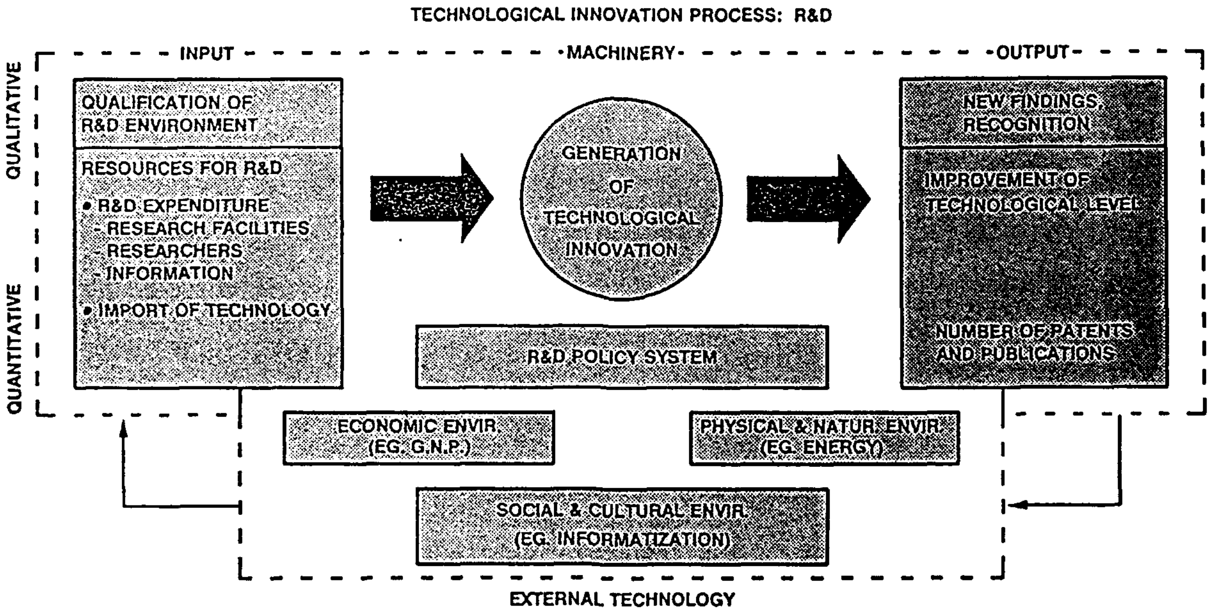


FIG. 1 THE PROCESSES OF CIVIL ENGINEERING



SOURCE: C. WATANABE, "JAPAN INDUSTRIAL SCIENCE AND TECHNOLOGY POLICY", JAPAN AND THE WORLD ECONOMY, ELSEVIER, AMSTERDAM, 1991

FIG. 2 THE JAPANESE MODEL FOR CONVERSION OF INTANGIBLE ASSETS TO TANGIBLE ASSETS

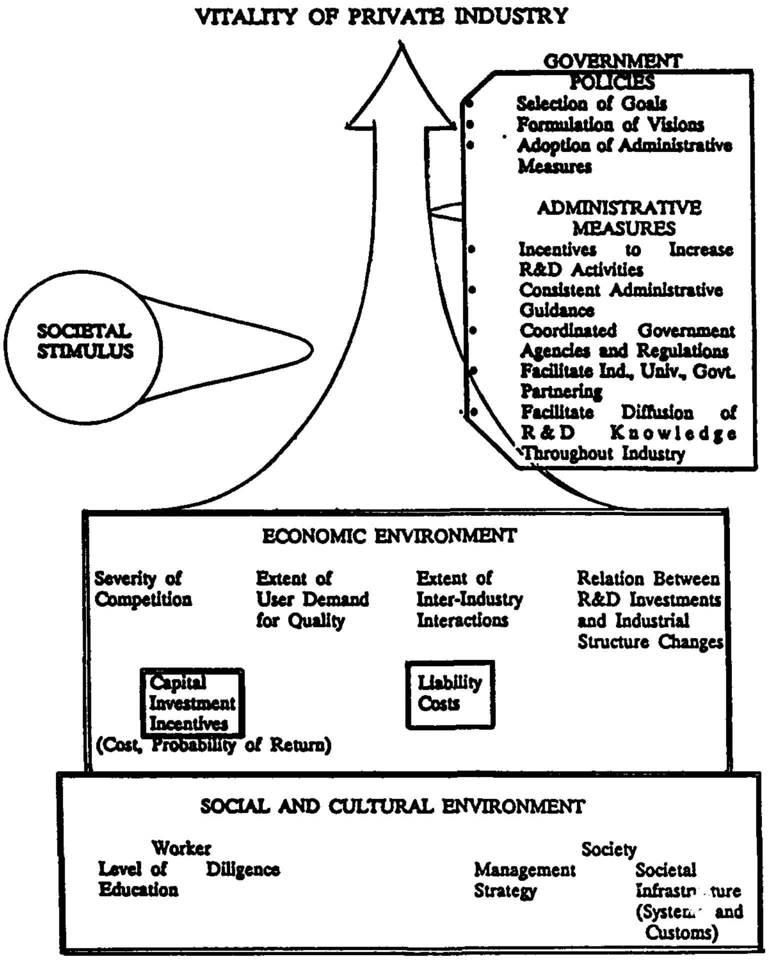


FIG. 3 JAPANESE MODEL FOR INCREASING THE VITALITY OF PRIVATE INDUSTRY

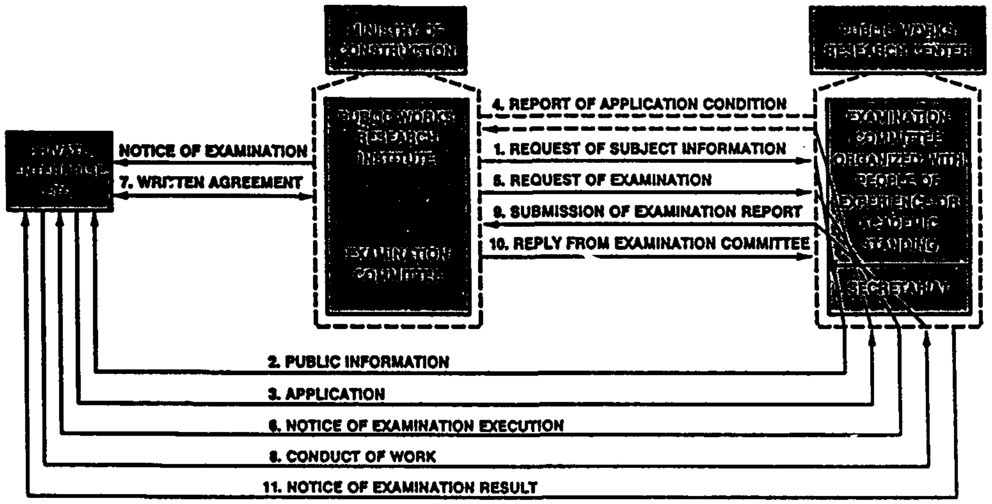


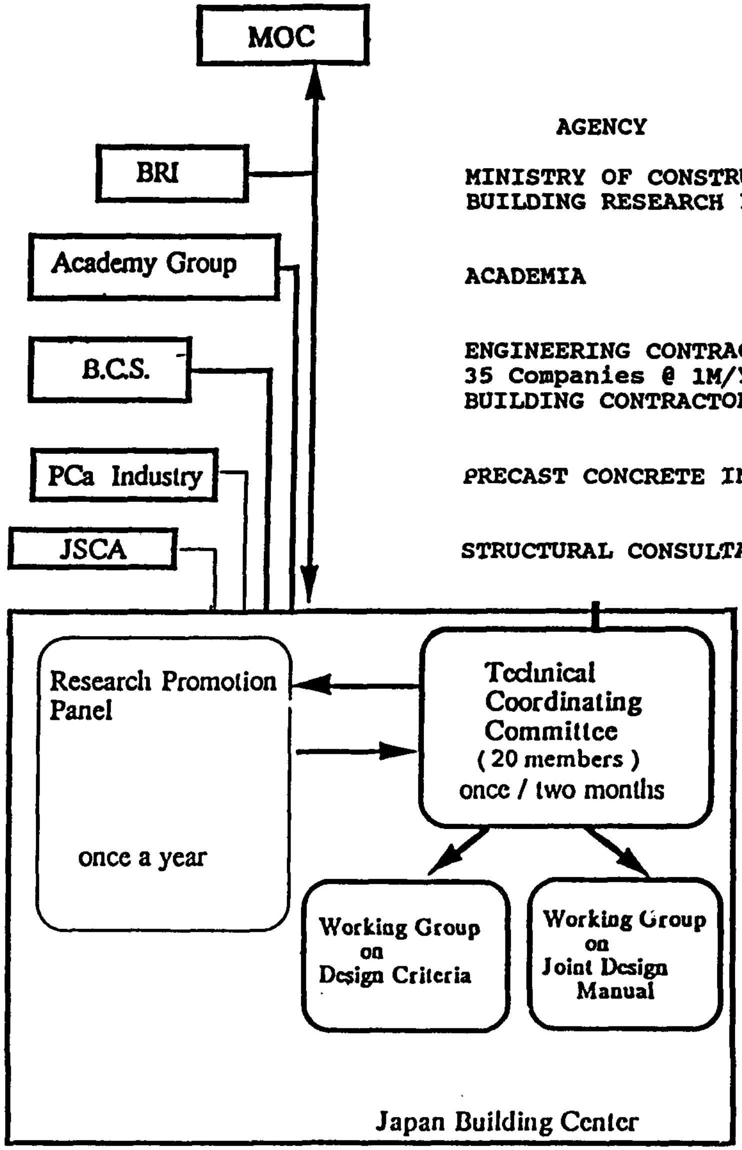
FIG. 4 JAPANESE APPROVAL SYSTEM REQUIRED FOR USE OF NEW TECHNOLOGY IN PUBLIC WORKS

	JAPAN	U.S.A.
* REASONS FOR RESEARCH	1. Need for housing 2. Lack of skilled labor 3. Lack of design standards (JBC screening required)	1. Lack of design standards 2. Lack of skilled labor
* OBJECTIVES	1. Design Guidelines for Precast Concrete Buildings 2. Design Manual for Precast Connections 3. Guidelines for Site Construction and Erection	1. Innovative Building Concepts 2. Connection Classification Modeling 3. Basic Analytical Platform 4. Design Recommendation Platform 5. Coordination
* MANAGEMENT	Ministry of Construction Technical Coordinating Committee	Technical Coordinating Committee
* REPORT RECIPIENT	Japan Building Center	National Science Foundation
* TIME FRAME	1989-1992 (4 years)	1990-1992 (3 years)

CASH FUNDING

JAPAN		U.S.A.	
Government	$1,231,000	Government	$ 890,000
Industry	<u>$1,085,000</u>	Industry	<u>$ 150,000</u>
TOTAL	$2,316,000		$1,040,000

FIG. 5 U.S.-JAPAN COLLABORATIVE RESEARCH ON PRECAST CONCRETE SEISMIC STRUCTURAL SYSTEMS



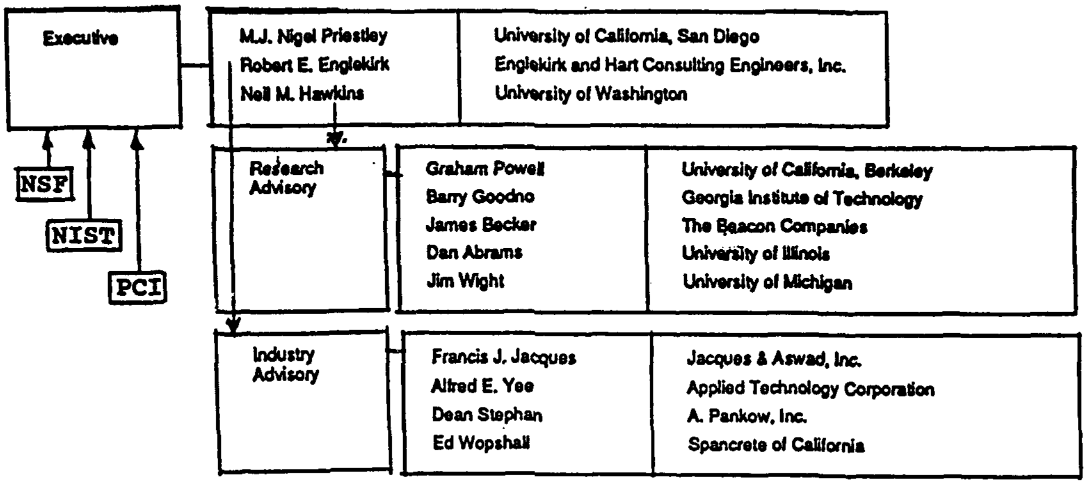
FINANCING in MILLIONS YEN

AGENCY	CASH	CONTRIB.	SUM	%
MINISTRY OF CONSTRUCTION	160		-	
BUILDING RESEARCH INSTITUTE		60	220	31
ACADEMIA		120	120	17
ENGINEERING CONTRACTORS 35 Companies @ 1M/YR to BUILDING CONTRACTORS SOCIETY	120	140	260	37
PRECAST CONCRETE INDUSTRY	21	21	42	6
STRUCTURAL CONSULTANTS		60	60	9
TOTAL	301	401	701	100

BY 1992 THERE WILL BE A MOC APPROVED MANUAL FOR USE BY CONSULTANTS. DESIGNS IN ACCORDANCE WITH THAT MANUAL WILL BE AUTOMATICALLY APPROVED FOR CONSTRUCTION BY MAYORS IF THEY USE ONE OF THE CERTIFIED CONTRACTOR SYSTEMS. CONTRACTORS CAN SUB-LICENSE THEIR SYSTEMS.

FIG. 6 FUNDING SOURCES AND PROJECTS OF JAPANESE PRESSS PROGRAM

U.S. PRESSS PROGRAM



M.J. Nigel Priestley	University of California, San Diego
Robert E. Englekirk	Englekirk and Hart Consulting Engineers, Inc.
Neil M. Hawkins	University of Washington

Graham Powell	University of California, Berkeley
Barry Goodno	Georgia Institute of Technology
James Becker	The Beacon Companies
Dan Abrams	University of Illinois
Jim Wight	University of Michigan

Francis J. Jacques	Jacques & Aswad, Inc.
Alfred E. Yee	Applied Technology Corporation
Dean Stephan	A. Pankow, Inc.
Ed Wopshall	Spancrete of California

FUNDING IN $1000

Project Title	Principal Investigators	CASH			CONT.	SUM	
		NSF	PCI	PMAC			
Conceptual Development for Precast Seismic Structural Systems	Robert Englekirk Susan Dow Nakaki	100	120	30	150	400	
Computer Integrated Manufacturing for Precast Seismic Structural Systems	NOT FUNDED						
Connection Classification and Modeling for Precast Seismic Structural Systems	John F. Stanton Neil M. Hawkins	137			40	177	
Analytical Platform Development	Graham H. Powell Filip C. Filipou	227			40	267	
Prestressed Concrete Materials Modeling	NON FUNDED						
Preliminary Design Recommendations	Gary C. Hart	160			20	180	
Coordination	M.J. Nigel Priestley	266			50	316	
		890	120	30	300	1340	SUM
		67	9	2	22	100	%

PRODUCT WILL BE RESEARCH REPORTS FORWARDED TO NSF, PCI AND OTHER INTERESTED PARTIES. NO FORMAL MECHANISM FOR TRANSFER OF RESEARCH INTO PRACTICE THROUGH ACI OR ICBO ETC. THIS FIRST PHASE OF THE WORK HAS NO NSF FUNDED LABORATORY TESTING

FIG. 7 FUNDING SOURCES AND PROGRAMS OF U.S. PRESSS PHASE I RESEARCH

BARRIERS TO THE ADOPTION OF NEW TECHNOLOGIES[1]

Pete Nowak, Professor, Department of Rural Sociology
University of Wisconsin-Madison

INTRODUCTION

There are a number of complex issues surrounding inducing innovation within the public works infrastructure. A multifarious institutional framework, segmented research and development of new technologies, and a shifting political context that attempts to balance differing interests while striving for effectiveness all occurring in the context of competitive world market. Underlying these complex issues is a rich and diverse research literature on the adoption and diffusion of new technologies. Contributions from many academic disciplines as well as the private sector has given us a fairly good understanding of how new technologies are adopted and diffuse through target populations.

Rather than try and summarize this literature, especially relative to those technologies associated with the public works infrastructure, attention will be given to a review of some research generalizations related to the purpose of this conference. In particular, the focus will be on reasons why individual adoption of a new technology may not occur. Understanding of these reasons needs to be considered in developing opportunities for innovation in the public works infrastructure.

REASONS FOR NON-ADOPTION

Why don't individuals adopt new technologies? Individuals do not adopt new technologies for two basic reasons; they are unable or unwilling. These reasons are not mutually exclusive. Individuals can be able yet unwilling, willing but unable, and of course both unwilling and unable. These may sound like minor semantical distinctions, but the difference between a individual being unwilling or unable is crucial when designing the appropriate remedial strategy. Accelerating the adoption of new technologies must be based on understanding why individuals are rejecting this technology; Are they unable, unwilling, or both?.

Being Unable to Adopt

Being unable to adopt a new technology implies presence of an obstacle or situation where the decision not to adopt is rational and correct. The important point is that the individual may be willing to adopt the system, but for one or more of the following nine reasons is unable to make this decision. Each reason for inability to adopt is followed by a brief summary of the appropriate remedial strategy.

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[1] Presented at the workshop on "Challenges and Opportunities for Innovation in the Public Works Infrastructure," March 3-4, 1992 Champaign, Illinois sponsored by the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory.

1. Information is lacking or scarce. A individual may be unable to adopt a new technology because some of the basic information needed for a sound functional or economic analysis is missing.

Generation and distribution of the needed information to those needing it.

2. Costs of obtaining information are too high. Even in our highly touted information age, the time, expense and difficulty (i.e., transaction costs) of obtaining site-specific information may be too high. Contrary to common belief, obtaining relevant information is not free to the individual. Too high of a cost and the individual will be unable to adopt.

Reduce the costs of obtaining needed information by increasing accessibility.

3. Complexity of the system is too great. A defining characteristics of any new technology is its simplicity or ease of use. There is an extensive research literature that shows the complexity of a technology is inversely related to the rate and degree of adoption. New technologies that are too complex make some individuals unable to adopt this technology.

Re-design or simplify the technology.

4. Too expensive of a new technology. Investment, operating costs and influence on net returns are major concerns of today's public and commercial sector. Designing a technology that is technically sound but has too high of a price tag will make many individuals unable to adopt.

Subsidize the adoption decision or re-design a less expensive system.

5. Labor or management requirements that are considered to be excessive. If the labor or management requirements associated with a new technology are perceived to be too high relative to the capabilities of the adopting unit, then the decision maker will be unable to adopt.

Re-design or package the new technology to reduce labor or management requirements, or subsidize the hiring of adequate labor or the training of managerial staff.

6. Planning horizon is too short. A new technology may be rejected by a decision maker because of the current planning horizon relative to the time associated with recouping initial investments, learning costs or depreciation of the present technology. Asking individuals to make a what might be a major investment within the context of a short planning horizon will result in their being unable to adopt.

Re-design the technology or subsidize a short-term unprofitable decision.

7. Availability and accessibility of supporting resources is limited. Few individuals adopt

innovative new technologies without significant support. This support can take the form of local businesses willing to take the risk of investing in technologies or services not currently being used in their market areas, other individuals using new technologies who are willing to share both successes and failures, and a information and assistance network capable of answering individual questions. The lack of any one of these could be the obstacle that creates a situation where a individual is unable to adopt.

Build the capacity of local assistance networks to meet local demands. Target the development of local assistance networks in the areas needing them the most. Develop methods to sell new technologies on the basis of need, not ability to pay or ease of sales.

8. Inadequate managerial skills. One dimension of diversity among target audiences is managerial skill. Too often new technologies are only designed for the above-average manager. This can create a situation where individuals with less-than-average management capabilities receive little or no assistance to build these skills. These individuals will then make the correct decision in rejecting the new technology due to a lack of requisite managerial skills or the opportunity to develop them.

Focus assistance and management enhancing opportunities on those individuals needing it the most, not just the most receptive.

9. Little or no control over the adoption decision. It is common to view a particular decision maker as some independent being who "calls all the shots" within a public or private sector organization. This individual, therefore, becomes the focal point of most efforts to promote new technologies. In many situations, however, a decision cannot be made without the approval of a executive board, partner, sources of financial credit, or even a public referendum. If these other interests are not convinced of the merits of the new technology, then the individual will be unable to adopt.

Determine who or the process associated with making the adoption decision, and then focus efforts on those persons or organizations.

Being Unwilling to Adopt

A individual may also be unwilling to adopt a new technology. This implies that the individual has not been persuaded that the new technology will work or is appropriate for intended setting. There are seven reasons for being unwilling to adopt.

1. Information conflicts or inconsistency. A individual may be unwilling to adopt a new technology because of inconsistency or even outright conflicts in the information about the technology. For example, an individual may hear that a new technology always requires more maintenance, may require more maintenance, or hears about the experiences of another local organization where the claim is that the technology requires less maintenance. This individual will often remain unwilling to adopt until these divergent messages become more consistent.

Work to develop a consistent information base. Where legitimate differences *exist, offer explanations of these differences.*

2. Poor applicability and relevance of information. In order to make a sound decision, individuals need information that is applicable and relevant to their situation. Data from a neighboring state or even across the county may be judged as not meeting local conditions. Until this data is adapted and made available relative to local situations, the individual will remain unwilling to adopt.

   Generate and distribute relevant information on a local basis.

3. Conflicts between current goals and the new technology. New technologies do not always easily fit into the existing infrastructure or support systems. In these cases the general expectation is that the adopting unit will adapt their situation in order to meet the adoption requirements of the new technology. The individual may be unwilling if it is felt that too much adaptation is required for adoption.

   Development of flexible new technologies capable of being altered to meet unique local conditions.

4. Ignorance on the part of the individual or promoter of the technology. Ignorance is not a pejorative term. Instead, it implies a situation where an individual has not had the opportunity to learn. This ignorance could be surrounding the basic economic and operating facts of a new technology, or for promoters of new technologies it could be a lack of sensitivity to the basic needs of a potential adopter. Regardless of the reason, the outcome of this ignorance is the same; the individual will remain unwilling to adopt.

   Determine the actual, not assumed, assistance needs and knowledge levels of potential adopters relative to those factors critical to adoption. Then design education and assistance programs based on individual needs, not agency or business expertise.

5. Practice is inappropriate for the setting. Another situation is where the individual is expected to adopt a new technology that may be deemed inappropriate for the current infrastructure. Some individuals recognizing this incompatibility remain unwilling to adopt.

   Specify the applicability of each new technology, or design the technology to be more adaptable to different institutional settings.

6. Practice increases uncertainty or risk of negative outcomes. A new technology may increase the probability of a negative outcome in many ways. The complexity of a system, importance of the timeliness of operations, and the interdependence of inputs can all increase perceived or real uncertainty and risk. Some individuals are simply unwilling to make a major decision under conditions of uncertainty, or where there is significant risk.

   Uncertainty can be addressed in two basic ways: either increase information so probabilistic outcomes can be calculated, or subsidize the individual to take a risk.

7. Belief in the traditional technology. Although we often scorn beliefs in traditional technologies, let us not forget that those "traditional" technologies often continue to survive in today's competitive environment. Some individuals are unwilling to change because those traditional technologies represent the least risk in a dynamic economic climate.

Demonstrating that a new technology is not only better than the old way, but also that the new technology does not increase risk.

CONCLUSION

One can make at least two general observations from the foregoing lists of why individuals are either unable or unwilling to adopt new technologies. First, many of the factors causing individuals to be unable or unwilling to adopt are beyond their control. Blaming the individual for not adopting a new technology is not only erroneous in many cases, it is also hypocritical. Instead of always focusing on the individual, more attention needs to be given to our efforts in understanding and addressing the many reasons why individuals are unwilling or unable to adopt. In many cases non-adoption is not so much a "individual failure" as it is a "system failure".

Second, broad-scale use of any one or even several of the remedial strategies suggested is doomed to failure. A "shotgun" approach in using technical, financial, or educational assistance is not the answer. Instead, considerable more effort needs to be spent trying to understand the reasons why an individual may be unable or unwilling to adopt. Based on that understanding, one must be able to deliver the specific type of assistance the individual needs in a format compatible with their capabilities. If we want accelerated rates of adoption for a new technology, then we must be as willing to accept new ideas and methods as we are expecting from potential adopters.

Inducing innovation within the public works infrastructure as part of a technology transfer process is complex. While much of the attention is often focused on the complexity of the technologies themselves, it is critical to also recognize the complexity of the social, economic and institutional environment in which these technologies are introduced. This brief paper has tried to present the perspective of a layperson on this complexity while focusing on the individual. Yet organizations also make adoption decisions. In fact, relative to public infrastructure innovations, many of the adoption decisions are made by organizations. This adds another layer of complexity to the process that needs to be summarized and translated into layperson terminology at another time.

WORKSHOP

CHALLENGES AND OPPORTUNITIES FOR INNOVATION IN PUBLIC WORKS INFRASTRUCTURE

CONSTRUCTION ENGINEERING RESEARCH LABORATORY

MARCH, 1992

FACTORS INFLUENCING TECHNOLOGY TRANSFER TO LOCAL PUBLIC WORKS AGENCIES

by

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The APWA Research Foundation has conducted several studies over the past year to identify factors which bear upon the acceptance by local public works organizations of innovation and new technology. This paper will review some of the pertinent findings which must be kept in mind as one seeks to induce local public works officials to consider adoption of innovation or new technologies.

Three general characteristics of public works officials are apparent. Public Works officials are:

1. Very conservative
2. Non-risk takers
3. Find little reward for innovation except their professional pride

The first two factors also generally are characteristics of consulting engineers serving local government as well as the state and federal regulatory agencies who may have to approve the use of an innovation process. Nevertheless, we have found that usually local public works officials believe that they can obtain permission to use/construct new products or techniques if they are personally convinced of its merit. However, public works officials do not want to be first to use/construct. They desire the opportunity to observe demonstrations and have peer evaluations. They have little interest or faith in "Black Boxes."

In 1974, for the National Science Foundation, APWA conducted a study which resulted in the publication of Dynamic Technology Transfer and Utilization. Public works officials indicated the following major influences (not necessarily barriers) to technology transfer:

1. Needs/objectives of the Agency. There must be a problem to be addressed rather than a solution looking for a problem.
2. Communications. The information available about the innovation must be available in sufficient detail and verified by reliable sources.
3. Finances. The innovation must be within the means of the agency to purchase and operate.
4. Regulations. The innovation must meet applicable state and federal regulations. It should be noted that health and safety regulators are as a class very conservative and that extensive testing and multiple demonstration projects may be required before acceptance.
5. Physical. The size or nature of the innovation in the case of equipment generally must be capable of installation within existing situations or property owned by the agencies.
6. Personnel. Operation of the new technology must be such that existing personnel can safely operate and maintain it.
7. Administration. Purchasing regulations must allow sole-source acquisition.

Table 1, *Ranking of Agencies or Groups Helpful in Adopting New Technologies,* is a ranking of the major groups reported as being used by public works officials in deciding whether or not they would consider use of a new technology experience shared at conferences and through informal networks are particularly important.

TABLE 1
Ranking of Agencies or Groups Helpful in Adopting New Technologies

1. OTHER PUBLIC WORKS PRACTITIONERS
2. MANUFACTURERS
3. PROFESSIONAL ORGANIZATIONS AND ASSOCIATIONS
4. CONSULTANTS
5. STATE GOVERNMENTS
6. FEDERAL GOVERNMENT PROGRAMS
7. UNIVERSITIES AND COLLEGES

As show in **Table 2,** *Ranking of Public Works Functional Areas by Relative Ease of Technology Application,* public works officials have firm perceptions concerning the interest areas in which new technology may be considered. The ranking of water resources, transportation and solid wastes at the bottom of the list may well reflect the controls exerted by state and federal regulatory and funding agencies.

TABLE 2
Ranking of Public Works Functional Areas by Relative Ease of Technology Application

1. MUNICIPAL ENGINEERING
2. PUBLIC WORKS ADMINISTRATIVE MANAGEMENT
3. BUILDINGS AND GROUNDS
4. EQUIPMENT SERVICES
5. WATER RESOURCES
6. TRANSPORTATION
7. SOLID WASTES

Table 3, *Influences to Public Works Technological Decision Making,* lists the 26 influences cited by public works officials having a potential impact on their decision to adopt or reject the use of a new technology. One or more factors may drive the decision making process.

TABLE 3
Influences to Public Works Technology Decision-Making

1. RULES, REGULATIONS, & LAWS BY HIGHER LEVELS OF GOVERNMENT
2. JURISDICTIONAL LIMITS
3. INTERJURISDICTIONAL SERVICE AGREEMENTS
4. LOCAL CODES AND STANDARDS
5. COMPETITIVE BIDDING, SPECIFICATIONS AND PURCHASING POLICIES
6. SHARED FUNCTIONS AMONG DIFFERENT LEVEL JURISDICTIONS
7. PUBLIC SUPPORT AND INTEREST
8. DEGREE OF POLITICAL RISK
9. TIMELINESS WITH RESPECT TO THE POLITICAL PROCESS
10. LOCAL INTEREST GROUPS
11. ADEQUACY OF APPLICABLE RESEARCH LEVELS
12. LEVELS OF SERVICE TO THE PUBLIC
13. CIVIL SERVICE OR PERSONNEL POLICIES
14. LOCAL GOVERNMENT FINANCIAL POLICIES
15. EMPLOYEE UNIONS
16. EMPLOYEE ACCEPTANCE
17. EMPLOYEE TRAINING
18. CLIMATE, TOPOGRAPHY AND OTHER PHYSICAL FACTORS
19. ADEQUACY OF EXISTING PROCESS, EQUIPMENT AND FACILITIES
20. NUMBER OF PERSONNEL AND SKILLS AVAILABLE
21. BUREAUCRATIC METHODS
22. FUNDING
23. INVESTMENT IN EXISTING FACILITIES
24. BUDGETING PRIORITIES
25. DEGREE OF ECONOMIC RISK
26. AVAILABLE INFORMATION ON NEW TECHNOLOGY

From the overall study, three generalizations can be drawn:

1. Public works officials believe that they can obtain permission for anything that they believe in.
2. Public works officials do not want to be first, they want to see process demonstrated.
3. Public works officials do not want black boxes, they want evaluation by peers and full information.

In 1983, the APWA Research Foundation conducted a workshop for U.S. EPA on the role of the private sector in conducting environmental research and development for meeting local agency needs. Proceedings were published as *Demonstration Projects and The Development of Environmental Technologies*. The public and private sector participants concluded that government must assume the primary role of environmental R&D sponsorship. Fragmentation of the market and constantly revised federal standards were concluded to be major impediment to the private sector assuming a larger role.

Finally, in 1988, the APWA Research Foundation conducted another workshop for the U.S. EPA on the role of demonstration projects in acceptance of new technology by public works officials. Proceedings were published as *Defining the Role of Federal and Private Sector Activities in Solving Municipal Environmental Problems.*

Table 4, *Findings,* lists the seven major findings from the workshop. It was concluded that before adoption of new technology, the innovation must be demonstrated. The test protocol for demonstration projects by local agencies must be established in a manner which will allow for testing over a variety of conditions in order that the demonstration need not be endlessly replicated. The local agency must have adequate resources to conduct the test and to prepare a comprehensive evaluation which will be of value to other agencies.

SUMMARY

Extensive research has been conducted to determine the influence which will impact the decision of local public works officials when adoption of new technology is being considered. Twenty examples of the adoption of new technology have been described in APWA Special Report No. 54, *Good Practices in Public Works.*

As we proceed to meet the needs to rehabilitate our existing infrastructure and meet the new requirements which are being mandated by Federal and State regulations, we must develop innovative methods to replace the present costly and sometimes inadequate techniques which have been in use. Adoption of innovations can be expected when the influences outlined in this paper are understood by those who would act as "change agents."

TABLE 4
Findings

1. PUBLIC AGENCIES MUST DEMONSTRATE NEW TECHNOLOGY BEFORE ADOPTION AT FULL SCALE.

2. PUBLIC AGENCIES MUST DEVELOP MEANS BY WHICH THEY CAN CONDUCT REQUIRED DEMONSTRATIONS OF NEW AND IMPROVED TECHNOLOGY.

3. DEMONSTRATION PROGRAMS MAY BE HARDWARE IMPROVEMENTS OR CHANGES IN OPERATIONAL PROCEDURES.

4. DEMONSTRATION PROJECTS MUST BE PROPERLY STRUCTURED AND ADEQUATELY FUNDED.

5. THE EVALUATION OF DEMONSTRATION TEST FINDINGS MUST BE CONDUCTED BY COMPETENT PERSONNEL AND THE RESULTS MADE AVAILABLE TO THE ENTIRE PUBLIC WORKS COMMUNITY.

6. THE ABILITY TO PROPERLY EVALUATE AS WELL AS TO PREPARE AND DISTRIBUTE RESULTS FROM DEMONSTRATION PROJECTS CONDUCTED BY LOCAL PUBLIC WORKS AGENCIES MAY WELL REST WITH THEIR ABILITY TO OBTAIN STATE OR FEDERAL FINANCIAL ASSISTANCE.

7. UNIVERSITIES PROVIDE A POTENTIAL SOURCE OF COMPETENT RESOURCES WHOSE PARTICIPATION IN A DEMONSTRATION PROJECT MAY ENHANCE THE PROSPECTS FOR SIGNIFICANT ADVANCEMENTS FOR THE STATE-OF-THE-ART.

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3. INTRODUCTION

The Nation's infrastructure provides an essential platform for most social, economical, and political activities. The relevance of the public works infrastructure, and the realization of the need to maintain it in adequate operation are highlighted by much publicized infrastructure failures. One of them is the recent flood that affected the political and economical heart of the city of Chicago -also known as the Chicago Loop. A part of an abandoned underground transportation system, now in use as a path for infrastructure lines (telephone, power, etc.) became flooded by the Chicago river and affected critical infrastructure systems and facilities. As a consequence, subway lines, streets, public and private buildings have been rendered inoperable, with dramatic impacts on all aspects of the life of Chicago. By still unconfirmed estimates, the damages so far are valued at one billion dollars. The disruption of normal activities is likely to span for several weeks if not months. This event, although unique in its magnitude, is useful to highlight the essential nature of the infrastructure.

The 80's were an important decade for the realization of the severe problems that affect the Nation's public works infrastructure, and for the building of consensus to address these problems. In the early 80's, several studies brought into public light important and timely concerns about the health of the different infrastructure systems and facilities [AGC 81, Choate 83]. These and other initial studies were followed by interest at different sectors. This interest translated into developing consensus on the magnitude of the problem, proposing very needed corrective actions, and initiating a few of these actions [NatResC 87, NCPWI 88, OTA 87]. The still young decade of the 90's is witnessing a continuation of this effort to build momentum for action [CERF 91a, OTA 91].

One of the key points in the recommended actions to enhance the condition of the public works infrastructure is the need to encourage the utilization of new technologies [CERF 91a, NCPWI 88, OTA 91]. Technology and innovation can play a major role in extending the lives of public works facilities and provide substantial cost savings. A recent OTA report emphasized that no Federal government agency has focused on R&D programs to make public works entities more productive and cost effective [OTA 91]. It also pointed out that State and local public works agencies benefit of R&D products only after a very long process of development, evaluation, and modification. This length of time, coupled with the lack of investment in public works R&D, make this area unattractive for researchers, leaving large gaps. The present report responds to the need to fill these gaps through an attempt to identify: the obstacles that challenge the successful generation and adoption of innovations; and the opportunities that exist to promote the incorporation of innovations in the public works infrastructure.

The term *innovation* is used in this report with an ample meaning. Successful innovation is a product, process, or procedure introduced into the market place to significantly reduce cost and time, to improve quality, or to increase performance and service to the public. Innovation can originate from research and development (R&D)

activities. Another important source of innovation consists of actual practice; practitioners often develop innovative solutions to their problems. Innovation areas are as varied as problem areas exist in practice, such as management, standards, products, materials, methods, finance, and other areas. Furthermore, innovation is relative to the potential user. Anything that is new for the potential user is an innovation.

As mentioned, this report addresses challenges and opportunities for innovation in the public works infrastructure. The term *public works infrastructure* also is used with ample meaning, and includes systems under public responsibility to provide support for: transportation (highway, rail, waterways, air, etc.), water supply and distribution, power and energy generation and delivery, communications, solid waste collection and disposal. The meaning of public works infrastructure also includes environmental remediation services.

Although it is very difficult to estimate the impact that innovation can have in rendering the public works infrastructure more efficient and effective, there are some numbers that indicate the potential that exists. Figures are available from different sources to support the value of R&D results applied in practice. The California Department of Transportation has concluded that cost savings directly attributable to R&D products in practice are between 2.8 and 5.4 times the investment in R&D [CalDOT 87]. The Army performed a measurement of R&D product payoff for selected successful innovations, and determined it to be $37 for each dollar invested in the R&D phase of these products [Shaffer 92]. It is clear that innovations can have a dramatic impact in lowering the effort of building and maintaining the public works infrastructure.

However, the US is not taking good advantage of this potential benefit from innovations. Comparisons have been made in some areas of research spending, with research spending in other industrialized countries. Figures provided by the American Road and Transportation Builders Association (ARTBA) indicated in 1989 a commitment of $2 million in the US for research in intelligent vehicle and highway systems, compared to a $750 million investment in Europe and a $700 million in Japan [GAO 89]. In addition to this lack of investment, there is a problem of transferring innovations into practice. The rate of adoption of innovations in the US is very slow, with more than 20 years required in many cases to reach most users.

This report is composed of two main parts. Part 1 attempts to summarize the challenges and opportunities for innovation in the public works infrastructure identified through a literature survey. This literature survey includes a review of recognized models of the process of generating and adopting innovations. It also addresses specific challenges and opportunities for innovation in the public works infrastructure, discussed in the literature. Finally, it provides some recommendations to overcome the challenges and make use of the opportunities.

Part 2 consists of the proceedings of a workshop that was held on March 3-4, 1992 at USA-CERL, to discuss the promotion of innovation in the public works infrastructure.

A group of recognized experts on issues related to innovation and the public works infrastructure were invited to share and examine their views. The participants were selected in such a way that their views and perspectives would cover most of the relevant challenges and opportunities for innovation.

IDENTIFYING, PROGRAMMING, AND EXECUTING INFRASTRUCTURE R&D

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INTRODUCTION

On behalf of Harvey Bernstein and the others at the Civil Engineering Research Foundation, I would like to express our appreciation for the opportunity to be a part of this seminar. As you can appreciate, we are much concerned about the issue under review here, namely innovation, and how to effectively translate it into the public works arena.

I have begun to shape a perspective on public works/infrastructure that I would like to share, if nothing else, as a conversation and thought piece. Let me begin by setting the stage. I assume many of you read in this morning's paper about the UofI co-ed's whose letter home truly impacted on both her father and mother. It appears that she hadn't communicated with her parents for about a month, a month during which something important had also impacted on her life. So, she wrote "I'm sorry that I haven't written sooner, but I didn't want you to worry and get upset by my telling you about the fatal fire in my dorm; fortunately, I wasn't hurt. The young man who helped save my belongings was really nice to me, and has even let me stay with him. We are getting along fine and I'm sure you will be pleased to hear that you are going to be grandparents!" At this point her father's temper soared out of control and the mother fainted. They didn't get to the next part of the letter, which read, "Dear Mom and Dad, don't worry! There was no fire, I haven't met anybody, and you aren't going to be grandparents. I just don't know of any other way to tell you that I failed my elective, "*Introduction to Innovation in Public Works Infrastructure*", and somehow put it into perspective for you. Our collective challenge, it seems, is to put into perspective what our nation's grade really is, with respect to public works infrastructure, and what actions are both necessary and possible.

My own purpose in this paper is to briefly consider the broad challenges of identifying, programming, and executing Public Works Infrastructure R&D.

PUBLIC WORKS INFRASTRUCTURE: THE CONCEPT AND THE PROCESS

The R&D challenges I will consider are imbedded in a process and are part of a concept that in themselves are imperfectly understood. What **is** Public Works Infrastructure for the Civil Engineer and the Civil Engineering profession? Definitions abound,

abound to the point where I have opted to define it as a concept that satisfies my perspective. It is simply that **Public Works Infrastructure is the set of common structures/facilities (constructed and natural) that enable a society to function.** Note that this definition does not judge the quality or complexity of either the society or the infrastructure; it applies equally to the greatest and the least of societies.

The process that creates a Public Works Infrastructure is likewise subject to diversity, diversity that challenges a common view. In a simple perspective, however, it is a classic supply and demand relationship, as depicted in Figure 1. Demand is created by a variety of forces (to include special interests), as is clearly evident in the case of the United States. Supply in this relationship is not the public sector, but rather the thousands of potential providers of material, equipment, financing and other services. The public sector, in a variety of forms, from local to regional to Federal, is the provider of Public Works Infrastructure. The end "product", in innumerable forms, is the result of the iterative and continuous interaction, feedback, and barriers associated with this process, as also depicted in the figure.

An additional perspective of Public Works Infrastructure is to understand it in the context of a decision function, integrated over time, in which the product, viewed either as a single output or the sum of outputs, is the result of complex, interdependent decision variables that encompass, among others, resources, vision, marketing, innovation and incentives.

IDENTIFYING PUBLIC WORKS INFRASTRUCTURE R&D NEEDS

It is very tempting to suggest that this is a challenge that has been confronted and solved! After all, I can point to a copy of the final report from the CERF initiated National Civil Engineering Research Needs Forum, and note that the Forum members have identified five critical Thrust areas and 35 specific high priority research issues. Furthermore, statistics suggest, and it has already been noted in earlier presentations, that the core of the problem must be insufficient public works infrastructure R&D, since our U.S. research appears low, relative to the other industrialized nations, notably Japan and Europeans. This is, in essence, what I suggested in some remarks at the National Institute of Standards and Technology (NIST), several weeks ago. However, I'm no longer so sure this is the core of our problem. It is obvious that many facets of public works infrastructure need the benefits of more R&D. As one example, we are now working with a number of other interested groups to formulate a national R&D program in high performance concrete and steel, a program that appears to be on the order of $200-300 Million, over 5-6 years. One can also expect that the program will expand to encompass other traditional as well as non-traditional public works infrastructure materials. But, is our Public Works Infrastructure challenge merely technical, or even largely technical?

Several weeks ago, I participated in another infrastructure workshop. Low quality, lack of innovation, and inadequate education were suggested as the fundamental problems in public works infrastructure. Are they fundamental, or are they merely symptoms of deeper problems such as risk, and lack of a coordinated, focused public/private approach? What isn't clear is that innovative technical possibilities, brought about by focused R&D, will lead inevitably to an improved public works infrastructure. After all, much of the successful research conducted in the U.S., is implemented in other countries, or returns to the U.S. as a foreign product. Likewise, innovation appears to be far more successful in the "industrial" component of U.S. construction. We can add to this other factors, such as the highly fragmented nature of both our public works infrastructure and our design/construction industry.

Two days ago, I noticed what appears to be a striking analogy to our public works infrastructure challenge. In a Washington Post article,[1] Zbigniew Brzezinski discusses the collapse of Soviet Communism under the heading, "The West Adrift: Vision in Search of a Strategy!" Let me excerpt some of his observations:

- The collapse of Soviet Communism calls for both a compelling vision of the future and coolly defined strategic goals.

- A vision is not the same as policy. A policy must define strategic priorities that are attainable even if short of the wholly desirable.

- As it (now) is, Western policy involves a mixture of: generalized hopes.., gnawing fears.., torrents of advice.., endless schemes for grand solutions.., short term pell-mell aid.., and, little attention to the longer range structural reforms...

He goes on to say that the "result is a policy remarkably lacking in strategic design and strategic coordination. It is not, however, contrary to the criticism that is often made - lacking in money or generosity."

Are his observations relevant for public works infrastructure? If we substitute the term public works infrastructure for his subject "Collapse of Soviet Communism," are the observations still true?

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[1] Washington Post Vol 87, 1 March 1992. "The West Adrift: Vision in Search of a Strategy."

Is the bottom line that the first barrier in identifying public works infrastructure R&D needs may be the lack of a compelling vision of the desired end state. What is the vision for a public works infrastructure, and of the constituency in this infrastructure which, unlike Adam Smith's "rational man," is not homogenous, not focused, and not necessarily predisposed towards decisions that are in the collective best interest? Indeed, they may have no opinion, or a limited opinion, of what a compelling public works vision should be.

PROGRAMMING PUBLIC WORKS INFRASTRUCTURE R&D

My experience suggests that there is a fundamental law which states that the energy level required for programming problem solutions is greater than that for identifying problems. The contrast between the National Needs Forum and its outgrowth, the CERF Implementation Task Force, or ITF, is probably proof of this. Another good example may be the Allied experience in Desert Shield/Desert Storm. Problem identification was not a problem as far as we know. On the other hand, programming the solution was incredibly complex, and costly. Underlying this effort, however, was both a compelling vision of the desired end state and attainable strategic goals. Are there identified attainable strategic goals for public works infrastructure? The National Needs Forum required three days to develop critical Thrust areas and a prioritized research needs list that has garnered general approval and acclaim. The Implementation Task Force has faced the programming challenge for about six months and it is not an easy exercise. We seem to be making progress and will soon make specific recommendations to the CERF Corporate Advisory Board, but it is not possible to suggest that these recommendations are linked to a compelling vision of what public infrastructure ought to be or to attainable strategic goals; they may reflect a more limited vision of what small pieces might look like. In all fairness, however, I must note that the effort of the ITF encompasses more than public works infrastructure.

The bottom line in programming for public works infrastructure R&D seems to require attainable strategic goals, goals that define what infrastructure components should encompass and/or be capable of doing, for example, performance, near and long-term capacity, interaction with other infrastructure components, durability, ease of maintenance and life cycle cost.

EXECUTING PUBLIC WORKS INFRASTRUCTURE R&D

One aspect seems critically important when we consider actual program execution; the research can't be allowed to be an end in itself! This, unfortunately, seems too often to be the case and it may be the norm unless we seriously tackle the barriers. Each research report should be required to have a well-thought out tech transfer plan, a plan that may not be developed by, or even involve, the researcher. A key focus here, and indeed throughout the R&D effort, is marketing. The other day I heard what I think is an innovative way of viewing marketing. Marketing was defined as the "engineering of the customer's mind." I believe it is something we have to become much better at, if public works infrastructure is to improve and truly be an asset, rather than a liability, for the nation. Our problem is greatly magnified by the fact that public works infrastructure involves not one customer, but as already noted, as diverse a group of decision makers and users as one is likely to encounter anywhere.

It also seems true that execution requires a continuous iterative approach, an approach that defines objectives, establishes the existing technical/non-technical baseline, determines the scope of the required research, performs the research, demonstrates the results, accomplishes the appropriate tech transfer, and then repeats the process, this time seeking to attain revised, more challenging objectives. In other words, a process somewhat similar to the progressively higher performance objectives in total quality management.

CONCLUSION

The philosopher Spinoza noted some several hundred years ago, that, "true excellence is as difficult as it is rare." If we are to achieve excellence in our public works infrastructure, we must create a compelling vision that allows accurate problem definition, build a strategic program on attainable goals, and execute in an iterative fashion that focuses on both the currently attainable, while not losing sight of the desirable, but continually evolving, end state. This may be a combination that spells success!

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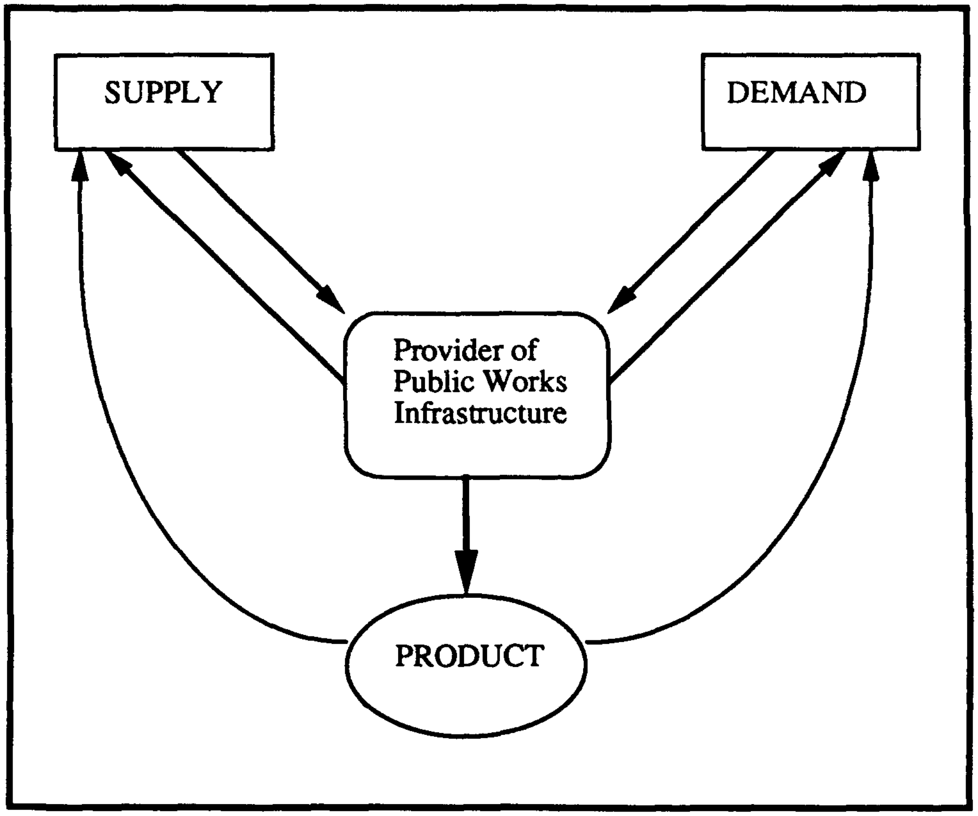

Figure 1. Supply/Demand Public Infrastructure Model

INFRASTRUCTURE FINANCING: THE STATE AND LOCAL GOVERNMENT PERSPECTIVE

Benjamin Mays, Manager
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The Government Finance Officers Association and the Association's Interest in Infrastructure

The Government Finance Officers Association (GFOA) is pleased to participate in this conference. The GFOA is a 12,500-member professional association of state and local government officials who are engaged in all areas of public finance. The Government Finance Research Center (GFRC), research arm of GFOA, performs research not only for the association, but on a contract basis as well for state, local and federal government agencies and other public and private organizations. Much of the Research Center's work for well over a decade has been in the area of infrastructure financing covering a variety of topics of concern to state and local governments[1].

Working with the U.S. Army Corps of Engineers is not new to the Research Center. In 1982, the GFRC assisted the Corps in determining local government financial capability for the proposed Chicago Deep Tunnel project[2]. Following Congressionally mandated changes in funding requirements for Army Corps projects in the late 1980s, the GFRC assisted the Corps in the Ohio River Basin Division in assessing the legal and financial mechanisms available for funding Army Corps projects at the state and local level throughout the six state region[3].

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* With assistance from Catherine L. Spain, Acting Director of the Government Finance Research Center and Barbara Weiss, Assistant Director, Government Finance Research Center.

[1] Recent projects have included "Tax Increment Financing in Maryland"; An Impact Fee Study for David M. Griffiths and Associates, Ltd.; and "Tax Reform and State Revolving Funds" for the Council of Infrastructure Financing Authorities.

[2] "Comparative and Sensitivity Analysis Municipal Fiscal Stress Study", for the Department of the Army, Corps of Engineers, Chicago District, May 1983.

[3] "State and Local Cost-Sharing in Corps of Engineers' Planning Studies and Water Resources Development Projects", Phases I and II Reports, for the Department of the Army, Corps of Engineers, Louisville District, January and August 1988.

The GFRC has assisted other federal agencies in infrastructure-related activities, particularly as a nationally recognized leader in the determination of municipal financial capability for sewer and water system compliance with the Clean Water Act. The Financial Capability Guidebook, authored by the GFRC became the U.S. Environmental Protection Agency's (EPA) "bible" for determining municipal financial capability. From the guidebook, the GFRC developed a microcomputer software template, FINCAP, enabling communities to determine their own financial capability.

Transportation and environmental infrastructure financing have also been GFRC specialties. Contracts analyzing transportation system financing for regional government's highway financing options have been undertaken for the U.S. Department of Transportation. In the area of solid waste services, GFRC efforts have included the establishment of a tipping fee structure for Portland Oregon, research on solid waste taxes for Baltimore County, Maryland, and development of complex computer models for solid waste system financing for a private consulting group

GFRC has also examined the fiscal impacts of growth, including the provision of new infrastructure facilities and structures. Its work has led to a microcomputer software package, the Total Impact Management Model, which allows governments to determine the impacts of specific developments and development scenarios on their operating budgets and on capital requirements ranging from governmental buildings and roads to schools and landfills.

Serving as a hands-on financial advisor to individual local governments, the GFRC has assisted with the debt issuance process, providing advice on financial markets and financing techniques. The financings have included projects have included waste-to-energy plants; court buildings; jails; schools; water and sewer system plant provision, expansion and upgrade; libraries; administrative complexes; landfills; and roads. This has included such innovative approaches as privately owned toll roads.

What is Public Infrastructure and Who is Responsible for its Provision?

There have been many studies on infrastructure and as many attempts to define it. While various categories of facilities appear on some but not other lists of "public infrastructure," there is a central core of categories that appears to be commonly accepted: transportation (highways, mass transit, bridges, railways, waterways and airports) and environmental facilities (water supply, sewage treatment, storm drainage and solid waste disposal.) For the purposes of this presentation, we will focus on these specific categories of infrastructure. Not included in this discussion is the substantial list of other public capital categories discussed or proposed as public infrastructure, including, but not limited to: human capital (education, health, libraries), energy supply (electric and gas utilities), and economic development. This presentation will specifically deal with the state and local government provision of a subset of infrastructure facilities, structures, and systems.

Under the American federal system of government, different levels of government bear direct responsibility for the provision of particular infrastructure projects. In some cases, one level of government will be responsible for the construction of a class of facilities and a different level of government responsible for the operation and maintenance of those facilities. Notwithstanding this diversity, there remains a continuous interaction of construction and operating financial responsibility occurring between and among all the different levels. Nowhere is this more evident than in the direct or indirect provision of funding for different project categories.

The federal government has <u>direct</u> responsibility for the provision, the actual construction, of infrastructure to a limited degree only; it is most clearly seen in federal military and civilian installations, in the extensive Department of Interior and Agriculture land holdings, and on Tribal reservations. The larger federal role in infrastructure provision is evidenced in its support of state and local government efforts through the use of grants, loans, maintenance of the tax-exempt status of municipal bonds, provision of credit assistance and other efforts.

Direct support of infrastructure projects is largely a state and local government responsibility. State governments generally have primary direct responsibility for most ground transportation infrastructure, while the remainder of transportation infrastructure and the bulk of environmental infrastructure responsibilities reside at the local level. Much of this local responsibility is shared by multiple jurisdictions through formal cooperative arrangements--regional transit or water and sewer authorities are but a few of these kinds of formal arrangements.

Financial Sources - - The Intergovernmental Dimension

Throughout the 1960s, 1970s and the early 1980s, infrastructure financing had a strong federal component[4]. During the last decade, however, that federal financing role has diminished concurrent with a rise in federal mandates for infrastructure facilities. As shown in Table 1, State and Local Fixed Capital Formation, the nonfederal role in financing infrastructure has increased dramatically during this period and has shaped the state and local government quest for alternative financing methods, which will be discussed later in this presentation. The outlook for the future indicates that some increases in the federal role may occur, even as state and local government funding sources become increasingly constrained.

The recent history of federal funding for infrastructure can be viewed along three continuing themes:

- a steep decline in federal grants and subsidies,
- an increasing reliance on federally backed or federally seeded loan programs, and
- steep increases in federal mandates.

The demise of the federal General Revenue Sharing Program, cutbacks for the Urban Mass Transit Administration (now the Federal Transit Administration) and Community Development Block Grant programs, the elimination of the EPA construction grants program, and the financing source restrictions on the Army Corps of Engineers water management and supply projects have all limited federal involvement in the provision of infrastructure. Budget constraints have also limited the federal government's willingness to use monies accumulated in the Highway and Airport Trust Funds.

Through its State Revolving Fund (SRF) program, established in the Water Quality Act of 1987, the federal government has encouraged the use of state loan programs to replace the EPA Construction Grants Program. Using federal grants for initial capitalization, these loan programs have become an important, though limited, source of local funding for wastewater treatment facilities. Expansion of the revolving loan fund concept to aid in financing other infrastructure facilities is under discussion. The concept has already been applied in the State Flexibility Program contained in the recent Intermodal Surface Transportation Efficiency Act

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[4] GFRC estimates from U.S. Department of Commerce, National Income Product Accounts

of 1991 which will provide federal monies to individual state fund programs for use on a variety of transportation projects.

The decline in federal funding of infrastructure has coincided with the promulgation of massive federal mandates for environmental infrastructure improvements. The Clean Water Act, Clean Air Act, Safe Drinking Water Act and laws concerning solid and toxic/hazardous waste, which have forced state and local governments to spend (collectively) billions of own-source dollars[5].

State governments have continued their historical role in financing a large portion of transportation-related infrastructure, but the decline in federal subsidies has had its effect. This traditional transportation responsibility has been forced to compete for revenues with the new requirements for environmental infrastructure financing. While the states have had to assume a greater role in transportation and environmental financing, as a result of waning federal funding and waxing federal mandates, local governments, especially the smaller or less wealthy municipalities, have been forced to depend upon state assistance to meet many of their increasing infrastructure responsibilities. State governments have responded with a variety of funding mechanisms, including new intergovernmental grants and matching funds, revolving loan funds, bond pools, and credit assistance programs. For example, the Washington State Department of Ecology has been able to provide construction grant monies to small or fiscally distressed communities that must comply with Clean Water Act standards, but lack the financial capability of constructing the mandated facilities themselves. These communities would once have been able to turn to the federal government for these grants, but now the state must direct its own tax revenues to these communities.

Local governments have borne the brunt of the infrastructure funding shifts of the last decade. Increasing responsibility for transportation improvements combined with expanded environmental infrastructure responsibility have left local governments grasping for funding alternatives. State governments have provided some relief for these conditions, but, the overall burden has increased. State and local governments also face a powerful constraint on infrastructure financing that the federal government does not share: the common requirement of an annually balanced budget. In some states and localities this proscription is formal and constitutional, while in others the requirement is informal or traditional. In either case, the

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[5] As evidenced by the increase in average long-term bond issuance for utility issues from less than $5 billion per year prior to 1985 and from $10 to 19 billion per year thereafter.

constraint upon state and local governments is significant. States are now facing cutbacks in their operating and capital programs due to recessionary pressures, and have been forced to transfer financial responsibility to the local level. Consequently, local governments have had to rely increasingly on their own-source revenues, rather than intergovernmental transfers from the state or federal government, and their own individual credit to meet these responsibilities.

The outlook for future financing sources is mixed. There is visible support for an increased federal role in infrastructure financing, as evidenced by the recent Intermodal Surface Transportation Efficiency Act of 1991, and the outlook for relief from federal tax code restrictions on tax-exempt bonds is brighter than in previous years. Members of Congress and others have publicly linked the lack of investment in infrastructure to declines in productivity. and indeed, there is a growing body of research establishing this linkage. On the other hand, the ability of state and local governments to continue to provide the bulk of infrastructure financing has become more limited: recessionary pressures on revenues have reduced the fiscal flexibility of most governments while declining revenues have coincided with a growing tax revolt movement in many states. These two trends have contributed to the increasing use of municipal debt for infrastructure finance.

Financing Methods - - The Menu of Options

During the 1970s the federal share, including direct construction and transfer/grant funding, of public capital construction spending rose from an estimated 32% in 1970 to a high-water mark of 51% in 1981 and has declined to 34% in 1990. While infrastructure and other public capital expenditure rose during this period, the federal share of this spending, in relative terms, declined. The absence of federal dollars has been made up by the increased use of state and local own-source revenues and tax-exempt municipal debt[6].

Own-Source Revenues (Pay-As-You-Go)

Governments finance their infrastructure improvements in a variety of ways. One of the most traditional funding mechanisms has been to pay for these improvements out of own-source revenues. This method is often referred to as Pay-As-You-Go. Over the past two decades, state and local governments have been increasingly forced to rely for infrastructure

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[6] Historical data calculated from Value of New Construction Put in Place: May 1991, Current Construction Reports, C30-9105; U.S. Department of Commerce, Bureau of the Census, Washington, DC , August 1991; and, *Fixed Capital Formation 1955-1990* , Government Finance Research Center, Washington DC, 1991.

expenditures on revenues that normally would go to their general governmental fund (the General Fund) and would, therefore, be used for the daily operation of government. The main sources of General Fund revenues vary widely among different governments: state governments generally rely on sales and/or income taxes, while most local governments receive the bulk of their funds from property and other ad valorem taxes. Local and regional utilities receive their main revenues from user fees, connection charges, and similar rate mechanisms. In some cases, special districts have been established that raise revenues based on special assessment property taxes or incremental taxes; these revenues are earmarked for specific capital purposes. Impact fees and other developer exactions also may provide significant own-source revenues. It must be remembered that own-source revenues, which are increasingly required for infrastructure provision, are the same limited revenues that are required to support the politically-sensitive operating budgets of governments.

Debt Financing for Infrastructure

It is clear that own-source financing available to state and local governments has not been sufficient to meet the need for infrastructure capital. The debt-financed share of state and local capital expenditure rose from 37% in 1981 to 55% in 1990. The dollar value of debt-financed capital construction rose from just under $20 billion in 1981 to $60 billion in 1990. While these numbers represent the total funding of state and local public capital, not just the infrastructure portion defined above, they demonstrate the significant changes in revenue sources available for infrastructure, and the resulting greater reliance on the municipal bond market.

That debt financing of infrastructure has increased dramatically is not surprising, given the high levels of construction activity over the last decade. Total state and local public construction rose from $54 billion in 1981 to $96 billion in 1990. Of that total, highway and street construction increased from $17 billion to $30 billion, wastewater treatment system construction rose from $6 to $10 billion, and water supply facility construction rose from $3 to $5 billion.[7] Comparable figures are not available for the other forms of public infrastructure, but there is no reason to believe that the trend for those facilities has been any different. The debt-financed share of these categories show similar increases: $5 billion in long-term bonds were issued for transportation purposes in 1982, and $15 billion was issued for similar purposes in 1991. For water supply and sewer system purposes, $4 billion in long-term debt was issued in 1982, while $19 billion was issued in 1991.[8]

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[7] Value of New Construction Put in Place: May 1991.

[8] *The Bond Buyer*, Tuesday, January 21, 1992.

To understand the implications of this increase in debt financing to provide infrastructure, a look at the recent history of the municipal bond market is instructive. Prior to 1987, the volume of tax-exempt municipal debt had increased every year in recent decades. Particularly high volumes occurred in 1985 and 1986 as a result of issuers rushing to market to avoid new restrictions contained in the Tax Reform Act of 1986. Indeed, those tax code changes prompted record levels of debt issuance for every category of capital construction. Significant fall-offs in tax-exempt volume in all categories occurred in 1987. The 1986 level was reached and surpassed in most categories in 1991.[9] The noteworthy difference in the mix of purposes of 1991 tax-exempt borrowings is the significant increase in the issuance of debt for purposes generally regarded as "governmental" (including infrastructure) and a decline in "private-activity" related issues. Again, a shift brought about by the provisions of the federal tax code.

Debt issued for transportation purposes has largely been in the form of general obligation (GO) bonds, bonds that are backed by the full faith and credit of the issuing entity. This means that the issuing government pledges to set its tax rate (sales or income for states, property for local governments) at a level sufficient to pay annual debt service requirements. This is the most secure form of pledge available from municipal debt issuers and usually less costly than other forms of bond issuance. Most governments are required to have voter approval through referendum to issue GO debt.

Other forms of security can also be pledged for payment of debt service. Limited obligation bonds exist in a variety of formats. The common traits of these instruments are that they have no legal claim on the general tax levy of the government, do not contribute to any statutory legal debt margin, and generally do not require voter approval.

Pledge or appropriation bonds are based on a moral obligation of the issuing government to appropriate sufficient revenues for meeting debt service requirements. Lease-purchase and certificate of participation issues, known as COPs, are based on the local government establishing, in essence, a pass-through issuance of debt using as the vehicle a private independent lessor entity, which holds title to the constructed facility. These instruments are, in practical usage, little different than the pledge and appropriation bonds.

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[9] *The Bond Buyer*, Tuesday, January 21, 1992.

Many infrastructure improvements are financed through debt issued by special assessment and tax increment districts. Backed by a special property tax on the value of property in the district which is in addition the regular ad valorem rate, special assessment debt has the advantage of targeting the beneficiaries of the improvement for the payment of the debt service. Tax increment districts issue debt that is backed by a tax on increases in property value that are presumed to have resulted from the provision of the infrastructure improvement. These formats are often used for either transportation or sewer and water improvements.

Specific revenue sources may also be pledged for debt service payments on revenue bonds. General sales taxes; sales taxes on specific items, such as gasoline or tires; water and sewer rate collections; lottery proceeds; toll revenues; licenses; and many other revenue sources may be pledged as security for the various forms of revenue bonds. Some revenue bonds are additionally secured by a pledge of general fund support. These bonds, referred to as "double-barrelled," bonds generally are issued when the revenue stream pledged for debt service payment is not deemed sufficiently reliable to attract investors at a low interest rate.

There are numerous variations of GO and revenue bond issue types, as local governments and their financial advisors continually search for ways to issue tax-exempt debt at lower cost. Some of these efforts aim at enhancing the credit quality of the issue, a strategy that is available through the use of letters of credit, bond insurance, restrictive bond covenants and the use of reserve funds, among other techniques. While the popularity of these techniques varies in relation to changes in interest rates, all have grown in usage over the last several years.

Municipal issuers also employ a variety of methods of sale and structure. Small-denomination bonds (also called minibonds), variable-rate demand notes, or foreign currency denominated instruments have all been used creatively to attract investors. Other innovative techniques currently in use include: Dutch auctions, guaranteed investment contracts (GICs), interest rate swaps, and capital appreciation or zero-coupon bonds.

All these techniques are used to attempt to lower the issuer's cost of borrowing. The promise of a government to meet its debt service obligations must compete with the government's desire to meet its service responsibilities, and any technique that lowers interest rates (and therefore reduces debt service) must be explored in these times of tight budgets.

Intergovernmental Sources of Funding

Intergovernmental revenues, the third source for infrastructure financing, include federal funding for the states, as well as federal, state and regional funding for the localities. Intergovernmental support takes a variety of forms: chief among them are grants, loans, and credit assistance.

Grant funding is available for some projects from either or both the state and federal levels. These grant monies often require a matching or percentage share from either the state or local government. Federal grant monies have declined in the past decade; however, states have had to provide some grant support, especially for the poorer or smaller communities.

State loan programs are currently the rage among federal lawmakers. The State Revolving Fund (SRF) programs are projected to be the forerunners of future intergovernmental financing arrangements. The SRF programs for sewer system improvements were funded with a capital contribution from the federal government. Those monies have been leveraged by the states through the issuance of debt and, in some cases, supplemented by state tax revenues to increase program resources. Some of these state loan programs, such as the one sponsored by the Texas Water Development Board, also require a matching or proportionate share of local funding[10].

One of the ways in which states aid local governments in providing infrastructure improvements is through credit assistance. Many states have agencies that act as a conduit for local governments in the issuance of debt: By pooling bond issuances of a number of jurisdictions, the state agency enables issuers that are too small to normally access the capital markets to borrow efficiently. Some states provide the pooled issues with some form of state guarantee or security, thereby allowing the more financially troubled communities to issue their debt at a rate lower than that which could be obtained under their own individual credit. As an example, the Virginia Resource Authority (VRA) purchases bonds from several local governments who are issuing debt for environmental infrastructure improvements, then the VRA issues a comparable amount of debt under its own name. This debt invokes the credit support of the Commonwealth and, therefore, offers many communities significant debt service savings over that which they would have to pay under their own credit.

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[10] GFRC is currently studying significant features of the various SRF programs for U.S. EPA and will publish its findings soon.

While not considered traditional intergovernmental financing, regional infrastructure programs have also been established to deal with increased capital requirements. In general, the bulk of the financing for regional programs and authorities comes from the individual member communities, with contributions either made from debt issuances or own-source revenues. As an example, the Massachusetts Water Resource Authority acts as a water and sewer "wholesaler" to over 40 Boston area communities. There are, however, many states that provide matching funds for some regional efforts, especially in the environmental infrastructure areas.

Public-Private Partnerships

The significant source of infrastructure finance is the various forms of public-private partnerships. "Privatization" means different things to different people. It can mean private ownership and operation of a facility, private operation alone, or something in between. Privately owned or operated toll-roads, bridges, water and sewer systems, airports and ports have all been proposed or inaugurated in recent years. When Loudoun County, Virginia was approached just a few years ago by private concerns armed with a proposal to build and operate a private toll-road extension, the idea was considered either revolutionary or a throwback to early Federalist days, depending on the philosophy of the officials. Now, that concept is vigorously supported by national leaders, and loans for such projects are contained in the federal Intermodal Surface Transportation Efficiency Act of 1991. In another example of partnership efforts, governments have entered into relationships with the private sector that have resulted in large equity contributions from directly affected entities. These kinds of private-sector solutions help to supplement the increasingly scarce resources available from governments for infrastructure and are clearly going to continue to be the subject of debate.

Barriers to Financing Infrastructure

Constitutional Restraints

One of the barriers to national solutions to infrastructure problems is the very nature of the United States. The elaborate federal system of government allows the individual states to retain tremendous unique institutional powers. This means, in effect, that there must be 50 separate adaptations to each national solution. Each state has its own distinct constitution, and its own unique relationship with its subordinate units of government. These basically distinct constitutions create significant differences in infrastructure provision between states and may contain provisions that retard or complicate that provision.

Tremendous differences exist among the states with regard to the independent powers of local governments. There are "Home-Rule" states in which all governmental powers not specifically given to the state are construed to reside at the city or county level. The opposite condition exists in the "Dillon Rule" states, where all powers not specifically provided to local governments by the state constitution or legislature are reserved for the state. Many states have structures of governmental power that lie somewhere between the two extremes. Governmental power restrictions can affect the ability of localities to issue debt, create new revenue sources, sign regional agreements, issue contracts for services or enter into private partnerships.

Some states also have specific constitutional requirements concerning the state and local issuance of debt. Many states require that different forms of state debt issuance be approved by public referendum. South Carolina is an example of a state that requires local government debt issuances to be approved by the state prior to the sale. Many states have provisions that limit the total amount of debt that the state, or a community in the state may have outstanding. This amount is most often limited to a specific percentage of the assessed value of property in that jurisdiction. Arkansas even has a state constitutional requirement that no state or local debt may be issued which will have an interest rate above a certain percentage. These constitutional limits on debt issuance may hinder the ability of state and local governments to provide needed improvements.

In several state constitutions there are also provisions that limit the ability of local governments to pay for infrastructure improvements out of own-source revenues. These restrictions have an effect on infrastructure provision by limiting aspects of revenue collection and which increases the competitive pressures from governmental operating requirements. The most common forms of restriction place limits on property tax levies or assessments, or on the property or other tax rates. Proposition 13 in California and Proposition 2 1/2 in Massachusetts are examples of these forms of barrier.

Statutory and Regulatory Barriers

There are statutory and regulatory impediments to infrastructure provision at every level of government. At the federal level, there are restrictions that serve to significantly drive up the cost of infrastructure facilities that are debt-financed. The Tax Reform Act of 1986, and earlier federal actions, contained numerous provisions that have hindered state and local governments from efficiently using tax-exempt debt for infrastructure improvements. Many of these actions, such as the severe limitation on banks' ability to deduct the purchasing and carrying costs of tax-exempt bonds and the imposition of the alternative minimum tax on certain tax-exempt securities, have had the effect of lowering the demand for tax-exempt debt which results in higher interest rates for the issuing governments. Other changes in the Tax Reform Act, such as the state volume cap and private-use test, which is described elsewhere in this paper, have forced issuers to substitute taxable debt for tax-exempt debt, which incurs significantly higher debt service requirements. The statewide volume caps limit the amount of "private activity" tax-exempt bonds that may be issued within a state in any given year to the greater of $50 per capita or $150 million. This means that tax-exempt debt for certain infrastructure projects such as facilities for solid waste disposal must compete with other tax-exempt debt such as mortgage revenue bonds and bonds for multifamily rental housing in order to obtain an allocation under the volume cap. The only solid waste disposal facilities not subject to the volume cap are those that are entirely government owned.

In addition, there are increased administrative costs of issuance associated with other tax law changes such as bond registration and the arbitrage rebate requirements that have prompted governments to eliminate or postpone improvements. The bond registration requirement, enacted in the 1982 Tax Equity and Fiscal Responsibility Act, closed down the ability of state and local governments to issue bonds in bearer form. The arbitrage rebate requirement, enacted as part of the 1986 Tax Reform Act, mandates that any income derived from the investment of bond proceeds that exceeds the yield on the bonds (known as "arbitrage earnings") must be "rebated" to the federal government. While there are exceptions to the requirement, one of which is described elsewhere in this paper, nevertheless the administrative costs associated with calculating and tracking bond proceeds and yield restriction where required by law or necessary to avoid rebate payments, place a tremendous financial burden on state and local governments.

State regulations may also provide barriers to infrastructure provision. The governmental power restrictions discussed earlier are particularly applicable at this level. The ability to initiate new revenue sources for infrastructure provision is an important at this time, and in several states that ability is limited by a requirement for authorization from the state government. In other states, Massachusetts is an example, the state control over the assessment process also has repercussions on a community's ability to raise revenues, due to limitations on the tax base.

Local governments are impeded by state regulations concerning purchasing and cash management. Some states have very conservative policies concerning the investment of public funds; these have the effect of lowering the amount of interest revenue localities can earn. In Georgia, the state constitution has provisions that will not allow localities to sign contracts for services, including construction, until the full cash amount required is on hand. Such an arrangement significantly lengthens the period of time between the decision to construct an improvement and the completion of that project. Even though some relief from the arbitrage rebate requirement described above was enacted in 1989 in what is known as the "2-year spend-down" provision, the Georgia constitutional requirement makes it difficult, if not impossible, for the state and its jurisdictions to take advantage of the provision. Under this provision, arbitrage earnings on bonds issued for certain construction projects need not be rebated to the federal government if the bond proceeds are spent according to a certain specified schedule within two years of the issuance of the bonds. For certain construction projects, two years is not enough.

State laws can also impede local governments in their issuance of debt. Many of the public referendum requirements are mandated at the state level. The state also may set regulations that limit the amount of debt that may be issued by localities. State governments have promulgated regulations concerning the security, method of sale, and structure of municipal debt that have the effect of driving up borrowing costs or creating other inefficiencies in the process. In Virginia, for example, the state government must approve all advanced refundings of local debt, based on specific criteria that it has established. This form of state regulation limits the flexibility of local governments to meet their infrastructure, as well as, operating requirements.

State regulations sometimes also limit the ability of local governments to enter into agreements with other jurisdictions and private concerns. This can be especially true when agreements have to cross state or national lines. Domestic content preferences ("Buy American") or similar state business preferences, and minority contracting rules can make regional or public-private cooperation more difficult. As an example, the Rappahannock and Potomac Transportation Commission is in the process of inaugurating a commuter rail system for the Virginia suburbs of Washington, DC. State and federal regulation has made the negotiations with Washington, three private and semi-private railroad companies, the Boston MTA (for temporary supply of cars), and the Brazilian car manufacturer very difficult and has set back the timetable for opening by over a year.

At the local level, city, county or district charter restrictions may limit the ability of governments to meet their infrastructure needs. These charter restrictions, along with other local resolutions, may create the same problems with debt issuance, purchasing, contacts, and revenue collection that have been discussed from the state level. Local governments often adopt fiscal policy documents and resolutions that restrict successor governments from efficiently meeting infrastructure needs. As an example, in the early 1980s, for purposes of maintaining credit quality, many localities adopted debt policies that stipulated that the ratio of debt per capita would not rise above $1,000. This level, while appropriate for the time, is too rigid a benchmark, and adherence to that level has inhibited some governments from financing needed projects, although that financing would have no negative impact on the localities' creditworthiness.

Economic and Financial Market Impediments

Current economic conditions have placed severe barriers in the way of governments attempting to meet their infrastructure requirements. Governments are facing great reductions in revenues from a variety of sources. Rising unemployment has slowed income and sales tax receipts for many jurisdictions. Negative trends in real estate values, weak new home construction, and large regional pockets of overbuilt commercial property have limited property tax collections, with sharp repercussions for local governments, and especially for special assessment districts. One of the few bright spots for governments has been the decline in interest rates, yet this has an adverse impact on revenues in view of the resulting declines in interest earnings for local governments. When the reductions of intergovernmental aid discussed earlier are factored in to the picture, the stagnation or outright decline of local governments' revenue bases is evident.

Governments are under increasing expenditure pressures as well. The current recession has added to the demand for social services, even as governments, especially at the state level, are reeling under the effects of over a decade of rapid growth in health and retirement expenses. The increasing costs associated with unfunded federal and state mandates have added significantly to fiscal stress. With both rising expenditure requirements and declining revenues, local governments are hard-pressed to meet current operating requirements, and have little flexibility left for financing infrastructure, even when some systems are in dire need.

Political Impediments

The final set of barriers to state and local infrastructure financing are the practical, political ones. Political pressures often result in short-term solutions to long-term structural problems. There is simply very little incentive for political leaders to take a pro-active approach to infrastructure. As an example, an East Coast resort city has had a history of very high population growth over the last three decades. This has created extreme pressure on some environmental systems, especially on its water supply, which was being purchased from a neighboring city. That neighboring city had issued warnings for years that the water supply was going to become inadequate, but the resort city's leadership chose to ignore the danger signs. With the contract for water from the neighbor set to expire shortly, the resort city is currently faced with either a project to pipe in water from another state, sixty miles away, which would be extremely litigious; a crash desalinization program; or to commence a water rationing program. Cooperative regional approaches to this problem were proposed fifteen years ago, but, short-term vision has ruled the day.

Current economic conditions have created a particularly cautious citizenry, with the result that it is exceptionally difficult to increase revenues by increasing taxes. Tax revolts have surfaced in several states, and the political repercussions in states like Michigan and New Jersey have been abundantly clear to political leaders nationally. This charged climate will make raising revenues for infrastructure provision extremely difficult. On the other hand, voters in some Massachusetts communities have approved increases in the tax levy to defray school and infrastructure costs. Many opinion polls have found that citizens are often supportive of limited tax, fee or toll increases when the revenues are mandated for specific infrastructure or educational uses. And surveys by the Advisory Commission on Intergovernmental Relations have consistently shown that local governments, the level closest to the citizenry, is the most popular.

While some form of public-private partnership for infrastructure provision is one of the attractive new solutions, there are political, statutory and economic difficulties in implementing these solutions. A provision of the Tax Reform Act of 1986, for example, (the "private-use test") requires that for a bond to be tax-exempt, no more than 10% of the proceeds of the bond may be used by any private business, and no more than 10% of the principal or interest is secured by private business. Prior to 1986, this test was 25%. While certain facilities are exempt from this restriction, such as governmentally-owned airports and docks and wharfs, the restriction has severely curtailed the ability of state and local governments to enter into public-private partnerships for the provision of certain infrastructure facilities. For example, tax-exempt debt could not be issued for a privately-owned road if the private business use limits were exceeded.

A close relationship between government and business can result in policies that create unease, criticism, and sometimes litigation by environmental and labor groups. At the same time, many of the private concerns that were very attracted to infrastructure improvements when the economy was growing are now faced with severe problems of their own. Proffers, exactions, and other developer contributions for infrastructure were available a few years ago, but, now the developer or the businessman may be looking for governmental assistance rather than helping to pay for public infrastructure.

Conclusion

The discussion of the barriers to infrastructure finance has presented a somewhat dismal picture, however, this discussion does serve as a step towards governments taking the pro-active approach that has been missing. Clearly, infrastructure financing has changed over the last several decades, with the rise and decline of federal involvement and the increasingly debt-financed state and local government efforts. But the dimensions of the problem have continued to steadily expand. The eventual solutions will have to come through the involvement of all levels of government, as well as an educated commitment by the citizenry and business.

While state and local governments have borne the brunt of infrastructure provision, at the federal government level, there finally appears to be a growing awareness of the importance of infrastructure and national economic health. The various studies linking infrastructure provision and worker productivity have drawn particular attention. As a result of this increased awareness, initiatives such as those contained in the Intermodal Surface Transportation Efficiency Act of 1991, the current efforts on an economic stimulus package in Washington, and Congressional interest in proposals such as GFOA's Mandated Infrastructure Bonds (MIFs)[11] indicate that some progress is possible and that the national, and specifically federal commitment, to infrastructure may finally be changing for the better.

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[11] The Government Finance Officers Association's Committee on Governmental Debt and Fiscal Policy has proposed that a new category of municipal debt, known as "Mandated Infrastructure Bonds," be created. These bonds would be issued by governments for projects mandated by federal laws such as the Clean Water Act, Clean Air Act, Resource Conservation and Recovery Act and others. These bonds would be fully qualified tax-exempt bonds and would be exempt from certain restrictive provisions of the Tax Reform Act of 1986. Specifically, they would be "bank qualified" so that banks could deduct 80% of the cost of purchasing and carrying them, and be subject to the pre-1986 25% private use test rather than a 10% test. They would also be exempt from the statewide volume caps and the arbitrage rebate requirement. All of these would have the effect of lowering issuance and debt service costs for the issuing governments and increase the number of infrastructure facilities that could be provided.

Table 1
Sources of Funds for State and Local Government Fixed Capital Formation
1955 - 1990

	(Aggregate amounts in billions)				(As a percent of Fixed Capital Formation)		
YEAR	FIXED CAPITAL FORMATION	FEDERAL GRANTS	DEBT FINANCED	CURRENT RECEIPTS	FEDERAL GRANTS	DEBT FINANCED	CURRENT RECEIPTS
1955	10.3	0.8	5.3	4.2	7.8%	51.5%	40.8%
1956	11.6	1.3	5.3	5.0	11.2%	45.7%	43.1%
1957	12.9	1.8	5.3	5.8	14.0%	41.1%	45.0%
1958	13.9	2.3	5.8	5.8	16.5%	41.7%	41.7%
1959	14.3	2.8	6.5	4.9	19.7%	45.7%	34.6%
1960	14.3	3.3	6.7	4.3	23.1%	46.9%	30.1%
1961	15.5	3.7	6.9	5.0	23.7%	44.3%	32.0%
1962	16.3	4.0	7.0	5.3	24.5%	42.9%	32.5%
1963	18.0	4.3	7.8	5.9	23.9%	43.3%	32.8%
1964	19.5	4.7	8.6	6.2	24.1%	44.1%	31.8%
1965	21.4	5.0	9.5	6.9	23.4%	44.4%	32.2%
1966	23.8	5.4	9.9	8.5	22.7%	41.6%	35.7%
1967	26.0	5.8	11.2	9.0	22.3%	43.1%	34.6%
1968	28.5	6.2	12.6	9.7	21.8%	44.2%	34.0%
1969	29.2	6.6	13.3	9.3	22.6%	45.5%	31.8%
1970	29.8	7.0	14.3	8.5	23.5%	48.0%	28.5%
1971	31.5	7.8	17.1	6.7	24.7%	54.2%	21.1%
1972	32.2	8.5	19.2	4.4	26.5%	59.7%	13.8%
1973	34.7	9.3	19.3	6.1	26.8%	55.6%	17.6%
1974	41.2	10.1	18.2	12.9	24.5%	44.2%	31.3%
1975	42.5	10.9	19.4	12.2	25.6%	45.6%	28.7%
1976	40.4	13.5	19.3	7.6	33.4%	47.8%	18.8%
1977	39.6	16.1	20.5	3.0	40.7%	51.8%	7.6%
1978	46.6	18.3	21.5	6.8	39.3%	46.1%	14.6%
1979	49.4	20.0	22.0	7.3	40.5%	44.6%	14.9%
1980	54.9	22.5	21.2	11.2	41.0%	38.6%	20.4%
1981	53.0	22.1	19.9	11.0	41.7%	37.5%	20.8%
1982	51.5	20.5	25.6	5.5	39.8%	49.6%	10.6%
1983	51.5	20.5	27.2	3.8	39.8%	52.8%	7.4%
1984	59.4	22.7	30.2	6.5	38.2%	49.2%	12.6%
1985	64.0	24.8	33.2	6.0	38.8%	51.9%	9.4%
1986	76.2	26.2	38.2	11.6	34.4%	50.1%	15.2%
1987	82.2	23.8	42.5	15.9	29.0%	51.7%	19.3%
1988	89.9	24.6	47.5	17.8	27.4%	52.8%	19.8%
1989	94.7	24.7	51.0	19.0	26.1%	53.9%	20.1%
1990	109.0	25.2	60.0	23.8	23.1%	55.0%	21.8%

Source: Data derived from Bureau of Economic Analysis' National Income Product Accounts

Table 2
Public Construction, 1964 - 1990
(in millions of dollars)

Calendar Year	Total Public Construction	Highways and Streets	Sewer Systems	Water Supply Facilities	Other	Total State and Local Public Construction	Total Federal Public Construction
1964	$20,203	$6,960	$1,325	$956	$7,244	$16,485	$3,718
1965	21,920	7,381	1,195	1,266	8,206	18,048	3,872
1966	23,846	8,157	1,300	1,066	9,520	20,043	3,803
1967	25,377	8,347	1,058	1,270	11,386	22,061	3,316
1968	27,437	9,088	1,551	1,541	12,058	24,238	3,199
1969	27,793	9,039	1,342	1,336	12,926	24,643	3,150
1970	27,908	9,728	1,543	1,093	12,434	24,798	3,110
1971	29,699	10,369	1,829	997	12,694	25,889	3,810
1972	30,030	10,130	1,700	1,077	12,879	25,786	4,244
1973	32,348	10,236	1,954	1,067	14,391	27,648	4,700
1974	38,133	11,808	2,681	1,381	17,172	33,042	5,091
1975	43,293	12,840	4,175	1,535	18,655	37,205	6,088
1976	43,969	12,032	4,704	1,442	19,008	37,186	6,783
1977	43,082	12,064	4,269	1,441	18,220	35,994	7,088
1978	50,146	13,748	5,275	2,074	20,903	42,000	8,146
1979	56,645	16,560	6,027	2,056	23,438	48,081	8,564
1980	63,645	17,753	6,775	3,082	26,394	54,004	9,641
1981	64,691	17,625	5,949	3,011	27,693	54,278	10,413
1982	63,064	18,217	5,771	3,024	26,044	53,056	10,008
1983	63,450	18,442	5,601	2,219	26,631	52,893	10,557
1984	70,217	20,285	6,357	2,667	29,668	58,977	11,240
1985	77,824	23,647	6,960	2,580	32,633	65,820	12,004
1986	84,593	24,916	7,654	3,183	36,428	72,181	12,412
1987	90,628	26,668	8,982	3,667	37,259	76,576	14,052
1988	94,782	28,797	8,818	4,000	40,903	82,518	12,264
1989	97,855	27,732	9,405	3,999	44,356	85,492	12,363
1990	108,657	30,337	10,403	4,973	50,590	96,303	12,354

Source: Value of New Construction Put in Place: May 1991, U.S. Department of Commerce, Bureau of the Census, Washington DC.

Table 3
Issuance of Long-Term Taxable and Tax-Exempt Municipal Debt By Purpose
1982 - 1990
(in millions of dollars)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Education	$5,422	$7,896	$9,271	$24,122	$19,457	$15,219	$18,458	$19,097	$21,658	$27,050
Electric Power	9,267	9,867	10,627	23,189	19,371	9,542	6,026	7,981	5,186	8,665
Environmental Facilities*	6,002	4,942	14,409	14,182	4,936	4,396	6,260	4,623	5,140	6,892
Health Care	9,434	10,208	10,153	32,166	9,673	12,893	12,871	15,788	14,155	18,140
Housing	14,207	17,453	18,895	37,304	10,843	11,977	15,397	11,875	15,686	14,336
Industrial Development	2,475	3,618	4,416	6,673	5,759	5,981	4,743	5,618	4,608	6,093
Public Facilities	921	1,119	2,450	6,276	5,785	2,922	3,678	4,954	6,144	8,546
Other	20,532	18,648	16,927	32,449	44,589	26,058	28,763	31,385	31,276	46,825
Transportation	$5,017	$4,847	$8,798	$14,672	$12,733	$6,018	$9,825	$10,546	$13,163	$15,617
Water and Sewer Utilities	3,901	4,751	5,936	15,957	18,112	10,434	11,776	12,368	10,919	19,018
Total Tansportation and Water and Sewer Utility Issues	$8,918	$9,598	$14,734	$30,629	$30,845	$16,452	$21,601	$22,914	$24,081	$34,635
Total Long-Term Debt Volume	$77,179	$83,348	$101,882	$206,991	$151,258	$105,438	$117,797	$124,234	$127,933	$171,181
Infrastructure Bonds as a Percentage of Total Municipal Volume	11.55%	11.52%	14.46%	14.80%	20.39%	15.60%	18.34%	18.44%	18.82%	20.23%

* These are primarily pollution control bonds, no longer issued as tax exempt after 1986

Source: The Bond Buyer

LEGAL IMPEDIMENTS TO INNOVATION IN REBUILDING AMERICA'S CRUMBLING INFRASTRUCTURE

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The United States faces a crisis, as its aging infrastructure, serving well beyond its life expectancy, deteriorates to failure. Much of the infrastructure is over a century old--bridges, water and sewerage systems and the like; it is a tribute to American technical prowess of the last century that the infrastructure continues to function at all, much less provide major service. Pause a moment to recall that the now moribund infrastructure was, at its creation, a triumph of American innovation.

America needs a resurgence of that innovation now to solve the infrastructure problems that threaten significant economic and personal dislocation. Unhappily, there are impediments to such innovation; this paper dwells on some of those created by the interrelation of the law with engineering and the practical process of construction.

A. Historical Perspective

Most modern construction contracting, particularly public works, is an arrangement of three parties: the Owner, the Designer and the Builder (or Contractor).[1] Typically the Owner contracts with a Designer to provide plans and specifications that detail the finished project; and the Owner contracts separately with the Contractor to build precisely what those plans and specifications detail. The roles of Designer and Builder are not inherently separate, but they are today by contract usually deliberately discreet. The Designer provides the design and inspects the project periodically to confirm that the work generally conforms to his design; he eschews control of, or responsibility for, the means, methods, techniques and sequences of construction, for job-site safety on the project site, and generally for the specific

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[1] Each of these entities is, in practice, usually a team, or chain of other entities. For example, the lead Designer who contracts with the Owner, e.g., architect for a building, usually subcontracts for required specialty design, such as soils, mechanical and electrical work. Similarly, the prime Builder will subcontract discreet parts of the work to subcontractors. The Owner's interest may likewise be divided among several parties, including lessors/lessees and lenders. For simplicity, this discussion uses the singular to refer to the three major, or lead, performers; but, in general, the notions expressed here frequently are relevant to the other actors.

requirements of construction; those are left entirely to the Contractor.

This contrasts with historical practice; in medieval times, and until relatively recently, the roles of Designer and Builder were fused in the Master Builders of the great cathedrals,[2] a model that persisted through the 19th Century.

For example, the Brooklyn Bridge, a paradigm of engineering innovation was designed by John Roebling as Chief Engineer[3]; when he died at the beginning of construction, his son, Washington Roebling, took over as Chief Engineer. As Chief Engineer, Roebling was involved in the work in a direct way that modern Designers usually do not; he participated directly in solving problems of construction technique, method and sequencing, which today would be left to the Builder. There has, at least in this respect, been a change in how things are built.

The current system, in which the roles of Designer and Builder are separate and distinct, is a relatively recent development. In this system the Designer prepares detailed plans and specifications which describe the finished project very specifically. Then (usually in commercial projects, and almost invariably in public projects) the specifications are advertised for letting to the lowest responsible bidder.

The low-bidder Builder constructs the Project while the Designer's participation is limited to certifying to the Owner that construction is done in accordance with the drawings and specifications. The Builder is usually solely responsible for means and methods, sequences and techniques of construction.[4]

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[2] A very readable novel describing in the practical terms the construction process of that time, is in Pillars of the Earth, by Ken Follett. The novel also described the evolution of the construction of the cathedrals, particularly the trial and error of innovations that evolved into the soaring arches and tall windows. See also J.E. Gordon, Structures, or Why Things Don't Fall Down (1978), pp 210-215.

[3] At the time its central span of 1595 feet was then the longest single span ever built. It was the first suspension bridge of steel, stronger than lighter than iron; and the steel wire was zinc galvanized to prevent rust. It functions today carrying loads much greater than those contemplated by its designer.

[4] In recent years the design-build concept, a modern refusion of design and construction responsibility, has grown in the commercial world. It has also increased in federal public works. See "ASCE Advocates Pre Qualifying for Federal Design Build Jobs," Engineering News - Record, April 27, 1992, p 7. But it is almost unknown in state and local public works, where most infrastructure replacement must occur.

There has been another change in the last century, life has become more valuable in the literal sense, which has changed how we build things. Because diseases and then-dangerous conditions regularly killed the young [5], society in general was less concerned about the sanctity of individual lives. For many people, particularly in the laboring class, life was, and as Hobbs put it, "poor, nasty, brutish and short."[6] In the first half of the 20th century, there was a burst of discovery that changed the face of medicine; discovery of antiseptic agents, antibiotics, and medicines, coupled with improvements in surgery and public health, combined to raise the life expectancy of the average American male from 46.3 years in 1900, to almost 75 years in 1986.[7] As mankind was subduing most of the causes of early death, there was a progressive surge that sought to improve the lot of the common man. These forces combined to elevate concern over the social cost of industrial death and injury; this led in turn to workmen's compensation laws, which allocated the cost of such death and injury to the industrial process itself through insurance premiums, to be passed on to consumers in the cost of goods. In later years the expansion of tort law has further added cost to my construction practice which injured people.

This change in attitudes militated against taking chances, including innovations in construction design and technique, which might involve risk to human life and limb. Technical innovation without regard to human safety on any large scale is over.

An additional legal problem for innovation is that science and technology are, to some extent, victims of their own good publicity. In the late 19th century years of effort to apply the discoveries of empirical science in a systematic way culminated

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[5] When the Brooklyn Bridge was finished in 1883, the world had just begun to accept the notion that infection could be prevented by cleanliness and antiseptic agents. Semmelweiss' discovery and publication of his findings occurred in the 1840's and 50's, but were not widely known in America until after our Civil War. The concept of surgical sterility as we now think of it was not known during the American Civil War. It would be another fifteen years before Walter Reed and others established that insects were vectors for the communicable diseases which seriously shortened the average life span. And so on.

[6] Thomas Hobbs' Leviathan Part I, Chapter 13.

[7] Life Insurance Fact Book, 1976, American Council on Life Insurance, page 89. The World Almanac.

in the birth of engineering as the profession we have today.[8] Thereafter, engineering progressed rapidly as a profession applying mathematics and empirical science with the impressive success. Everyone came to accept that engineers could, and should, be able to calculate very accurately all that needed calculating. There is today a popular conception that scientists can do almost anything they want to; most don't understand that technology has always had frontiers, the "edge of the envelope", and that progress in all ages requires exploring beyond the edge of the envelope.

B. The Legal Problems

Against the background of those observations, we turn to the principal problem which deters innovation in the construction process: What happens if the project doesn't work and is useless to the Owner; worse still, what happens its failure maims or kills someone?

As a general proposition, whoever is damaged by such a failure now almost invariably sues everybody, seeking recourse from any source possible.

Legal responsibility, and consequent fiscal liability for damages, under such circumstances can arise from several sources: (a) Liability can be imposed or assumed by contract; that is, a party may by contract undertake a duty to do or not do something; and if he violates that duty, he becomes liable for damages caused by the breach;[9] (b) The duty can be imposed by statute, that is the law requires people under certain circumstances to do (or not do) things, and if they break them and the breach

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[8] Engineers on the continent had earlier begun coupling mathematical analysis with empirical experimentation to solve engineering problems; but in England and America, engineering was dominated until the middle of the 19th century by "practical men" who regarded as useless theoreticians who dabbled in mathematics. J.E. Gordon, Structures, Or Why Things Don't Fall Down, (1978), pp 61-65, 179-181.

[9] This is to some extent an oversimplification. Many duties or responsibilities are legally allocable, so that parties can allocate the duty, and with it the responsibility for failure in the duty. For example, the law is not concerned with surveying responsibility so any party may agree to provide the side survey, be responsible for providing field surveying controls and staking out the work. But on the other hand, in some states a property owner owes a non-delegable duty to avoid using his property in a way which will damage his neighbors; in addition any party undertaking inherently hazardous activity through an agent usually cannot delegate responsibility for damages caused thereby. See, for example, D'Albor v. Tulane University, 274 So.2d 825, (La. App. 1973) writ ref. (Property owner absolutely liable for pile driving damage to adjacent property. Notwithstanding contractor's assumption of responsibility; owner did have indemnity right against the contractor if pile driving negligent.)

causes damage they can be liable for that damage;[10] (c) There is also a general duty under most circumstances that people conduct themselves so as not, absent special circumstances, to do anything which reasonable foresight indicates would cause damage to another; failure of this general duty can create legal liability for damage caused by the failure;[11] and, (d) An additional source of liability relevant here, liability imposed strictly upon a party by law, regardless of fault of duty; for example, in some jurisdictions, the owner of real property is absolutely liable to anyone damaged or injured by a defect or disrepair in the property.[12]

Most--including particularly lawyers not experienced in construction matters--don't know, and construction professionals sometimes forget, that construction contracting is largely a process of risk allocation; there are few immutable rules imposing responsibility on particular actors in the process.[13] Contracting parties thus

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[10] See Palm Bay Towers Corporation v. Cram & Crouse, Inc, 303 So.2d 380 (Fla. App. 1974) Engineer held liable for damages resulting from failure to comply with city ordinance requiring notification to city officials of design changes.

[11] The key factor is foreseeability that the victim will suffer the specific harm from the Designer's improper performance or non-performance of the duty. Compare, for example, Howard v. Palmer & Baker Engineers, Inc., 302 So.2d 228 (Ala. 1974) (in which possible damages from petroleum fires in as vehicular tunnel were held sufficiently foreseeable that inspecting engineer liable for failure to recommend proper equipment for fighting such fires) with Zeigler v. Blount Brothers Construction Co., 364 So.2d 1163 (Ala. 1978), in which increase in utility rates not sufficiently foreseeable from collapse of dam.

[12] For example, See D'Albora v. Tulane University, discussed in note 9, supra. See also Shepherd and Bourque, "Strict Liability in the Construction Context," 3 The Construction Lawyer (No. 3) p. 3, Summer, 1982.

[13] One such rule, rarely articulated with the bluntness used here, is that any party with actual knowledge of a significant threat to human safety, who has some authority to abate the threat or prevent the injury, must do what he can to protect life; failure to do so will usually impose liability. In most standard contract documents Designers have attempted to impose upon Builders all responsibility for compliance with safety rules and regulations, i.e., assuring safety and protecting life and limb on the job. However, most standard documents also make the Designer a contract administrator with the duty to assure that the contract is performed in accordance with its terms; if a Designer acquires actual knowledge that a Contractor is violating safety standards in breach of the construction contract, the Designer ignores it and fails to enforce the contract terms, he does so at his peril. The Kansas Supreme Court held a Designer to have such a duty in Balagna v. Shawnee County, 668 P 2d 157 (Kansas 1983). Compare, however, Fox v. Jenny Engineering Corporation, 505 N.Y.S. 2d 270 (App. Div. 1986), and Conti v. Pettibone Companies, Inc., 445 N.Y.S. 2d 943 (Misc. 1981), in which a Designer's general duty of inspection, without specific responsibility

allocate known risks among themselves.

Innovation, the use of new or not-yet-used technological solutions to practical problems, is per se a risk; the new solution might not work, or work as well as older methods. The question is, whose risk? As a practical matter, local government entities responsible for most of the infrastructure are rarely interested in anything more than the cheapest and surest fix for a problem. They are rarely anxious to be on the cutting edge of technology, and never want to bear the consequences of failure.

Of course, in the larger sense, almost every contractual undertaking in construction is a risk; perhaps the biggest risk is the Builder's promise to complete the project for a fixed price within a fixed time. The contractor "guarantees" his performance, in spite of all the risks that might prevent performance.[14] The reason he takes those risks is simple: Profit. A contractor estimates what it will cost him to do the work, usually adds an amount for risks or contingencies, and profit on top of that. If his cost estimate is accurate, and he is reasonably lucky on the risks, he can make money.

Innovation is a risk; and the greater the innovation, the greater the risk. Contractors use innovation where appropriate, for the same reason they take the risk of contracting in the first place, for profit; a contractor who can dramatically enhance his profits by finding and using some new or better technique will do so. There is evidence that this sort of innovation is alive and well in construction.[15]

But, there is likely to be less innovation in the design process, and that is the focus of this paper.

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for safety, or authority to supervise and control, held sufficient to make engineer liable for injury to workmen. The comment in the text is meant to suggest that if a design professional actually knows of or observes significant safety violations, and fails to try to get them remedied, he might well find himself liable for the subsequent injuries from that breach.

[14] Such as weather, fluctuations in the price of labor, materials or in interest rates, the health of his key supervisory employees, the financial stability of subcontractors and their ability to meet their commitments, to name a few.

[15] See, for example, "Home Built Scissors Lift Speeds Ceiling Installation," Engineering News-Record, August 26, 1991, which was found in a random search of back issues of that magazine, which frequently features such stories.

The question is why might there be less tendency to use innovation and design, as opposed to construction. The reason is that not only is there no profit in it, there is a profit disincentive.

Generally speaking a Designer must perform his contractual undertakings in accordance with his standards of skill and care prevailing in his particular profession in the same general area.[16] Typically, if a project fails or there is a problem with it, in any subsequent lawsuit the designer's performance is thus tested against the standard of care for that sort of work in the vicinity.[17]

Similarly in many states, it has been held that architects or engineers have a general duty to the public which can be anticipated to use the facilities being designed and the care and skill which are used in making such projects safe for use by the public are those generally prevailing among that profession in the vicinity.[18]

When a Designer is informed of his Owner-Client's goals, i.e., desires for the completed project, the Designer has a duty to inform or advise the client if the goals are incompatible, or unobtainable.[19] And a Designer has a duty to "investigate and advise" the Owner about all equipment, materials or design solutions the Designer specifies; and his specification of such is assumed to be an assurance that the specified material or equipment is satisfactory for the purpose specified.[20] This latter duty can be particularly burdensome, since rarely does the standard engineering fee on a

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[16] "One practicing a learned profession must do so with a degree of professional care and skill customarily employed by others of the same profession in the same general area. This standard has been held applicable to engineers." Bowman v. Coursey, 433 So.2d 251, 253 (La. App. 1983).

[17] This standard must generally be proved by the testimony of an expert professional familiar with standards in the area, City of Eveleth v. Ruble, 225 N.W. 2d 521 (Minn- 1974), although a court can find negligence from disregard of an ordinance, Palm Bay Towers Corporation v. Cram & Crouse, Inc., supra, note 10, or from a particularly egregious act, such as falsely certifying inspections which were not made, City of Houma v. Municipal and Industrial Pipe Service, Inc. 884 F.2d 885 (5th Cir. 1989), or egregious omission, such as failing to size properly a water intake pipe at a water treatment plant, City of Evele v. Ruble, supra.

[18] Howard v. Palmer & Baker Engineering, Inc., supra, note 11.

[19] Rowe v. Moss, 656 S.W. 2d 318 (Mo. App. 1983)

[20] White Budd Van Ness Partnership v. Major Gladys Drive Joint Venture, 778 S.W. 2d 805 (Tex. App. 1990) (Architect liable for failure of new tile product specified for shopping center.)

routine infrastructure project fully compensate a engineer, particularly a small local engineer to investigate one or more new technologies adequately.

Paraphrased then, it can be said that as long as an engineer or architect designs his project the way most of the other design professionals in his area do, i.e., using tried and true material requirements and designs, he should not be held responsible should there be some problem with the project later.

We have already seen that the process of construction contracting is the process of accepting or transmitting risks. But why, one might ask, would engineers be less willing to take the risk of innovation if contractors are. The answer, again, is profit, or lack of it.

Over the years there has been consistent pressure to reduce the fees of design professionals as one way of cutting the overall cost of new projects. In earlier times designers routinely charge substantial percentages of contract price as fees. The fee covered not only design but, contract inspection and administration. But in recent years there has been considerable pressure to reduce those fees.

Most engineers today feel that the fees have been reduced to the point where engineers are cutting service to survive, so that the fees are absolutely inadequate to compensate for any additional risk.

For there to be widespread innovation in this field, it will probably be necessary first to convince the hundreds of small local government bodies, which are responsible for most of the infrastructure, that innovation and experimentation are desirable. No small order. That will include convincing these owners to accept all or part of that risk, or to compensate the engineer for accepting it. Although this is an area of speculation, the writer suggests that will be a hard sell.

However, once an Owner is determined to have advanced technology, it can be handled in a number of ways. The Owner can require in the design contract that the Designer explore innovative techniques, materials and equipment before deciding on a design solution and report on them as part of conceptual design, to allow the Owner consciously to decide what risks might be acceptable. It could also provide profit incentives for the Designer, such as payment percentages of Owner's savings from the use of innovation.

Some forward looking Owners and Designers will reach for such solutions without additional incentive; but in the writer's experience, most small local government entities, and their regular Designers are risk-averse. They prefer time tested solutions to a problem, with little desire to reach for the brass ring of future savings or benefits.

Perhaps the federal government could provide some impetus to innovation, through the enormous leverage it enjoys from grant financing of much of the infrastructure work. This incentive could take several forms. For example, there would be "innovation grants" under which concepts qualified as true innovations, could be performed with the government agreeing to accept all or part of the risk of the failure of the innovation. Coupled with, and added to such a grant program, federal agencies could, based on empirical data from innovation grants, develop standards which would hasten the acceptance of innovative solutions into the mainstream, i.e., make the innovation acceptable to designers practicing in a particular specialty, i.e., part of the norm. A problem with this, however, is that most federal civil servants who administer such programs tend to be as risk-averse as most local government officials.

On balance, it seems unlikely that there will be any surge to accept innovative technologies. Good people will continue to build better mouse traps, and the best of these mouse traps will, sooner or later, find their way into the mainstream. But one suspects that the country will, in the main, lose countless benefits-savings enhanced performance, and the like-from delayed use of the innovative technology.

Innovation and Technology Transfer Opportunities: Industry/University/Government Partnerships

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Innovation, technology transfer, and competitiveness issues are receiving more attention recently, and with good reason. Clearly to be competitive on a global basis, the United States must innovate and move technologies to practice more effectively, as well as rebuild the national infrastructure. This paper will explore opportunities from the perspective of a university research center created to enhance the competitive position of the large structures and construction industries through the development and implementation of advanced technology. Large structures include bridges, buildings, offshore structures, and other major infrastructure facilities.

The ATLSS Center was established by the National Science Foundation in 1986 with a mission in four areas: research, education, industry collaboration and technology transfer, and large scale experimentation. ATLSS is one of nineteen Engineering Research Centers currently funded by the National Science Foundation. The emphasis on the industry partnership is an important requirement and was clearly seen as a mechanism to enhance innovation and technology transfer.

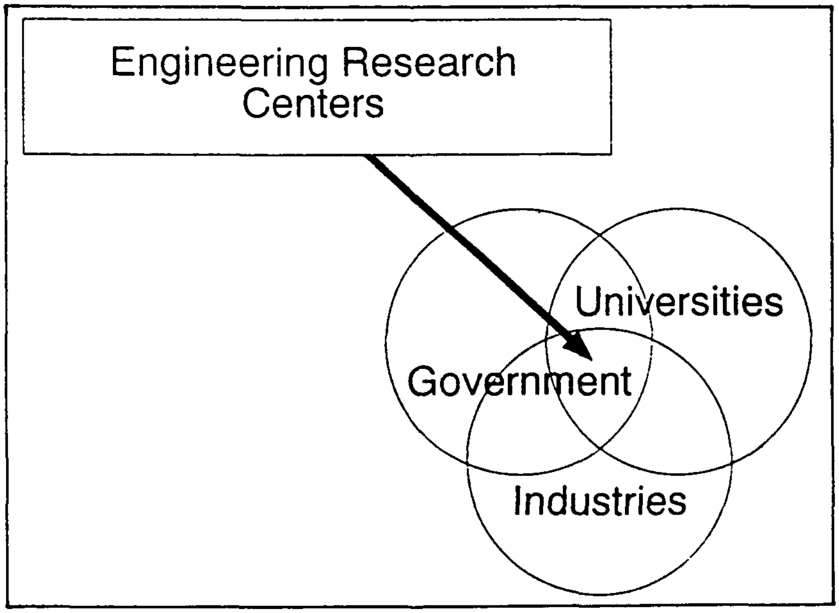

FIGURE 1

Industry and Government Participation in the Research Program

Industry and Government participation is critical for a research program which meets the needs of industry and which will be accepted and implemented in practice.

Several mechanisms are used to enhance industry participation, including an Industry Advisory Council, Project Advisory Panels, workshops, one-on-one contacts, and industry-funded graduate study. Participation levels annual partnership support, specific project funding, and technical include advisory roles.

The Industry Advisory Council, composed of representatives from General Partners and invited advisors, meets twice per year. These meetings have several purposes:

- To update industry partners and advisors on research progress.
- To solicit input on the direction of the research program.
- To address specific issues to enhance interaction with industry or the research program.
- To enhance technology transfer by early involvement of the users of the ATLSS research and to develop technology transfer teams.

These Council meetings are designed to be an interactive forum to encourage effective dialogue between our researchers and industry. In addition to plenary sessions and presentations on ATLSS research projects, project panel meetings are held, typically on the day preceding the main meeting. These project panel meetings bring together the ATLSS researchers, students, industry partners, and invited industry experts.

Technology Transfer

A unique opportunity for an Engineering Research Center to implement its results lies in the early and continuous involvement of industry in the research program. Such industry involvement allows early assessment of results, provides continuous guidance so that industry issues are being addressed, and establishes an early "buy-in" of the technology user to facilitate acceptance and implementation. The key to transferring technology is the "adoption and diffusion" process which clearly depends upon the active role of the user. The successful transfer requires a "demand-pull" from the user of technology, rather than a "technology-push" in which the developer of technology seeks out users of the technology after its development. The Industry Advisory Council, Project Advisory Panels, Short Courses, and Workshops are vehicles to develop the "demand-pull" from the user community.

Technology Transfer Plan for Each Project

As part of the project planning process, each ATLSS project now has a Technology Transfer Plan which includes as a minimum:

- o End users of the technology, to be involved on the project panel.
- o Identification of codes and specifications to be impacted by the project. Formation of industry committees relevant to the projects.
- o Description of other research work in the field, to assist in collaborative efforts. (Industry, Government, and University.)
- o Timetable for transfer to practice.
- o Conferences, symposia or publications where papers should be submitted.
- o If project is exploratory, identified fundamental contributions which could be made to advance procedures or processes of current practice.

Project Activities

Industry and government collaboration are critical at the project level. Several examples are discussed here.

The **Bridge Fatigue Investigator©** is a knowledge-based system developed to assist bridge inspectors in inspection of steel bridges. At the recommendation of our Project Panel, follow-up meetings were arranged for in-depth review of the program. In addition, a presentation was made at the Seventh International Bridge Conference in June, 1990. The audience consisted of 450 practitioners, transportation officials, and academics, with an emphasis on practical problem solving. In May, 1991, an additional presentation was made to the Bridge and Structures Subcommittee of the American Association of State Highway and Transportation Officials (AASHTO), introducing BFI to the national user community. Bridge Engineers from all 50 states participate on this subcommittee. AASHTO has a mechanism to develop and maintain software related to highways and bridges. Several demonstrations to the Federal Highway Administration have been encouraging for incorporating BFI into the FHWA Demonstration Project program. Additional development steps were identified at these meetings, including the inclusion of Hypermedia applications. A Technology Transfer Plan has been developed to complete development and implement BFI in practice.

The **Corrosion Monitor** is an electro-chemical device developed to monitor corrosion of steel on bridges. The project has advanced under two years of field studies and further research partially sponsored by the American Iron and Steel Institute (AISI). AISI has agreed to continue funding for a third year, but this will be the year for a larger consortium effort to be launched. An implementation plan has been developed to move the project into practice, including acceptance by standards and specifications groups such as AASHTO or ASTM. One of the reasons that this project has this potential is that a technology transfer team was established early and Bethlehem Steel has been active in assisting in the transfer. (See Figure 2.) A proposal for further funding was also submitted to the Federal Highway Administration after a meeting there in June 1991. The topic of corrosion has been identified as a high priority in the FHWA Structures Research Program. A patent (U.S. Patent No. 5,045,775) was issued in September, 1991, for the Coulometer, further strengthening the ATLSS position in transferring the technology to practice.

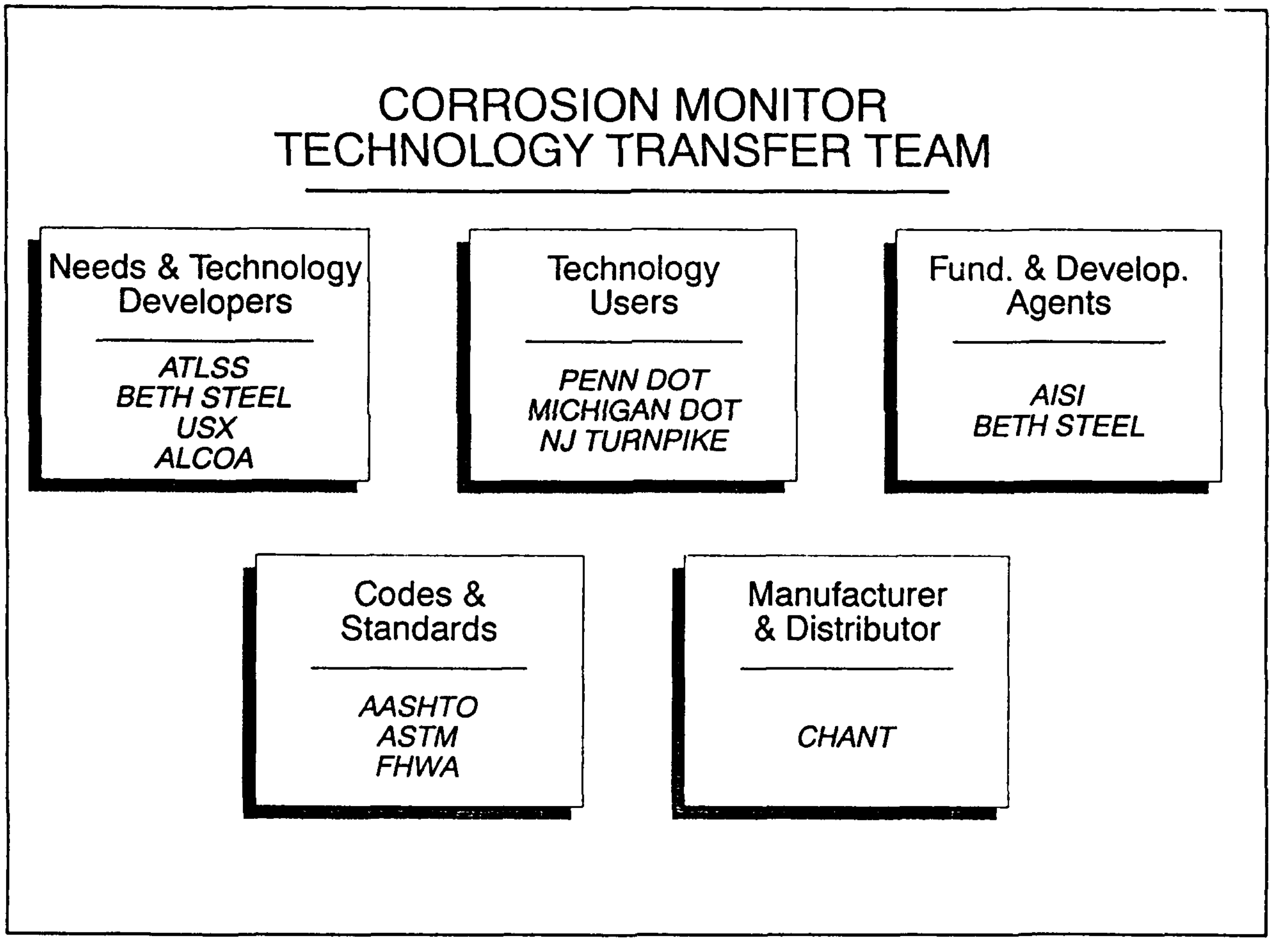

FIGURE 2

The **ATLSS Integrated Buildings System** has generated significant interest from practitioners and the National Institute of Standards and Technology (NIST). The dual-pronged approach of an automated crane platform (Stewart Platform) plus the development of new structural connections offer an opportunity to implement an entire system for automated construction of steel framing systems. (See Figure 3.) In addition to project meetings at the ATLSS Center and meetings with NIST, three fabricator/erector companies have expressed interest in working with us, and we are planning to develop a consortium to launch a demonstration project in the field.

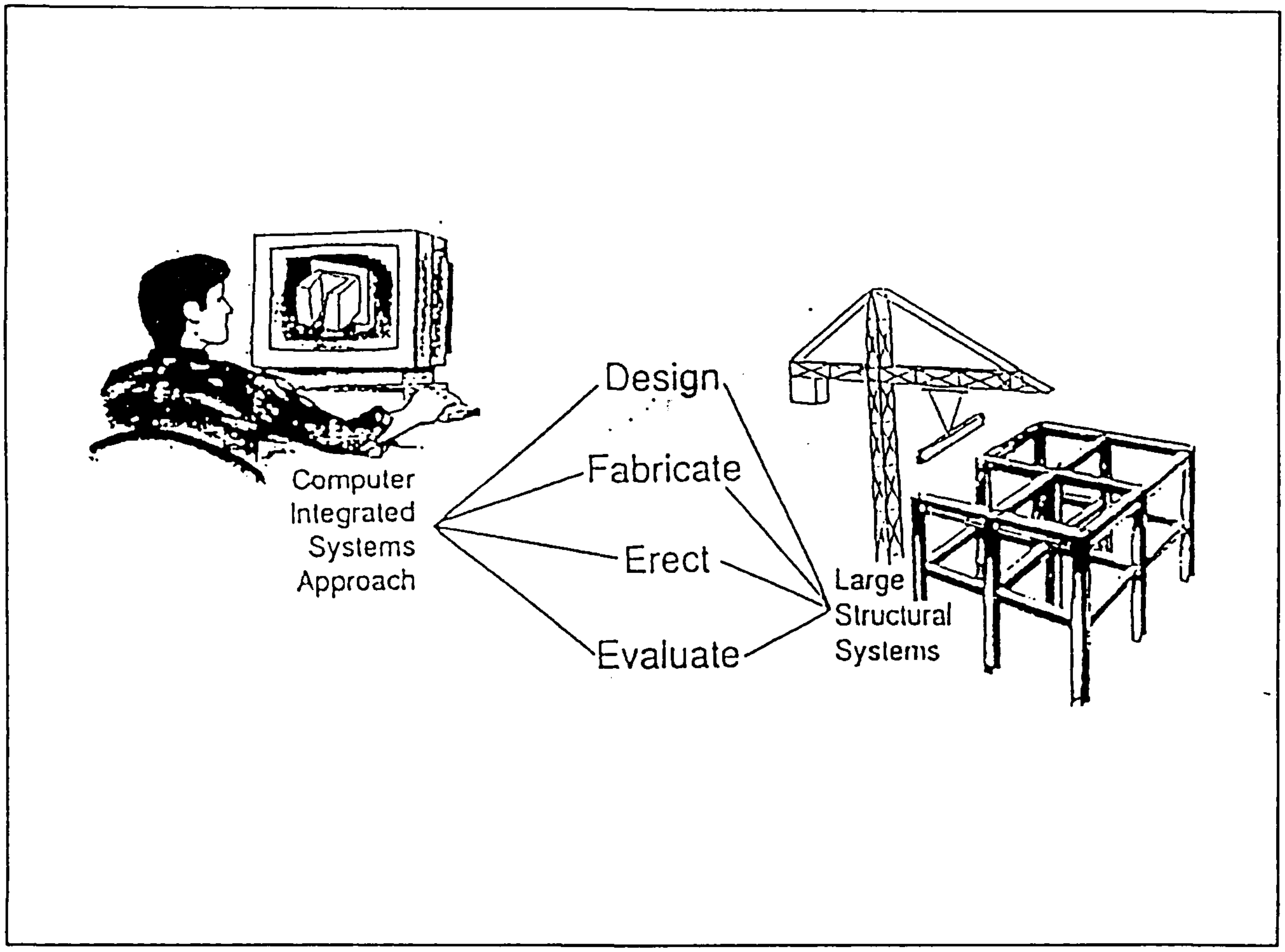

FIGURE 3

Competitive Technologies, Incorporated

Recognizing the need to coordinate and expand **technology transfer** activities within the Lehigh University research programs, a new wholly-owned subsidiary has been established, called Competitive Technologies, Inc. (CTI). ATLSS is working closely with CTI to perform the following activities:

- Develop and implement a comprehensive Technology Transfer Plan for ATLSS
- Develop consortia to transfer current technologies to engineering practice
- Develop and implement specific commercialization plans for ATLSS technologies
- Manage our industry partnership relationships
- Provide funding and other tools for implementation of new technologies
- Provide liaison to other Lehigh University technology opportunities as well as other activities on a national and international level.

CTI will assist the researchers in identifying potential innovations at our early stage and providing tools and mechanics to effectively demonstrate and implement these innovations. The industry and government participants are playing a key role in these transfer activities as users and facilitators to enhance the implementation.

Conclusion

The Engineering Research Center concept is one example of an effective partnership among government, universities, and industry, providing continuous dialogue and participation of industry. The emphasis on technology transfer assists in the implementation of new technologies as part of the ongoing research program - not as an afterthought. The National Science Foundation played a critical role in creating the original structure, which has now progressed to an effective partnership including leveraging of funds through the private sector and other Federal Agencies.

These Centers could be considered as models to create partnerships and to encourage innovation and more efficient implementation of new technologies for the public works infrastructure.

Technology Transfer (T^2) as a Work-Practice Change Process: An Essay

by

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"To every action there is opposed an equal and opposite reaction."[1] Technology Transfer (T^2) demands change and departure from a work-practice process that is intricately woven into the professional and personal lifestyles of working individuals. For most working people, continued job security and recognition are based on successfully achieving predefined measures of performance. Individuals can easily construe the application of new technologies to their work-practice process as a threat to the formula for obtaining success, i.e., continued job security and recognition. Tinkering with an individual's professional means to succeed can quickly propagate to the personal level, inducing anxiety and fear as well as endangering an individual's personal lifestyle. The effort involved in absorbing and conquering new technologies is likely to consume the time dividends distilled from efficiently applying tested means and ways. Time dividends are usually applied to discretionary tasks which are undertaken to precisely control and space out day-to-day schedules. Thus, whether or not the fears of failure associated with change are warranted, reactions from the individuals being affected by the adoption of new technologies should be anticipated.

Technology Transfer (T^2) is good for your company. Top management has long recognized that the individuals within an organization represent the single most important financial asset. After all, if it were possible to replace everyone overnight, the company's reputation and image, which largely form the basis for on-going business, are not automatically carried over with the new work-force. T^2 improves the individuals' competence leading to an increase of assets which in turn leads to a better image and reputation for a company. Thus, individuals at all tiers of the corporate ladder need to believe that the adoption of new technologies is an important means to enhance the performance of individuals, and consequently, the longevity of the company.

Corporate culture shock. Preparing for Technology Transfer requires not only remolding individuals' attitudes towards change, but it also implies redefining the firm's traditional organizational culture. Corporate cultures evolve over a period of time. They are outlined by senior management, influenced by the market, and brought to existence by the work-force. Corporate cultures manufacture postures, attitudes, and shields against internal and external forces, only a few of which are real. Corporate cultures sanction work-place behaviors and set the stage for an organizational environment that is either recalcitrant or conducive to innovation and Technology Transfer. Institutionalizing T^2 and

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[1] Newton's third law; Essential Engineering Information and Data, Ganic, E.N., and Hicks, T.G., McGraw Hill, 1991.

innovation can cause an organizational cultural shift that induces a culture shock within the work-force; this should be recognized, addressed, and phased out.

"Change is proportional to the force exerted against an object and to the time during which the force is exerted."[2] A Technology Transfer Task Force (T^3F) represents the engine that, if continuously fueled by top management, can provide the initial thrust to launch an all-out cultural metamorphosis fostering tolerance for innovative change. The charter of the T^3F is to act as a permanent catalyst for innovation and T^2. Permanent and rotating memberships maintain the vitality, acceptance, and focus for the T^3F. While permanent members are needed to provide vision, continuity, and senior management representation, rotating members are essential to ensure balance, undue bias, and work-force representation. The T^3F main roles are two-fold: 1) to seduce top management to distill a visible commitment to innovation and T^2; and 2) to empower the masses to constructively leverage the control they exert over the work-practice process. These roles are achieved through awareness, motivation, and most importantly, involvement of decision-makers and decision-takers.

"If an object is at rest, it will remain at rest, or if in motion, it will move uniformly until acted on by some force."[3] As top management promotes a corporate environment conducive to T^2 and innovation, individuals who are better challenged outside their comfort zone will emerge from their dormant state to take on the roles of technology gatekeepers, technology champions, and technology change agents. The gatekeeper is the individual who identifies new technologies and envisions their implementation in the organization. These individuals should have a high vantage point so they can better match emerging technologies with the long term business objectives of the organization. Champions are the individuals who risk not only committing resources to a technology, but also risk evaluating it and persuading senior management to adopt or reject it. Should management decide to adopt the new technology, change agents undertake the task of diffusing the technology through the organization. While the technology gatekeeper should be a permanent member of the T^3F, the membership of the champions on the T^3F should be transitory because there are bound to be different champions for different technologies. Furthermore, representatives of the group being impacted by the specific technology should also be transient members. Dynamic membership in the T^3F ensures that affected individuals are involved and aware and that they avoid misconceptions about the technology, which could kill the T^2 process before it even starts. Sabotaging a T^2 process for the wrong reasons is the ultimate triumph of unmanageable corporate cultures. Interestingly, there will be individuals or groups within any firm who will jump at the opportunity to try something new. A new technology can be the springboard that is necessary to launch these individuals forward. Without it, they stand little chance of getting ahead.

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[2] Newton's second law; Essential Engineering Information and Data, Ganic, E.N., and Hicks, T.G., McGraw-Hill, 1991.

[3] Newton's first law; Essential Engineering Information and Data, Ganic, E.N., and Hicks, T.G., McGraw-Hill, 1991.

In the end, one may find that there are three distinct groups in a company. They are: the forward-thinkers group, the opportunistic group, and the masses. The challenge is then to motivate, involve, and work with the masses who seem satisfied with the status quo.

"I'd be glad to improve myself," he said, "but I don't know how to go about it. What shall I do?."[4] Computer-Aided Drafting and Design (CADD) is a technology whose application in the AEC industry can be utilized in all phases of the life-cycle process. CADD technology has matured to the point where it is prudent to expect habitual and sporadic owners to participate in the design process using CADD. That is, owners could start communicating their vision of the project using specialized software packages built on CADD platforms that let the owner express building concepts, performances, and requirements.

A/E firms, on the other hand, have already been very progressive in their adoption of CADD technology. Despite its primary utilization as a drafting tool, as opposed to a drafting and design tool, CADD technology within A/E firms has been largely transferred. As design evolves from schematic to preliminary and from preliminary to detailed, the continuous communication feedback with the owner can again be implemented in a CADD environment. Are CADD-based designs better than pencil-based? They had better be. Because making changes to computer CADD models is a relatively painless process, design options in the later phases of the design process continue to be explored as vigorously as they were in the earlier stages. When it is all done, however, the print or plot commands are executed.

The easiness with which paper is produced using CADD software and hardware easily matches the contractors' demands for paper plans and specifications. It is, however, detrimental to the contractors when too many CADD layers are collapsed into a single sheet, making it almost impossible to read the designs. This is certainly the result of a technological mismatch between the design and construction professions. Unfortunately, this occurs at a very critical junction in the AEC life-cycle process, which is far from being seamless. Since CADD and the design industry have long passed the point of no return, history will record that this technological differential contributed to the building industry's accelerated adoption of CADD technology.

Why do we continue to demand plans and specifications in paper media? Computer-based specification systems are evolving so rapidly that coupling specifications-writing software with CADD-based drawings is imminent. Write-Once-Read-Many-times (WORM) technology can be readily utilized to centralize design changes and ease the concerns of many people regarding the un-coordinating proliferation of sources of design changes.

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[4] Quote from Saggy Baggy Elephant by K.& B. Jackson, © 1947 by Western Publishing Company, Inc.

If one looks at the AEC life-cycle from the traditional perspective (design->build sequence), the pre-construction phase offers the contractor many opportunities to utilize a CADD model. For example, the contractor would benefit greatly from a CADD model during the cost engineering phase because it can be utilized to perform automatic quantity take-offs, costing, and pricing. The coupling of the Critical Path Method (CPM) methodology with the 3-dimensional (3D) capabilities of CADD software can be used to develop construction activity sequencings as well as construction schedule animations. Constructability reviews is another pre-construction task which clearly benefits from the use of 3D modeling capabilities. Simulating, visualizing, and animating construction methods and activity sequences equals or supersedes the typical process of mentally building the project.

During the construction phase, the contractor can generate CADD-based as-built plans in real time. In doing so, the contractor and/or inspector can compare as-built coordinates of critical objects with as-planned specifications. The advent of real-time x-y-z positioning software and hardware means this task can be readily executed. Shop drawing preparation, yet another construction task, has a prepare-submit-review cycle that the CADD platform can enhance. Since design intent could be electronically embedded within the CADD model, contractors or sub-contractors would have no problem in accessing it. Periodic payment requests can be also automatically generated with the input coming from as-built CADD models.

At the end of construction, as-planned and as-built CADD models can be transferred to the owner of the facility for utilization during the operation and maintenance stages. This closes the loop in which the owner receives a CADD model that can be interfaced with commercially available or in-house developed software to perform facilities planning and management. In this context, already matured CADD technology can be readily utilized, becoming the common environment in which to communicate design requirements, performances, intent, artifacts, changes, and as-built data. CADD technology is thus capable of leveraging all phases of the life-cycle process; and last, but certainly not least, CADD technology is capable of empowering the owner to optimize the facility aspect of their mission execution.

Towards a paperless AEC industry. One can easily speculate and brainstorm other applications for CADD. One of those future applications falls in the construction phase in which the superintendent carries, still in his/her back pocket, a floppy disk containing the plans and specifications. Should the superintendent need to look up a detail, he or she would go to the nearest weather-proof visualization site station, insert the disk, call up the desired drawing either with voice commands or with pen-computing technology, zoom in as required, and yes, locally print a section of the details if paper is absolutely necessary.

T^2 Flavors and T^2 Mixins. If CADD technology has matured to the point that all the tasks described above are now possible, and many more are within range, why has technological progress not happened yet? Many researchers and practitioners who have studied the T^2 process agree on the basic notion that the T^2 process is a metamorphosis with different evolutionary stages. Each of these stages has its own purpose, function, behavior, players, barriers to overcome, dangers, and rewards.

Contrary to a predicable single metamorphosis process, one can envision an array of T^2 principles variations for the different key players of the AEC industry. That is, one size does not fit all. Therefore, each of the T^2 stages needs to be studied to determine viable ways of performing it; I call this the development of "T^2 Flavors". Each flavor corresponds to an alternative, yet plausible, way of executing each individual T^2 stage. Transferring a specific technology to a specific AEC key player requires selecting T^2 flavors from each of the T^2 stages; I call this the development of a "T^2 Mixin". It is a forgone conclusion that technology-dependent "T^2 Mixins" need to be developed for each player in the AEC life-cycle process.

The uniqueness of the flavors and mixins terms conveys the idea that there is not a single answer for every firm and for every technology. Instead, developing a variety of options is needed to customize the best combination that fits the idiosyncracies of a specific firm. This is just like going to the ice cream parlor and buying a gallon of ice cream (non-fat of course) made of one scoop of chocolate, two of vanilla, one of strawberry, and so on. What you get is an ice cream mixin that suits your taste.

The AEC industry is at a crossroads. 'Where do we go from here depends a great deal on where we wish to take the AEC industry, for if we do not care much, then it does not matter which way we go.'[5] I have chosen an essay format style to summarize a few Technology Transfer issues which in my opinion need further comprehension and investigation. These issues with which I dealt are certainly not of my own creation or postulation alone; they have been shaped by the contributions of many renown researchers and practitioners over a period of time. The contributions made by Bob Tatum of Stanford University, for example, have distilled formalisms, concepts and terminology which have proven very relevant in our understanding of the intricacies and idiosyncracies of the AEC industry players [Tatum 1986, 1987, 1988, 1989a, 1989b, Hansen 1989]. Generic models of innovation development and deployment and their adaptations to the needs of a research laboratory have provided the underpinnings for subsequent studies in the areas of innovation and technology transfer [Rogers 1983, Shaffer 1985]. Furthermore, specialized technology transfer models for expert systems have validated and expanded previous formalisms and models [Bonnett 1989, De La Garza and Mitropoulos 1991, 1992, Feigenbaum, Nii and McCorduck 1988, Helton 1990, Hester 1991, Mahler 1989, 1991, Matsuda 1991, Stretton 1991]. Developers of state-of-the-art software technology, as well as organized consumers of it, have also confirmed technology transfer and innovation postulations made by organizational behavior scientists [Cleveland 1991, Bowlin 1991, Moorhead 1989]. It is interesting to notice how Buddy Cleveland of Jacobus Technology, for example, uses as much space in his newsletter articulating the upcoming visualization software for the AEC Industry as the roots and remedies of fear associated with automation [Cleveland 1991]. I

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[5] Quote adapted from Alice in Wonderland by Lewis Carroll.

think this is a good sign. Developers of technology should be as sensitive to the issues of T^2 as the consumers.

Recommendations. In this section, I shall try to summarize the key issues with which I dealt as well as outline areas needing further study.

- The winds of change are blowing. It is time to start making things happen and stop watching and waiting while things happen.
- Warranted or not, the fears associated with change are real.
- Pro-technology, reputation, and image are interrelated concepts.
- Job performance suffers during change.
- The functions of technology transfer and innovation need a formal organizational apparatus to exist.
- A Technology Transfer Task Force needs to be recognized as a formal standing organizational unit.
- Computer-Aided Drafting and Design technology is ready to serve the entire life- cycle process of constructed facilities.
- A single model of technology transfer and innovation does not apply to all circumstances.
- A matrix of T^2 Flavors for habitual key players in the AEC industry needs to be developed. This matrix should be arranged according to their function, business line, and size.
- An array of T^2 Mixins for specific technologies for habitual AEC industry players needs to be developed.
- Case studies of successful and unsuccessful attempts to T^2 need to be elicited, formalized, structured, and disseminated.
- Pilot project guidelines specifically designed for T^2 need to be developed.

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TECHNOLOGY TRANSFER AND PUBLIC INFRASTRUCTURE DEVELOPMENT: FINANCING CAPITAL IMPROVEMENTS THROUGH THE CREATION OF KNOWLEDGE[*]

Michael B. Goldstein[**]

The traditional models for the improvement of public infrastructure depend upon a few sources of capital. By far the largest portion has come directly from the public fisc, most commonly in the form of debt amortized out of tax revenues. Next in importance is public debt financing where the revenues generated by the facility amortize the debt. Finally, there is the commercially-financed facility that is leased for public use: that is, the capital cost is amortized through lease payments out of current revenue sources, either tax levy or revenues generated through the use of the facility.

In recent years, two opposing trends have resulted in a rapidly growing backlog of infrastructure improvements. On the one hand, local, state and federal debt burdens have grown to a point where the carrying costs represent a significant portion of the current-fund budget. In the case of state and local governments, statutory or constitutional debt limits have been reached or approached, while in the case of the federal government, the magnitude of public debt is seen as jeopardizing the stability of the economy. At the same time, an aging infrastructure, large portions of which were constructed during two boom periods -- 1930s and early 40s and again in the 1960s -- is in need of massive repair and replacement.

The alternative of revenue-driven financing is appears to be available for only a minority of projects. A highway can generate significant revenues through the imposition of tolls, a dormitory can create rental income and a dam can result in the generation of saleable electric energy. If the revenue stream is sufficiently deep and predictable, such projects can be financed. But absent such sure revenue generators, financing alternatives are more limited: most needed projects appear not to hold a prospect of immediate revenues sufficient to pay back a short term advance let along maintain a reasonable amortization schedule.

In the search for financing alternatives, governments and quasi-governmental entities (such as universities, which for the purpose of this analysis will be considered quasi-governmental since they fulfill a public purpose and receive public support) have sought to capture the value added of newly created knowledge. This "intellectual property," whether in the form of a breakthrough in molecular biology or a new design for a snow plow blade, has a monetary value in the marketplace. Yet that value has historically been underutilized as an institutional financing vehicle.

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The typical approach for the capture of the value added by a discovery has been to license its commercial exploitation for a fee representing a percentage of the ultimate commercial value. Over an extended period of time, this time-honored approach can indeed generate substantial revenues as a discovery moves into the market place. However, that value is ordinarily spread out of a period of years, so that the immediate financial value of the discovery is relatively small. (While the alternative of selling the discovery for a fixed price has the advantage of an early burst of resources, unless the discovery is of known and immediate value, the total value realized tends to be materially less, since the buyer is taking all the risk of commercialization.)

The revenue stream that is created by commercialization typically lacks the reliability that is necessary to use it as a base for amortizing capital debt. Yet it is a resource that, under the right circumstances, can be used to support infrastructure development. The key is to create ongoing financial linkages that transcend single projects and discoveries. The research and development partnership and its progeny provide vehicles for just such a capital financing mechanism.

In recent years, an increasing number of colleges and universities and other government-sponsored research entities have become directly involved in "technology transfer." That term encompasses a broad range of activities intended to lead to the commercialization of discoveries arising out of the work of members of the academic community. Indeed, although the term itself is of recent vintage, "technology transfer" has been a fact of life in higher education virtually from the inception of the first universities, as discoveries have made their way into the stream of commerce. The difference, and the focus of this analysis, is the transformation of the role of the institution from that of a passive vehicle into an active participant in the process of technology transfer, through that process creating a mechanism for infrastructure improvement.

There are several restraining forces on the utilization of newly-created knowledge as a significant financial instrument. One, quite obviously, is uncertainty over the value of the discovery. However, another less obvious factor is uncertainty respecting the nature and magnitude of the risks faced by institutions that become directly involved in the commercialization of research. The advantages of a revenue stream can readily be outweighed by liabilities that quickly sap those same resources -- and then go on to invade the general resources of the entity.

It should be clear at the outset that there is no such thing as a "risk free" involvement in technology transfer, any more than it is possible to design a <u>perfectly</u> safe chemistry laboratory. But just as it is eminently feasible to design, construct and operate a <u>reasonably</u> safe laboratory, so it is possible to develop a technology transfer program that reasonably protects the interests of the institution (and its personnel).

There are several generic models of technology transfer that seek to capture the value-added of discoveries in an economically efficient manner consistent with protecting the integrity of the institution. Of course, the general proposition is that the more risk-adverse the structure, the less the financial gain, and visa-versa. While this, like most general propositions, has some exceptions, it is inescapable that in a venture that involves the commercial sector the transference of risk carries with it a considerable economic cost.

The principal active models of technology transfer are as follows:

1. The creation of commercialization entities that bring discoveries into the stream of commerce. The entity may be an operating division of a government agency or institution, or it may be a wholly-owned subsidiary.

2. The creation of start-up companies to develop discoveries, with the agency or institution providing some or all of the initial capital, holding all or a substantial portion of the equity and providing management and administrative services. The difference between the commercialization entity and the start-up company is that the former is intended to be an ongoing activity, while the latter is designed to be spun out, optimally through an acquisition by a commercial buyer.

3. The creation of joint ventures with commercial entities to provide for the commercialization of discoveries.

Each of these mechanisms can create revenue patterns that in turn may be used for infrastructure improvements. The first two options enable an agency or institution to go into the capital marketplace to finance the facilities needed to develop the discovery, and incidentally support the ongoing research and other activities of the organization. In the first option, investment in the commercialization entity, either in the form of debt or equity, provides the needed capital. In the latter case, the initial investment is compounded by the buy-out value, which can provide the agency or institution with a significant intermediate-term infusion of capital (assuming, of course, that the discovery is developed as commercially valuable).

The third option, the joint venture, affords the agency or institution an entirely different array of capital improvement options. In addition to the infusion of funds arising out of the commercial exploitation of the discovery, the joint venture can provide a direct vehicle for the development of facilities outside of the ordinary financing framework. Most common is the situation where the joint venture is capitalized to construct facilities, which are then leased to the agency or institution for the purpose of conducting further research, the agency or institution utilizing the value of the discovery as all or a significant portion of its lease cost. Thus, the agency or institution can obtain a facility that is outside financed, without incurring the attendant debt.

There are, however, fundamental differences between government research and commercial activity. There is a philosophic difference: commercial ventures are organized to deal with the financial risks of commercialization, through limiting the liability of investors, loss shifting through insurance or indemnification and, perhaps most important, by a general understanding among the participants in the venture that the risk of loss does exist. Conversely, in the traditional government setting there is little attention paid to the economic risks of research, save perhaps the risks attendant upon overrunning one's research budget and incurring the wrath of the agency head. The term "risk adverse" quite accurately describes most agencies and institutions, with good cause. Businesses fail with some frequency: that is a fact of commercial life. However, financial loss occasioned by imprudent involvement in commercial activities is far more serious a loss when the victim is a government agency or institution. The bankruptcy of a government agency is not easy to visualize, precisely because the underlying pockets are so deep. In short, the issue of risk management in technology transfer must be of primary concern.

The proposition is simple: how may an agency or institution assess the risks arising out of its involvement in technology transfer activities, and, having assessed those risks, what steps should a prudent administration take to minimize them, consistent with continuing to benefit from the value of its commercialization efforts? Unfortunately, in far too many instances, both aspects of this analysis are sadly lacking. Without risk assessment, control of risk is impossible. Yet risk assessment alone is insufficient if, after determining that a risk exists, either nothing is done or the response is simply to withdraw from the field. Administrators need a matrix of risk elements and risk control mechanisms that can facilitate technology transfer while protecting the integrity of the agency or institution.

This analysis is divided into two parts. First is a discussion of the nature of the risks attendant upon technology transfer activities, followed by a discussion of methods of risk management.

I. NATURE OF THE RISKS

The risks attendant upon technology transfer activities arise in three broad categories: economic loss to those who have invested in the activity, breach of a contractual obligation to a party to the transaction and harm to those affected by the discovery. Each may result in financial loss to the agency or institution.

Risks arising out of losses by investors are relatively easily defined and controllable through a variety of organizational methods. Risks arising out of harm to third parties, on the other hand, are difficult to predict, complex to protect against and potentially devastating in terms of the financial consequences. Risks arising out of a breach of contractual obligations are intermediate in difficulty to avoid and control.

Common examples of losses arising out of harm to third parties are damages occurring as a result of a defect in a product (commonly referred to as "products liability") or injuries sustained as a result of the operations of the commercialization activity itself. Contractual violations often involve conflicts of interest, disputes arising out of the terms of an investigator's contract of employment and violations of intellectual property rights.

A. FIDUCIARY LIABILITY - PROTECTING THE INVESTMENT

Investors in any commercial undertaking stand to lose all of their investment if the undertaking is a failure. In the commercialization of discoveries, it is painfully common that the costs of development of a promising discovery are never recovered through its commercial sales, if indeed the discovery ever makes it to the marketplace at all. In such a case the funds invested in the commercialization of the discovery are gone without hope of recovery. That kind of loss is readily measurable: it is simply the value of the direct investment in the commercialization venture.

In the case of an agency or institution whose contribution to the equity of the commercial entity is the discovery itself, the failure of the invention to be commercially viable may not bear with it any direct financial loss -- although if commercialization would have been possible through a different approach or with different partners, there are certainly lost <u>opportunity</u> costs. However, where the agency or institution backs up the discovery with a financial commitment, either directly or through a related entity, the loss will be more tangible and may, depending upon the magnitude of the investment, be substantial. But such a loss can be anticipated and quantified, and if the agency or institution or its entity cannot afford the loss, it -- like any other investor -- has no business being in the game in the first place.

The greater risk is that <u>other</u> investors -- if they believe their interests were not properly protected by those running the venture -- will bring suit to recover <u>their</u> losses. This is a considerably more material risk than that arising from the loss of direct investment, since the value of the loss may be <u>more than</u> the <u>aggregate</u> amount invested in the venture. The legal principle is straightforward: the persons or organizations responsible for the management of the entity in which the funds were invested have a <u>fiduciary responsibility</u> to the other investors; that is, they are obligated to act with reasonable care to protect the interests of the investors. In turn, the failure to exercise reasonable care can make the managers liable for the losses of the "passive" (that is, non-managing) investors.

An agency or institution that does no more than license discoveries to commercial entities that in turn are responsible for their further development and introduction into commerce is well insulated against fiduciary liability, since in fact the agency or institution does not have any fiduciary <u>duty</u>. (However, as discussed below, it may nonetheless be liable to investors if it has, for example, misrepresented the nature of the discovery when it sold its rights.)

The situation is different in the case of agencies or institutions that invest their own resources in the commercialization of a discovery, or that take a material equity (that is, ownership) position in a commercialization entity in return for providing the intellectual property. Ordinarily, like any investor, the agency or institution that is also an investor stands at risk only for the value of its own investment. However, if the liability is not "limited," the agency or institution could be held responsible for losses well beyond its own investment.

B. LIABILITY ARISING OUT OF NEGLIGENT CONDUCT

There are two distinct types of liability arising out of negligence. The first, termed "simple negligence," usually involves harm to persons or damage to property arising out of the conduct of the commercialization operation. The second results from the use of the product arising out of the commercialization activity by its ultimate consumers.

While simple negligence is a rather straightforward concept, products liability is one of the most complex areas of the law. It is far more difficult to predict and therefore protect against precisely because it only manifests itself after the discovery has become a commercial product and has been distributed in commerce. It arises when a commercial product causes harm as a result of an inherent defect that was known -- or should have been known -- by those who offered it in commerce. To prevail, a products liability claim must contain certain specific elements:

1. Evidence that the product caused the harm;
2. Evidence the harm was caused by the conduct of the defendant (or defendant's agent, for example, the investigator or the defendant's surrogate);
3. Evidence that the defendant was negligent in allowing the harm to occur, and
4. Evidence that the plaintiff was actually harmed by the defect in the product.

C. CONTRACTUAL LIABILITY

A third major cause of financial risk arises out of violations of contractual rights. There are many possible sources of such risk. For example:

1. An investigator may claim that he or she is entitled to a different share in the financial benefits arising out of the commercialization of his or her discovery than that which the agency or institution believes to be the case.
2. A partner in a commercial venture may claim that the agency or institution failed to deliver on what it was contractually obligated to provide, most commonly a failure to provide a discovery that does not infringe on another protected (that is patented or copyrighted) discovery.
3. An investigator may contract with a commercial entity to develop his or her discovery outside of his or her employment with the agency or institution, resulting in a dispute between the agency or institution and the entity over rights.

4. An agency or institution may accept a sponsored research agreement that gives the sponsor protection against premature disclosure, but the investigator may nonetheless release information that vitiates the patentability of the discovery.

Contractual liability is different from liability arising out of negligent conduct in that the agency or institution could be acting in good faith and still violate a contractual obligation. The violation of intellectual property rights is form of contractual violation, since intellectual property rights are established under the terms of an agreement entered into between the agency or institution (or its surrogate) the investigator and a third party, typically an entity involved in the commercial development of the discovery. (Even where there is no formal intellectual property policy, there is a contractual relationship between the investigator and the agency or institution, since in such a case the respective rights of the investigator and the agency or institution are defined by statutory principles.)

So long as the sequence of property rights is followed, the ultimate assignee or licensee of the rights has no grounds for complaint. But if the chain is broken, the agency or institution (or their intermediaries) can be at risk for purporting to convey defective rights.

A third aspect of contractual liability concerns conflict of interest. This is not only one of the most complex and certainly most contentious element in any discussion of technology transfer, it is also a significant contributor to institutional liability. In its simplest form, conflict of interest can be defined as a situation where a party acts to the detriment of another party to whom it owes a particular duty. The most common manifestation is that of the investigator who becomes a principle of a company that negotiates a license for the investigator's discovery from the investigator's institution. More complex issues arise where it is the institution that creates the entity that is the licensee of the discovery -- a "spin-off" company -- and the investigator is given an interest in or a managing role in that entity.

Liability arises from conflict of interest in several ways. The conduct of the investigator in serving "two masters" can cause either party to challenge his or her actions as not in their best interests. Particularly sensitive are investors who might be lead to challenge the commitment of the investigator to the work of the commercial entity. The investigator may also challenge an institutional conflict of interest policy as unreasonably intrusive. Critically, a suggestion of conflict of interest can diminish an institution's ability to defend itself against other forms of liability.

III. CONTROLLING RISK

Risks arising out of commercialization activities may be controlled in several ways. First, the conduct of the technology transfer activity can be <u>organized</u> in such fashion so as to limit or minimize the risk of loss to the parent institution. Second, the burden of losses which do arise and which otherwise would be the responsibility of the institution (or a commercialization entity under its control) can be shifted to some other party. Finally, the technology transfer activity can be structured to provide the agency or institution with a degree of insulation from loss.

The manner through which an agency or institution engages in technology transfer activities has a great deal to do with its ability to control the risks arising out of those efforts. The organizational, loss shifting and structural issues begin well before the terms of a licensing agreement or joint venture are developed. Indeed, they start with the degree to which the agency or institution exercises control over the technology transfer process, beginning with the rules governing the conduct of investigators and their relationship with and responsibilities to their agency or institution, and they continue through every step of the technology transfer process. Nor does any one approach guarantee absolute protection. Rather, it is the combination of methods of risk identification and control that can be provide an institution with the protection it requires.

A. MANAGEMENT OF TECHNOLOGY TRANSFER

The organization of an agency or institution contributes significantly to its ability to identify and control risks arising out of technology transfer, as well as its ability to identify and exploit the benefits of such activities. Assuring that the organizational components and policies are appropriate to the agency or institution is an essential first step. The only thing worse than not having an appropriate management structure is putting the structure in place and then ignoring it in practice.

The key organizational and management control elements include:

1. **The existence of comprehensive, agency or institution wide policies on intellectual property and technology transfer, and assurance that the policies governing the conduct of professional personnel adequately address the issue of rights to all forms of discoveries and provide standards for and require disclosure of interests in any commercial ventures which are in any fashion related to an investigator's research activities.**

2. **The existence of an agency- or institution-wide office with responsibility for the oversight of all technology transfer activities.**

3. **Assurance that all agreements for technology transfer, including sponsored research, are subject to review and approval by qualified counsel.**

4. **Assurance that each discovery is evaluated to determine it patentability or protection under copyright laws, and that the agency or institution provides an expeditious and professionally managed mechanism for the assertion of such rights.**

5. **Assurance that each discovery is separately evaluated to determine the nature of potential product liability risks.**

6. **Assurance that the qualifications of each potential commercial participant in a technology transfer venture are thoroughly reviewed respecting the participant's financial and technical capacity and capabilities.**

The adequacy of each element must be independently measured to assure that the management structure and the organization of the institution affords the appropriate level of control consistent with the need to protect the financial integrity of the institution.

The most delicate aspect of any technology transfer effort is the selection of the commercial partner. It is this entity that will bear all or a major portion of responsibility, depending upon the form of technology transfer, for the transformation of the discovery into a commercializable form, the development of a means of production and the marketing of the resultant product. The commercial partner may also assume responsibility for the perfection of intellectual property rights and will certainly play a major role in the financing of the enterprise. This being the case, it is remarkable the degree to which agencies and institutions are ready to do business with entities that lack demonstrated capacity to fulfill those tasks.

There is an affirmative obligation on the part of the agency or institution to very carefully and diligently screen potential commercial partners to ascertain that they have the ability to perform in the expected fashion. Such a review must cover both the substantive expertise and experience of the company in the commercialization of the specific discovery <u>and</u> its financial situation. It must at all times be recalled that it is the agency or institution that is transferring something of value to the commercial entity, and it is therefore as much the <u>latter</u> that must prove itself worthy as the institution must demonstrate the value of the discovery. Such a position is as important from the perspective of risk management as it is a component of an effective negotiating strategy.

B. SHIFTING THE BURDEN OF LOSS: INSURANCE, INDEMNIFICATION AND ASSUMPTION OF RISK.

The best internal management cannot assure complete protection from losses arising out of technology transfer activities. It is therefore incumbent upon the agency or institution to make use of available methods of <u>risk transfer</u> to ensure that such losses as may occur do not impair the functioning of the institution. It is important to note that the shifting of the burden of loss does not in any way affect the issue of <u>liability</u>. Rather, it speaks to the question of <u>who pays</u> one liability is established. Thus, primary attention must be paid to reducing the risk of loss: indeed, the cost of risk transfer devices is to a significant extent driven by the degree of risk against which the protection is sought. To the extent the agency or institution has reduced the risk of loss through the various techniques discussed in this analysis, the availability and the economy of loss transfer mechanisms will be enhanced. Conversely, to the extent an agency or institution fails to properly manage and structure its technology transfer activities, it may not only increase the risk of loss but also decrease the availability of loss transfer mechanisms and increase the cost of those that remain accessible.

There are three basic approaches to loss transfer: insurance, indemnification and assumption of risk. The most common way to shift the burden of loss is insurance. Insurance is simply a contractual agreement through which a third party agrees that, upon the occurrence of specified events under specified circumstances, to defend the insured against specified claims and to pay for any losses arising out of such claims, up to a specified sum. The insurance contract (the "policy") will typically not only state the kinds of things covered by the insurance, but also those that are not. Often, the policy will also provide for a retention of risk by the policyholder; that is, an initial portion of any loss would be borne by the insured, not the insurer. Insurance carriers intensely dislike being surprised, and they write their policies to minimize that eventuality. Obtaining adequate insurance for technology transfer activities requires an extremely careful analysis of the agency's or institution's present loss control situation as well as examination of alternative strategies to control potential losses.

The distinguishing characteristic of a technology transfer program is the fact that it is typically an activity outside of the customary role of the agency or institution. Thus, it is likely that in writing general liability coverage for the agency or institution, the insurance carrier did not contemplate university in technology transfer, and therefore may have excluded coverage for claims arising from such activities. The primary question, therefore, is whether existing general liability insurance extends to all aspects of the technology transfer activities of the agency or institution. Such policies typically also exclude product liability claims where such claims arise from goods and services in commercial use. Finally, policies commonly only cover separate corporate entities related to the agency or institution if they are specifically identified in the application for coverage (or in an amendment to that application). Obviously, such exclusions would leave an institution naked with respect to key aspects of its technology transfer activities. It is therefore essential that the terms of the contract of insurance be carefully reviewed by the risk manager or counsel to ensure that all aspects of the technology transfer operation are insured, to the extent that a separate risk assessment (as discussed in this analysis) determines that liability arising from those activities might be assessed against the institution. Where the agency's or institution's existing insurance policies are not determined to extend to its technology transfer activities or to provide adequate coverage for such activities, it is necessary to obtain either separate coverage or to negotiate an extension of coverage to afford adequate protection.

The second means of shifting the burden of loss is through indemnification. Indemnification is nothing more than a private form of insurance. However, instead of a regulated insurance carrier agreeing through a contract of insurance to defray the cost of defense and pay for losses arising out of certain causes, a private party contracts to do so. In the context of technology transfer, indemnification is commonly utilized in the negotiation of licenses for the use of the agency's or institution's discoveries. The licensee agrees, as a condition of receiving the license, to "indemnify and hold harmless" the agency or institution from "any and all losses, including attorneys fees" arising from the company's exploitation of the licensed discovery.

While indemnification can provide substantial protection, indemnification agreements are carefully scrutinized and narrowly construed: a putative indemnifier will only be held responsible if the conduct of the licensee creating the liability falls within the narrow confines of the indemnification agreement. However, indemnification does suffer from a very major drawback: it is only as good as the financial capacity of the indemnifying entity. Indeed, having an indemnification agreement is a great deal like hiring the services of a bodyguard. If he or she is able to fend off adversaries, the investment is a good one; conversely, if the bodyguard is weak and scrawny, the protection is illusory. Thus, if the indemnifying entity has little or no assets (as is often the case with startup companies), then it is unlikely that it would be able to mount an aggressive legal defense, let along pay material settlements.

It is particularly inappropriate for an agency or institution to consider itself protected by an indemnification clause in the agreement between itself and its own technology transfer subsidiary or spin-off. Unless the subsidiary has very substantial independent assets, the value of such an indemnification agreement is not only illusory, but can provide a pathway for directing liability back to the agency or institution itself.

Aside from the financial capacity of the indemnifying entity, the agency or institution must ascertain that the entity has the legal authority to enter into such an agreement. This is particularly the case with public bodies, which are often excluded under provisions of state law from indemnifying any other entity. The fact that an entity signs an indemnification agreement does not resolve the question whether it has the legal capacity to do so. Counsel must also be consulted relative to the scope of indemnification allowed under state law. Public policy considerations have driven statutes that prohibit losses arising out of certain kinds of claims, particularly those arising out of gross negligence or violation of law, from being shifted through indemnification. Conversely, the institution or agency must not allow itself to become an indemnifier if its organic law does not so permit.

The third method of risk transfer involves disclaiming responsibility for subsequent losses; that is, the exclusion of all warranties. In its simplest form, the licensee takes the license to the discovery without any expectation that the discovery is in fact marketable, effective, safe or operational. That is, the license is granted without any "warranties, express or implied." Then, if something is found to be wrong with the discovery, the licensee would presumably not have any recourse against the institution, and if the licensee were to be sued, it would not be able to bring in the institution as a defendant. Likewise, if an ultimate user of the discovery brought an action against the university arising out of the development of the discovery, the university could mount a defense that since it transferred the discovery to the licensee without any representations that it would work or be safe, and the licensee took it on that basis, the institution has no responsibility for what subsequently happened.

While express disclaimers of warranties are useful, they have two key limitations. First, to the extent the agency or institution disclaims an warranties, it is to some extent degrading the value of the discovery. Second, a disclaimer of warranties will generally not protect the agency or institution from claims arising out of its negligent conduct. Therefore, although the practice of avoiding warranties is a helpful risk limitation measure, it is not comparable to either insurance or indemnification in affording significant protection.

C. THE STRUCTURING OF COMMERCIALIZATION SPIN-OFFS AND OTHER RELATED ENTITIES.

It is clear that a well-structured commercialization subsidiary can afford an agency or institution an increased level of protection against losses while enabling the entity to capitalize upon its research activities. Separate technology transfer entities afford agencies and institutions a variety of advantages in the commercialization of discoveries, including increasing the realization of the economic value of those discoveries and protecting from certain types of loss.

However, the mere creation of another corporate entity does not, of itself, necessarily afford the agency or institution any additional protection. Even the best thought-out separation of responsibilities between an agency or institution and a separately created entity can come to naught if that separation is breached in certain key ways. Confining research activities to a separately incorporated entity does not necessarily absolve an agency or institution from liability arising from their development and commercialization. While corporations, along with limited partnerships, do afford investors a shield against unlimited liability, establishing such a subsidiary structure is emphatically not a guarantee that the institution will henceforth be protected from the risks attendant upon technology transfer.

Nonetheless, when an agency or institution decides to become involved in technology transfer activities in order to generate needed capital, it should certainly consider the use of a separate legal entity, whether created for the purpose or already existing.

However, an existing entity may not be structured appropriately for the particular use. A non-profit, tax exempt entity with a self-perpetuating board may certainly represent a desireable model for the holding of endowment funds, but it may not be the right structure for the commercialization of a discovery. The notion that there is something magical about a tax exemption is misplaced in the context of commercialization activities: in many cases a taxable entity is a more effective instrument for maximizing the return to the institution and to its investigators. The nature of the entity needs to be matched to its purpose, a persuasive reason not to simply implant commercialization activities in any readily available subsidiary.

There are also several good reasons not to rush to create a separate entity for the commercialization of faculty discoveries. The nature of the agency or institution has a considerable amount to do with the value of such structures. For example, a public agency or institution may benefit from the creation of a separate entity to afford it more flexibility in contracting and to allow it to retain income that might otherwise flow into the general treasury of the state. An independent institution or quasi-public agency, on the other hand, may not necessarily need a separate entity to benefit from this flexibility, and the imposition of another entity may simply add a layer of overhead and increase span of control problems. A small organization with limited administrative resources may have particular difficulty in overseeing the management of a separate entity, while a larger one may be more readily able to designate staff to carry out this important purpose. However, an entity that is established and then left on its own may pose more of a risk than a benefit: effective control, consistent with the maintenance of legal and operational independence, is an important consideration in establishing entities that will be part of an agency's or institution's technology transfer program.

There are also rather complex tax issues that come into play in the decision whether to set up one or more separate entities. A large, inclusive entity (such as the institution itself) can shelter substantial unrelated business income, something that might be impossible for a small, single purpose non-profit entity. Likewise, the amount of commercial activity that can take place within a large organization is substantially greater than that which would be allowed within a small spin-off. In the former case, the taxes levied on the technology transfer activity might be increased by using a separate entity, while in the latter the entity's tax exempt status might be jeopardized. Finally, although the relationship of the entity to the agency or institution can facilitate its favorable tax treatment, the close ties that assure preferential tax treatment in the form of recognition as a supporting organization may weaken the liability protection the entity may have been established to provide. Thus, tax considerations must be carefully weighed against other intended purposes of the subsidiary structure.

Regardless of whether an existing or a new entity is to be used as the instrument for technology transfer activities, there are several key questions to allow the agency or institution responsibly assess whether the entity will actually serve the intended purpose of isolating the risks arising from the technology transfer and capital formation efforts of the agency or institution.

1. **Is there an opinion of counsel that under applicable law the entity has entirely separate existence?**

2. **Is the governance of the entity distinguishable from that of the institution?**

3. **Are the operational relationships between the institution and the subsidiary sufficiently distinct so that a court might not be encouraged to ignore the intended separation?**

4. **If a major part of the ministerial management of the entity is be contracted back to the institution, is the agreement providing for such transfer explicit in the delineation of delegated responsibilities?**

Each question bears on the degree to which the technology transfer entity will be able to stand between the institution and potential third-party liability arising out of the technology transfer program.

V. TECHNOLOGY TRANSFER MODELS

The methods used by agencies and institutions to move discoveries into the stream of commerce have undergone considerable evolution in recent years, with considerable ingenuity and imagination in evidence. The structure of the technology transfer activity affects a variety of elements, of which risk management is but one. In the process of deciding upon a technology transfer model, the organization must balance such elements as administrative burden versus immediacy of economic benefit versus risk of loss. A comparative examination the attributes of several technology transfer models can afford the agency or institution an opportunity to make a reasoned decision as to the most appropriate strategy in keeping with its own structures and priorities. The five attributes considered are:

Commercialization flexibility: the degree to which the parties are free to make use of different structures and strategies to achieve commercialization.

Benefit to the organization: the potential return to the agency or institution of the value of the discovery.

Benefit to the investigator: the potential return to the investigator of the value of the discovery.

Administrative burden: the extent to which the organization must devote administrative resources to the management of the technology transfer process.

Institutional risk control: the degree to which the agency or institution can define and set limits upon its exposure.

Institutional risk exposure: the potential exposure of the agency or institution to losses arising out of the technology transfer activity. This is further divided into fiduciary liability and liability arising from negligent conduct.

Applying these attributes to generic models of technology transfer, a matrix of costs and benefits can be developed, allowing institutions to evaluate the virtues of each approach. It is also important to note that the nature and status of the research must be considered in evaluating appropriate vehicles. Applied research that results in prototypes that may be tested in a commercial setting is different from the establishment of a production facility. The former is a common institutional activity and generally does not require the imposition of substantial risk-controlling structures. However, the line between the development of a prototype to test a theory and a production device is not a clear one, and care should be taken not to inadvertently cross from one to the other without evaluating the exposures that may arise.

The models examined are ownership of rights and control of commercialization by investigators; licensing of discoveries by the agency or institution, either directly or through a third party; and organization involvement in the commercialization of the discovery, either directly or through intermediaries such as joint ventures or spin-off entities.

A. Ownership and Control of Commercialization by the Investigator.

The simplest, although for most agencies and institutions no longer the best, way to deal with the commercialization of discoveries is to treat them in the same fashion as the authoring of books and articles. Among educational institutions, it is common that the institution does not retain any residual rights in the work and does not receive any direct benefit from its publication, except where the authoring involved a very specialized use of institutional resources.

Some institutions continue to treat all intellectual property created by their faculty as undifferentiated, even without regard to the locus of the work out of which the discovery may have arisen. A faculty member who creates a new superconductor in his or her laboratory at the institution stands in the same position relative to the ownership of that discovery as one who writes a new textbook: both are free to sell all or some of the rights their work, in the latter case through publication and the former through production, most often under a licensing agreement.

Under such an arrangement, there is no oversight by the institution respecting the manner through which the investigator seeks and obtains commercialization of his or her discovery, and often no restrictions on the manner or degree to which he or she may be personally involved in that process.

This approach has the positive attributes of requiring a minimum of institutional involvement, and therefore virtually no overhead investment, as well as affording the investigators the utmost freedom in the management of their affairs, including their ability to profit from their efforts. However, the absence of institutional involvement is a double-edged sword. First, regardless of the niceties of academia, a an investigator is an employee of the institution, and work done by such an employee on the employer's time (that is, while being compensated by the institution) and while using the facilities of the institution is work for the institution. While under prevailing intellectual property law, the creator of a work (whether a writing or an invention) "owns" the work, the fact that the discovery was made by its paid employee on its premises under its overall supervision inextricably links the institution, as a legal entity, to the resulting product. Even though an institution may allow a faculty member free rein to commercialize his or her discovery, that does not necessarily relieve it of potential liability, although in some instances it might. Thus, such an exercise of rights does not absolve the institution from responsibility respecting the effects of the discovery on third parties. Of course, the institution and the faculty member may agree that the faculty member will, as a condition of receiving all rights to the discovery, indemnify the institution from any liability arising out of its commercialization. However, if, as is probable, the faculty member lacks the wherewithal to satisfy the claim of the injured party, the institution still may stand directly at risk.

Second, such an arrangement leaves with each faculty member the total responsibility for negotiating the commercialization of his or her discovery. For a very few, this is a reasonable burden. For most, however, the costs of acquiring adequate protection, let alone obtaining qualified professional advice, is more than can be reasonably expected. Whether the faculty member attempts to handle negotiations on his or her own, engages an agent who negotiates for him or her for a fee or in return for a share of the value, or enters into an agreement with a commercial entity for it to handle commercialization, the interests of the institution are simply not on the table. While the totally open playing field would seem to allow for the widest possible range of commercialization strategies, in fact the exclusion of the institution from the equation denies the process an important and effective player.

Third, the institution is denied any benefit from the discovery, particularly its value in capital formation, even though it may have invested substantial resources in making it possible.

The attributes of this approach are as follows:

Value for capital formation: Nil.

Commercialization flexibility: High, but potentially limited by a lack of tangible resources on the part of the resources.

Benefit to the institution: Nil, except for possible sponsored research indirect cost recovery.

Benefit to the investigator: Potentially very high in comparison to other alternatives, but in practice aries from very low to very high. In large measure dependent upon negotiating skill of investigator and nature of transaction.

Administrative burden: Very low.

Institutional risk control: Very low.

Institutional exposure to fiduciary liability: Probably low.
Institutional exposure to product liability: Varies, but could be very high.

B. Licensing of Discoveries.

By far the most common way organizations are able to transfer discoveries into the stream of commerce is through the negotiation of a license with a commercial entity that will complete development and produce and market the resulting product. Such licensing activities are carried out through several structural models, each of which has different risk assessment attributes.

1. Direct licensing by the agency or institution.

The most straightforward licensing approach is for the institution to hold all rights to the discovery and issue the license in its own name. The organization must determine which discoveries are of commercial potential, secure appropriate patent or other protection, identify potential licensees, negotiate a license and oversee the collection of royalties and the protection of its rights.

The advantages to this strategy are its relative simplicity and immediacy of control. Possible disadvantages include a lack of flexibility respecting the use of royalties (a particularly serious problem for public institutions) and the absence of any insulation between the institution and the licensee, as well as the substantial administrative burden. The utility of this approach for capital formation is obvious: the revenue stream is generally insufficiently defined to support debt financing and inadequate for immediate capital development.

This approach has the following attributes:

Value for capital formation: Low.

Commercialization flexibility: Low.

Benefit to the institution: Varies.

Benefit to the investigator: Varies from very low to moderate.

Administrative burden: High.

Institutional risk control: High.

Institutional exposure to fiduciary liability: Low.

Institutional exposure to product liability: Low to moderate.

2. Licensing of Discoveries Through an Outside Entity.

While direct licensing is an attractive approach, it requires a commitment of significant resources, not only in terms of the negotiation of the licenses but also in the screening of discoveries, the identification of potential licensees and the supervision of the royalty process. To avoid this burden, a number of organizations have turned to the use of an outside licensing entity. Such an organization is typically granted a right of first refusal, allowing it to examine each discovery and to seek to license those in which it has determined there exists a commercial opportunity. The outside entity identifies potential licensees and attempts to negotiate a license. If a license is issued, the outside entity and the institution share in the royalties, and the outside entity is typically responsible for oversight of the royalty process.

This approach has the following attributes:

Value for capital formation: Low.

Commercialization flexibility: Low.

Benefit to the institution: Varies, but lower than direct license, since the licensing firm must share in revenues.

Benefit to the investigator: Varies from very low to moderate, but tends to be lower than direct license for the same reason.

Administrative burden: Low.

Institutional risk control: High.

Institutional exposure to fiduciary liability: Low.

Institutional exposure to product liability: Moderate.

3. Licensing Through a Related Entity.

To overcome the disadvantages of a direct licensing program while not surrendering control to an outside entity, a growing number of agencies and institutions have established various forms of related entities, most commonly a tax-exempt university foundation, that carries out the licensing function for the institution in the same manner as an unrelated third party.

In some cases, the related entity is assigned the rights to all or specified discoveries, either, in the case of some public institutions, through a statutory enactment, or by contractual agreement between the organization and the related entity. In other situations, the related entity either has a right of first refusal to all discoveries or may request transfer of a specific discovery. In the latter case, the agency or institution or the investigator, or both, retain the right to decide whether the related entity will control licensing. Unlike arms-length third party licensing arrangements, related licensing entities are not typically subject to "march in" provisions.

This approach has the following attributes:

Value for capital formation:Varies.

Commercialization flexibility: Low.

Benefit to the institution: Varies, depending upon the aggressiveness of the related entity.

Benefit to the investigator: Varies, depending upon the aggressiveness of the related entity and the policies of the institution. from very low to moderate

Administrative burden: Low for the institution; high for the related entity.

Institutional risk control: High.

Institutional exposure to fiduciary liability: Low for the institution; low to moderate for the related entity.

Institutional exposure to product liability: Moderately low for the institution; moderate for the related entity.

C. INVOLVEMENT IN THE COMMERCIALIZATION PROCESS

The alternative to licensing the rights to commercialize a discovery is the involvement of the agency or institution in the actual commercialization process, either by bringing the product to market itself or in entering into some form of joint venture with one or more outside entities. Instead of assuming the traditional role of passing the discovery to a commercial entity through the vehicle of a license, leaving to that entity the risks -- and therefore most of the benefit -- attendant to commercialization, an increasing number of agencies and institutions are maintaining an <u>operational</u> involvement with the discovery through all or most of the commercialization process. On the one hand, this approach allows the institution to substantially increase its share of the value of the discovery. At the same time, the direct involvement in commercial activity opens the institution to risks that are either not present or minimal in the context of passive licensing.

This is not to say that institutions ought not consider direct involvement in commercialization. The benefits that can attend such efforts may be considerable, and for certain types of discoveries the ongoing involvement of the institution can play a critical role in the success of the commercialization process.

To a substantial degree, the particular structure that is utilized to achieve commercialization affects the nature and degree of the risks and benefits to the institution. There are three general models for institutional involvement in the commercialization process: direct commercialization, commercialization through a related entity and commercialization through a joint venture, typically involving what are referred to as "spin-off" or "spin-out" companies.

It is important to note that there do not exist clear distinctions between these models: commercialization through a related entity or direct commercialization may also involve joint ventures with other entities, as well as the involvement of outside sources of capital and debt. The relationship of the institution to the commercial venture, and to its partners and investors, significant affects the exposure of the institution to the attendant risks. The interposition of a subsidiary or related entity can to varying degree depending on the specific circumstances limit those risks, but they cannot be altogether eliminated: as stated in the introductory section, there is no free lunch. It is immutable that the price of an increased share in the value-added of the discovery is an increased share in the risks. However, the relationship is not linear: an institution <u>can</u> significantly increase its share of the benefits without an equal increase in its exposure through the use of sophisticated structuring of the transaction as well as the appropriate application of risk control and loss shifting techniques. Conversely, the failure to carefully structure the transaction, and to diligently apply risk control and loss shifting devices can easily result in a significant increase in institutional exposure <u>without</u> an attendant increase in benefit. In all cases, however, the nature of the transaction drives the risks and the benefits, which in turn requires that the entirety of the transaction be designed and implemented with both great care and an understanding of all of its implications.

1. Direct commercialization.

An agency or institution can simply establish a manufacturing and marketing arm to bring a discovery into the stream of commerce. Such an approach certainly reduces any sharing of value with outside entities, except to the extent that the institution must go to the capital marketplace for financing and to outside entities for marketing and other services. However, it bears with it not only very substantial financial potential but also very significant risks. The obvious advantage is that all of the profits are retained by the institution and the investigator. The disadvantage is that the risks that ordinarily attend the commercialization of a discovery are firmly rooted within the institution.

While most administrators express horror at the idea of engaging in direct commercialization activities, such efforts are in fact common, albeit on a limited scale: for example, research laboratories often fashion a limited number of pieces of sophisticated equipment and instrumentation developed by its researchers and sell them to other institutions, government agencies and commercial entities. Despite the limited number of production units, this is indeed direct commercialization, with all the attendant risks. There are many other examples of institutional "industries," some of the most venerable having been embedded within agriculture programs.

This approach has the following attributes:

Value for capital formation: High.

Commercialization flexibility: Very high.

Benefit to the institution: Potentially very high.

Benefit to the investigator: Varies, but usually high.

Administrative burden: Extremely high.

Institutional risk control: High.

Institutional exposure to fiduciary liability: Very high.

Institutional exposure to product liability: Very high.

2. Commercialization through a related entity.

As an alternative to directly engaging in commercial activity, agencies and institutions have created related entities that assume the commercialization role. These entities are either wholly or substantially owned by the institution, and the net profits of the subsidiary are returned to the institution in the form of dividends or limited partnership distributions. Related entities may be taxable or tax-exempt, and they may be corporations or partnerships.

One key advantage of using a related entity for commercialization lies in the greatly enhanced flexibility that operating outside of the institutional framework affords, an attribute that is particularly apparent among public institutions. Such an approach also allows the institution to better direct the flow of revenues and, if the structure is properly designed, to deflect risks from the institution itself. The degree and the effectiveness of the separation between the related entity and the institution will dictate the extent to which the entity actually affords protection against risk exposure.

This approach has the following attributes:

Value for capital formation: Very high.

Commercialization flexibility: Very high.

Benefit to the institution: Very high.

Benefit to the investigator: Varies, but usually high.

Administrative burden: Low to the institution; very high to the related entity.

Institutional risk control: High.

Institutional exposure to fiduciary liability: Low to moderate for the institution; very high for the related entity.

Institutional exposure to product liability: Low to moderate for the institution; high for the related entity.

3. Commercialization through spin-off companies controlled by an entity related to the institution.

Finally, there is the model of a related entity controlled by the agency or institution that does not engage in commercial activity itself but rather licenses the rights to a discovery to a spin-off company that is then capitalized and, usually as a joint venture with a commercial partner, brings the discovery into the stream of commerce. Typically, when the discovery is successfully commercialized, the spin-off company is sold to the commercial partner, with the institution (through its related entity) receiving the capital appreciation. There are many models for this type of enterprise which may use joint ventures, various corporate forms and limited partnerships to accomplish their purposes. The institution may own a major share of the equity of the spin-off, either directly or through an intermediary, although as the commercialization process progresses the institution's interest in the spin-off may decline. The relative degree of institutional ownership may significantly affect the exposure of the institution.

This approach has the following attributes:

Value for capital formation:Very high.

Commercialization flexibility: Very high.

Benefit to the institution: Very high.

Benefit to the investigator: Varies, but usually high.

Administrative burden: Low to the institution; high to very high for the related intermediary entity.

Institutional risk control: High.

Institutional exposure to fiduciary liability: Low to moderate for the institution; moderate for the intermediary entity.
Institutional exposure to product liability: Low for the institution; moderate for the intermediary entity.

Note that while the spin-off entity may be a joint venture or have outside investment, that need not be the case. There are a number of examples of the entities being wholly owned by the agency or institution or its intermediary (or a combination thereof), with the whole of the earnings going back to the institution and with management vesting with the institution. To the extent the spin-off entity appears entirely controlled by the institution, the attributes are altered as follows:

Value for capital formation: High.

Commercialization flexibility: Very high.

Benefit to the institution: Very high.

Benefit to the investigator: Varies, but usually high.

Administrative burden: Low to moderate to the institution but high to the related entity.

Institutional risk control: High.

Institutional exposure to fiduciary liability: Moderate to very high.

Institutional exposure to product liability: Moderate to very high.

VI. CONCLUSION

Involvement in the transfer of technology through the commercialization of discoveries is becoming an inescapable fact of life for an increasing number of agencies and institutions. Such a process can not only accelerate the dispersion of discoveries into the stream of commerce, but also afford organizations a new medium for the formation of capital necessary for the replacement and expansion of its infrastructure.

These ends can only be accomplished through an understanding of the available structures, their attendant risks and the management of those risks. Through aggressive internal organization, the use of loss shifting techniques and the creation of appropriate structures, some risks can be eliminated entirely and others can be reduced to manageable levels. None need be seen as so threatening as to preclude the involvement of an agency or institution in the process of moving discoveries from the laboratory into the stream of commerce.

Implementation Innovation Through Total Quality Management (TQM)

James A. Broaddus
Associate Director
Construction Industry Institute
The University of Texas at Austin

As a newly appointed member of a committee to develop a proposal for the implementation of total quality management (TQM) at The University of Texas, I watched as our group outlined the research process in a process flow diagram. The last block of the model read "publish the findings of the research." To complete major research projects to the point of publication is a formidable challenge, but what about the adoption and use of the research results. As I surfaced the issue of continuing the process into technology transfer, my colleagues said, "You're right. We should include it, but that's the hard part." That group, like this one, recognized that technology transfer or implementation, as we call it in CII, is difficult, and we all continue to struggle with that very same issue.

CII started with this in mind. From the beginning, our mission has included the words "research" and "implementation." Despite this, there has been much in the way of research, but as far as we can gather, much less in the way of implementation than we would like to see. Nevertheless, we are endeavoring to put more and more effort behind expanding our implementation efforts.

First, let me introduce you briefly to CII. CII has a staff of 14 people located in Austin at The University of Texas. We are an organization that is funded largely by owners and contractors from the private sector. However, we do have a handful of public sector members, each of which contributes $30,000 a year in grants to the Institute. The membership is fairly evenly divided between owners and contractors. Twenty-seven universities also participate primarily by providing research for CII through their universities. The triad between academia, owners, and contractors is a graphic statement of how research and other activities of the Institute are carried out.

One of the real keys to CII's success has been the participation of its membership. The contributions of its companies go far beyond the $30,000 a year in grant money provided to CII. Participation on task forces, boards, action teams, etc. normally numbers about 700 people per year, with their companies funding the employee's participation. As a result, we have estimated that services in kind to CII have numbered as much as $25 million a year, which is about 8 times the cash budget of CII.

In the area of research, the companies and universities participating have produced a prolific amount of material. As you can see from the sampling of products, a wide range of material, particularly those that affect the management of projects, has been published and is available to the industry at large.

Currently, CII has 34 active task forces which are in various stages of their research effort. A task force is made up of approximately 15-20 industry volunteers, teamed with an academic who physically accomplishes the research. One of the keys to the effectiveness of this research has been the close involvement of the member companies of CII. For example, the Board of Advisors, representing all the companies of CII, selects the subject areas of task force inquiry. The task force then develops the specific topics for study and seeks approval from the CII Executive Committee on those topics. The task force then develops a detailed research plan and schedule, as well as budget figures. When all this information is gathered, the task force plan and budget are presented to the Board of Advisors again for approval. No research is initiated without considerable involvement from the industry members of the task force, and no commitment is made to proceed with the research without a majority vote of the Board of Advisors. As a result, the relevance and value of the research have been high.

Now comes the hard part--implementation. The history of implementation in CII has also been an interesting development. A significant implementation step was a decision to produce summary pamphlets for the research of the Institute. These pamphlets boiled down the key elements of research into executive summary form for ease of reading and implementation by industry members. Shortly after the formation of CII, an Implementation Committee was formed to promote this effort. They viewed their role primarily as a quality and consistency check for CII products which translates into review of the summary pamphlets. Later, it became apparent that more needed to be done to promote implementation of these valuable research products. Organizationally, new groups, called action teams, were formed. Action teams, like task forces, were composed of industry participants and were established to promote implementation in specific areas. The next development in CII implementation became education of project management personnel, which we will discuss later. The last significant step in CII's implementation history has been the development of an Implementation Strategy Subcommittee and long range implementation plans.

We feel like a significant effort in implementation is worth the effort. A recent study completed between the costs and benefits of maximum use of CII/CICE concepts is quite revealing. When categorized into eight management areas, the CII products were shown to have potential gross savings of anywhere from 5 to 15 percent and a benefit to cost ratio never less than 10 to 1. This was based on the replies of over 400 respondents from members of CII companies. There is a strong motivation for and significant energy being expanded on the implementation activities of CII.

Recognizing that only companies can implement, CII implementation activities need to make implementation more company friendly. The CII Strategic Plan, revised and published in 1990, noted that under the key pursuits of our Institute that implementation should aggressively address planning, communication, education, and measurement. As a result, a number of action teams were formed to address various issues. Currently, CII has 15 action teams which are working in virtually all the areas laid out by the Strategic Plan.

One fundamental truth is demonstrated by the "typical company." To date, most of the involvement in CII has been at the corporate level where the awareness of the product has been high. However, implementation takes place at the project level. CII products must be applied to the projects if the paybacks from implementation are ever going to occur. As a result, project managers not only need to be more aware of CII products, but to be knowledgeable in their application.

One of the first implementation products of CII dealt with planning and organizing a CII implementation program. The Plants and Divisions Action Team of CII has recently completed a publication called, "Implementation Process for Improved Quality." It is built on the total quality and management model. The manual lays out a typical process for implementation and allows a company to tailor that process to their own uses. Another action team, the Pilot Projects Action Team, produced a brief publication on pilot projects and how they can be used as an implementation tool. The pamphlet describes how the barriers to organizing a pilot project can be overcome, and what guidelines should be followed in executing CII products through a pilot project. Additionally, another planning tool has been the "Manual for Small Project Management." This addresses the often ignored small projects, and how CII products can be applied to them. It is organized by the phases of a project with some special subject areas as well. It serves as a good reference manual and menu for CII product applications on small projects. If you will note, the word "small" is actually scratched out and the word "special" is inserted. This is because in defining small projects, what is small to one company may be large to another and vice versa. However, each organization seems to have small projects which frequently are ignored.

In the area of communication and awareness, we have produced a success story video called "The CII Experience." It highlights more successes on different projects by interviewing the participants in the projects. The purpose of this video is to create an awareness that products have been used in actual practice, and what are the results from the use of some of those products. Also in the communications area, one of our action teams has produced a CII Speakers Resource List that is available to local user councils and any other groups who would like access to participants of CII who are willing to speak on a subject in an area where they have been involved. The goal is to make the programs from CII available to more and more groups.

The primary thrust of our current implementation effort is in the area of education. The education thrust is primarily focused on bridging the gap from the board room to the project level. The principal effort has resulted in translating CII research products into education modules. The education program concept is shown on this simplified graphic. Essentially, pilot university short courses of one-week in length are taught by combining six to eight different subject areas or modules. The courses are targeted for experienced project managers and are team taught by faculty experts and industry practitioners. They are "piloted" in Austin near the CII headquarters and are overseen by action teams formed around specific subject areas. Each of these pilot courses is used to develop the individual subject into completed "hard copy" modules. A module then becomes a complete, "ready-for-instruction" package consisting of an instructor's guide, a student's or participant's manual, and all audio visual material, including slides and videos necessary for course instruction. The modules are designed with adult learning in mind and should maximize class interaction through workshops and discussion.

Currently, 15 modules are at the end of their development and production phase. The goal will be to use the modules in a number of different ways. Individual modules can be used for (1) in-company training programs, using in-house or other instructors; (2) regional workshops at local user councils, etc. normally half a day to a day in length; or (3) combined, the modules can be used in short courses nationwide. Currently, CII is building a network at regional universities to participate in this program. The first two, Clemson and Arizona State, will begin teaching these courses in September and November.

To date, we have taught five sessions in Austin, with over 150 project managers in attendance. The education modules under development are shown here, and a new set of topics which include partnering, total quality, and contractual issues will begin development in Fall of '92. The schedule for short courses is shown with our next courses in Austin to be available in the April and May time frame. The current level of CII implementation activity is high, and we are excited about the possibilities for seeing more widespread industry use of CII products.

The question is where do we go from here? I feel that total quality management offers much potential for our future progress. At CII, you may say, we have "backed into" it. In reviewing our history, we recognize the customer's needs. We involved everyone in the process. Now we have developed significant education and training programs. There is even considerable talk about how we can benchmark best practices and make that information available to the industry so we can all continuously improve.

For implementation or technology transfer, there are many barriers. There is difficulty with company policies, cultures, reward structures, perceived loss of power, to name a few, but TQM is changing that. It is causing folks to look at its customers and its processes, and it is enabling and empowering people to do something about it. Essentially, all TQM efforts have some key core elements. These elements are customer focus, an emphasis on processes, continual improvement and innovation, people involvement, and management leadership. In many ways, the bits and pieces of this are what we at CII have been doing. In reviewing successful applications of our products, all of these elements appear to be present. Conversely and probably more extensively, the lack of success of implementation or technology transfer efforts can be attributed to situations where one or more of these elements of TQM are missing. Just imagine how much more success we could achieve in the transfer of technology if it were carried out in organizations committed to TQM.

I would like to stand here and tell you that the staff of CII is a corps of visionaries who have led the way to the "alter" of TQM. No, our members are those who have been adopting TQM in increasing numbers and have led the way. They have grown into TQM, and their growth has just begun. They are also telling us that this is the path. We are adapting to the new industry standard. We are finding that instead of selling our product, the environment for TQM creates a demand for it. As organizations look to improve their processes, they need solutions. If we have been working on the right thing, then our products will fit the bill. If we haven't, they will go unused.

So what does this have to do with infrastructure, which generally translates to public sector projects? TQM has no public/private sector limits. It is applicable to all organizations and situations. TQM has as much applicability in the public sector as in the private sector. It has as much applicability in the research labs as it does in construction companies. It is more important where the interfaces are diffucult. Infrastructure, in general, is going to require exceptionally astute use of limited funds, and "value-adding" innovation as well. As long as the core elements of TQM exist around infrastructure projects, then the potential for "value-added" implementation is high. TQM will not just happen, but with appropriate leadership, it can become a reality.

Examples of innovative applications in TQM focused organizations are emerging. In the Department of Defense, more extensive use of partnering is emerging. Constructability programs have started to catch hold in the Navy. At the state level, the Arizona Department of Highways is aggressively pursuing partnering. Even in our own city of Austin, a Malcom Baldridge Quality Award has been offered for the first time, and yes, even in the university environment, TQM is being strongly considered for research, curriculum, and administration. A commitment to total quality will enhance our ability to effectively transfer technology.

Implementation of Innovation through Total Quality Management

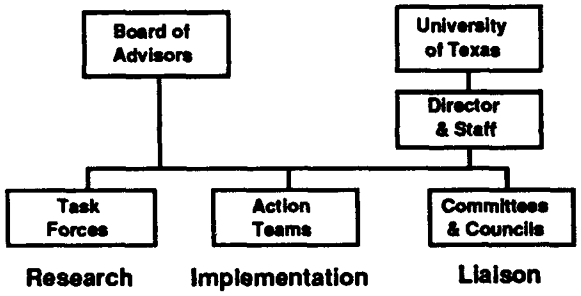
James A. Broaddus
Construction Industry Institute

Champaign, Illinois
March 4, 1992

Mission

To improve the total quality and cost effectiveness of the construction industry through research and implementation for the purpose of providing a competitive advantage to American business in the global marketplace.

CII Structure



Board of Advisors

University of Texas

Director & Staff

Task Forces

Action Teams

Committees & Councils

Research

Implementation

Liaison

CII Owner Members

AT&T
Air Products & Chemicals, Inc.
Aluminum Company of America
American Cyanamid Company
Amoco Corporation
Anheuser-Busch Companies, Inc.
Atlantic Richfield Company
Atochem North America Inc.
BP Oil Company
Chevron Corporation
Consolidated Edison Co. of N.Y., Inc.
Dow Chemical U.S.A.
E.I. duPont de Nemours & Co., Inc.
Eastman Chemical
Exxon Research & Engineering Company
FMC Corporation
General Electric Company
General Motors Corporation
Glaxo Inc.
Hoechst Celanese Corporation
Hoffmann-LaRoche, Inc.
Houston Lighting & Power Company

CII Owner Members

(continued)

ICI Americas Inc.
International Business Machines Corp.
International Paper Company
James River Corporation
Mobil Research & Development Corp.
Monsanto Company
Northern States Power Company
Ontario Hydro
Pfizer, Inc.
Phillips Petroleum Company
Potomac Electric Power Company
The Procter & Gamble Company
Shell Oil Company
Southwestern Bell Telephone
Tennessee Valley Authority
Texaco Inc.
U.S. Bureau of Reclamation
U.S. Department of Defense
U.S. Department of the Navy
U.S. Department of State
Union Carbide Corporation
Weyerhaeuser Company

CII Contractor Members

ABB CE Services, Inc.
ABB Lummus Crest Inc.
AMEC Holding, Inc.
Guy F. Atkinson Co. of California
BE&K Construction Company
The Badger Company, Inc.
Bechtel Group, Inc.
Belcan Engineering Services, Inc.
Black & Veatch Engineers-Architects
Blount, Inc.
Bovis, Inc.
Brown & Root, Inc.
John Brown E&C Inc.
Burns & Roe Enterprises, Inc.
CRS Sirrine Engineers, Inc.
CUH2A
Cherne Contracting Corporation
Cianbro Corporation
Davy McKee Corporation
Day & Zimmermann, Inc.
Ebasco Constructors Inc.
Eichleay Holdings Inc.
Fluor Daniel, Inc.
Ford, Bacon & Davis, Inc.
Foster Wheeler Constructors, Inc.
Fru-Con Corporation
Gilbane Building Company
Gilbert/Commonwealth, Inc.

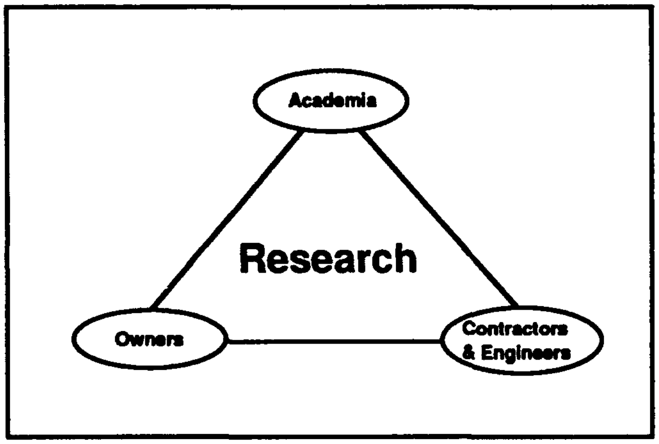
CII Contractor Members

(continued)

- Graycor, Inc.
- Gulf States, Inc.
- Jacobs Engineering Group, Inc.
- Jones Group, Inc.
- The M. W. Kellogg Company
- Korte Construction Company
- Marshall Contractors Inc.
- Morrison Knudsen Corporation
- North Bros. Company
- The Parsons Corporation
- Rust International Corporation
- S&B Engineers and Constructors Inc.
- Sargent Electric Company
- Sordoni Skanska Construction Co.
- Stone & Webster Engineering Corp.
- Torcon, Inc.
- Turner Construction Company
- United Engineers & Constructors International
- Woodward-Clyde Consultants
- H. B. Zachry Company

Universities

- Arizona State University
- California-Berkeley
- Carnegie-Mellon University
- University of Cincinnati
- Clemson University
- Colorado State University
- University of Colorado
- Georgia Institute of Technology
- University of Houston
- Iowa State University
- Louisiana Tech University
- University of Kentucky
- Lehigh University
- University of Michigan
- University of New Mexico
- North Carolina State University
- Oklahoma State University
- Oregon State University
- Penn State University
- Purdue University
- Stanford University
- Texas A&M University
- University of Texas at Austin
- University of Washington
- University of Wisconsin, Madison
- Virginia Polytechnic Institute
- Worcester Polytechnic Institute



CII Participation

Task Forces	450
Action Teams	150
Councils	100
Committees	100
	800

Level of Effort

(in millions of dollars)

CII Budget	3.5
Volunteer Effort	24.5
Total	28.0

Research

Sampling of Products

- Constructability
- Design Effectiveness
- Cost & Schedule Controls
- Scope Definition
- Project Organization
- Materials Management
- Contracting
- Risk Management
- Partnership
- Quality

Active Task Forces

- Advanced Technological Systems
- Change Order Impacts
- Claims
- Computer Integrated Design & Construction
- Constructability Implementation
- Construction 2000
- Construction Work Force
- Contracting, Phase II
- Education & Training
- Electronic Data Management
- EPC Flexibility
- Insurance
- International Construction

Active Task Forces
(continued)

- Modularization
- Overtime
- Owner Engineering Organization
- Partnering
- Project Team Building
- Project Team Risk/Reward Allocation
- Quality Performance
- Retrofit Projects
- Technology Survey
- Total Quality Management
- U.S. Navy Demonstration Project
- Zero Accidents

Task Force Cycle
(Normal)

Year 0 - Task Force creation

Year 1 - Research plan definition

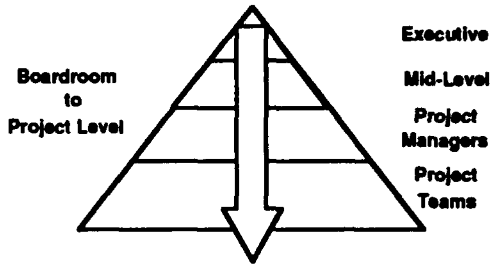
Year 2 - Research

Year 3 - Implementation planning

Year 4 - Implementation

Implementation

Bridging the Gap



Boardroom
to
Project Level

Executive

Mid-Level

Project
Managers

Project
Teams

CII Implementation History

Summary Pamphlets

Implementation Committee

Product Review

Action Teams

Education

Long-Range Strategy

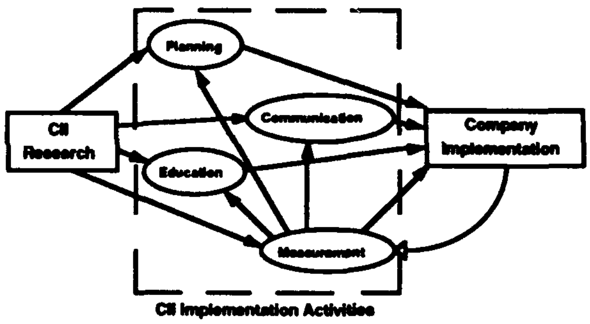
Cost/Benefit:
Maximum Use of CII/CICE Concepts

Management Category	Potential Gross Savings	Range of Gross Savings	Benefit to Cost Ratio
Strategic Project Organizing	15	10 to 20	20:1
Design Effectiveness	10	5 to 20	15:1
Human Resource Management	10	5 to 20	15:1
Project Controls	10	5 to 15	10:1
Management of Quality	8	5 to 10	10:1
Materials Management	5	3 to 8	10:1
Contracting Practices	5	3 to 10	10:1
Safety	5	2 to 8	10:1
Integrated Effect	25	15 to 30	15:1

Implementation Process

Implementation Process

Pursuit Areas



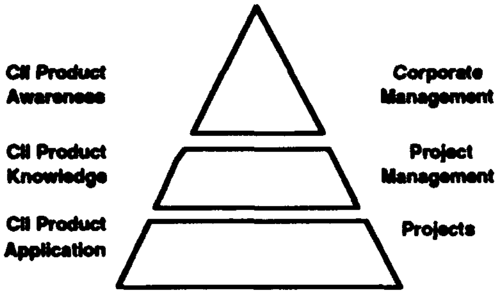
Action Teams

- Marketing
- Plants and Divisions
- Pilot Projects
- Local User Council Support
- Small Projects

Action Teams

- Project Management Education Module
- University Short Course
- Project Organization Education
- Design Effectiveness Education
- Constructability Education
- Safety Education
- Materials Management Education
- Quality Management Education
- Cost/Schedule Controls Education
- Partnering Education
- Contracts Education

Typical Company



CII Product Awareness — Corporate Management

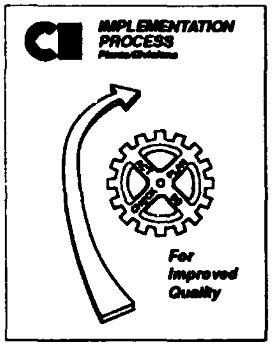
CII Product Knowledge — Project Management

CII Product Application — Projects

Product Catalog

- Publication abstracts
- Cross-reference index
- Order form

Planning and Organizing a CII Implementation Program



Pilot Project

- Definition
- Consideration
- Overcoming barriers
- Guidelines

Products

- 31 Publications
- 69 Source Documents
- 25 Special Publications
- 68 video tapes
- 7 annual reports

Special
Manual for ~~Small~~ Project Management
Contents

- Organization Solutions
- Planning Phase Guidelines
- In-Process Management Guidelines
- Revamp Projects
- Contracts
- Project Controls
- Total Quality Management
- Safety
- Environment

CII Success Story Video

"CII Experience"

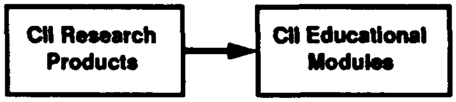
CII Conferences

- Annual Conference
  - CII participants
  - new research products
  - case studies
- Construction Project Improvement (CPI) Conference
  - attendees from CII and non-CII companies
  - program similar to Annual Conference
- Implementation Workshop
  - for implementation "champions"
  - implementation programs

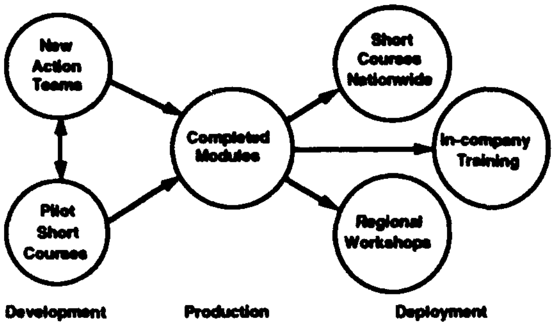
CII Speakers List

- 100 participants
- Direct access to speakers by LUCs/others
- Goal-expanded programs nationwide

CII Implementation through Education


CII Research Products
CII Educational Modules

CII Education Program



New Action Teams

Pilot Short Courses

Completed Modules

Short Courses Nationwide

In-company Training

Regional Workshops

Development

Production

Deployment

Pilot Short Courses

7-8 modules taught in one week

Sessions:

- Targeted for experienced project managers
- Team taught by faculty & industry
- Piloted in Austin
- Starting point for module development
- National application

Education Modules Under Development

- Optimizing Project Schedules
- Project Organization
  - Team Dynamics
  - Managing Uncertainty
  - Project Objective Setting
- Design Effectiveness
  - Objectives Matrix
  - Inputs to Design Impact on Project Outcome
  - Scope Definition
- Constructability
  - Improving Project Constructability
  - Modularization & Pre-Assembly

Education Modules Under Development

- Safety
- Materials Management
- Project Quality Measurement
- Cost/Schedule Controls
  - Work Packaging
  - Planning for Start-up
  - Productivity Measurement
- Partnering
- Total Quality Management
- Contracts
  - Incentives
  - Impact on Types and Clauses
  - Risk Allocation

Scheduled Short Courses

Topics	Dates
Project Organization	May 17-22, 1992
Design Effectiveness	September 1992
Constructability	November 1992
Safety	April 12-17, 1992
Materials Management	June 21-26, 1992
Quality Management	September 1992
Cost & Schedule Controls	November 1992

Total Quality Management

Barriers

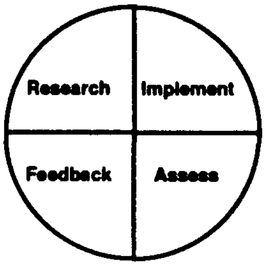
- Loss of control
- Policy
- Culture
- Rewards structure
- Industry applicability

CII TQM Task Force

- Implementation Guide for TQM in construction industry
- Lessons learned from 19 companies
- "*Roadmap*" for TQM implementation—deployment flow chart
- Available—Fall '92

Total Quality Management

Potential Model



Total Quality Management

Core Elements

- Customer Focus
- Process Emphasis
- Continual Improvement and Innovation
- Total Employee Involvement
- Management Leadership

THE END

10 May 1992

Technology Transfer and Marketing: Army-Style
Presentation at Infrastructure Workshop - 4 Mar 1992
Champaign, IL

by
Jeffrey J. Walaszek

Technology transfer means many different things to many people. Researchers often equate it with publishing articles on research in scholarly journals. Lawyers define it as the development of joint agreements between research laboratories and private sector corporations. At the U.S. Army Construction Engineering Research Laboratories (USACERL), we define it as getting our products into daily use by our many military and nonmilitary customers. This effort is the same effort undertaken by private sector companies trying to market their products to consumers.

We need to learn from our marketing counterparts in the private sector to improve our ability to transfer technology. What we at USACERL are trying to do is to get people to use our products. Taking it a step further, what we're really trying to do is change people's behavior -- to try to get our customers to stop doing things the way they're used to doing them and instead doing it our way. In order to change behavior we first need to change attitudes.

This paper will examine the barriers to adoption, provide an overview of a technology management approach in the Army, and discuss a marketing approach to technology transfer used by the Army.

Barriers to Adoption

The transfer of infrastructure research into use poses a challenge uncommon to most government organizations. The challenge is to integrate new technologies into the daily activities of the wide variety of public and private sector organizations involved in infrastructure activities.

The literature provides a wide offering of reasons for the failure of efforts to transfer technology to potential users. These barriers to adoption typically fall into three general areas: ineffective communication, human resistance to change, and organizational and industry constraints.

Ineffective Communications

Communications activities in support of technology transfer activities often fall short in getting the word out to potential users and in presenting information of value to users. Many people are simply not aware of the results of innovative research.

Another obstacle is that information may not be available at a time and place that is convenient to the users. Information which does reach a potential user may go unnoticed if the user has no immediate need for the technology. When a problem arises that could be resolved by the technology, the potential user may not remember that the technology exists or where to get information on it.

Another problem is that researchers do not present their findings in the form or language that can be immediately translated into practice. The practicing engineer is more interested in the practical applications of the technology over the methodology or significance of the research.

The language used by researchers to convey information on a technology may not be understood by non-research personnel. A researcher who devotes his or her life to a technology will be intimately familiar with it. The practicing engineer who performs a wide variety of duties may understand the concepts, but not have the detailed knowledge of the researcher.

Another communications related issue is complaints that researchers do not fully understand the needs of practicing engineers and others whose problems are seldom communicated in terms of research needs. The end result is that the research community may not be studying the problems which would directly assist the practicing engineers, or their technology solutions may not fit in with the operational environment of the practicing engineer.

Human Resistance to Change

The ultimate goal of technology transfer activities is to produce a behavior change. The user will change his or her work activities to use a new technology. However, many efforts to implement new ideas and processes fail not because of the lack of good technological planning or leadership, but because those promoting change fail to take into consideration the human factor--the resistance to change.

Learning to use a new technology can be a very time consuming process. The practicing engineer is under much pressure to complete a large number of tasks within a limited time frame. Why should the engineer take the time to draw up new pavement design plans for some new approach, when he can take some older plans off the shelf, make some minor changes, and be done with it? Time spent on learning to use new technologies could be viewed as nonproductive time by infrastructure engineers who are under much pressure to justify their own productivity.

The risk in trying something new may prevent individuals from trying a new technology which may not have a proven track record. Using a new technology requires a financial commitment by the infrastructure engineer. If the technology fails to perform as expected, the engineer will have to account for his decision to use the technology and may have to seek additional funding to correct the situation. The use of funds by public agencies is always under close scrutiny by various review organizations.

Organizational and Industry Constraints

Successful technology transfer is a management process which can be successful only if the organization makes a commitment to conducting such activities. This commitment towards technology transfer by the organization must consist of 1) the support of top management, 2) adequate funding, 3) an effective organization supporting transfer activities, and 4) cooperation from all elements involved both at headquarters and in the field.

Also, many of the infrastructure research products will be incorporated into military facilities largely through the civilian construction industry. The construction industry is quite diverse in the size of individual companies and the skills and resources they make available. Numerous industry standards govern the daily work of infrastructure activities.

Building codes, design guidance, and other technical documents governing construction and infrastructure activities are often out of date. The process of updating such codes and industry standards takes several years. Such documents do not allow the consideration and application of innovative approaches. Infrastructure engineers are less inclined to risk using a technology which is not accounted for under existing industry standards or technical documents.

Another obstacle which prevents the use of new technologies is the ability to easily acquire the technology through existing procurement processes. Some technologies are so new that only one contractor can provide the technology or service for it. Government procurement regulations are designed to promote fair competition for Government contracts among potential suppliers of a service. Purchasing a service from a single supplier of that service can be done within existing procurement procedures. However, engineers may not be aware of these procedures, nor be willing to undertake the additional paperwork required.

Even when a technology is not limited to one vendor, finding qualified vendors capable of providing an innovative service may be difficult. Army attempts to demonstrate an innovative cracking and seating technique for pavement repair resulted in the Army first having to train the contractor in the technique.

Another issue is why should the practicing engineer innovate. The profit motive of the private sector often spurs innovation. Private organizations offer financial incentives to employees to save money and improve efficiency. Often public employees actually have disincentives to innovation resulting from headquarters requirements to review nonstandard procedures.

Institutionalizing Change: The Army's Approach

Transferring technologies to potential users can best be achieved through a structured process. Such a process ensures adequate time is spent in the development and testing of the technology before transfer. The process also delineates actions needed to adequately transfer technology to users. The process is used for infrastructure applications by the U.S. Army Construction Engineering Research Laboratories (USACERL).

The research and development/technology transfer process consists of six steps. These steps can be grouped into a research phase and a technology transfer phase. The first three steps--problem identification, research, and development--make up the research phase. The technology transfer phase consists of the last three steps--the field demonstration, the product authorization, and product application. This process is shown in figure 1.

The innovation-development-transfer process begins with the identification of a problem or Army need. Problems in the infrastructure area are identified for USACERL in a variety of ways. User input is critical to the development and transfer of a technology. Input is obtained from national teams of users, lab personnel, and headquarters sponsors of the research.

The research on how to solve the problem occurs in the second step of the research, development, and transfer process. Several possible solutions to a problem are investigated to find the optimal solution to a technology. A lab-tested prototype is often the result of the research effort.

Once the optimal solution has been identified and agreed to by sponsors of the research, the technology goes into the development phase. User groups are used as needed to provide input on the development of a product during this step. The technology goes from prototype testing to a production version. The production version undergoes a rigorous pilot test to ensure it meets the needs of the ultimate user. Detailed technology transfer plans are developed during this step.

The field demonstration--step three--is designed to demonstrate the use and effectiveness of a technology in a wider and more visible application than the pilot test. It is the first step in the transfer of the technology which is visible to potential users.

Once the value of the technology has been proven in the field demonstration, a decision has to be made by someone to begin transferring the technology to potential users. A prerequisite to the decision to authorize is the availability of support to the field. USACERL has initiated a variety of mechanisms involving the public and private sector to provide this support. Engineering guidance documents, industry standards, and building codes will need to be updated during this phase to allow the use of the new technology.

During the implementation step, the technology begins to be used outside the field demonstration sites. The technology transfer plan is put into effect in this step. This plan consists of an extensive information or awareness program to inform potential users of the existence of the technology, its applications, and sources of support. Additional components of this plan include distribution of the technology, training activities and after-the-sale support. Commercialization and support mechanisms worked out earlier are put into place in this step to assist users in implementing the innovation.

The Importance of Demonstration Programs

The demonstration of an innovation at a field site is the first step in the transfer of the technology which is visible to potential users. It takes the technology out of the research laboratory and places it in the real world environment of the user. The demonstration will identify the benefit of using the technology, whether it be improved quality, time savings, or cost savings. This information can be later used by others in deciding whether to adopt the technology. Another important function of the demonstration is to gain information on operational problems faced by users of the technology at demonstration sites. Insight can also be obtained on the effectiveness of training and support mechanisms.

The Army has initiated several programs to facilitate the transfer of innovative technologies into the field. Two of these programs directed towards the Army infrastructure are the Facilities Engineering Applications Program and the Technology Transfer Test Bed Program. These programs fund the demonstration of new technologies in the field and initial technology transfer activities. Information from the demonstrations is then disseminated to potential users to assist them in determining how the technology may be used locally.

The Facilities Engineering Applications Program (FEAP) is intended to transfer technologies into Army use in the operations and maintenance of facilities. Engineering personnel at installations are the primary users of these technologies. Steering groups for each technology area provide input on the technologies, sites for demonstrations, and methods for technology transfer.

Under FEAP, technologies are being demonstrated in seven technology areas: energy conservation, building maintenance and repair, pavements and railroad maintenance and repair, environmental quality, natural resources, corrosion, and management systems. Over 140 demonstrations have been conducted under FEAP since the program was initiated in 1984. These demonstrations cover over 60 technologies and more than 60 installations.

The Technology Transfer Test Bed (TTTB) Program is directed towards transferring technologies into the design and construction effort of the Corps of Engineers Divisions and Districts. The TTTB program is patterned after the very successful Corps of Engineers National Energy Team (CENET).

CENET consists of representatives from installations, Corps Districts and Divisions, laboratories, and MACOM headquarters which form a National Team. The charter of the CENET team is to facilitate the use of energy saving technologies in the field. The CENET group identifies technologies for demonstration and recommends sites. The team also provides input on research priorities.

Technology Transfer--The Private Sector Approach

Technology transfer is the term used by Government research organizations to describe what the private sector calls marketing. The ultimate goals are very similar. Just as the private sector attempts to convince housewives to purchase laundry detergents and other household goods, the research community is attempting to convince engineering professionals to use infrastructure related technologies. The only real differences are the sophistication and cost of the product and the educational background and motives of the two consumers.

The private sector recognizes several elements which make up the marketing of products. These elements together make up the marketing mix of product, price, place, and promotion. The transfer of technologies consists of several related elements to include product, production and packaging, distribution, promotion, and training and support.

The product has to meet some need of the consumer. An infrastructure product can be a hardware item, a document describing the implementation of some innovative procedure, software program and user manual, or just a different way of doing business.

The product has to be produced and packaged for procurement by the user. This includes documentation or instructions to assist the user in applying the technology. The production of a technology also implies the assignment of a price for purchasing the technology. The price has to be perceived as being outweighed by the total benefits of using the product. The packaged product has to be delivered to the user through some means. The Army is in the process of developing a format for technology transfer plans which is based on the commercial marketing approach. A draft of this format is provided as enclosure 1.

The Army has developed and implemented an aggressive marketing communications program under the Facilities Engineering Applications Program (FEAP) to provide the engineering personnel at Army installations with information on innovative technologies. The communications strategy was designed to overcome some of the obstacles to technology transfer identified through research. The program is implemented by Public Affairs (PA) personnel at each of the Corps laboratories and the Army Engineering and Housing Support Center.

The FEAP Information Center was established at USACERL. Working with PA personnel at the Corps labs, the center publishes a quarterly technology transfer bulletin, develops technology product fliers, distributes fact sheets, maintains technology transfer exhibits, and manages a mail-in request service for loaner videotapes and information. Samples of the newsletter, ad fliers, and the mail-in order form are enclosed.

Summary

Critical to the success of any technology transfer effort is the input of the customers -- the actual users of the technology. Customers need to be involved in the entire research and development effort. Developing innovative products with the needs and input of the users will go a long way to ensure the product meets their needs and will work within the operational constraints of their environment.

Technology Transfer Plan (DRAFT)

Work Unit Title & Number

Date/Revision No:

Name of Principal Investigator:

Name of Technical Monitor:

Customers Served:

I. Demonstration

Briefly describe the FEAP, TTTB, or other means (such as reimbursable projects or special arrangements) for demonstrating that the technology can be used successfully by the customer and identifying the actual benefits from field use of the technology.

II. Implementation Documents

Identify formal documents which will enable users to implement the technology. Within the Army this would include Corps of Engineers Guide Specifications, Technical Manuals, and Engineering Regulations. Other non-Army mechanisms that may be applicable include professional society standards, handbooks, and guidelines.

III. Availability/Commercialization

Can the technology be obtained by potential users? How will it be packaged and distributed? Who will be responsible for doing this? If the technology will be provided commercially, are there more than one vendors who can compete to provide this service through Government procurement processes?

IV. Customer Awareness/Promotion

Describe the promotional activities that will be used to inform and motivate potential users to procure and implement a technology. These activities will 1) generate an awareness of the existence of a technology among potential users, 2) provide information on its uses and benefits, and 3) identify on procedures and sources of assistance for obtaining the technology and related services. The ultimate goal is to provide information to assist the user in making a decision to acquire the technology.

V. Support and Maintenance

Some organization or individual may need to be readily available to assist users. Typically, such a center should be able to assist users with questions over the phone, conduct onsite visits to assist with technology problems, and provide them with updates or new information on the product. Arrangements must also be made to maintain and update the technology using input from customers.

VI. Training

Instructional material included with the technology may only serve to get the user started on applying the technology on a limited basis. Advanced training may need to be developed to further the user's knowledge of the more specific applications of the technology. Special training courses may also need to be developed for different types of users of the same technology.

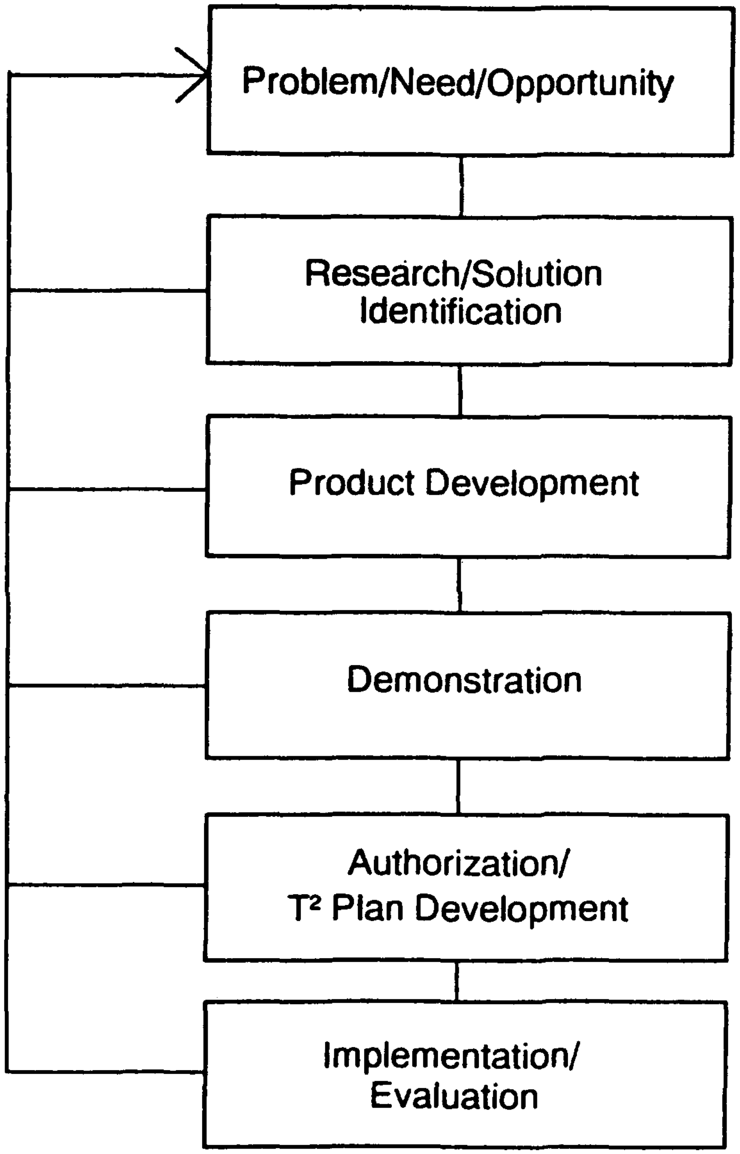
VII. Cost and Schedule Summary

The various implementation activities need to be scheduled in some type of sequence to ensure successful implementation. For example, the timing of the promotional activities typically should not precede the establishment of mechanisms to distribute and support the technology. Training materials and courses should be available when users are expected to implement.

Calculate an estimate for the funding required for managing the technology transfer of the products. Provide simple breakdown for one-time items and then annual totals which include recurring costs (such as support centers or technical centers of expertise). Additional consideration should be given to funding mechanisms or programs to assist the field in acquiring the technology.

Signature Laboratory Representative	Signature Proponent Representative

TECHNOLOGY MANAGEMENT PROCESS



R & D ACTION	STEPS	MECHANISMS	INPUT
MADS	Problem/Need/Opportunity		National Teams Field Review Groups Customer Feedback
Pilot Test	Research/Solution Identification	CRDAs CPAR SBIR REMR	User Groups Proponent
Field Test	Product Development	CRDAs CPAR SBIR REMR	User Groups Proponent
Operational Test	Demonstration	FEAP TTTB	User Input (Site) Proponent
	Authorization/ T^2 Plan Development	CRDAs PLAs MOUs	
	Implementation/ Evaluation	TCX SSC Vendor Support	

Implementation Mix {
- Promotion (FEAP Information Center)
- Funding
- Packaging
- Training
- Distribution
- Support/Maintenance

Jeffrey J. Walaszek
USACERL, Public Affairs and
 Marketing Communication
217-373-7216
27 February 1992

CPAR -- Construction Productivity Advancement Research Program
A cost-shared research program between the U.S. Army Corps of Engineers and non-federal organizations to jointly develop technologies of interest to the construction industry.

CRDA -- Cooperative Research Development Agreement
A joint research agreement between a Federal laboratory and non-Federal partner to conduct a specific research project or support technology transfer of a product.

FEAP -- Facilities Engineering Applications Program
A demonstration and technology transfer program to introduce innovative technologies in support of operations and maintenance activities for Army facilities.

MOU -- Memorandum of Understanding
An informal delineation of responsibilities pertaining to a joint venture between organizations.

PLA -- Patent License Agreement
A formal agreement between a Federal laboratory and non-Federal partner which provide exclusive rights to a Federal patent for commercialization purposes.

REMR -- Repair, Evaluation, Maintenance, and Repair Program
A U.S. Army Corps of Engineers research program supporting the operations and maintenance of Corps civil works structures.

SBIR -- Small Business Innovation Research Program
A Federal program which funds the research and development of innovative technologies initiated by small businesses.

SSC -- Strategic Support Center
An arrangement with a university or industry partner to provide phone support & training to users of a Corps developed technology.

TCX -- Technical Center of Expertise
Assignment of responsibilities usually to a Corps District or Laboratory to provide design or technical assistance to other Corps offices related to some specific innovation.

TTTB -- Technology Transfer Test Bed Program
A demonstration and technology transfer program to introduce innovative technologies in support of the design and construction activities at Corps Districts and Divisions.

Innovative Ideas for the Operation, Maintenance, & Repair of Army Facilities

TECHNOLOGY TRANSFER BULLETIN

FEAP
FACILITIES ENGINEERING APPLICATIONS PROGRAM

Vol. 3, No. 92-1 Winter 1992

Program News

DEH O&M Chiefs Exchange Ideas

by Jeffrey Walaszek

Several Chiefs of Operation and Maintenance (O&M) Divisions from the installations met with personnel at the U.S. Army Engineering and Housing Support Center (EHSC) to exchange ideas on how to improve technology transfer under the Facilities Engineering Applications Program (FEAP). Eighteen participants traveled to Fort Belvoir, VA, last summer for two week-long Technology Transfer Leadership Workshops funded under FEAP.

The purpose of the workshops was to promote a dialog between personnel in the Directorate of Facilities Engineering at EHSC and the O&M Chiefs at installation Directorates of Engineering and Housing (DEHs). Participants met with EHSC personnel during breakout sessions to learn about FEAP innovations and discuss issues facing the DEH in the field. Several attendees also presented innovative ideas they have implemented at their posts.

(See "O&M Chiefs" on page 2)

New Product Fliers in This Issue:

- Pipe-Loop System
- Noise Monitor and Warning System
- Pipe Mole

From the Field

Railer Keeps Tooele's Railroad Network on Track

by Dana Finney

Managing 104 miles of railroad track is no easy chore, but at Tooele Army Depot, UT, the track network is being maintained in top condition using the Railroad Maintenance Management System (RAILER).

"Locating areas that need to be repaired is so much faster than it used to be, mainly because of RAILER's track inventory," said Sam Hunter, former civil engineer at Tooele. "The network is divided into sections with permanent marks to identify them. In the past, Tooele spent a lot of time hunting for the problems that needed fixing, but now they can almost go straight to the spot—within a few feet."

RAILER is an engineered management system developed by the U.S. Army Construction Engineering Research Laboratory (CERL) to help railroad track managers allocate scarce maintenance and repair (M&R) dollars. The system combines inventory and inspection with a computer program to optimize M&R spending. It has been fully implemented at Tooele under FEAP, with CERL turning over the version 3.0 software in May 1990.

"This is the largest track network we've managed with RAILER as a FEAP project," said Don Uzarski, CERL principal investigator who led RAILER's

(See "RAILER" on page 3)

A two-man team conducts the RAILER survey.

Prepared IAW AR 25-30. Issued by: U.S. Army Construction Engineering Research Laboratory in cooperation with U.S. Army Engineering and Housing Support Center

"O&M Chiefs"

from page 1

"The workshop introduced not only new technology, but older technologies new to me," said Leon Howard of Fort Hood, TX. "The time was well spent and will improve my ability to operate effectively in the field," he added.

The workshops were specifically intended for branch and division chiefs with O&M responsibilities. "The O&M Chiefs are probably in the best position to influence decisions on adopting FEAP technologies at the installation," stated Dr. Robert Wolff, former Director of Facilities Engineering at EHSC. "We wanted to specifically get them involved in the technology transfer process."

Most participants agreed that technology adoption is their responsibility and that programs such as FEAP are needed. "As a whole, O&M Chiefs are continually in search of new technologies to counterbalance shrinking resources ... this lends merit to FEAP," said Gary Reasnor from McAlester Army Ammunition Plant, OK.

In addition to exchanging information on new technologies, another goal of the workshops was to obtain input on proposed FEAP initiatives. The first workshop group devoted a full day to reviewing and commenting on draft FEAP user guides. The user guides are intended to provide DEHs with specific information on the use and procurement of FEAP technologies. The second workshop group sat in on the annual meeting of the FEAP Executive Oversight Committee. O&M participants provided input along with Major Command (MACOM) attendees on proposed activities such as videoconferencing and a 3-year strategy.

"The participants told us the user guides are critical to our efforts to transfer FEAP technologies," said Richard Karney, FEAP Executive Director. "Their recommendations will help us ensure the value of user guides and that FEAP continues to be responsive to the field."

The workshop also served to introduce personnel at the different organizations attending. John Paris of Watervliet Arsenal, NY, stated, "One of the most useful things was establishing a network of contacts here at EHSC and the other installations." Reasnor added, "I like to know the faces, who does what, and what's available."

Most participants commented that the workshops provided valuable information and should be held again in the future. "The take-away books with papers, fact sheets, and draft user guides were excellent and will be highly useful at the installation," commented Frank Cooper of Fort Jackson, SC.

"I'm familiar with the FEAP program, but it was good to get an update on 'how goes it'," said Vance Mitchell from Fort Lee, VA. "As these technologies mature and prove themselves, we at the DEH level need to be aware that 'this works, this doesn't' so we can make decisions."

Similar Technology Transfer Leadership Workshops are planned for FY92. For more information, contact Jeffrey Walaszek at CERL, PO Box 9005, Champaign, IL 61826-9005, COMM 217-373-7216 or toll-free 800-USA-CERL (outside IL), 800-252-7122 (within IL). ■

FEAP

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Malcolm McLeod CEHSC-FU-S, Corrosion

Commentary

COL John Motes II

Innovation – Key to Efficient O&M

In my earlier experience as a DEH, I was often dismayed that we were relying on outdated management tools and technologies. Today that situation is improving. I'm especially pleased to see the favorable impact that FEAP is having on the application of new technologies at Army facilities.

Facility engineers need every tool they can get to ensure that the technology they implement will be the most cost-effective choice over the long term. The FEAP demonstrations have produced real life-cycle data that helps in making these decisions. Several FEAP technologies have shown impressively rapid paybacks — some under 1 year.

As I visit you folks at the DPWs and DEHs in the coming months, please let me know what you think about the FEAP technologies we are publicizing. Is FEAP helping you with its innovative ideas? How can we speed the technology transfer process?

Technologies of the type we've been demonstrating under FEAP hold the key to substantial cost savings in maintaining and repairing Army facilities. And with today's fiscal constraints, we can't afford not to put these innovative technologies to work.

JOHN MOTES II
Colonel, Corps of Engineers
Director of Facilities Engineering
U.S. Army Engineering and Housing
Support Center

(Editor's note: With his assignment as Director of Facilities Engineering for EHSC last year, COL Motes became the FEAP Program Coordinator.) ■

"RAILER"

from page 1

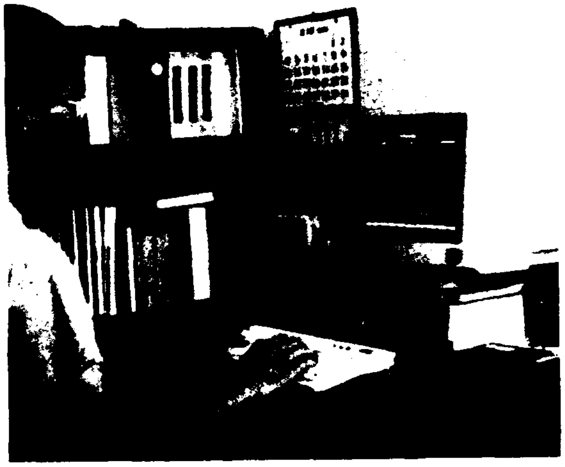
development. "The database was so large that we decided to split it into two parts to speed up the reports." However, he said this was easy to do with the database management system used in the program.

CERL completed the track inventory in 1986 when the first version of RAILER was introduced at Tooele. The procedure involves complete documentation and labeling of the existing track by breaking it down into track segments. Each segment has a unique letter-number combination, depending on its location relative to a point of origin.

RAILER's database can incorporate results from commercially available rail flow inspection equipment. "The X-ray inspection showed several minute structural cracks in the rails that you couldn't see on the surface," Hunter said. "They were really pleased that they had the chance to replace those rails before they failed."

The Tooele track network supports daily traffic for transporting supplies to the depot. As at other Army installations, this track also has a role in the event of a national mobilization. And as Hunter points out, that role cannot be taken lightly.

"Last year, to support Operation Desert Storm, Tooele was to transport a large amount of conventional munitions. The RAILER inspection had identified flaws in one of the tracks designated for that purpose, but the mobilization began before they could repair them. As a result, the crew was greatly limited because they couldn't make best use of the damaged track."



RAILER's software calculates a Condition Index for the track.

Hunter noted that crews had to work day and night seven days a week to keep up with the demand for munitions. The unrepaired track could only handle small loads at a maximum of 5 miles per hour.

"I think it's worth the time and money to maintain our railroads," he said. "RAILER lets us make the best decisions for allocating the resources to do that."

For further information on RAILER, contact Dr. Don Uzarski at CERL, PO Box 9005, Champaign, IL 61826-9005, COMM 217-398-5215 or toll-free 800-USA-CERL (inside IL), 800-252-7122 (outside IL); or Scott Thompson at EHSC, Fort Belvoir, VA 22060-5516, 703-355-3582. ■

Tech Transfer Notes

Technical Reports

The following technical reports on FEAP technologies have been published. These reports are available from the CERL Library, 217-373-7217:

- *An Analysis of the System Installation Costs of Diurnal Ice Storage Cooling Systems for Army Facilities*, by C. Sohn and R. Taylor, E-91/09.

- *Self-Help Service Center Management System User's Manual*, by J. Kirby et al., FEAP-ADP-P-91/38.

- *Rehabilitation of Military Training Areas Damaged by Tracked Vehicles at Fort Carson, CO*, by R. Hinchman et al., FEAP-TR-N-91/01.

New Videos for Loan

The FEAP Information Center has added three new videotapes to its loan library. To borrow these tapes, see the order form attached to this bulletin. The videos are:

V-9 - Annual and Long-Range Work Planning With Micro PAVER—Introduces the most recent microcomputer version of the Pavement Maintenance Management System.

Videos, cont'd

V-10 - ROOFER—Presents applications and benefits of using ROOFER, a maintenance management system for built-up roofs.

V-11 - Railroad Maintenance—A four-part video that covers 1) Tie Renewal, 2) Spot Alignment, 3) Spot Surfacing a Joint, and 4) Turnout Inspection.

BLAST Ice Storage Models

Time-of-use and demand pricing rate structures have sparked interest in thermal energy storage technologies such as ice storage. Three different diurnal ice storage systems (DIS) were demonstrated under FEAP with payback periods as short as 4 years. However, the return on investment can vary greatly, depending on site-specific conditions. To determine if a cooling storage system would be feasible for your building, HVAC equipment, and weather, you can now use the ice storage models available for the BLAST program. BLAST can simulate any building with time-of-use rate structures to show whether ice storage would provide a savings. For more information, contact the BLAST Support Office, 800-UI-BLAST or 217-333-3977. ■

FEAP Executive Oversight Group

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Demo News

Polyscann^{R} System Automates Butt-Fusion Inspection

A demonstration at Fort Hood, TX, has shown the benefits of using an ultrasonic butt-fusion inspection system to detect flaws in joints connecting polyethylene pipes. Marketed by T.D. Williamson, Inc., the Polyscann system can immediately detect poor bonding, inadequate fusion, voids, and inclusions. After the inspection, Polyscann issues a "flaws found/no flaws found" report.

This technology replaces traditional destructive testing in which every fifth butt-fused joint had to be cut out and tested in the field or at a laboratory. Connections where samples were removed had to be re-fused.

The ultrasonic system completely inspects 100 percent of all fusion joints without damaging them. Flawed joints can be repaired, avoiding costly leaks.

At Fort Hood, the system was used to inspect 13 butt-fusion joints in 8-inch polyethylene pipe sections that were connected to an existing 8-inch natural gas pipeline. All of the butt-fusion joints were inspected. Personnel from CERL and the Fort Hood DEH operated the system during the demonstration.

The Polyscann system identified two defects during the inspection. The immediate feedback let operators repair the joints quickly and place the pipeline in service.

The Polyscann system costs about $18,000. For more information, contact Orange Marshall at CERL, PO Box 9005, Champaign, IL 61826-9005, COMM 217-373-6766, toll-free 800-USA-CERL (outside IL) or 800-252-7122 (inside IL). At EHSC, contact Malcolm McLeod, Fort Belvoir, VA 22060-5516, 703-355-3151. ■

New Burners Have Low Nitrous Oxide Emissions

by Sherri Senffner

Boilers serving Army buildings can now be upgraded with burners that ensure lower nitrous oxide (NOx) emissions.

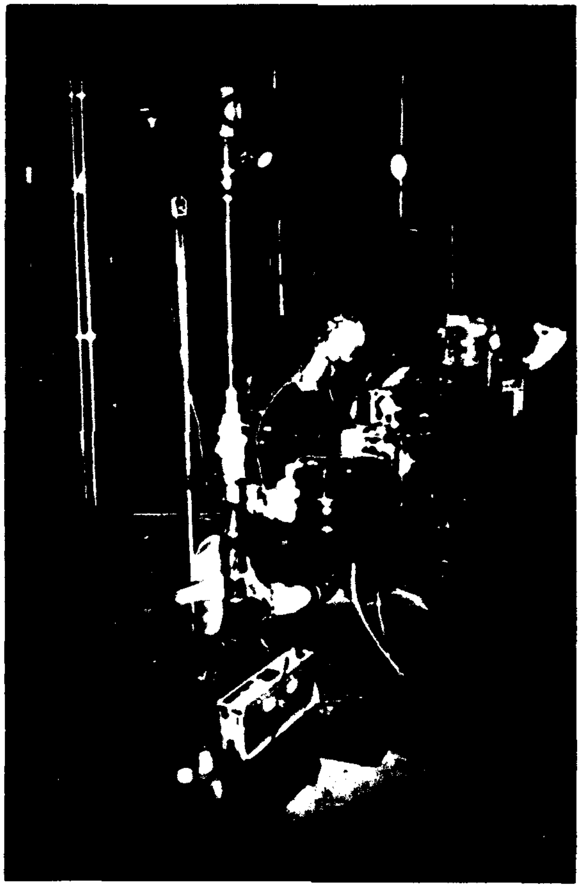
CERL began testing these burners in FY90 at a dormitory heating plant at Fort Knox, KY. In early FY91 a low NOx burner also was installed at a small central heating plant at Yakima Firing Center, WA, and testing is scheduled to begin in mid-FY92.

Preliminary test results show the burners emit approximately 35 percent less NOx than conventional burners. It was also found that the new burners are 1/2 percent more efficient. This relatively small increase offers a 10-year payback period. CERL engineer Noel Potts says the burners may prove to be at least 1 percent more efficient — which would reduce the payback period to less than 5 years.

"I believe it will prove more efficient because of its sensors," Fort Knox boiler mechanic Ruel Allen agrees. "If it senses excess oxygen, it decreases air intake, and if it reads less oxygen, it increases air."

Unlike the conventional burners, the low NOx burners have a system that compensates for changes in combustion air temperature and pressure. This allows the burners to maintain an optimum fuel-air mixture. Fuel is adjusted based on combustion air pressure in the burner, according to Potts.

Most Army bases have a demand for steam that fluctuates both seasonally and during the day. Low NOx burners offer an excellent turndown ratio of 5:1, allowing continuous operation for low demands without wasting energy by frequently switching boilers on and off. Potts says most conventional burners can achieve up to a 4:1 ratio at best.



Boilers can be retrofitted with a new type of burner that can reduce nitrous oxide emissions by up to 35 percent.

The test sites were chosen because each had an identical pair of oil-/natural gas-fired boilers allowing side-by-side comparisons of conventional and low NOx burners.

Although the new burners emit lower levels of NOx, conventional burners do comply with the U.S. Environmental Protection Agency (USEPA) NOx emission limits for boilers under 100 million BTU per hour capacity.

"Both comply," Potts says, "but low NOx burners release less concentrated pollutants into the environment."

CERL is still collecting long-term test data. The first short-term demonstration, con-ducted at Fort Knox in April 1990, proved the installed unit reduced NOx by 35 percent while burning natural gas — dropping from approximately 99 to 64 ppm.

While the short-term data shows only a small increase in efficiency, the new burners still offer an attractive option when replacing old burners because of their low NOx emissions. More than 600 Army boilers serving single buildings or small building clusters could be retrofitted with these low NOx burners.

For more information, con-tact Noel Potts at CERL, PO Box 9005, Champaign, IL 61826-9005, 217-398-5545 or toll-free 800-USA-CERL (outside IL) and 800-252-7122 (within IL); or Satish Sharma, EHSC, Fort Belvoir, VA 22060-5516, 703-355-3577. ■

Coming Next Issue...

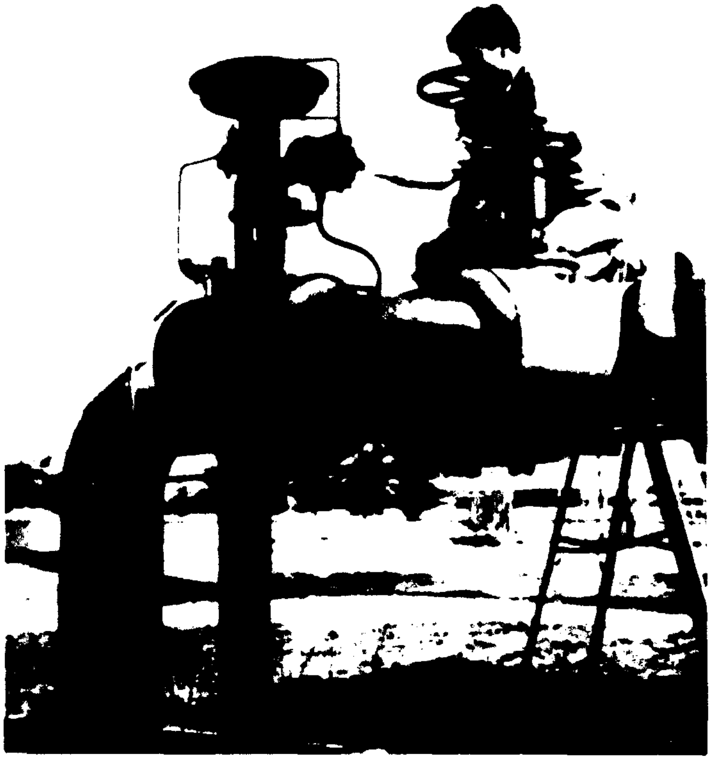
FROM THE FIELD--
Exterior Insulation and Finish Systems

Fort Harrison Expects Quick Payback on New Steam Controller

A new steam dispatching control system (SDCS) being demonstrated at Fort Benjamin Harrison, IN, may save up to $190,000 in its first year of operation. CERL installed the SDCS on Fort Harrison's district steam distribution system last year under FEAP.

In this steam distribution system, the steam demand depends mainly on the outdoor temperature. The SDSC uses a temperature sensor interfaced with a controller that dispatches just slightly more steam pressure than is needed to serve the most remote customer's demand.

This strategy differs from traditional district steam heating systems, which maintain a constant steam pressure regardless of demand. The SDCS's lower pressure means lower temperature, so that energy is saved by reduced heat loss and by lower steam losses through leaks and faulty traps.



Steam dispatching control system senses customers' needs by outdoor temperature and automatically adusts steam production to meet the demand.

The SDCS at Fort Harrison cost about $180,000. If it continues to perform as it has during the 8 months of the study, the annual savings can be projected at $190,000 for a simple payback of 1 year.

For more information on SDCS technology, contact Ralph Moshage at CERL, COMM 217-398-5544 or toll-free 800-USA-CERL (outside IL), 800-252-7122 (within IL); or Bernie Wasserman, EHSC, 703-355-2238. ■

Comments? Suggestions?

Do you have a topic you would like to see featured in an upcoming issue of the ***FEAP Technology Transfer Bulletin***? An idea about how we might improve our publication to serve you better? We'd like to have your input!

Please send your comments to:

FEAP Information Center
CERL/ATTN:CECER-ZP
P.O. Box 9005
Champaign, IL 61826-9005

Reed Bed Dewaters Sludge, Leaves Low Residuals

An innovative sludge dewatering system can end many of the problems experienced with conventional sand drying beds -- long dewatering times, media clogging, and weather vulnerability, to name a few.

A reed bed system uses the common reed Phragmites which is planted on a modified sand bed. Sludge is dewatered by drainage and evaporation, and the reed stabilizes the organic matter.

Advantages of reed beds include low costs for: initial purchase, operation and maintenance, and sludge disposal.

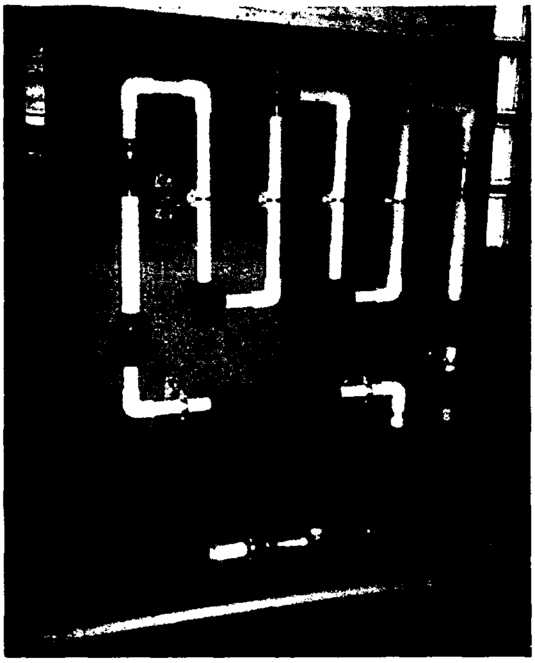
A 20,000 square foot reed bed system has been installed at Fort Campbell, KY, to demonstrate this technology. The reed was planted in spring 1990 and was fully grown as of summer 1991. The system is currently handling about half of the sludge generated by Fort Campbell's 3 million gallon per day wastewater treatment plant. The reed bed leaves a very low volume of residual that must be hauled away for disposal.

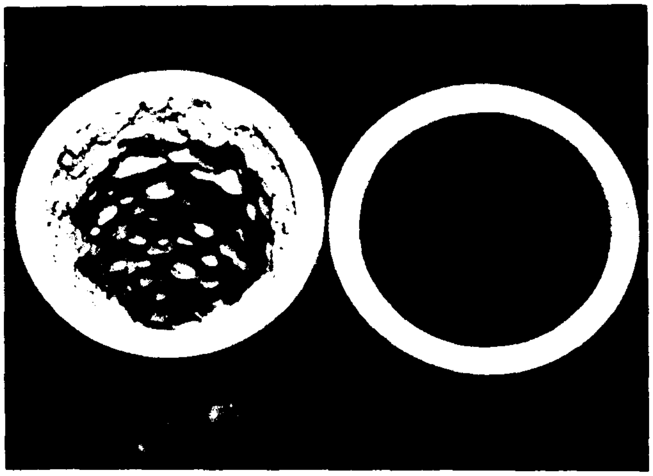
For more information on alternative dewatering technologies, contact Dr. Byung Kim at CERL, COMM 217-373-7281; or Malcolm McLeod, EHSC, 703-355-3151. ■

FEAP
FACILITIES ENGINEERING
APPLICATIONS PROGRAM

Innovative Ideas for the Operation, Maintenance, & Repair of Army Facilities

Pipe Loop System





Above: **Compared with a new pipe, a pipe insert from the Pipe Loop System shows the effects of the water after a 90-day period.** ***Left:*** **The Pipe Loop System is easily assembled with off-the-shelf materials and mounted on a wall.**

Inexpensive Technology Solves Expensive Testing Problem

PROBLEM: Testing potable water in distribution systems at installations is difficult and expensive. Testing is required to determine:

- Overall water quality, including lead and copper content
- Optimal chemical treatment to reduce corrosion
- Interactive effects of water and pipe.

TECHNOLOGY: The Pipe Loop System allows testing of multiple chemical treatments and their effects on pipe materials.

DEMO SITES:

- Fort Ord, CA - FY88
- Fort Irwin, CA - FY89
- Aberdeen Proving Ground, MD - FY89
- Fort Bragg, NC - FY88
- Fort Lewis, WA - FY89

BENEFITS:

- Meets testing criteria of environmental regulations
- Extends the life of existing water distribution systems by providing information needed to develop the least expensive chemical treatment that reduces corrosion
- Monitors test results easily and inexpensively.

Test Water Quality at Minimal Cost

Pipe Loop Solves Problem of Difficult and Expensive Testing

The potable water supply at every Army installation is different. Corrosive elements in the water can cause severe deterioration of pipes without chemical treatment. The Pipe Loop System, developed by the U.S. Army Construction Engineering Research Laboratory (USACERL), allows water plant personnel to test the amount and effects of various water treatments on different pipe materials at specific sites with minimal effort and expense.

A Pipe Loop System can be built using off-the-shelf materials and mounted on a 3-foot x 4-foot board on a wall. The water flow through the system can be easily controlled and quantified. Pipe material samples in the form of pipe inserts and coupons are easily removed and evaluated.

The design allows distribution system materials to be placed in direct contact with water under conditions simulating typical operation. It also allows water chemical treatments to be tested before actual use. The chemical treatments may be tested individually or in side-by-side comparisons.

Pipe Loop System Widely Demonstrated

The Pipe Loop System was demonstrated at five Army installations. At Aberdeen Proving Ground's Edgewood water treatment plant, the Pipe Loop System was used to develop an optimal water treatment for reducing lead dissolution. The testing represents a protocol for meeting the testing requirements proposed by EPA in 1988 for evaluating options that reduce lead and copper dissolution from household plumbing.

The Pipe Loop System at Fort Bragg, NC, is saving the installation money. Not counting the potential maintenance savings, Fort Bragg estimates that they have saved approximately $15,000/year by determining the optimal water treatment using the Pipe Loop System. Without sacrificing water quality, the amount of chemical additives was reduced, thereby lowering chemical and labor costs.

Multiple Benefits

- Determines overall effect of water quality on distribution systems
- Operates with minimal supervision
- Allows side-by-side tests with chemicals to determine optimal amount of chemical additive, thereby improving the water quality and extending the life of the water distribution system
- Helps installations meet evaluation criteria of environmental regulations:
    - National Interim Primary Drinking Water Regulation (NIPDWR)
    - Safe Drinking Water Act
    - Copper and Lead Rules of the Clean Water Act

Available Through Exclusive Licensing Agreement

USACERL Technical Report N-88/12 (1988) describes the development and evaluation of the Pipe Loop System. Installations can purchase a system through Evans Machine & Tool Co., 410 Summit Ave., Perth Amboy, NJ, (908) 442-1144, with whom USACERL has an exclusive licensing agreement.

Points of Contact

Richard Scholze, U.S. Army Construction Engineering Research, Laboratory, P.O. Box 4005, Champaign, IL 61824-4005, COMM 217-373-6743; or Malcolm McLeod, U.S. Army Engineering and Housing Support Center (USAEHSC), Fort Belvoir, VA 22060-5516, COMM 703-355-2003

Issued by USAEHSC, Fort Belvoir, VA, IAW 25-30. Additional copies are available from the FEAP Information Center, P.O. Box 4005, Champaign, IL 61824-4005, phone 217-352-6511 x386

FACILITIES ENGINEERING
APPLICATIONS PROGRAM

Innovative Ideas for the Operation, Maintenance, & Repair of Army Facilities

Noise Monitoring and Warning System

Above: **Realistic training requires use of equipment that can produce blast noise.** ***Top right:*** **A microphone installed outside the post picks up noise levels; this is the monitor for the Noise Monitoring and Warning System.** ***Lower right:*** **The range officer is notified immediately if noise levels are too high.**

Noise Monitor Promotes Community Relations

PROBLEM: Noise from training activities on Army installations annoys residents of nearby communities; in some cases, public pressure threatens to shut down training.

TECHNOLOGY: The Noise Monitoring and Warning System uses a remotely placed microphone and a "smart" monitor to detect and record noise levels in areas where blast noise occurs.

DEMO SITES: Fort Richardson, AK--FY86 Aberdeen Proving Ground, MD--FY86

BENEFITS:

- Correlates complaints from community with specific noise-producing activities to help the base develop effective noise mitigation strategies
- Helps verify compliance with established noise-zone standards
- Identifies whether training activity is the actual noise source.

Noise Monitor Helps Installations Respond to Community

Noise Data Supports Efforts to Reduce Training Noise

The days of isolated military posts are long past with the spread of urban communities into areas previously unpopulated. Termed *encroachment* by DOD, this trend of siting civilian dwellings near installations has introduced some problems that most neighborhoods never face.

Noise is among the most sensitive issues between the installations and their neighbors. Many mission-critical activities such as training and vehicle maintenance produce noise that may be annoying to members of the community.

The Noise Monitoring and Warning System gives range officers a tool to manage noise-producing activities. The system uses microphones connected to a controller panel. The microphones are installed on poles at field stations in or near the area where noise could be a problem. The system detects and records noise levels automatically. A software program interprets the data by comparing it to a preset level and isolating it from the background noise. The source noise level, in decibels, can be retrieved by a telephone call, or the controller can be programmed to send the DEH a notice if a certain noise level is exceeded.

Demonstration Validates System

The FY86 demonstrations at Fort Richardson, AK, and Aberdeen Proving Ground, MD, had two objectives: 1) to determine the learning curve for installation personnel who would be using the system and 2) to prove that data from the system could be correlated with range operations and complaints received from the community.

Both objectives were met successfully. Installation personnel were able to use the noise monitor with about 2 hours of training; instruction was provided onsite at the time the systems were installed.

Benefits

Installation noise levels are set by DOD and Army regulations, and must conform to the Installation Compatible Use Zone (ICUZ) program. The noise monitor collects data that allows installations to 1) meet these criteria and 2) prove compliance.

The demonstrations showed that noise levels from specific activities could be correlated with complaints. This information allowed training coordinators to either reschedule or relocate activities as needed to reduce the noise. Another important finding was that the actual noise source could be identified: at Fort Richardson, about 50% of the complaints were called in when no training was in progress; instead, it was found that the noise was generated offpost at a highway construction site.

Finally, the Noise Monitor and Warning System improves community relations in two ways. First, by introducing this system and explaining its purpose to the public, the installation shows it is making a good faith effort to address noise problems. Second, by having immediate feedback on the noise level, trainers can stop activities that could produce noise complaints, thus reducing the frequency of noise problems in the community.

Cost

A controller panel can accommodate up to 60 microphone connections and costs $5000 to $7000. Each field station where a microphone is located costs $36,000; this cost also covers consulting to determine the best site(s) for the stations and site preparation (e.g., installing poles). The total system cost varies, depending on the number of field stations the installation needs.

Procurement Information

The noise monitor is available from the U.S. Army Construction Engineering Research Laboratory (USACERL); see points of contact below. For more information on the system or demonstration, a technical report can be ordered from USACERL: *An Army Blast Noise Monitoring and Warning System*, TR-N-88/03. Potential users are also encouraged to contact the demonstration sites to learn more about the system and its applicability to a specific installation.

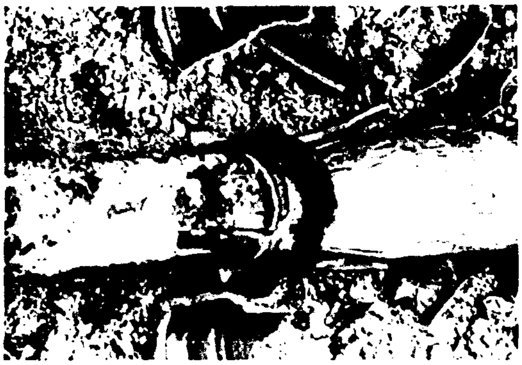
Points of Contact

Dr. Paul Schomer or Mr. Jerry Benson, USACERL, PO Box 4005, Champaign, IL 61824-4005, COMM 217-373-7229 or -7253, toll-free 800-USA-CERL (outside IL) or 800-252-7122 (in the state). Mr. Malcolm McLeod, U.S. Army Engineering and Housing Support Center, COMM 703-355-2003. LTC Hans Graven, Army Environmental Office, 703-693-4635.

FEAP
FACILITIES ENGINEERING
APPLICATIONS PROGRAM

Innovative Ideas for the Operation, Maintenance, & Repair of Army Facilities

Pipeline Insertion Method (PIM)



Top left: **Impact mole just before connection to HDPE pipe, showing air line inside HDPE pipe.** ***Bottom left:*** **Impact mole bursts a cast iron pipe and forces it into the surrounding soil.** ***Above:*** **HDPE pipe is inserted into the pit.**

Replace Buried Pipes With Minimal Site Disturbance

PROBLEM:	Replacing underground pipes by digging trenches often disrupts local activities and incurs high costs for restoring damaged surfaces.
TECHNOLOGY:	The pipeline insertion method (PIM) has an impact mole that breaks up existing pipe in the ground and forces fragments into the surrounding soil. It then replaces the old pipe with a high-density polyethylene (HDPE) pipe.
DEMO SITE:	Fort Belvoir, VA - FY87
BENEFITS:	● Replaces old pipe with a new one of equal or larger diameter ● Can be used in areas where digging is difficult or impossible ● Avoids interruptions to traffic and other operations ● Minimizes the cost of surface restoration ● Applies to any brittle, fracturable pipe--including sewer, water, and gas lines

Trenchless Pipe Replacement

PIM: The Technology

There used to be only one way to replace a buried pipeline: dig it up, tear it out, and install a new one. This process can be very expensive, with much of the cost tied up in restoring surfaces damaged during digging.

Today an alternative to this trenching process is the pipeline insertion method (PIM). Nicknamed the "pipe mole," this technology breaks up an existing pipe while it is still in the ground and replaces it with HDPE pipe of equal or larger diameter. PIM requires very limited digging at every other manhole, for lateral connections, and where the mole exits.

The pipe mole looks like a missile with four fins. It carries a pneumatic hammer in its nose which literally bursts its way through an old pipe while dragging the new pipe behind it. The mole is air-driven. A hydraulic jack "pushing machine" behind it feeds the new pipe. A cable is attached to the front of the mole and to a winch that guides it through the pipe. In addition to the pneumatic pipe mole, a hydraulic model is now available.

Fort Belvoir FEAP Demonstration

At Fort Belvoir, VA, a 240-foot section of sewer pipe was replaced using PIM technology. An 8-inch main sewer line replaced an existing 6-inch main that traveled between two manholes and under two parking lots, one well traveled street, a retaining wall, and a fence. None of these structures was disturbed.

The demonstration included tests to determine the mole's effect on adjacent utilities. Results for stress on adjacent pipes, vibrational damage, and pipe deflection were all in acceptable ranges.

Saves Excavation, Replacement Costs

With trench pipe replacement, site restoration accounts for up to 80 percent of the total project cost. Thus, PIM brings the highest savings to job sites where surface restoration will cost the most. For example, 1989 replacement costs for a hard-to-reach easement averaged $100 per linear foot using PIM, depending on the length of pipe replaced and other considerations for upgrading a 6-inch to an 8-inch sewer line. The savings over trench-type work can be expected to be up to 44%, depending on surface conditions which are site-specific.

PIM's Benefits

The Fort Belvoir FEAP project successfully demonstrated several of the pipe mole's benefits, which include:

- Limits disruption to the landscape and adjacent structures
- Avoids interruption to traffic and other local activities
- Easily corrects hydraulic overloading by inserting larger diameter pipe
- Reaches areas hard to access even by digging--easements, rough terrain and sites with limited work surface
- Improves safety to workers and local residents.

Gaining Acceptance

First developed in Great Britain, PIM is becoming widely accepted in the U.S. for replacing and upsizing all types of buried pipes (water, sewer, gas). PIM is patented and marketed in the U.S. by PIM Corp., Piscataway, NJ. USACERL technical report N-89/07 (April 1989) describes the Fort Belvoir demonstration in detail. A technical manuscript on the technology is also available from USACERL.

Points of Contact

Richard Scholze, U.S. Army Construction Engineering Research Laboratory, PO Box 4005, Champaign, IL 61824-4005, COMM 217-373-6743. Malcolm McLeod, U.S. Army Engineering and Housing Support Center (USAEHSC), Fort Belvoir, VA 22060-5516, COMM 703-355-2003.

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Innovative Ideas for the Operation, Maintenance, & Repair of Army Facilities

FEAP

FACILITIES ENGINEERING APPLICATIONS PROGRAM

Information Order Form

The FEAP Information Center has a wealth of information on FEAP technologies to share with you. If you are interested in learning more about a FEAP demonstration, please complete this order form and mail to:

FEAP Information Center
USACERL/ATTN: CECER-ZP
P.O. Box 9005
Champaign, IL 61826-9005

or call:
COMM 217-352-6511 ext 386
800-USA-CERL (outside IL)
800-252-7122 (inside IL)

FACT SHEETS – one-page information sheets on the status of FEAP technologies

_____ **FEAP-1** The Facilities Engineering Applications Program

Building Technology Demonstrations

_____ **BDG-1** Voice-Activated Inspection System (VAIS)
_____ **BDG-4** Polyscann^R Butt-Fusion Joint Inspection System
_____ **BDG-11** Roof Blister Vents

Corrosion Technology Demonstrations

_____ **COR-1** Antiscale/Corrosion-Resistant Coating for Heat Exchangers
_____ **COR-2** Copper Pipe Rehabilitation
_____ **COR-3** Cathodic Protection (CP) Diagnostic System

Energy Technology Demonstrations

_____ **NRG-1** Diurnal Ice Storage Cooling Systems
_____ **NRG-2** Infrared Radiant Heat Effectiveness
_____ **NRG-8** Small-Scale Packaged Cogeneration System
_____ **NRG-9** Microprocessor-Based Combustion Optimization for Packaged Boilers
_____ **NRG-10** Retrofit of Single-Loop HVAC Control Panels
_____ **NRG-11** Installation Steam Dispatching System
_____ **NRG-13** Ground-Coupled Heat Pumps
_____ **NRG-14** Low-Temperature Hot Water Heat Distribution Systems
_____ **NRG-15** Retrofit Lighting
_____ **NRG-16** Heat Recovery in Industrial Facilities
_____ **NRG-17** High-Temperature Hot Water System Demonstration
_____ **NRG-18** Standard Interface for DDC/UEMSC in USAREUR Facilities
_____ **NRG-19** High-Efficiency Heating Unit Conversion
_____ **NRG-20** Underground Steam Distribution System
_____ **NRG-21** Steam Trap Demonstration at Fort Ord, CA
_____ **NRG-22** High-Efficiency/Low NOx Dual Fuel Burner System

Environmental Quality Technology Demonstrations

_____ **ENV-2** Improved Sludge Dewatering Technology
_____ **ENV-5** Pipe Loop System
_____ **ENV-6** Sludge Freezing Bed
_____ **ENV-10** Innovative Waste Treatment at Remote Sites
_____ **ENV-11** Hazardous Waste Management Information System
_____ **ENV-12** Modeling Water Quality Degradation in Water Distribution Systems

Management Technology Demonstrations

_____ **MGT-1** Interactive Automated Telephone Response System for DEH
_____ **MGT-2** Work Management System

Natural Resources Technology Demonstrations

_____ **NAT-2** Techniques for Cost-Effective Revegetation of Cold Regions Facilities
_____ **NAT-3** Prescription Athletic Turf for Cold Climate Parade Fields

Pavements & Railroads Technology Demonstrations

_____ **PRR-1** New MicroPAVER Technology
_____ **PRR-2** Nondestructive Pavement Evaluation
_____ **PRR-3** Paving Blocks
_____ **PRR-7** Railroad Track Maintenance Management System (RAILER)

____ **PRR-8** Geotextile Applications
____ **PRR-10** Technology Application Process
____ **PRR-11** Pavement Drainage: Open-Graded Base

____ **FEAP Fact Sheet Book** -- Collection of all FEAP Fact Sheets.

VIDEOTAPES – To borrow a videotape, please check the desired size. If you would like a personal copy, please make one and return the tape to us. Do not distribute or sell the tape to others.

		(VHS)	
V-1	Instructions for the Use of the Army Paint Test Kit	____ 1/2"	____ 3/4"
V-2	Structural Enhancement of Railroad Tracks	____ 1/2"	____ 3/4"
V-3	Fuel-Resistant Pavement Sealers	____ 1/2"	____ 3/4"
V-4	Potholes: Causes, Preventions, and Cures	____ 1/2"	____ 3/4"
V-5	Dustproofing	____ 1/2"	____ 3/4"
V-6	Repair of Concrete Water Storage Tanks	____ 1/2"	____ 3/4"
V-7	Repair of Concrete Footings and Structures	____ 1/2"	____ 3/4"
V-8	Reroofing With Protected Membranes	____ 1/2"	____ 3/4"
V-9	Annual and Long-Range Work Planning With Micro PAVER	____ 1/2"	____ 3/4"
V-10	ROOFER	____ 1/2"	____ 3/4"
V-11	Railroad Inspection (Four Parts: Tie Renewal; Spot Alignment; Spot Surfacing a Joint; Turnout Inspection)	____ 1/2"	____ 3/4"

PRODUCT FLIERS – One-page, full-color "ads" describing technologies that have been demonstrated successfully under FEAP and are ready for implementation.

____ **PR-1** Dustproofing
____ **PR-2** Pothole Patching
____ **PR-3** Railroad Track Inspection
____ **PR-4** Cracking and Seating
____ **PR-5** Asphalt Stabilization of Railroad Track
____ **PR-6** Geotextiles
____ **PR-7** Fuel-Resistant Sealers
____ **PR-8** Installing Pavement Crack and Joint Sealants
____ **PR-9** Asphalt Rubber and Geotextile Interlayers for Pavement Overlays
____ **CT-1** Ceramic Anodes
____ **MG-1** Automation of Self-Help Program
____ **BD-1** Paint Test Kit
____ **BD-2** EPDM Roofing
____ **BD-3** Protective Membrane Roof
____ **BD-5** Fire Protection Management System (FIRMS)
____ **ET-1** Diurnal Ice Storage
____ **ET-2** Condensing Heat Exchangers
____ **ET-3** High-Efficiency Boilers
____ **ET-4** Photovoltaic Power Systems
____ **ET-5** Exterior Insulation and Finish Systems
____ **EQ-1** Remote Site Latrines
____ **EQ-2** Trickling Filters
____ **EQ-3** Noise Monitor and Warning System
____ **EQ-4** Pipe Loop System
____ **EQ-5** Geographic Resources Analysis Support System (GRASS)
____ **EQ-6** Pipe Mole

NAME____

ORGANIZATION____

ADDRESS____

____

TELEPHONE____

SUMMARY OF WORKING GROUP DISCUSSIONS

Group A: Identification of Potential Areas and Opportunities for Innovation in the Public Works Infrastructure (PWIS)

Participants

Prof. Arthur Baskin
Prof. John Eberhard
Dr. Francois Grobler (Recorder)
Dr. Andrew Lemer
Prof. Joseph Murtha (Chairman)
Prof. Michael Walton
Prof. Thomas White
Mr. Ronald Zabilski

The meeting started with introductions of group members, clarification of the group's goals, and discussion of the most productive approach to achieving the group's goals.

The following outline was suggested as a framework for the discussions:

1. The definition of a template or matrix to use in the identification, characterization, and prioritization of opportunities for needed innovation.

2. Review of important innovations presented in the prepared papers.

3. Identification of applicable innovations existing in other disciplines.

4. Group preparation for a plenary presentation.

The group discussed what innovation is and accepted John Eberhard's suggestion to distinguish between ideas, inventions, and innovation.

The group defined innovation as:

A product, process, or procedure successfully introduced into the marketplace to significantly reduce cost and time lines, to improve quality, or to increase performance desired by the public.

It was also pointed out that innovation can occur in different areas, including:

1. Management and Information Systems
2. Policy
3. Standards
4. Products and Materials.

Some group members felt that 15 percent perceived improvement is the minimum threshold before an innovation will find acceptance. At 30 percent improvement innovations "take off" in the marketplace without help.

After addressing these initial matters, the group continued its discussions of innovation in the public works infrastructure. These discussions were diverse and searching, but can be roughly grouped under the following issues:

How to achieve acceptance and implementation of innovation

The need for help with documenting the current status was recognized (i.e., how providers of PWIS can improve the accuracy of the documentation of current cost, performance, etc.). Further help is needed to evaluate and estimate the benefits and performance of innovation. Even if help can be provided, the question still remains: "By whom will the risk be taken?"

Assumption of the risk of innovation

Risk is inherent in the implementation of innovation. Current legal and professional liability provides strong disincentives to designers to try innovation, and most political decisionmakers, it was felt, would rather avoid PWIS investments that have a high potential benefit, but could be unsuccessful. The solution was seen as an assumption of the risk of innovation at Federal, State, and local government levels, and the following proposals were made:

1. Research. Some group members suggested that a central research institution – similar to a Rand Institute – is needed to conduct high-potential research considered too risky, expensive, or broad to be performed through the existing research channels. It was pointed out that most other developed countries have such central institutions (at least for construction in general). Many of the most developed countries are developing programs to actively market and commercialize the research products from such laboratories, thereby recovering some of the government funding risked on innovative research.

2. PWIS Bank. This bank would fund PWIS projects considered too risky to attract funding through normal channels. The funding would be derived from an initial Federal grant, and supported by contributions by State and local governments. Simultaneously, a program should be created to provide incentives for the implementation of innovation in a fraction of PWIS projects.

3. Risk Assumption. In small or unsophisticated communities with limited resources, risk-taking can be promoted through the availability of funding, as the World Bank is enforcing international standards in Third World countries.

Lessons from the transportation industry

The group considered transportation, among the PWIS industries, as the best model of innovation implementation. It was stated that transportation is unique in the funding it derives from the taxation of gasoline and other fuel products, and that other PWIS components do not have such lucrative sources of funding.

The Intelligent Vehicle Project was cited as an example of a successful innovation project, but it was emphasized that this project was not "sold" on the basis of transportation, but rather exciting technology. While this is an example of risk assumption at various levels of government, it clearly demonstrates the importance of careful planning of the presentation and approach of innovation. The lesson is that a clear constituency should be identified and carefully nurtured. The message of innovation should be communicated in "an exciting, grand way," and the process of partnership building should be emphasized throughout.

A pragmatic approach to dividing the overall PWIS spectrum should be followed, since too much needs to be done to be accomplished in one gigantic project. Some overlap of segments is needed, such as with the airline industry, which had very little input to the Maglev train initiative, yet both serve intercity public transportation.

Information systems

Developments in information systems were seen as an opportunity to change the "way people do business." Research is needed to determine the best use of information systems, and how to integrate them into the business. It was commented that proactive information systems are needed (i.e., systems which will watch their data and initiate appropriate action).

Perspective from the construction industry

From this perspective, innovations should be targeted to specific benefit groups (i.e., owners, designers, contractors, or suppliers/manufacturers of materials) or should address intergroup issues. The Construction Industry Institute was successful, it was felt, because it created a market for itself by bringing construction owners and practitioners together.

Innovation should specifically be focused on the project initiation phase, where the most potential benefit can be derived. It was acknowledged that the current legal and competitive bid environment make changes difficult in PWIS. It was strongly suggested that attention should be given to changing the practice of typical competitive bidding in PWIS.

An example of partnership was cited, where the City of Albuquerque, NM, hired one of the group members to help create a public works consortium of local government, PWIS consumers, and designers and constructors of PWIS.

Performance contracts were also examined and recommended as more appropriate in PWIS. Ehrenkrantz, who required "clean floors for 20 years" in his New Jersey school procurement experiment, is often mentioned as a proponent of performance contracting.

The desirability of equity holding by the constructor of a facility was considered next. Among elements of PWIS, only the electrical power industry came to mind, where there are some constructors who are also equity holders. This concept was looked upon favorably by the group, and it was recalled that toll roads are often better maintained than other roads. It was envisioned that cities could arrange to have elements of PWIS constructed, owned, and operated by private companies, based on performance requirements.

Sharing and dissemination of innovation and information

Electronic meeting systems enable designers to proceed simultaneously on design in different locations. It was reported that the design of Japan's Osaka Aquarium proceeded around the clock between Japan and Boston using electronic communications. It was pointed out, however, that integration problems persisted and organizational barriers were still formidable.

A better way of disseminating innovation was considered. In pursuing this topic the effectiveness of a Dutch example was reported. The Dutch government sponsors high-level workshops, to which international experts are invited, expenses paid, and generously compensated. The best ideas from this forum are then rapidly integrated into Dutch research or industry, thereby saving much time and money.

Concluding thoughts

The chairman asked each group member for their concluding thoughts on areas of innovation in PWIS. The following points are a summary of these thoughts:

Biotechnology – could be applied to municipal waste, air pollution, and high production of wood for construction.

Modularization – should be pursued in PWIS design and construction.

Education – Universities do not produce engineers with the needed interdisciplinary approach to problem solving. Innovative programs for creativity and integration are needed.

PWIS workshops – should be arranged with participants from broadly diverse backgrounds to examine problems in PWIS. The point was made that PWIS is "ripe for real creativity."

Leadership – is needed in the whole area of PWIS.

Focus of innovation – The most benefit can be derived from focusing innovation at the beginning of project phases.

Demonstration projects – are needed to demonstrate technology in a manner that would not create disastrous consequences for individual communities.

Group B: Barriers to Innovation, and Recommendations To Overcome Them

Participants

Mr. Joel Catlin American Waterworks Association (AWWA)	Mr. Charles Seemann Partner, Deutsch, Kerrigan & Stiles
Dr. Diego Echeverry U. S. Army Construction Engineering Laboratories (Session Recorder)	Mr. Jesse Story Federal Highway Administration Research (FHWA) (Session Chairman)
Mr. Carl Magnell Civil Engineering Research Foundation (CERF)	Mr. Richard Sullivan American Public Works Association (APWA)
Mr. Benjamin Mays Government Finance Officers Association (GFOA)	

Issues discussed

The group started the discussion by trying to define the term "innovation." It was agreed to define innovation as any idea that is new to somebody, even if that idea has been known and used by others in the past. For example, the APWA has had experience with ideas used for years by public works managers in one area, but totally unknown to managers in other areas. These ideas are innovative to the group of managers for whom they were unknown. Similarly, the GFOA has seen innovative financing ideas based on old financing alternatives that may become attractive once again.

The discussion focused next on identifying barriers that challenge innovation in the public works infrastructure, and trying to provide recommendations to overcome these barriers.

Legal barriers were mentioned first as an important obstacle to innovation. Examples of these barriers occur in design, specifications, etc. This resistance to change is mainly due to risk aversion (what if the innovative ideas fail?). A recommended avenue to tackle this obstacle is to legitimize innovation in design, specifications, etc., via peer review. Professional associations like the National Society of Professional Engineers (NSPE), the American Association of Civil Engineers (ASCE), and the American Institute of Architects (AIA) can facilitate the utilization of new ideas through peer validation.

In the opinion of a discussion participant, the biggest barriers for innovation in public works are related to financing and legal issues. For example, there are stringent limitations for the use of tax exempt debt to finance projects that have some private participation. Another dimension of this obstacle is the difference in regulations from state to state affecting the diffusion of innovative financing alternatives.

At this point another discussion participant intervened to mention that there are innovative management practices that have less obstacles for their application. New management practices, as opposed to new technological ideas or new financing alternatives, can be easier to adopt and implement.

The APWA has been very successful in disseminating innovative management practices among its members.

The discussion moved into the issues of vision and changing the mindset. If there is an adequate vision that fosters a positive mindset towards innovation, then innovation becomes normal and not the exception. A participant responded that this change can be achieved with incentives that promote innovation. For example, an ideal scenario was described where a designer was motivated with the incentive of a share of operations and maintenance (O&M) savings to make design improvements.

The major disincentive seems to be risk. Innovative ideas are inherently risky. A mechanism should be created to allow risk reduction for different participants. Providing incentive to innovate by minimizing risk could be a role of the Federal Government.

Another disincentive for innovation in the public works infrastructure is the high visibility of failures involving innovative ideas, coupled with the lack of exposure of successful cases. Although media coverage of failures is unavoidable, the successful application of innovation should be promoted.

As mentioned, the public works infrastructure suffers from a visibility problem. Another facet of this problem is that it is normally taken for granted until it breaks down. This is compounded by the longevity of the different components of the infrastructure (i.e., roads, water lines, etc.), which can last several decades. On one hand this can be detrimental at the moment of constructing an infrastructure system, because the decisionmakers know that the constructed facility will likely last well beyond their retirement. On the other hand the public is used to "inheriting" an operational infrastructure. This may promote an "if it ain't broke don't fix it" attitude. It is believed that these issues can be addressed via effective education and communication.

There are several management styles differentiated on the basis of how much voice each managerial level has in a decision. Three were mentioned in the discussion:

- Command or control ("the top level says it, it happens")
- Participatory
- Empowerment.

It was proposed that the Japanese generally follow the first style. This style can facilitate innovation sponsored by top management. An anecdote was mentioned to illustrate this situation. A research institution related to the Japanese Government indicated that well-defined innovative solutions can be provided by its suppliers within 2 weeks.

A participant responded that the comparison with Europe and Japan may be unfair. There are substantial national, geographical, density, and cultural differences. Actually, the diversity of the United States can be an obstacle to the dissemination of innovations. What works in one area is not necessarily guaranteed to work in other places within the country.

Another barrier to innovation discussed by the group was labeled the "slide-rule syndrome." It consists of the possible resistance of established sectors against an innovation that may make them obsolete. An example was mentioned of an innovative approach to risk distribution in construction projects. This was successfully opposed by a professional group representing the interests of those that could be affected by this idea.

The group next discussed privatization. Tollways are common in the European highway system. They have also been used successfully in the United States (it was argued that they are better maintained than freeways because of the continuous cashflow). Some sectors of this nation's infrastructure are privately owned and operated (telephone system, many power supply companies, etc.). It was pointed out that the telephone system is highly innovative. It was also noted that after a recent natural disaster the privately owned sector of the infrastructure was repaired and operational within 2 weeks; its publicly owned counterpart took months to be back to normal operation. It was argued during the meeting that this difference was due to an enhanced ability of the private infrastructure sector to spread the risk (when repairs were needed, private manpower and equipment were sent from neighboring states to help). Another topic of discussion related to privately owned and operated infrastructure was the comparison of local power supply entities publicly and privately owned. It was mentioned that the publicly owned entities deliver cheaper power. One possible explanation is profit. However, the question of whether this is only due to profit was posed.

The group came back to the issue of promoting innovation. The need for demonstration projects was discussed. The group recommended the creation of mechanisms to test and demonstrate innovative ideas in real projects. These mechanisms should primarily address the minimization of risk for the innovators. The Federal Government should play a key role in developing these demonstration projects.

Another vital role for the Federal Government is to continue the promotion of research in areas related to the infrastructure. It was argued that research cannot happen without Federal help because the market is too fragmented. The discussion moved to the issue of patented products and government regulations. There is a disincentive to use products patented by the Federal Government. Agencies are encouraged to identify nonpatented alternatives whenever possible. It was also mentioned that a 1986 act limited the use of innovative funding alternatives (it limited the way debt can be used to fund infrastructure projects).

Also, the issue of marketing the infrastructure was revisited. It was agreed that the infrastructure is not a "sexy" issue. However, to create a clear public vision of infrastructure needs and relevance for sustained economic development, it is necessary to develop an improved public relations (PR) approach. Education should be an essential part of this effort, as well as identifying the key constituency market.

A brief discussion followed related to the issue of enhanced PR. A parallel was made with fire departments, which are so successful in securing funding. It was concluded that their success, although affected by visibility, is likely to be based on liability and insurance problems caused by deficient fire safety.

The discussion moved next to answer the question: "Why do people innovate?" Innovation incentives mentioned were:

- Quality of service
- Professional and community pride
- Financial reward
- Response to changing environment (new regulations, for instance).

The space program was given as an example of a government operated and funded enterprise that was extremely successful in developing and applying innovations in diverse fields (technical, managerial, financial, etc.). It was argued that the strongest incentive was the pride of the nation, of being second to none.

Another avenue to innovate discussed was the "just do it" attitude. This can be especially useful when there are regulatory constraints that oppose innovation. The "just do it" attitude may be used to challenge these constraints for justifiable situations. Such a process of appealing regulatory barriers can be institutionalized to facilitate the incorporation of innovations that do not fit the regulatory mold.

At this point the discussion moved to the identification of supply and demand in the public works infrastructure. Participants attempted to relate the different barriers to innovation with either the supply or the demand. The same approach was used to relate the recommendations to overcome the identified barriers. It soon became evident that several players may be part of both the demand and the supply side of the public works infrastructure. It was decided instead to use the model proposed by Mr. Magnell (see Figure 1) and acknowledge that innovation can be applied anywhere in this model. It was also acknowledged by the group that innovation may take many forms (i.e., financial, managerial, social, technological).

Mr. Magnell also proposed an eyecatching expression that conveys the importance of innovation for the public works infrastructure:

$$PWI=\int Vi^2MRdt$$

where: PWI = public works infrastructure
V = vision
i = innovation
M = marketing
R = resources
t = time.

The discussion further identified barriers and corresponding recommendations. This part of the discussion focused on summarizing the issues identified by the group for presentation at the plenary session.

Barriers to innovation identified by group

- Fear of failure (disincentive):
    - potential litigation
    - loss of expected service
    - cost of replacement
    - publicity
    - accountability
- Absence of motivation (lack of incentive)
- Regulatory constraints
- Fiscal constraints
- Geographical constraints (local vs. national)
- Fragmentation of governmental responsibility

- Lack of vision (mindset)
- Political component of decisions.

Recommendations to overcome barriers

- Promotion of incentives to counteract risk aversion (i.e., economical incentives, risk reduction via demonstration projects, make whole if failure)
- Legitimization via peer review
- Communication and technology transfer
- Professional or organizational pride as an incentive
- Publication of successes
- Multigovernment cooperation.

Group C: Enhancing Technology Transfer

Participants

Mr. Kyle Schilling, Water Resources Institute (Chair)
Mr. James Thompson, Water Resources Institute
Dr. James Broaddus, Construction Industry Institute
Professor Neil Hawkins, University of Illinois, Dept. of Civil Engineering
Mr. William Michalerya, Lehigh University, ATLSS
Professor Jesus De la Garza, University of West Virginia, Dept. of Civil Engineering
Mr. Thomas Napier, USACERL (Recorder)

Introduction

Mr. Schilling opened discussions by soliciting each members' viewpoint on technology transfer. He offered a case that innovation is not equivalent to technology transfer. Innovation can emerge from R&D, incremental improvement on existing technology, evolution of "best practice," or similar sources. These still need to be transferred into more widespread use. Summaries of the members' opinions follow.

- Innovation may take place without technology transfer, although implementation is unlikely. A technology transfer infrastructure must be in place to diffuse an innovation throughout an organization. Conversely, a technology transfer mechanism without innovation is meaningless. Technology transfer needs the input of the innovators.

- There are two levels of technology transfer: the big-picture and detailed methods of implementation. Perhaps the most useful product of this workshop is a description of more specific mechanisms that can be implemented.

- Clarification of the term "innovation" is necessary. Innovation is not always a great leap forward, but is more frequently incremental advances. The technology transfer process itself is part of the innovation process. Perhaps emphasis should be given to "transferring advances in technology into practice." The role of codes and standards in public works relative to technology transfer needs to be examined.

- A list of issues, problems, and priorities would be useful. Operational mechanisms, such as codes, procurement practices, and risk allocation practices, can be targeted for change.

- The scope of technology transfer should be clarified. Consideration should be given to marketing principles, such as market push, consumer pull, authorization for an item's implementation or practice, and the consumer's ability to be comfortable or have confidence in an item. The process, phases, and participants involved in technology transfer should be identified. Then specific mechanics can be developed.

- Discussions should also include implementation of technology into the private sector. This process may be largely similar to public sector practices on which a more universal process can be built.

Two ingredients are necessary for technology transfer. An "energy force" is necessary to promote the technology, and the technology must be demonstrated and validated. An impartial check in the system is necessary to minimize risk to the end user.

Mr. Shilling summarized these opening discussions by recognizing that there are larger institutional barriers affecting innovation and technology transfer, such as government setting, codes and standards, and litigation practices. Innovation through technology transfer (i.e., innovation through scientific, academic, or laboratory resources) is a relatively marginal portion of the larger issue; necessary but not sufficient to deal with the whole innovation issue.

Within the context of developing a Federal strategy, it is appropriate to promote the Government as a more reliable partner in transferring technologies into practice. Consider the "best practice" analogy from the legal system. The implied full weight of the Federal Government behind a process in court, in the absence of a code or standard, implies "best practice." The transfer of technologies in implied "best practice" is an improvement on the situation of making the Federal Government, academic community, and others more reliable partners.

Discussions

It was recognized that the Federal Government should take a leadership role. The notion of a "National Public Works Academy" was raised as a possible higher level of support. There are pockets of national leadership and viable mechanisms to implement technologies (within the National Science Foundation, for example), but there is no national cohesiveness or cooperative interaction; no reliable partner role.

Discussions continued around the role of the Federal Government as a more reliable partner. A "national catalyst" is needed to provide cohesiveness. Existing technology transfer systems do work in some places and should be used to the greatest extent possible. Additional mechanisms may be identified to fill gaps. Any national body must not be a bureaucracy, but must rely on existing systems to the maximum extent possible. Finally, it was emphasized that a national catalyst should focus on empowering others and not assume a directive posture.

Conclusions and recommendations

Group C concluded their discussions by posing the question: "How can the Federal Government be a more dependable partner?" The following recommendations address this question.

A "national catalyst" for infrastructure technology transfer (or implementation, or adoption) should be established. The title "National Public Works Academy" was suggested. The "national catalyst" terminology seemed to be favored because it implied more of a capability and less of a standing body of any specific organization or structure.

A national catalyst can work within existing systems and mechanisms. However, it is recognized that existing systems are necessary, but not sufficient. There are gaps that must be identified and filled. The national catalyst **must work toward the larger goal of improving the national institutional structure.**

A national catalyst must not be a bureaucracy, but must rely on existing systems to the greatest extent possible. It must also be emphasized that a national catalyst should focus on empowering others, and not assume a directive posture.

A national catalyst should assume a leadership role through the following activities and responsibilities.

> Facilitate partnering — act as a "matchmaker" with Federal, academia, industry, and other relevant entities.
>
> Be an honest broker for infrastructure-related action; be instrumental in identifying needs and priorities, broker opportunities and actions, and assign leadership roles.
>
> Lead by example in validating and demonstrating technologies through Federal agencies. Facilitate "learning-by-doing" by Federal agencies. Disseminate both successful and unsuccessful experiences.
>
> Facilitate technology transfer by disseminating information and establishing training requirements and services. Identify resource allocation, planning, and action strategies.
>
> Diversify resources in the Federal Government's technology transfer processes and activities. Expand the Army Corps of Engineers' Construction Productivity Advancement Research (CPAR) program to other Federal agencies. Expand the Government's partnering and customer niches to others who are not currently involved in technology transfer. New partnering approaches may include industry and regulatory participation, as well as other forms of academic participation.

APPENDICES

APPENDIX A

WORKSHOP AGENDA

Tuesday March 3, 1992

Welcoming Remarks: Dr. Louis R. Shaffer

SESSION A: OPPORTUNITIES FOR INNOVATION

"Performance Challenges to Infrastructure Design: Enhancing the Role of Innovation in Public Works"
Prof. John P. Eberhard, Carnegie Mellon University

"Searching for the Infrastructure of Tomorrow: National Research Council Activities, Federal Interests and Federal Roles"
Dr. Andrew. C. Lemer, Building Research Board

"How Effective is our Investment in Roads, Streets, and Highways ?"
Prof. Thomas D. White, Purdue University

"An Example of Successful Innovation: Three-Dimensional Graphics on Construction Projects"
Mr. Ronald Zabilski, Stone & Webster Engineering Corporation

"Issues in Technology Transfer: Sharing Experience Between Manufacturing and Construction"
Prof. Stephen Lu and Prof. Arthur Baskin,
Dept. of Mechanical Engineering, University of Illinois

"Advancing Innovation in Transportation Through Research"
Prof. Michael Walton, Transportation Research Board (TRB)

"Technological Advances and Public Works: A Synergistic or Antagonistic Relationship"
Prof. Neil Hawkins, Dept. of Civil Engineering, University of Illinois

Summary of Session A and Group Discussion Agenda
Prof. Joe Murtha, Dept of Civil Engineering, University of Illinois

SESSION B: BARRIERS TO INNOVATION

"Barriers to Adoption of New Technologies"
Prof. Peter Nowak, Dept of Rural Sociology, University of Wisconsin**

"How Demonstration Programs Improve Potential for Utilization"
Mr. Richard A. Sullivan, American Public Works Association (APWA)

"Identifying Programming, Executing Infrastructure Research and Development"
Mr. Carl Magnell, Civil Engineering Research Foundation (CERF)

"Drinking Water Infrastructure Research"
Mr. Joel Catlin, American Water Works Association*

"Infrastructure Finance: The State and Local Perspective"
Mr. Benjamin Mays, Government Finance Officers Association

"Legal Problems with Innovation in Public Works"
Mr. Charles Seemann, Partner, Deutsch, Kerrigan & Stiles

Summary of Session B & Group Discussion Agenda
Mr. Jesse Story, Federal Highway Administration

SESSION C: ENHANCING TECHNOLOGY TRANSFER

"Innovation and Technology Transfer Opportunities: Industry/University/Government Partnerships"
Mr. William D. Michalerya, Center for Advanced Technology for Large Structural Systems, Lehigh University

"Technology Transfer as a Work-Practice Change Process"
Prof. J.M. De La Garza, Civil Engineering Dept., Virginia Polytechnic Institute and State University

"Financing Capital Improvements Through Technology Transfer: Public-Private Collaboration in Research Commercialization"
Mr. Michael B. Goldstein, Partner, Dow, Lohnes & Albertson**

Wednesday March 4, 1992

"Implementation of Innovation through Total Quality Management"
Dr. James A. Broaddus, Construction Industry Institute (CII)

"A Marketing Approach to Technology Transfer"
Mr. Jeff Walaszek, U.S. Army Construction Engineering Research Laboratories

Summary of Session C & Group Discussion Agenda
Mr. Kyle Shilling, U.S. Army Institute of Water Resources

Group Discussion
Group A: Potential Areas of Opportunity
Group B: Barriers to Innovation
Group C: Enhancing Technology Transfer

* Paper unavailable at time of publication
** Paper submitted without presentation

APPENDIX B

ANALYSIS OF WORKSHOP PRESENTATIONS

The following paragraphs summarize the contributions of the workshop participants. The summaries are organized to reflect the major issues relevant to the seven categories of barriers and opportunities discussed in Volume 1, Chapter 2.

Cultural Values and Social Perception of Innovation and Infrastructure

"Technological Advances and Public Works: A Synergistic or Antagonistic Relationship," by N. Hawkins

Hawkins looks at the cultural, educational, and social foundations as factors that can be used to promote or interfere with innovation. In his paper he parallels U.S. and Japanese innovative programs as a mechanism to determine the mentioned factors. He mentions the fragmentation of the U.S. construction industry as an obstacle for innovation. He describes the leadership role exerted by the Japanese Government through the Ministry of Construction, as well as the tight partnership between Government, academia, and industry to develop and implement innovations in practice.

"Barriers to Adoption of New Technologies," by P. Nowak

Nowak focuses on understanding the reasons that affect an individual's decision to adopt or reject an innovation. An individual can reject an innovation if he is unable or unwilling to adopt. Nowak indicates some causes of the inability to innovate are: lack of information, cost of information, complexity of innovation, limited support available, and inadequate managerial skill. An individual may be unwilling to adopt for reasons such as conflicting information, poor applicability, incompatibility, or risk.

Governmental Structure and Regulations

"Searching for the Infrastructure of Tomorrow: National Research Council Activities, Federal Interests, and Federal Roles," by A. Lemer

As the Director of the Building Research Board (BRB), Lemer describes BRB's active participation in the search for solutions to the infrastructure problem. Many of the facilities that are part of the public works infrastructure have a long life and are difficult to remove or retire. Also, in comparison with other sectors, the public works infrastructure has had few innovations in the last century (i.e., sewer systems, roads, and rails). He also mentions local distrust of the Government, which discourages investment and innovation.

A lot of potential exists for successful innovations which improve the condition and capacity of existing facilities. Also, it is important to address cross-cutting research. The BRB is pursuing efforts to: encourage research, motivate changes in policy, and have better coordination of national and local efforts both private and public. There is also an ongoing effort to develop improved measurements of infrastructure performance.

"Identifying, Programming, Executing Infrastructure Research and Development," by C.O. Magnell

Magnell is the Director of Research for the Civil Engineering Research Foundation (CERF). He provides a very broad description of infrastructure as all the common structures and facilities enabling the society to function. He indicates that there is a shortage of R&D activities focused on the public works infrastructure. He also asserts that the major problem affecting the nation's infrastructure is the lack of vision of a desired end state for the public works infrastructure.

Magnell cautions about research activities that are an end in themselves. This approach cannot provide the badly needed solutions to infrastructure problems. He emphasizes the need for an adequate technology transfer process that, through user involvement, allows the generation of R&D products that are applicable and useful in field practice.

"How Demonstration Programs Improve Potential for Utilization," by R.H. Sullivan

Sullivan describes findings of the American Public Works Association (APWA), of which he is the Executive Director, on acceptance of innovations by public works organizations. The APWA found that, in general, public works officials are conservative, avoid risks, and (except for professional pride) are not motivated to innovate. Public works organizations are interested in demonstrations of innovative ideas, in peer evaluations of these innovations, and want to avoid "black boxes." The APWA also found that several factors impact the decision and ability to innovate (i.e., regulation by higher levels of government, jurisdictional limits, codes and standards, public support, risk, and employee training).

The APWA recommends the development of innovation demonstrations that are adequately monitored and recorded. It also recommends disseminating the findings of the demonstrations to all potential users.

"Advancing Innovation in Transportation Through Research," by C.M. Walton

As past president of the Transportation Research Board, Walton provides insightful guidelines to shape the transportation R&D efforts. This is especially critical now when there is growing interest and funding to sponsor transportation research. His proposed approach is to continue and expand on the success of the Strategic Highway Research Program (SHRP). Also, he recommends additional involvement from the private sector. He also recommends seizing opportunities that exist for transportation R&D. Among others, he cites: leveraging advanced technologies, multidisciplinary teaming, public/private/academic partnering, facilitating risk taking by innovators, leadership at all levels, and others.

"How Effective is our Investment in Roads, Streets, and Highways?" by T. White

White focuses on the transportation infrastructure, which is a major component of the nation's infrastructure by several measures (i.e., contribution to GNP, number of jobs, etc.). However, the Federal R&D investment in transportation is very small (3.3 percent).

White provides several obstacles and opportunities for innovation in transportation. Among others, he proposes an integrated approach for R&D that covers the different modes of transportation and the establishment of long term policies for infrastructure development. He also notes a number of issues that interfere with the ability to innovate in transportation: technical issues being affected by political agendas, shortage of knowledgeable personnel, etc.

Risk and Liability

"Legal Problems with Innovation in Public Works," by C.F. Seemann

Seemann starts his paper by describing the historic trend in facility construction that moved the responsibility of construction from a single design-builder (master builder) to a team of participants contractually related to the owner. He also mentions the increase in social value for human life. These two factors have contributed to an added legal responsibility for contractors, designers, and owners.

Innovation in facility acquisition implies risk due to this legal responsibility and the probability of failure. Seemann argues that in spite of the risks involved, construction contractors can still derive profit from innovations. However, he asserts that designers are not motivated to innovate, due to lack of reward (low fees in competitive market), desire to stay in the mainstream to avoid liability in case of failure, and unwillingness by owners to motivate innovation.

He proposes a more active role by the Federal Government to promote innovation. This can be accomplished through the assumption of risk by the government in innovative projects and by developing flexible standards to accommodate design innovations.

Public and Private Partnership

"Implementation of Innovation Through Total Quality Management," by J.A. Broaddus

The ultimate goal of R&D activities is the transfer of technology. Broaddus describes the Construction Industry Institute (CII) and its total quality management (TQM) approach to overcoming the barriers that oppose technology transfer. TQM involves customer focus, emphasis on processes, continuous improvement of these processes through innovation, and people involvement.

CII is another example of successful partnership between private industry and academia. It also involves a few public entities. The emphasis is to have products delivered to the industry partners. To accomplish this, CII has used action teams conformed by industry participants to promote implementation of R&D products; educational programs that translate R&D results into course programs for training of construction personnel; and a consistent approach of making implementation "company-friendly."

"Innovation and Technology Transfer Opportunities: Industry/ University/ Government Partnerships," by W. Michalerya

Michalerya illustrates the potential for partnerships among industry, academia, and Government to develop R&D in the public works infrastructure. The Center for Advanced Technology for Large Structural Systems (ATLSS) at Lehigh University is supported by the National Science Foundation and industry partners. This industry partnership is valuable not only in the funding of projects but also in providing timely feedback from potential users of R&D products.

Funding

"Infrastructure Finance: the State and Local Perspectives," by B. Mays

Mays discusses the trend for the reduction in infrastructure spending by the Federal Government, which places increased burden on State and especially on local governments. There are several alternatives available for funding of public works projects, such as debt financing, own-source revenues, and public-private partnerships. However, there are also barriers that interfere with local government access to these alternatives. Mays discusses barriers like constitutional and regulatory constraints, political pressures, etc.

Size and Type of Infrastructure Projects and Facilities

"Performance Challenges to Infrastructure Design: Enhancing the Role of Innovation in Public Works," by J.P. Eberhard

Eberhard claims that the present infrastructure is the result of innovations developed more than a century ago (i.e., telephone, elevator, steel structural systems, indoor plumbing, sewers, automobile, etc.). He asserts that infrastructure innovations can be promoted by describing the functional performance demands for infrastructure systems. This description is void of any specific solutions: (1) a means of movement for persons and goods, with horizontal and vertical components, (2) a means for communicating between persons and between organizations, (3) a "metabolic" process providing energy, materials, and disposal of wastes, and (4) a shelter for protection and for providing space.

Education, Research, and Technology Transfer

"Issues in Technology Transfer: Sharing Experience Between Manufacturing and Construction," by A. Baskin and S. Lu

Baskin and Lu share their experience in technology transfer for manufacturing support, applicable to construction of infrastructure facilities. They see as obstacles to innovation the fragmentation of the design-construct process, the presence of risk, and the lack of reward for innovators. One of the recommendations is to develop a more integrated approach for facility design and construction that eliminates the antagonistic relationship motivated by the present fragmented approach. They also indicate the potential value of innovative information systems to help in this integration, but caution about information systems that are incompatible with the user's way of doing things. They describe in detail their work in concurrent engineering to support integration of the design-manufacturing process.

"Technology Transfer as a Work-Practice Change Process," by J.M. De La Garza

De la Garza examines technology transfer as the procedure through which an organization adopts and implements innovations. Technology transfer implies change, and opposition to change is always to be expected (fear of change, reduced job performance during implementation, etc.). To promote the transfer and adoption of innovations within an organization, De La Garza recommends, based on his analysis and on his survey of relevant work by others: top management commitment; active change agents; active technology gatekeepers; and a technology transfer task force within the organization. De La Garza illustrates some of the key points with the transfer of computer-aided design and drafting (CADD) technology into the construction industry.

"Financing Capital Improvements Through Technology Transfer: Public-Private Collaboration in Research Commercialization," by M.B. Goldstein

Goldstein proposes strategies to perform technology transfer so research institutions can reduce their risks. He also proposes using the value of knowledge (in the form of innovations) as a possible source of revenue to help finance the solution of infrastructure needs. His premise is that through commercialization of innovations revenue can be raised by research institutions.

Goldstein lists three main alternatives for technology transfer of innovations into the marketplace: commercialization entities, start-up companies, and joint ventures (research institution/private company). He discusses the issue of risk associated with technology transfer. Risk originates by the possibility of occurrence of three major scenarios: economic loss, breach of contract, or harm by a defective innovative product. Goldstein suggests several avenues to control the risk associated with technology transfer based on risk analysis and minimization.

"Technology Transfer and Marketing: Army-Style," by J. Walaszek

Walaszek reviews some of the barriers to the adoption of innovations, categorized in three major classes: ineffective communications, human resistance to change, and organizational and industry constraints. He describes the solution to these barriers within the Army R&D and user community. The solution consists of a technology transfer process as described in Volume 1, Chapter 3. He emphasizes the importance of gathering user input and having user involvement throughout the different phases of the technology transfer process. This guarantees that the R&D products conveniently address the user needs, and that they fit within the operational constraints of the user's environment.

"An Example of Successful Innovation: Three-Dimensional Graphics on Construction Projects," by R. Zabilski

Zabilski describes the successful transfer and implementation of innovative computer-based graphical techniques for the planning and management of construction projects. The mentioned innovation allows engineers to visualize designed components, in place, long before actual construction. This makes for more effective planning and cost estimating of the facilities. The described tools also allow for improved construction control and delivery of as-built information to the owner/operator of the facility. From a general perspective, this paper restates the importance of innovative information systems as aids for the design, construction, operation, and management of facilities.

APPENDIX C

BIOGRAPHICAL SKETCHES

Arthur Baskin

Arthur Baskin holds a Ph.D. in Computer Science and is presently the Director of the Automation Support Center at the University of Illinois. Dr. Baskin's research interests are in group decision support systems, support for professional decisionmaking, and complex systems theory.

Dr. Baskin's work with decision support systems in the U.S. Army began in the early 1980s. Working with USACERL, the group introduced one of the first local area networks in the Army at a DEH at Fort Leonard Wood, MO. Over the past 5 years, Dr. Baskin has worked on network tools to support group productivity at VCorps in Germany.

For the past 5 years, Dr. Baskin and Dr. Stephen Lu have been collaborating on the design and implementation of computer software to support concurrent engineering. They have organized two international workshops on Cooperative Problem Solving for Engineering Problem Solving.

James A. Broaddus

James Broaddus joined the Construction Industry Institute (CII) in 1990 as Associate Director for implementation programs. He holds B.S., M.S., and Ph.D. degrees in civil engineering from the University of Texas at Austin.

Before coming to CII, he served 20 years in the U.S. Navy Civil Engineer Corps, where he managed all aspects of major projects. His service included several assignments in the Seabees (the Navy's military construction forces) as well as field and engineering responsibilities on a wide variety of major contract design and construction work. Key positions included: (1) responsibility for the $500 million/year engineering and construction program in the Navy's 11 state southern region, (2) major project planning and budgeting for the Chief of Naval Operations in the Pentagon, and (3) a unique assignment as Commanding Officer of the Presidential Retreat at Camp David, MD, during President Reagan's second term.

Major construction projects for which Dr. Broaddus was responsible as a field construction manager included a major pier complex, industrial waterfront utilities upgrade, and a major medical clinic and training facility. In the Seabees, he directed a 700-person construction work force overseas in the Pacific and Europe in accomplishing a wide variety of projects. In the Navy's Southern Division, his most notable projects were the $500 million construction of three new homeports on the Gulf Coast, $200 million of fast-track restoration work in South Carolina in 1989 after Hurricane Hugo, and implementation of CII constructability and incentive contracting.

Dr. Broaddus' research includes the effect of planning inputs to the design process on ultimate project success. He is a senior lecturer in Construction Engineering and Project Management at the University of Texas at Austin and a member of the team charged with implementation of total quality management throughout the University. He is a member of the American Society of Civil Engineers, National Society of Professional Engineers, and the Society of American Military Engineers. He is a registered Professional Engineer in Texas and has consulted in the area of project management innovation and improvement.

Joel Catlin

Project manager for the AWWA Research Foundation involved in contracting and managing research projects for the drinking water industry, Joel Catlin has more than 12 years experience in engineering management, design, and analysis of water and wastewater activities for private consulting firms. He received a Bachelor of Science in Civil Engineering from Colorado State University in 1976, and is currently enrolled in graduate studies in Civil Engineering - Water Quality, at the University of Colorado, Denver. Mr. Catlin was appointed to the Standards Committee on Polyolefin Pressure Pipe and Fittings and is a member of the "Low Cost Small Systems Treatment Technology Committee," established by the USEPA to develop low-cost, small system treatment technology. Member of AWWA, WPCF, and a Registered Professional Engineer.

Jesus M. De La Garza

Dr. Jesus De La Garza received his Bachelor of Science degree in Civil Engineering in 1978 from the Monterrey Institute of Technology in Mexico. Upon graduation, he acquired 3½ years of progressively responsible industrial experience. Dr. De La Garza attended the University of Illinois at Urbana-Champaign from 1982 to 1988 where he received his Master of Science and Doctor of Philosophy degrees in Civil Engineering in 1984 and 1988, respectively. In August 1988, Professor De La Garza joined the faculty of the Civil Engineering Department at Virginia Tech.

Dr. De La Garza has received funding from the National Science Foundation's prestigious Research Initiation Award. This project encompasses two research studies, namely: (1) a technology transfer investigation to expedite the adoption of expert systems in the AEC industry and (2) a design-construction integration investigation to enhance the estimating process through the articulation of design intent. Professor De La Garza's scholarly achievements have been disseminated in 11 journal articles, 19 conference proceedings, three book chapters and four technical reports.

Dr. De La Garza is an active member of the ASCE Expert Systems Committee, the ASCE Project Controls Committee, and the ASCE Construction Research Council.

John Paul Eberhard

John Eberhard is Professor of Architecture, Head of the Department of Architecture, and Chairman of the Architectural Faculty at Carnegie-Mellon University. He has taught Urban Infrastructure, Research Management, and Design Management. He received his Bachelor of Science from the University of Illinois, School of Architecture, Architectural Design (1952). He also attended Massachusetts Institute of Technology, School of Industrial Management for his Master of Science in Industrial Management (1959).

His teaching experiences are at the State University of New York at Buffalo, School of Massachusetts and Environmental Design, as Dean, 1968-1973, and Massachusetts Institute of Technology, School of Industrial Management as Visiting Lecturer, 1959-1963. Professor Eberhard has professional experience as Executive Director, Building Research Board, National Academy of Science-National Research Council, Washington, DC, 1981-1988; President of AIA Research Corporation, Washington, DC, 1973-1978; Dean of the School of Architectural and Environmental Design, State University of New York at Buffalo, 1968-1973; Director of the Institute for Applied Technology, National Bureau of Standards, 1966-1968; Visiting Lecturer, School of Industrial Management, Consultant, Sheraton Corporation of America, Director of Research, 1959-1963; and President (and one of the incorporators), Creative Buildings, Inc., 1951-1958.

Publications include: "The Management of Design in an Industrialized Building Industry," master's thesis, Massachusetts Institute of Technology (June 1959), "Horizons for the Performance Concept in Building," Proceedings of the First Conference on Performance Concept, Chicago, IL (October 1965); "Technology for the City," International Science and Technology, No. 57 (September 1966); "Management of Design," AIA Journal (October 1968), pp 80-81; "The City as a System," in Beyond Left and Right, Radical Thoughts for Our Times, edited by Richard Kostelanetz (William Morrow & Co., Inc., New York, 1968), pp 161-166; with Abram Bernstein, "A Conceptual Framework for Thinking About Urban Infrastructure," Built Environment, Vol 10, No. 4 (Oxford, England, 1984); "Technology and the Future City," published in the transactions of Lambda Alpha's International Biennniel Congress of October 1985; "Building the City of Tomorrow," published in the Outlook section of the Washington Post, June 22, 1988.

Mr. Eberhard is a Fellow, The American Institute of Architects and a Member, The Cosmos Club, Washington, DC. He has received the Alfred P. Sloan Fellowship, Massachusetts Institute of Technology, 1959 and Engineering News Record Citation as Construction Industry Who's Who in America.

Mr. Eberhard managed more than 400 projects for MIT, Sheraton Hotel Corporation, The Institute for Applied Technology, State University of New York at Buffalo, AIA Research Corporation, and the Building Research Board.

Mr. Eberhard has served on editorial advisory committees of more than one dozen journals, 1966-1988, as Chairman, Montgomery County, MD, Waste-Water Treatment Study, 1984, and as Vice-Chairman, Research Foundation, American Consulting consultant to AIA Vision 2000 Program.

Michael B. Goldstein

Michael Goldstein is a partner with the Washington, DC law firm of Dow, Lohnes and Albertson where he is in charge of the firm's higher education, nonprofit organizations, and government grants and contracts practice. He serves as general counsel to a number of national higher education associations, including the American Association of Community and Junior Colleges, the American Association of State Colleges and Universities, the State Higher Education Executive Officers Association, and the Association of Urban Universities.

Mr. Goldstein was formerly Associate Vice-Chancellor for Urban and Governmental Affairs and Associate Professor of Urban Sciences at the University of Illinois at Chicago, where he taught graduate courses in urban policy. Before that he served as Assistant City Administrator and Director of University Relations in the Office of the Mayor of the City of New York.

He was the first Executive Director of the New York City Urban Corps and directed the Urban Corps National Development Office, a project sponsored by the Ford Foundation to encourage the establishment of student intern programs in the nation's cities. While in New York, he was an Adjunct Assistant Professor of Government in the graduate public administration program at John Jay College of Criminal Justice of the City University of New York, where he taught administrative law and public policy courses.

Mr. Goldstein is Vice-Chairman of the Education Law Committee of the Federal Bar Association and Chairman of the Education Law Committee of the Federal Administrative Law Section of the American Bar Association. He was a member of the Board of Advisors of the Forum for College Financing Alternatives of the National Center for Postsecondary Governance and Finance and a Fellow of the Columbia University Seminar on the University and the City, and is presently a Fellow of the Stanford Forum for Higher Education Futures.

Mr. Goldstein served as board Chairman of the Chicago Urban Corps and President of the National Center for Public Service Internship Programs, and was Instrumental in the formation of the National Society for Internships and Experiential Education, which arose from the merger of the National Center with the Society for Field Experience Education. He served as chairman of the Task Force on Public Policy of the Commission on the Higher Education and the Adult Learner of the American Council on Education and was the author of the Commission study on Federal policy impediments to adult learning. Mr. Goldstein was counsel to the Legal Issues Task Force of the joint SHEEO-COPA Project on the Assessment of Long Distance Learning via Telecommunications and presently serves on a multi-state task force assembled by the New York State Education Department to develop new strategies for the authorization of telecommunicated distance learning.

Mr. Goldstein serves on the executive committees of the boards of directors of the Greater Washington Research Center, the Washington Ballet, and the Washington Center for Internships and Academic Seminar. He also serves as a Trustee of Mount Vernon College and of the Fielding Institute, where he is chairman of the Budget and Finance Committee. He is Co-Vice President for Special Grants of the John Eaton Elementary School Home and School Association.

Mr. Goldstein has written extensively on nontraditional higher education, nonprofit organizations, policy issues involving telecommunications and higher education, technology transfer and higher education finance, including articles on debt financing, use of ancillary entitlements and state policy impediments to facilities financing. He also holds a law degree from New York University, a Bachelor of Arts in Government from Cornell University, and was a Loeb Fellow in Advanced Urban and Environmental Studies at Harvard University. While at Cornell, he was a Newspaper Fund Fellow and an intern with United Press International in New York City, where he later worked as a reporter.

Neil Hawkins

Neil Hawkins has been Head, Department of Civil Engineering, University of Illinois at Urbana-Champaign since March 1991. He assumed that position after 23 years on the faculty of the University of Washington in Seattle where he was Chairman of Civil Engineering from 1978 through 1987 and Associate Dean for Research, Facilities and External Affairs from 1987 through 1991. His primary research interests are in earthquake engineering and in the application of fracture mechanics concepts to predictions of the behavior of concrete materials.

Dr. Hawkins is a Fellow of the American Concrete Institute and served on its Board of Directors from 1982 through 1985. He is a member of the American Society of Civil Engineers and the Earthquake Engineering Research Institute and served on its Board of Directors from 1985 through 1987. He is a member of the Technical Advisory Board of the Post-Tensioning Institute and was their representative for the 1985 and 1988 reviews of the NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings. In 1988 he was a UNESCO Visiting Scientist at the International Institute of Seismicity and Earthquake Engineering of Japan's Building Research Institute. Currently he is a member of the Executive Committee for the NSF's project on Precast Concrete Seismic Structural Systems.

Dr. Hawkins has been interested in concrete construction since his student days. His BSCE thesis at the University of Sydney in Australia in 1957 was on anchorage zone stresses in post-tensioned beams and his Ph.D thesis from the University of Illinois in 1961 was on two-span continuous prestressed concrete beams. From the American Concrete Institute he received the Watson Medal in 1969, the Reese Award in 1976 and 1978, and the Structural Research Award in 1991. From the American Society of Civil Engineers he received the State-of-the-Art Award in 1974, the Reese Award in 1976, and the Lin Award in 1988. He is the author of over 180 publications and reports on structural engineering and in 1991 was a member of the blue-ribbon panel created by the Governor of Washington State to investigate the sinking of the I-90 Murrow Bridge during rehabilitation.

Andrew C. Lemer

Andrew Lemer received his B.S., M.S, and Ph.D. degrees in civil engineering from the Massachusetts Institute of Technology. An engineer-economist and planner, he was formerly Division Vice President with PRC Engineering, Inc. He is a member of the American Institute of Certified Planners, the American Society of Civil Engineers, the Urban Land Institute, and the American Macro-Engineering Society.

Stephen C-Y. Lu

Stephen Lu received his M.S. and Ph.D degrees from the Department of Mechanical Engineering and the Robotics Institute of Carnegie-Mellon University, Pittsburgh, PA. He is currently a tenured Associate Professor and the founding Director of the Knowledge-Based Engineering Systems Research Laboratory in the Mechanical and Industrial Engineering Department at the University of Illinois at Urbana-Champaign (UIUC). He is also a Research Associate Professor of the Computer Science Department and the Beckman Institute for Advanced Science and Technology at UIUC. His research interests are in the development of artificial-intelligence-based techniques for advanced engineering automation, and in the integration of these techniques with traditional engineering methods.

Currently, he is developing knowledge processing technology to support various concurrent engineering and system management tasks. He has published over 100 technical papers, reports, and book chapters in this area, and served as a keynote speaker for several national and international conferences. Dr. Lu is an associate editor of the *Journal of Engineering for Industry*, *ASME Transactions*, and the *International Journal of Computer-Integrated Manufacturing Systems*. He also serves on several editorial committees including *ASME Transactions*, *Journal of Intelligent Manufacturing*, and the *International Journal of System Automation*. He has organized many technical conferences and workshops, and was the Chairperson of the 1986 ASME Symposium on Knowledge-Based Expert Systems for Manufacturing and the 1989 ASME Symposium on Concurrent Product and Process Design.

He is an active member of American Society of Military Engineers (ASME), SME, IEEE, and AAAI, and is a corresponding member of the International Institute for Production Research (CIRP). He has served as a technical consultant and expert panelist to various industries and Federal agencies. He received the Presidential Young Investigator (PYI) Award from the National Science Foundation in 1987, the Outstanding Young Manufacturing Engineer Award from the Society of Manufacturing Engineers in 1988, and was selected as an Outstanding Young Man of America in 1988. In 1990, he received the Xerox Senior Faculty Research Award from UIUC for his high quality research accomplishments over the previous 5 years. In the same year, he was also appointed as a University Scholar for his excellent contributions to scholarly activities.

Carl O. Magnell

Mr. Magnell is the Director of Research for the Civil Engineering Research Foundation (CERF). He joined CERF after 27 years as an Army officer. His last military assignment was as Director of the Department of Defense Panama Canal Treaty Implementation Plan Agency (TIPA). Before that, he served as the Director of the Army's Construction Engineering Research Laboratory (USACERL) in Champaign, IL. While at USACERL, he oversaw a research program totalling approximately $60 million annually. The scope was international, with work and research in the United States, Europe, Asia, and Central America, and a diverse program encompassed, among other things, a large and diverse environmental effort, engineering materials, energy, and facility systems management. He also has served as the Engineer for U. S. Forces in Korea and commanded the 18th Engineer Brigade in Germany.

Mr. Magnell's diverse assignments while in the U.S. Army Corps of Engineers include 12 years leading engineer organizations of as many as 6000 personnel. He has hands-on experience in master planning, programming, budgeting, construction, negotiations, contracts, and construction/environmental R&D. His experience also includes directing executive level professional staffs of 10 to more than 100 personnel, including planners, human resource managers, design/construction engineers, and research scientists.

Mr. Magnell has 8 years experience interacting and negotiating with members of Congress and their staffs, senior officials in the U.S. Departments of Defense and State, and senior government officials in Germany and Korea.

Mr. Magnell received a Masters in Science in both Civil Engineering and Political Science from the Massachusetts Institute of Technology and a Bachelor of Science from the U.S. Military Academy at West Point. He is also a graduate of the Army War College and the Executive Development Program of the University of Maryland.

Benjamin W. Mays

Benjamin Mays directs the financial advisory activities of the Government Finance Research Center (GFRC). He was part of the research team that provided bond registration cost-related data for the Supreme Court case of *South Carolina v. Baker*. Mr. Mays' publication credits include an extensive analysis of reciprocal immunity between the Federal Government and the States. The analysis was included in an article entitled "Arguments on Bond Registration: On the Way to the Supreme Court."

Mr. Mays has also been active in most of GFRC's financial advisory projects, including water and sewer system improvements, toll roads, jails, administrative and judicial centers, parking lots, reservoirs, libraries, landfills, bridges, streets and sidewalks, and a variety of other governmental structures.

Mr. Mays recently completed work on the GFRC's role in the U.S. Environmental Protection Agency's (USEPA's) efforts to apply the Clean Water Act to Boston Harbor. He has also been active in the GFRC's other Clean Water Act compliance programs with USEPA and several State agencies. Mr. Mays is a graduate of the College of William and Mary in Virginia.

William D. Michalerya

William Michalerya received a Bachelor of Science in Civil Engineering from Cornell University in 1976 and a Master of Engineering in Civil Engineering from Cornell University in 1977. He received his Master of Business Administration from Lehigh University in 1988.

Responsibilities at Lehigh University include management of the Advanced Technology for Large Structural Systems (ATLSS) industry program and joint research projects as well as technology transfer activities such as short courses, seminars, demonstration projects, and development and implementation of technology transfer plans.

In addition to the ATLSS position, Mr. Michalerya recently was appointed Vice-President and Chief Operating Officer of Competitive Technologies, Inc. (CTI), a subsidiary of Lehigh University. CTI has a mission of technology transfer, development of collaborative R&D programs, and patenting and licensing of new technologies.

Before joining ATLSS, Mr. Michalerya spent 10 years in private practice as a civil engineer and project manager. His project experience includes a wide range of structural and geotechnical work, including bridges, buildings, industrial, and waterfront facilities. His management experience includes supervision of technical staff, preparation of proposals, reports, and specifications, and client development responsibilities. From 1984 to 1988 he was project manager at Bergmann Associates, Philadelphia, PA. From 1979 to 1984 he was a civil engineer for Bethlehem Steel Corporation, Bethlehem, PA, and from 1977 to 1979 he was a geotechnical engineer for the Quality Assurance Group, D'Appolonia Consulting Engineers, Inc., Pittsburgh, PA.

Mr. Michalerya is a member of the American Society of Civil Engineers, Chi Epsilon Honorary Fraternity (Civil Engineering), and Beta Gama Sigma Honor Society (Business). He is a registered professional engineer in Pennsylvania.

Fred Moavenzadeh

Dr. Fred Moavenzadeh is the George Macomber Professor of Construction Engineering and Management and Director of the Center for Construction Research and Education at the Massachusetts Institute of Technology. His professional field of interest is construction engineering and management, with a primary focus on international construction, construction finance, and strategic management. He has taught the basic courses in construction, facility design, and engineering and management of infrastructures, both in the Department of Civil Engineering at MIT and at the Graduate School of Design at Harvard University.

Joseph P. Murtha

Joseph Murtha received B.S. and M.S. degrees in civil engineering from Carnegie-Mellon University in 1953 and 1955, respectively; and his Ph.D. in Civil Engineering from the University of Illinois at Urbana-Champaign in 1961.

He served on the faculty in civil engineering at the University of Illinois from 1958 to 1966 as a research associate, assistant professor, associate professor, professor, and Water Resources Center Director. From 1966 to 1969 he served other organizations in leadership positions in harbor and ocean structures research.

In 1969 Dr. Murtha returned to the University of Illinois as Professor of Structural and Hydraulic Engineering. During the 1976-77 academic year he held a Fulbright-Hays Senior Research Fellowship in the United Kingdom. In 1986 he became the Director of the Advanced Construction Technology Center at the University of Illinois. In 1991 he served as Chairman of the National Civil Engineering Research Needs Forum sponsored by the Civil Engineering Research Foundation. He currently serves as vice-chairman of the task force overseeing implementation of the Forum recommendations.

Peter J. Nowak

Dr. Nowak received his Ph.D. from the University of Minnesota's College of Agriculture in 1977. He served as both an assistant and associate professor of rural sociology at Iowa State University prior to joining the faculty at the University of Wisconsin-Madison in 1985. At Madison, he holds a research appointment as a Professor in the Department of Rural Sociology and an extension appointment as a Soil and Water Conservation Specialist in the Environmental Resources Center.

His work has focused on the transfer of agriculture technologies to farm audiences. This has included examining individual decision processes on whether to adopt or reject these technologies; the socioeconomic impacts of innovative technologies; and how institutional settings influence technology transfer processes.

Dr. Nowak has publications in professional books, journals, and periodicals resulting from research at the local, regional, and national levels. He has also served on a number of national committees and advisory groups including the U.S. Congress Office of Technology Assessment, the National Academy of Science's Board on Agriculture, U.S. Army Corps of Engineers, U.S. Office of Management and Budget, American Farmland Trust, and the Soil and Water Conservation Society.

Charles F. Seemann, Jr.

Mr. Seemann's practice relates to matters of the construction industry, surety and professional responsibility, fidelity and financial institution bonds, and public contract law. Mr. Seemann has been the President and Director of both the New Orleans Association of Defense Counsel and New Orleans Legal Assistance Corporation. He joined the firm in 1965 after 3 years active duty in the U.S. Navy. In 1959, Mr. Seemann earned a Bachelor of Science in Geology, and in 1962 an LLB, both from Tulane University. He has lectured on construction topics at national meetings of the ASCE, ASME, the National Institute of Municipal Law Offices, at continuing education programs of the Louisiana and Florida Bar Associations and at Loyola University and the Deep Foundations Institute.

Kyle E. Schilling

Kyle Schilling is Director of the U.S. Army Corps of Engineers, Institute for Water Resources. He manages a diverse and rapidly responsive program of studies and research relating to current issues in the changing national water resources environment. His experience centers on comprehensive resources planning, water supply, and water conservation planning. He directed the staff efforts of the 1977 White House Drought Study Group and the 1980 President's Intergovernmental Water Policy Task Force Subcommittee on Urban Water Supply. He was also the principal author of the National Water Resources Infrastructure Needs Study completed in 1987 for the National Council on Public Works Improvement. He recently organized and directed a North Atlantic Treaty Organization (NATO) Advanced Research Workshop on Urban Water Infrastructure.

Mr. Schilling graduated in 1963 as a civil engineer from the Pennsylvania State University. He began his professional career as a summer intern with the Pennsylvania Department of Highways. This was followed by employment with the Baltimore District of the U.S. Army Corps of Engineers where he worked on the Potomac and Susquehanna River Basin Studies until 1966. Before assuming his present position, he was employed from 1972 to 1976 by the North Atlantic Division of the Corps of Engineers as the Senior Interdisciplinary Study Manager for the Northeastern United States Water Supply Study (NEWS) and as Regional Study Director for the 1975 National Assessment conducted by the Water Resources Council. He worked for the Bureau of Reclamation in 1971 and 1972 as plan formulation and study management specialist on the Western U.S. Water Plan. From 1969 to 1971 he served as plan formulation specialist for the North Atlantic Regional Study (NAR) conducted by the North Atlantic Division of the Corps of Engineers. He was also employed by the State of Nebraska from 1966 to 1969 as head of Nebraska's Public Law 566 (small watershed) planning program and as a state work group representative on the Missouri Basin Interagency Committee. He has been employed at IWR since 1976, serving as Chief of the Policy Studies Division prior to selection to the position of Director in 1990.

Louis R. Shaffer

Dr. Shaffer graduated from the Carnegie-Mellon University School of Engineering in 1950 and graduated from the University of Illinois at Urbana-Champaign in 1957 with a Master of Science degree. He received his Ph.D. from UIUC in 1961.

Since 1969, Dr. Shaffer has been the Technical Director of the U.S. Army Construction Engineering Research Laboratories (USACERL) in Champaign, IL, one of the largest organizations dedicated to infrastructure research and technology transfer in the United States. He has been a member of the faculty of the University of Illinois at Urbana-Champaign since 1954 and was Professor and Head of the Construction Engineering Group in the University Department of Civil Engineering from 1961 to 1969. Under his technical direction, USACERL has leveraged Army R&D resources by developing successful partnerships with UIUC and many other universities.

Dr. Shaffer has published two books and numerous articles on systems design procedures based on modern mathematical and scientific methods for use in decisionmaking in the planning, designing, bidding, scheduling, and monitoring of construction operations. He is a registered professional engineer in Pennsylvania and a Fellow of ASCE.

Dr. Shaffer has received numerous awards, including the prestigious Puerifoy Construction Research Award of the American Society of Civil Engineers (ASCE), an Exceptional Civil Servant from the U.S. Army, the Walter L. Huber Research Prize by ASCE, and the Construction Management Award by ASCE. He has been designated as a Distinguished Executive and twice a Meritorious Executive in the Senior Executive Service in the U.S. Government.

Jesse A. Story

Mr. Story is a native of Southern Illinois and attended the University of Missouri at Rolla (formerly the Missouri School of Mines), graduating in 1961 with a Bachelor of Science in Civil Engineering.

Mr. Story started his career in 1961 with the Illinois Department of Transportation (IDOT) District Office in Carbondale. His primary positions with IDOT were Project Engineer and Resident Engineer for interstate construction projects. In 1966, he accepted an appointment with the Federal Highway Administration as an Area Engineer in Kentucky. He has held various positions with the Federal Highway

Administration since 1966 and is currently the Chief of the Program Management Branch of the Construction and Maintenance Division in Washington, DC.

Richard H. Sullivan

Mr. Sullivan is the Executive Director of the American Public Works Association in Chicago. Before his position as Executive Director, Richard served as the Associate Executive Director for Management and Research at APWA. During his 20 year tenure in that position, he designed, implemented, and was responsible for technology transfer for over 60 research projects. The research program Mr. Sullivan manages and oversees as Executive Director is broad-based, ranging from pavement rehabilitation techniques, new technologies for water resources, and administrative procedures such as privatization.

Before joining the APWA staff, Mr. Sullivan worked as Public Works Director in Atwater, CA, and as Assistant Public Works Director in Phoenix, AZ.

Author of numerous publications that focus on results of APWA Research Foundation activities, Mr. Sullivan is an active member in the International City Managers Association, Water Environment Foundation (formerly known as Water Pollution Control Federation), and the American Society of Association Executives.

Mr. Sullivan will present his technology transfer activities in promoting proven technologies to public works departments. He will focus his presentation on demonstration programs–what works and what doesn't–from the APWA perspective.

Jeffrey J. Walaszek

Mr. Walaszek is Chief of Public Affairs and Marketing Communications at the U.S. Army Construction Engineering Research Laboratories in Champaign, IL. Mr. Walaszek manages the Army Corps of Engineers Facilities Engineering Applications Program Information Center, which promotes and publicizes the availability of innovative technologies for military facilities. Mr. Walaszek had been involved in several Army-level technology transfer initiatives, most recently chairing a committee to develop a technology transfer planning process. Mr. Walaszek brings a marketing perspective to technology transfer, with a Bachelor's degree in Public Relations from Northern Illinois University and a Master's degree in Mass Communications from the University of Illinois at Chicago. His master's thesis described a communications strategy to support technology transfer.

C. Michael Walton

C. Michael Walton received his Bachelor of Science in Civil Engineering from the Virginia Military Institute in 1963, and his Master's (1969) and Ph.D. (1971) in Civil Engineering (Transportation) from North Carolina State University. Administrative and management experience include Transportation Economist, Office of the Secretary, U.S. Department of Transportation and Transportation Planning Engineer, North Carolina State Highway Commission. He is Paul D. and Betty Robertson Meek Centennial Professor in Engineering and Chairman of the Department of Civil Engineering at the University of Texas at Austin. He holds a joint academic appointment in the Lyndon B. Johnson School of Public Affairs. In addition, he has been active in sponsored research and consulting related to public and private participation and transportation engineering and analysis for approximately 28 years.

Dr. Walton has been involved in research associated with truck sizes and weights, economic and engineering implications of LCV's, intermodal operations, containerization and institutional issues impacting productivity in domestic freight service and advanced technology (IVHS). He has served as policy consultant for the Heavy Vehicle Electronic License Plate (HELP/CRESCENT) project, an international, multistate authority, and motor carrier industry effort to explore applications of new technology.

Dr. Walton served as Chairman of the Transportation Research Board Committee on Motor Vehicle Size and Weights and the Committee of Relationships between Vehicle Configurations and Highway Design (Turner Proposal). He was a member of the National Academy of Sciences/Transportation Research Board Technical Review Panel for the National Truck Size and Weight Study, and the National Academy of Sciences Double-Trailer Truck Monitoring Study mandated by the Surface Transportation Assistance Act of 1982. Currently, he chairs the technical committee on Commercial Vehicle Operations in IVHS America.

Dr. Walton serves as Past-Chairman of the Executive Committee of the Transportation Research Board. The American Society of Civil Engineers has recognized Dr. Walton as the recipient of both the Harland Bartholomew Award and the Frank M. Masters Transportation Engineering Award for his contributions to urban transportation planning and transportation engineering, respectively.

In related activities he is a member of the Transportation Research Board, American Society of Civil Engineers, Institute of Transportation Engineers, Operations Research Society of America, Urban Land Institute, National Society of Professional Engineers and IVHS America. He has published approximately 240 journal articles and reports on transportation engineering, planning, policy, and economics and presented over 250 invited papers and lectures.

Thomas D. White

Thomas White is an Associate Professor of Civil Engineering at Purdue University, where he received his Ph.D. in 1981.

Past work experience includes the position as Chief of the Materials Research Center (MRC), U.S. Army Waterways Experiment Station (USAWES). The MRC laboratory conducts research and paving materials evaluation for the U.S. Army Corps of Engineers, U.S. Air Force and Federal Aviation Administration. Consultant support was provided to the Chief of Engineers in evaluating pavement failures and in pavement construction. Before joining the staff at Purdue, he was Chief of the Pavement Systems Division at USAWES and was responsible for conduct of research and investigational activities of a staff of between 50 and 60. Over half of these were professionals involved in studies in areas such as pavement management, analysis, materials, design, construction, evaluation, and maintenance involving laboratory tests, field investigations, and analytical studies of pavements.

Dr. White has conducted laboratory and field investigations of pavement materials, pavement test sections, and prototype pavements. He has participated in analysis of test sections and development of pavement design criteria. Currently he is the principle investigator on projects to develop an overlay design procedure for flexible and rigid pavements in Indiana and evaluation of nondestructive testing equipment. He is also involved in projects concerned with developing pavement maintenance and management systems.

Ronald J. Zabilski

Ron Zabilski is a civil engineer with 14 years of experience in facility construction and maintenance. He has been with the Stone & Webster organization for 10 years.

For the past 6 years, Mr. Zabilski has been demonstrating the feasibility of three-dimensional computer graphics in the construction environment with computer-generated construction sequence models, construction accessibility studies, and crane sizing and rigging studies.

In this time he has been responsible for managing development of the integrated construction management system, COMMANDS, which integrates three-dimensional computer graphics with a central relational database for automatic quantity takeoffs, construction sequence planning, automated project scheduling, and construction progress reporting. Mr. Zabilski has published six papers on these subjects.

Mr. Zabilski is also a specialist in the Construction Innovations Group, and is responsible for development and review of new cost-saving construction techniques and practices in support of field construction activities. Recently he became a member of the new CII Constructibility Education Action Team.

Mr. Zabilski has a B.S. in Civil Engineering (1978) and an MBA (1990) from Northeastern University.

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This report documents the results of an indepth study and workshop which could be applied to overcome barriers to innovation and the use of innovative technology within the nation's public works infrastructure. This is the third in a series of reports prepared to support the Federal Infrastructure Strategy Initiative, a 3-year program to explore the development of an integrated Federal infrastructure strategy. The program was initiated as one of the President's budget items for Fiscal Year (FY) 1991 and approved by Congress. The program is overseen by the U.S. Army Corps of Engineers (USACE) Directorate of Civil Works, and the Corps' Institute for Water Resources (IWR) has detailed management responsibility.

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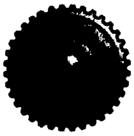

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