CHAPTER FIVE

INSTITUTIONAL AND POLICY ISSUES

The nature and effectiveness of R&D depends to a large extent on the institutional environment in which it is carried out. In the case of public works infrastructure R&D, this environment is characterized by:

- Governmental Decentralization-- over 38,000 government have a role.
- Monopoly-like characteristics --each governmental unit has sole jurisdiction.
- Inflexible Procurement Systems
- Fragmented Sellers -- with the exception of large structures, such as bridges, tunnels, and large dams, most construction is done by a large number of small local firms.
- Nature of the Operations-- much construction work involves large tonnages of low cost materials; the training and skill levels of construction labor inhibits the use of sophisticated technologies.[56]

These factors universally point to the tremendous difficulties in funding, completing R&D on, and disseminating new and worthwhile technologies-- particularly where both information and skills are involved.

OTA found that America's traditional inventive abilities and achievements remain unquestioned. A recent article states:

> The fact remains that the United States is still a creative hothouse. Its laboratories churn out important advances and whole new technologies from biotechnology and fiber optics to superconductivity. And foreign

[56] Alan E. Pisarski, "The Role of Technology," unpublished draft chapter of a report to the National Council of Public Works, May 1987.

students flock to U.S. universities, where they now account for 20 percent of all students and a staggering 55 percent of those studying engineering. So the failure is not American technology--it is American manufacturing. U.S. industry has big trouble when it comes to transforming ideas into products that can be sold on world markets. That's the missing link in the innovation process.[57]

Although U.S. manufacturing firms have difficulties translating invention into innovations and saleable products, the problems and failures are much greater in construction. Technologically, construction has primarily been and is likely to continue to be largely a "borrowing" industry. Most technological advances originate from or are shared with other industries--little has been invented that is used solely in construction. The "invention" problem for construction is what technologies to borrow and how to adapt them to construction applications.

However, OTA concludes that key elements of the Nation's institutional and industrial structures have become incompatible with an ability to capitalize on the benefits of R&D. As examples--the United States has no Federal agency responsible for construction matters comparable to the Japanese Ministry of Construction. Research funding is fragmented and in many cases insufficient to accomplish very much. Construction firms rely for R&D on government, universities, and manufacturing firms that develop and sell the technologies. Little accountability has been required for practical results or benefits in applications obtained from government-funded R&D. Tax incentives for R&D in the private construction sector have been largely ineffective; apparently they have been insufficient to offset the disincentives.

Regulatory and procurement practices, and the lack of risk sharing, economic incentives, and industrial and intergovernmental cooperation, are powerful disincentives to R&D for many construction companies. Remedies for the institutional impediments to the effective application of public works R&D are as essential for technological progress in infrastructure construction as the R&D itself. With appropriate changes in public institutions and strategies, the private sector

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57 Business Week, Apr. 20, 1987, p. 56.

might be able to remedy many R&D problems with little government help, Moreover, it will be extremely difficult for the Federal Government to remedy the problems of infrastructure R&D without changes in the institutional environment and greater attention to economic incentives.

Accordingly, this chapter describes the institutional and policy issues that need to be addressed if the United States is to develop a stronger national effort for public works infrastructure R&D. The discussion also identifies other institutional issues that need further investigation and study before it is possible to develop a sound basis for determining public policy alternatives. Finally, while the subject is not addressed in this paper, OTA recognizes that a detailed examination of the economic impacts of R&D in public works infrastructure is necessary for full understanding of the institutional framework.

REGULATORY AND PROCUREMENT SYSTEMS

Regulatory systems in the United States differ among types of infrastructure. For certain types or categories of infrastructure, government procurement systems are the regulatory systems.

As an example of the complexity of the procurement and standard systems, the States set construction standards for water and sewer systems. Pursuant to the Clean Water Act, the Environmental Protection Agency establishes performance standards for water purity. The States consider and may utilize other construction guidelines or standards adopted or recommended by the American Society of Testing Materials, the National Sanitation Foundation, and the American Water Works Association. Other organizations such as the Occupational Safety and Health Administration, the American Society of Civil Engineers, and the Corps of Engineers may become involved. In the case of highways and bridges, the American Association of Highway and Transportation Officials (AASHTO), has a formal process for review, adoption, and amendment of standards, which individual States may then adopt or use. The Federal Highway .Administration sets standards in cases where Federal funds are used.

The Bureau of Reclamation applies a concept of "sound and accepted engineering practice" in design and construction of small dams and waterways, without a formal process. Some States require licensing for construction of privately owned small dams, which are reviewed and approved on a case-by-case basis.

The Corps of Engineers has a rigorous internal review process for setting and revising what are referred to as "acceptable engineering standards" applying to the public works for which they are responsible. Technical reviews for standard-setting are linked to their R&D projects. While the Corps standards are keyed to accepted commercial and industry standards, they also must meet the Corps' own criteria.

Each of these groups is concerned with one or perhaps two or three types of public works. Yet a large construction firm may bid on numerous public works projects in different public works segments as well as pursue private sector contracts, often in a different area. Realizing economic payback for the heavy front end costs of developing a sustained R&D program is possible only with economies of scale unavailable to all but the very largest firms, The need to meet different sets of standards poses a formidable obstacle to achieving those economies. Other related problems include the fact that contractors for public works are generally not prequalified, reducing opportunities for R&D investment recovery .[58]

Moreover, most contracts for infrastructure construction are awarded on a low-bid basis with specifications that are heavily weighted toward existing technologies and experience-based methods. Further analysis is needed to ascertain whether this type of public works infrastructure procurement achieves real economies. It may, in fact, impede technology innovations that could be cost effective, especially if they reduce life cycle costs.

Various agencies have included "value engineering" clauses in contracts for some years. These clauses, effective after contracts are awarded, are intended to provide contractors with an

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58 Henry L Michel, president and Chief Executive Officer, parsons Brinckerhoff, Inc, Personal communication, May 18, 1987.

incentive to develop new designs or technologies. The usual incentive offered is that the government shares with the contractor any cost savings that result. The Bureau of Reclamation, for example, offers contractors 50 percent of cost savings realized through value engineering. However, OTA was able to identify few new or improved infrastructure construction technologies that have resulted from the value engineering. The one significant technology development attributable directly to value engineering is the use of roller-compacted concrete in the Corps of Engineers' gravity dam on Willow Creek in northeastern Oregon. This innovation uses roller-compacted concrete in place of pouring concrete in the normal manner, creating a net saving for the dam of $11.6 million and reducing construction time for the dam by 25 percent.[59]

Nor did OTA find examples in the United States of a European technique, design competition. In a design competition, contractors bid and are selected on the basis of alternative designs and methods to those of government specifications. This approach is related to value engineering, but applies before, rather than after, contracts are awarded.

Recognized problems with building construction regulations are probably analogous and can be used to illustrate the impediments that regulation and procurement systems provide for public works infrastructure construction. Technology innovations in building construction are impeded by a number of factors. First, a wide variance exists in State and local building codes and inspections across the United States, complicating product and construction requirements and adding significant costs for large producers and builders. Secondly, taking a new building product or technology through the model code and State and local code approval processes typically requires considerable time and money, Moreover, code approval processes favor existing producers and technologies in various ways, making it difficult to obtain approvals for new products and technologies. Finally, "performance" standards, which might encourage inventive-

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59 Paul V. Dobrous, Chief of Value Engineering Office, Corps of Engineers, personal communication, April 1987. Also see: "Rolled Concrete Triumphs," Engineering News Record, Oct. 21, 1982. Other applications for roller-compacted concrete are discussed in chapter seven.

ness and innovation and lower costs, are much more difficult to administer from a regulatory perspective than commonly used design or prescriptive standards.

The extent to which the numerous and varied regulatory and procurement systems for infrastructure construction inhibit R&D and technology innovation remains unclear. Additional research to identify changes in regulatory and procurement systems that might encourage or provide incentives for infrastructure R&D and technology innovation could be useful. A Public Works Management Program funded by the State of Ohio and located at the Cleveland State University is just beginning and may illustrate one method of addressing some of these issues. The "program will train civil engineers to understand the economic, political, and social, as well as technical aspects of providing public works."[60] The course was developed through consulting with public works officials to determine their needs.

SAFETY. OUALITY. AND LIABILITY CONCERNS

OTA found that liability issues are serious impediments to construction technology innovation as well as to R&D. U.S. construction firms are understandably reluctant to take the risks associated with new or different construction methods and materials that are not common practice or in general use. Undertaking R&D is pointless if a firm believes it may not use resulting technologies because of fears of litigation. Thus, to industry, the prospect of litigation often outweighs the possible advantages of new or improved technologies.

Liability is not a stand-alone problem. It is linked to and reflects other mutually reinforcing problems, inside and outside the legal system, which adversely affect technology innovations in the construction industries. The nature and extent of these problems are not fully understood and need to be researched to provide a basis for considering solutions. Among the

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60 Cleveland State University, "Public Works Management Program, " unpublished program description prepared for the National Workshop on the Role of the University in Public Works Management, Apr. 28-29, 1987.

problems are accidents, which are more prevalent on U.S. construction sites than is generally realized. Insurance costs are high, reflecting the risks of liability and litigation.

At the same time, public safety concerns related to inspections and quality control are frequently justified. To a greater or lesser extent, each construction project is unique. Large construction sites in particular pose problems of quality control that are much more difficult to address than problems of quality control on factory production lines. Construction is still a "craft-based" industry; it has never been a "high tech" industry; and training of workers, especially for maintenance and repair of increasingly advanced systems, is usually minimal. Consequently, cost and performance benefits from more advanced technologies are difficult or impossible to retain. In many cases, as more advanced technologies are used, inspection problems are compounded. For example, to protect themselves, some owners and developers employ private engineering firms to do independent inspections, as they lack confidence in public building inspectors who have neither the knowledge nor experience to keep pace with new or different technologies. The United States does not have a credible, institutional "authoritative voice" to test and approve new or different construction technologies in a timely and cost effective manner, as some foreign countries do. Moreover, the United States has not institutionalized arrangements for sharing risks of new or more advanced technologies, as have some other countries.

The failure and consequences of using new technologies without R&D are cited by the director of one of NSF Engineering Research Centers:

> ". . . both industry and government often implement construction technology without any significant research and development. This in turn has resulted in substantial costs in repairs and corrective measures when these construction technologies fail to perform. In most cases, the research and development is only done after this lack of performance. The cost of subsequent study, repair and litigation is an enormous expense and ineffective way to achieve economy and performance of the infrastructure. A case in point is the utilization of electroslag welds in bridges. Very little research and development was carried out on this process before it was extensively put into use in the 1960's. Failure of the I-79 bridge at Neville Island near Pittsburgh led to banning the use of the method in

bridge tension members in 1977 by the Federal Highway Administration. The process is still not accepted for use, and many of the structures with these welds have had costly repairs and retrofits installed. This same experience is repeated often in both private and public sector applications."[61]

While tort reform is tempting as a way to mitigate some of the risks of new or different technologies, it will not remedy the underlying technology-related problems associated with liability.

EFFECTIVENESS OF TECHNOLOGY TRANSFER AND INNOVATION DIFFUSION

Movements of technologies from the R&D phase into construction application fall into two categories. The first is technology transfer--moving new or improved technologies from laboratories to innovative firms that can utilize it. The second is innovation diffusion--creating widespread uses of new or improved technologies across infrastructure segment lines. As an example, innovations in dredging equipment developed for the mining industry also are applicable for dredging waterways, ports, etc., but these research efforts are uncoordinated. City public works departments may not use new or improved technologies either because they do not know about them or have other personnel limitations. Moreover, the city may receive bids from numerous small, less sophisticated firms that are similarly uninformed, rather than from large-scale infrastructure construction firms with staffs of professional architects and engineers.

Research is needed to determine whether or not there are problems different from those already identified. It is also important to explore positive methods, such as incentives, which might be created to improve or speed-up innovations in infrastructure construction. Some new or improved construction technologies appear to be implemented quickly with good results, while others are not. Because of the nature and size of projects, the types of firms and profes-

61 John w Fisher, Director of the Engineering Research Center for Advanced Technology for Large Structural Systems at Lehigh University, personal communication, May 22, 1987.

sionals involved, and the contracting procedures used, problems of technology transfer or innovation diffusion may differ among sectors of the industry. A systematic analysis and case studies that explore these issues could be very useful in identifying the factors involved.

PROTECTING TECHNOLOGY DEVELOPMENT

The role and importance of protecting technologies to provide incentives for R&D need further examination. According to one source, the advantage that a company receives from developing a new or different construction technology lasts, at most, for only two projects. At that point, the technology is known and available to other companies. While OTA did not examine procurement or contracting procedures in detail, it was told that specifications for construction contracts written by public agencies for large projects frequently specify the construction technologies to be used. While such specifications provide equality for bidders, they discourage innovative methods. T'his manner of procurement also provides a disincentive for companies to incur costs for R&D from which they may not benefit financially very much nor for very long. On the other hand, the specifications can help diffuse technologies, as procurement or contracting procedures become a vehicle for innovation diffusion.

OTA determined that U.S. construction firms infrequently seek patents. The lack of advantage may explain why U.S. firms spend money for “environmental scanning” (continuously searching the global environment to see what is being used or developed that they may wish to use). They obviously consider such scanning to be more cost and profit effective than R&D and seeking patents. (See chapter 3 for examples.) This may also relate to the periodic fluctuations in U.S. construction markets, which make financial commitments to R&D difficult or unwise. According to some, the human technical and organizational skills of applying a technology in large-scale construction are far more important than the proprietary advantages of construction technologies themselves which are difficult or impossible to protect.

It appears that Japan offers a contrasting case.[62] Japanese construction firms obtain patents numbering literally in the thousands, which may fit their longer time horizon and other differences in strategies for obtaining domestic and international business.

COMPETITIVE ENVIRONMENT OF THE U.S. PRIVATE SECTOR

During recent years, the competitive environment in the United States has become less hospitable for private companies to undertake R&D for the construction industries generally, As firms have sought to avoid takeovers and be more competitive domestically and internationally, they have focused on short-term profitability. In some cases, an immediate improvement in cash flow and earnings has become a company's primary objective. Often the easiest way to improve short-term profitability is to cut costs by reducing or eliminating operations that do not immediately contribute to profits. R&D operations often fall into this category as such operations. A noteworthy example is Owens-Corning Fiberglass which, faced by a takeover attempt, cut its annual R&D budget in 1986 from approximately $94 million to $48 million and cut its research staff from about 1,000 to 500 employees. Although no data were available on manufacturing firms specifically supporting infrastructure construction, some manufacturers (including Manville Corporation, Owens Illinois, Libby Owens Ford, and U.S. Gypsum) have drastically cut back their R&D efforts supporting other types of construction.[63]

The Owens-Corning Fiberglass experience is instructive in showing some of the effects of financial pressures. The company's large exploratory research program, aimed at developing new product lines, was eliminated entirely. Research supporting product lines that the company

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62 Information and discussion in this chapter of Japanese Construction activities is based, in part, on information obtained at a meeting of the Committee on the International Construction Industry of the Building Research Board, Commission on Engineering and Technical Systems, National Research Council, April 21, 1987, Representatives of the Japanese Government and four of the largest Japanese construction firms made presentations at the meeting.

63 Dr Robert C. Doban, Senior Vice President for Science and Technology, Owens-Corning Fiberglass Corporation, OTA interview, Apr. 24, 1987.

sold as part of restructuring was also halted. The company narrowed and focused its remaining R&D on short-range objectives supporting business lines that the company retained.

It appears that the push for bottom-line profitability to avoid takeovers has had a chilling effect on R&D carried on within many private companies, both those directly threatened, and those fearing a possible take over. This factor may provide a powerful new disincentive for private companies in the United States to undertake R&D activities for the construction industries broadly, including infrastructure construction. And the commitment to competition makes cooperative research efforts difficult even among firms with common needs and limited resources.

Many questions remain to be answered about the effects on competition of further internationalization of construction in general, and the effects on the American economy of Japanese and European companies entering U.S. domestic construction markets in particular. In the context of technology however, Japanese entries into American construction markets may have positive effects. Increased competition could heighten interest in R&D for construction technologies to gain competitive advantage. In consequence, technology innovations in the United States could be accelerated, and construction productivity and quality could be enhanced.

ISSUES NEEDING FURTHER STUDY

U.S. federally-funded infrastructure research emphasizes design techniques, evaluations, and other topics pertaining to domestic infrastructure projects. Although essential for good management, these types of research do not advance or support infrastructure construction technologies. Furthermore the amounts of advanced, basic, and incremental R&D for construction technologies being funded by the Federal Government are minimal. The emphasis and priorities as well as organization and magnitudes of infrastructure research pose important issues for Congress to consider. After this initial look at public works construction R&D in the United States, OTA finds a number of issues warranting further study. Among them are:

- the complex interrelationships between design and construction processes and materials choice,
- the impact of legal issues, such as risk and liability,
- identification and analysis of legal issues related to shared risk,
- alternative standards setting processes more conducive to innovation,
- an in-depth study of the economic framework for industrial and public works R&D, and innovation, and
- development of performance and certification standards for acceptance of new technologies to facilitate their use in public works.

CASE STUDY

Japanese Institutions-- A Contrast and A Challenge

Although Japan differs from the United States socially and institutionally, an examination of construction technologies R&D in that country shows both similarities and contrasts with the United States. In particular Japan has institutions that employ a strategy of using R&D to create advances in construction technologies that are then used to gain advantages in international markets.

Large Japanese construction companies operate in an institutional environment that may enable them both to enter U.S. construction markets and to compete effectively against U.S. companies in foreign markets. This institutional structure includes the establishment of significant R&D capabilities and a market strategy in which R&D and technology innovation play important roles.

Construction R&D was observed as a practice of some Japanese construction firms as early as the 1950s, and significant laboratory work was being done by the late 1960s. Around 1974, large Japanese construction companies apparently planned more extensive R&D activities leading to current levels of spending and laboratory-based research, which were achieved by the early 1980's. All this was unlike large U.S. construction firms that continued to do little, if any, R&D.

Japanese institutional support for R&D includes: (1) The Japanese Government funds feasibility studies giving initial entrance, intelligence, and influence affecting contract awards.[64] (~) Loan mechanisms from Japanese sources for financing projects in the United States often

64 The U.S. Government has a similar funding mechanism for overseas work, but not for domestic work.

specify that monies are available only with the choice of a Japanese construction firm and not otherwise. OTA was told that U.S. construction firms may enter into joint ventures with Japanese companies to participate in this advantage. (3) Japanese manufacturers have factories built in the United States by the Japanese construction firms they are allied with in Japan. (4) Japanese real estate investments in the United States are large and growing. When construction is planned as part of a real estate deal, Japanese construction firms may be used. (5) A Japanese banking mechanism has been established in the United States useful for handling construction financing. (6) Significant R&D capabilities located in Japan in large Japanese construction firms focus on specific technologies and applications with some undetermined amount of generic or basic R&D research being done by the Japanese Ministry of Construction. (7) Construction projects in Japan are used to develop technologies. U.S. construction firms are not permitted to participate in these projects. (8) Relationships developed in the United States are used to tap into U.S. technology advances, especially in advanced areas. (9) Subsidiaries and offices of at least five of the six largest Japanese construction firms are now located in the United States with "localization" or blending efforts by the Japanese companies--for example, Shimizu Construction Co., Ltd. now has offices in 13 cities across the United States. Some projects in the United States have been built by Japanese construction firms, probably drawing on several elements of this structure.

AMOUNTS. TYPES. AND STRATEGIES OF R&D

Data on private sector R&D expenditures by large American and Japanese construction companies, presented in chapter 4, indicate that company size does not explain why Japanese construction firms do significant amounts of R&D and American firms do not. Measured by dollar or dollar-equivalent value of contracts, six U.S. construction firms led the world in size among the firms doing over !$3 billion in total contract work in 1985. Each US. company did contract work valued at more than $5 billion. Six Japanese companies followed these U.S. firms in rank order of size, each doing between $4 to $5 billion in contract work. The gap between the largest U.S. company and the largest Japanese company in the lineup was S4 billion--considerable difference.

Each of the Japanese construction firms spent roughly 1 percent annually (amounting to an average of 8 billion yen, or about $34 million using the 1985 exchange rate) of its contract revenues and employed between 900 and 1,000 people in R&D work. Comparable data for the U.S. companies are incomplete. Moreover, it is uncertain exactly what R&D activities are included in the data available for either the Japanese or American companies. Nevertheless, OTA is certain that American firms spent smaller amounts and undertook less R&D than their Japanese counterparts.

American construction firms also appear to do far more "environmental scanning" than R&D--that is, they look for new or different technologies that others are already developing or using that they might also utilize, rather than creating their own new or different methods, machinery, materials, or components. Japanese construction firms also look at what others are doing; however, their greater emphasis on and expenditures for R&D for innovation appear to be parts of their market strategy.

INSTITUTIONALIZED R&D

It appears that the Japanese have institutionalized R&D by organizing and integrating operations of large construction firms in a manner that recognizes exactly what technologies to borrow and how to adapt them to construction. It appears that Japanese construction project managers can call for R&D support when they believe it can be useful, and R&D projects may originate from field experience. Design/build contracting arrangements are frequently used, facilitating some of the integrated work, and R&D appears to be connected to specific projects and applications even in large companies. Furthermore, construction projects are planned in a manner that identifies problems on which R&D should focus, often several years in advance. For example, it required at least 8 years to develop or refine technologies to stabilize the seabed for the new Kansai Airport in Osaka Bay. One firm undertook the necessary R&D with reasonable assurance it would receive contract for that portion of the job. The Japanese thus use domestic projects requiring R&D to develop both technologies and the labor skills to apply the technologies. Both are later marketed in competitions for other projects within Japan and in foreign countries.

The manner in which the Japanese have institutionalized R&D makes it eminently suitable for translating U.S. inventiveness into construction technologies--something U.S. companies are not doing and are not organized to do. Given the present institutional mechanisms, benefits for the construction industries originating from U.S. inventiveness may be captured more by Japanese companies than by U.S. companies.