

THE ROLE OF R&D IN CONSTRUCTION FIRMS

by

Satoshi Someya

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Signature of Author

Department of Civil Engineering
May 8, 1992

Certified by

Fred Moavenzadeh
Director, Center for Construction Research and Education
Thesis Supervisor

Accepted by

Ole S. Madsen
Departmental Committee on Graduate Studies

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ABSTRACT

For some years many researchers have been claiming that the U.S. construction industry is deteriorating in terms of its productivity and competitiveness. The U.S. design and construction industries which maintained a dominant position until the early 1970s no longer hold the dominant position in international construction markets. They are losing their competitiveness in both the international and domestic construction markets. Specific causes for this decline are not fully understood, but it is widely accepted that the deterioration of the industry's technology base is one of the major cause.

The objectives of this thesis are to analyze the problems that the U.S. construction industry has, and to discuss the importance of technological development, as well as research and development for the construction industry, and to investigate the underlying obstacles which prevent the industry from committing to research and development which eventually will result in the decline in its competitiveness. Then, the potential consequences derived from the differences between those two approaches towards research and development taken by U.S. firms and Japanese firms are analyzed. Comparisons with the automobile industry are also discussed to make the problems which the U.S. construction industry has clear, and to analyze possible solutions for the problems. Subsequently, the role of internal research and development for construction firms is discussed from a strategic point of view.

Through this research, it is found that research and development are essential for the U.S. construction industry, as well as for the entire nation. To prevent the U.S. construction industry from losing its competitiveness and market share, the construction industry should increase its commitment to R&D understanding the strategic benefits of R&D, and the U.S. government should find more effective ways to encourage industry level R&D.

Thesis Supervisor: Dr. Fred Moavenzadeh
Title: Professor of Civil Engineering

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Chapter I

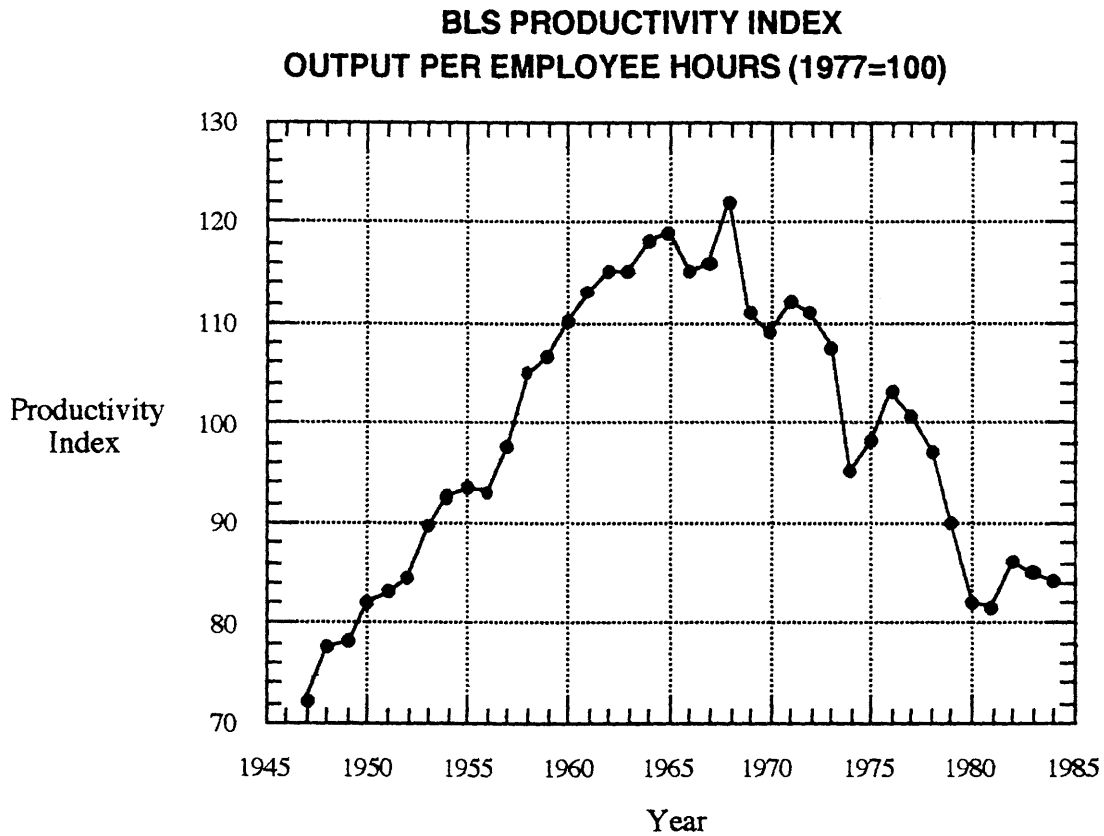
INTRODUCTION

Problem definition

Declining Productivity

For some years many researchers have been claiming that the U.S. construction industry is deteriorating in terms of its productivity and competitiveness. Although the definition of the productivity varies among researchers, Cremeans claims that the productivity of this largest industry in the United States has been going down at 1%-2% per year since the 1960s (Cremeans 1981). There are also lots of data which show the industry's productivity far from desirable. The Bureau of Labor Statistics has documented the alarming deterioration in productivity in the U.S. construction industry since 1969. Figure 1 shows the labor productivity index over time in output per employee hour conducted by Bureau of Labor Statistics. Although there are some fluctuation in the output, overall pattern clearly shows the declining productivity over the past 20 years. This trend seems startling when we consider the continuous improvement of productivity in other industry especially in automobile, electronics and pharmaceutical industry in conjunction with the rapid technological development not only in the construction industry but other industry. Specific causes of this decline are not fully understood but it is widely accepted that the deterioration of the industry's technology base is one of the major cause.

Figure 1.1 US Labor Productivity in Construction



(Source: Bureau of Labor Statistics)

Declining Competitiveness

Losing Market Share

The U.S. design and construction industries which maintained dominant position until the early 1970's no longer hold the dominant position in international construction market. They are rapidly losing their competitiveness in both the international and domestic construction markets due to increased cost and decreased productivity. The percentage of the dollar value of the foreign contracts awarded to U.S. contractors decreased from 38 percent in 1984 to 36 percent in 1990 while the percentage awarded to their European competitors increased from 38 percent to 43 percent and to their Japanese competitors from

9 percent to 14 percent in the same period. In the domestic market, foreign firms have been winning a growing share. According to an article in the Wall Street Journal (April 5, 1991), "foreign-owned firms (primarily from Japan and Europe) controlled 6 percent of U.S. building contracts in 1989, compared with about 2 percent in 1982." Although the percentages do not look quite large, given the size of the industry, these figures show quite serious problems the U.S. construction industry faces.

Losing Technological Leadership

Superior technology which U.S. construction firms possessed was the main driving force that had brought the dominant position in the international construction market until the early 1970s. Recently, however, corresponding to the losing market share the U.S. construction industry has been losing its technological leadership as well. Not only the construction industry but also other industries have been losing their technological advantage. Over the past six years, many studies have been conducted to investigate the U.S. position in technological field. In case of the construction industry, one of these studies published in 1987 by the Office of Technology Assessment (OTA) indicated that in the area of engineering and construction the U.S. is strong in data intensive technologies (OTA, 1987). However, most of the innovative technologies related to physical systems and methods of design and construction over the past 20 years are from Europe and more recently from Japan.

Objectives of this thesis

One of the main reasons why the U.S. construction industry has been losing its competitiveness in the international as well as domestic market is its relatively weak technological development due to several factors that will be discussed later. Among those factors, many researchers claim the lack of commitment of the U.S. construction industry on research and development, whether it is in-house or not, to maintain its competitiveness

and competes with foreign competitors that are spending much more portion of their revenues on research and development. Among those foreign competitors, the Japanese large engineering and construction firms have been heavily invest in research and development compared with the American counterparts. According to the National Research Council of the National Academy of Sciences and a Japanese Government R&D Survey for 1987, Japanese construction firms spent over \$800 million in R&D that year that was more than 15 times as much as their U.S. counterparts. Besides, the Japanese Ministry of Construction reports that the top 30 E&C contractors in Japan maintain their own research institutes and ten of them have more than 100 researchers each. The U.S., on the other hand, only five such firms have their own research institutes, each employing approximately six personnel. Although those researches are not always related to the improvement of productivity or competitiveness directly at least in a short term, it seems clear that while the U.S. construction industry continued to deteriorate in its productivity and lose its technological status against foreign competitors, both its competitiveness and market share would continue to decline. To keep up with the foreign competitors and regain its technological leadership, industry wide commitment to technological development and research and development would be essential.

The objective of this thesis is to understand the problems the U.S. construction industry has and to analyze the importance of technological development as well as research and development for the construction industry, and to investigate the underlying obstacles which prevent the industry from committing to research and development which eventually would result in the decline its competitiveness. Then the potential consequences derive from the differences between those two approaches toward research and development taken by U.S. firms and Japanese firms are analyzed, and the role of internal research and development for construction firms is discussed.

Chapter II

INITIAL SITUATION ANALYSIS

Global Trend

Importance of technology

Innovations can lead to successful projects, in terms of obtaining the work, reducing costs and satisfying the customers. Innovation is essentially a life force in the international marketplace. To maintain a vital industry in the U.S. we must be innovative¹

The management of technology is a current research interest in business and industrial engineering. In the past, technology was perceived as the means of improving operational efficiency that could reduce the cost of production and improve the productivity. These views of technology have been changing toward more strategic implication as a competitive advantage. This strategic implication of technology is especially apparent in manufacturing industry where technological innovation has been recognized as a major factor of success. Although, in many cases, construction itself

¹ Civil Engineering Research Foundation, *SETTING A NATIONAL RESEARCH AGENDA FOR THE CIVIL ENGINEERING PROFESSION*, August 1991

requires highly innovative technologies to successfully execute challenging projects, those technologies have not been generally perceived as the major contribution to competitive advantage. One of the reason is that most of those innovative technologies are project-driven or market-driven technologies which usually are not perceived as the means of creating new market opportunities. When the necessity arose, construction firms acquired those technologies on the project by project basis and made little effort and investment to improve those technologies.

However, those perceptions have been changing recently and many countries see technology development as a major factor to remain competitive in international design and construction markets. Among those, major Japanese engineering and construction (E&C) firms has been eagerly investing its capital and resources in their research and development to develop new technology or improve state-of-the-art technology. Those major Japanese firms are now perceiving technology from different point of view that is to see technology not only as the means of improving productivity or reducing costs but also increasingly as the means of creating new market opportunities. In this sense, U.S. design and construction firms and Japanese E&C firms are going two different ways in terms of their interpretation of the importance of technology.

Although it is difficult to determine which way is better without further investigation, the importance of technology would be unarguable. New technology will influence all aspects of design and construction. Evolution of traditional materials may change the way we design buildings and fabricate structures. It may change the way we construct facilities and could make unfeasible construction in the past feasible. As technology evolves customers' demand is also changing. It is increasingly clear that the pace of technological change is so rapid that virtually no industry can be remain effective and prosperous without improving its technological capability.

Importance of R&D

Historically, the design and construction industry has conducted limited formal research compared with the automotive, electronics or pharmaceutical industries where firms have been investing their capital and human resources eagerly into research and development. From the motivational point of view those industries are obliged to invest in research and development in a sense. It is clear for firms in those industry where the pace of technological development is rapid and product life cycle is continuously shortening that they cannot remain competitive unless they keep up with the state-of-the-art technology by committing to research and development.

The construction industry differs from those technology intensive industries in a fundamental way. First, most of the case in the construction industry, technology itself has not been perceived as the crucial factor of competitiveness because technology itself does not directly relate to the attractiveness of the products. Second, the product development cycle has been much longer than those industries and the life cycle of the products is also much longer than those industry. Third, products have been made based on the orders placed by customers. Finally, each product is one of a kind and there is little economies of scale except material suppliers or housing market. Those peculiarity of the construction industry will be discussed later in this chapter. Adding the uncertainty of the payoff which is the very nature of research and development, those characteristics are main causes which prevent the construction industry from conducting research and development and application of innovative technology.

However, this perception toward technology development and research and development is changing and design and construction firms especially in Europe and Japan are increasingly putting importance on technology development perceiving technology as a crucial factor of success and an important element of competitive advantage. As mentioned earlier, Japanese E&C firms are spending more than 15 times as much as their U.S.

counterparts. The Japanese ministry of Construction reports that the top 30 engineering/construction contractors in Japan maintain their own research institutes and ten of them have more than 100 researchers each. In a sense, they seem to be following the notion advocated by Japanese manufacturing industry which has accomplished tremendous success in the international marketplace; long-term success can only be achieved through long-term planning and the ability to fund future-oriented projects which don't require quick implementation immediate return². A good example is the automated building construction which every major Japanese E&C firms are proposing and continue their research and development effort. Among those Shimizu Corporation is now constructing a 20-story steel-frame office building in Nagoya which Shimizu implemented the automated construction floor system. Although it is far from fully automated construction, Shimizu is surely moving toward 21 century step by step. Regarding the U.S. construction industry, there are virtually no design and construction firms which has their own research institutes.

Recently, numerous comparison between U.S. and Europe and Japan have been conducted and many researchers in the United States have been alarming the industry's lack of commitment to research and development and advocating the necessity of industry wide change of the reluctant attitude toward research and development.

By neglecting research on the science and technology of buildings, other facilities, and their construction, we not only reduce sharply the chances that we will discover new ideas and develop new inventions before our competitors gain a crucial advantage, we also limit our abilities to accept and use those new ideas and inventions that are developed. Our future construction will then bring us many fewer benefits than it otherwise might, and we suffer as individuals and as a nation.³

² Bernstein, Harvey M., "Forget the bottom line; invest in R&D," *Construction Business Review*, January 1992.

³ Lemier, Andrew C., "Construction for the 21st Century," *Construction Business Review*, July/August 1991.

Global Competition

World economy has been moving toward borderless world. There are two large movement in the world economy; one is the trend toward globalization and the other is the trend toward regionalism. Former is represented by General Agreement on Tariffs and Trade (GATT) and its Uruguay Round-multilateral trade negotiation, and latter is represented by the movement of European Community (EC) toward the integration of European market. Along with the promotion of free trade, the improvement of transportation and the rapid progress of communication technology have made enterprises possible to construct international network. Electronics, automobile and financing industries are good examples. The movement of management resources by direct investment to overseas and become localized reduces the cost of gathering information about the business and market as well as the risk from uncertainty of the market, and also can hedge the risk arises from the change in currency exchange rate. This trend toward global localization have become increasingly important among manufacturing industry where trade friction became the serious issue. This trend would also be strengthen by the integration of EC community.

This trend toward global localization also exist in the construction industry among internationalized large engineering/construction firms. One of the main motivation toward globalization is off course to expand their market. Those large firms are eagerly seeking the opportunity to expand their market to keep their size. Since the overhead of those large firms is larger than small firms they have to maintain large market and sales. Given the cyclical nature of the construction industry, it is difficult to maintain their sales in only one country since they cannot export their products: constructed facilities. For example, the Japanese major E&C firms rapidly expand their business in overseas corresponding to the first oil crisis in 1973. In this period, domestic demand decreased seriously and they had to seek other opportunity to keep the size and employees. Aside from building materials, the construction industry is not the exporting industry in terms of its physical products and

there are different motivation for global localization. It is quite important for internationalized E&C firms to become localized because actual physical works are usually exclusively performed by local subcontractors and building codes are diverse geographically and customers are also fragmented. Therefore, communication between those subcontractors and customers or other specialists is extremely important, and this cannot be remotely controlled from distant head quarter.

Give those backgrounds, the U.S. construction industry is facing fierce competition with foreign counterparts especially with European and Japanese construction firms both in the domestic and international marketplace, and losing its competition in both marketplaces. Clearly, the construction industry is becoming international. Construction-related goods, services, and knowledge now travel with relative ease across national boundaries. Huge multi-national firms increasingly compete head-to-head in the global marketplace. By the evolution of information technology and communication technology and trend toward localization, it would become difficult to keep the geographical advantage. No firm can remain bystander. To remain competitive in domestic market as well as foreign market, the U.S. construction industry should become internationally competitive. To keep its competitiveness in the international marketplace, it is quite important to develop technological competitiveness by conducting industry wide research and development.

Industry Analysis

Structure

When we consider the structure of architecture-engineering-construction (AEC) industry, we notice that huge number of firms are involved in this industry even when we exclude material suppliers as manufacturing industry. According to the census of the U.S. construction industry, there are over 1,400,000 firms and among those firms over 930,000 have no employees and the remainder have an average of only ten employees. Designers

are also fragmented by specialty area. Although AEC industries in other countries are also highly fragmented compared with other manufacturing industry, the degree of fragmentation in the U.S. is incomparable where no single firm controls more than 2% of the total sales. For example, in Japan where AEC industry is also fragmented, there are about 510,000 firms in 1991 and 99% of them have less than 300 employees and capitalized at less than 720,000 U.S. dollars. Given the size of the market (Japan=\$590billion, U.S.=434.9billion in 1990), U.S. AEC industry is clearly more fragmented than Japanese counterpart. This fragmentation causes many problems that not only affect productivity and competitiveness of AEC industry but also affect the entire economy since constructed facilities account for over half of the capital investment of manufacturing industries, and more importantly they affect the infrastructure that is the foundation of the nation.

Fragmentation of AEC industry

Background

The U.S. architecture-engineering-construction (AEC) industry is highly fragmented compared with many of its Asian and European competitors. This fragmentation exists both vertical (from planning thorough design, engineering and construction into facility management and operation) and horizontal (between specialists within each phase of project phase). The essential notion of fragmented industry is the absence of market leaders who have the power to shape industry events and can strongly influence the industry outcome. There are several reasons for this fragmentation. Michael Porter described principle reasons for fragmentation as follows⁴:

- Low Overall Entry Barriers.
- Absence of Economies of Scale or Experience Curve.
- High Transportation Costs.

⁴ Porter, Michael E., *Competitive Strategy*, 1980

- High Inventory Costs or Erratic Sales Fluctuations.
- No Advantages of Size in Dealing with Buyers or Suppliers.
- Diseconomies of Scale in Some Important Aspect.
- Diverse Market Needs.
- High Product Differentiation, Particularly if Based on Image.
- Exit Barriers.
- Local Regulation.
- Government Prohibition of Concentration.
- Newness.

Although all of these are not applicable to the construction industry, followings are quite well fit to the characteristics of this industry.

Low Overall Entry Barriers. Nearly all of fragmented industries have low overall entry barriers and AEC industry is no exception. For example, only one person may be enough to start design business and only a few people are essential to start construction business by subcontracting and a small number of skilled workers are enough to become subcontractor such as plumbers and plasterer.

Absence of Economies of Scale or Experience Curve. Most fragmented industries are characterized by the significant absence of economies of scale and learning curve in any major aspect of the business. Although there exist economies of scale to some extent in some segment of the construction industry such as prefabricated housing, on the most part there are little economies of scale. This absence of economies of scale derives from the characteristics of the products of the industry. Unlike manufacturing industry, every product of the construction industry is unique in terms of its design, size and materials used. Besides, every facility is built on the site not in a factory. These peculiarities prevent the construction industry from achieving economies of scale. Learning curve does exist in the construction industry. However, the slope is quite gentle and each specialist usually takes years to become effective because even though each process of construction is nearly

identical, since each project is unique every time somehow, like producing prototype, modification of the process is inevitable, consequently there is no completely repeating work between two different projects. Since the effects of learning curve are limited in terms of project cost, it is difficult to achieve significant advantage from the learning curve effect in cost intensive environment like conventional construction market.

High Transportation Costs. Since construction is executed on site and the products are huge, it is impossible to transport the products from remote location. Furthermore, construction machines are also large and the transportation of those machines is costly.

Diseconomies of Scale in Some Important Aspect. In the environment like construction market in the United States where lower cost is the crucial to success, to maintain low overhead is quite important and this factor can favor the small firms. This is quite important factor that prevents firms to merge into large firms in the US construction industry.

Local Regulation. There are quite a few different local regulations and codes throughout the United States. Those regulations have favored the local firms and made geographically integrated operations difficult.

Problems Arise from Fragmentation

The U.S. construction industry has experienced various problems arose mainly from fragmentation that affect productivity and competitiveness throughout the AEC industry. The most serious problem is the inefficiency of decision making which produces tremendous costs on projects. Since projects especially large ones are executed by many specialists both through the project phases and within each phase, effective communications between each phase as well as each specialist and management, and effective management of entire projects becomes quite difficult and there are much waste in terms of time and money and human resources.

Construction and Technology

Introduction

Although construction itself requires various kinds of technologies which include highly advanced ones, the construction industry as a whole has not been perceived as a high-tech industry. One reason for this is that the technological change in the construction industry has been rather gradual compared with manufacturing industries such as automobile and electronics industry. Since no project is identical and each project requires somehow different technology and process to execute, it is as if developing a new product every time new project takes place and every participant who involves in the project has to be creative and innovative in a sense. However, most construction projects do not usually use state-of-the-art technologies and rely mostly on conventional technologies and methods that are well known and proven effective through long time and frequent usage. Besides, most of the innovations occurring in construction are incremental change based on proven technologies. The other reason is the project-orientedness of the construction industry which is indicated by Tatum (1987)⁵. He stated that "project demands force many innovations." The construction industry is not a technology-driven industry such as electronics, chemical, and bio industry that originally derived from scientific or technological discoveries. In the construction industry, technologies have been basically developed and applied as the means of executing each project. When specific problems arise in a project, people seek appropriate technologies and methods and if they cannot find suitable ones, they try to modify available technology or methods so that they can use those to perform their work or they try to find out the new method to solve their specific problems. This passive attitude toward technology makes the construction industry being perceived as non-innovative or low-tech industry.

⁵ Tatum, C.B., "Innovation on the Construction Project: A Process View" Project Management Journal, Vol. 18, No.5, December 1987.

Technology Development in Construction Industry

In the past 100 years, construction technology has achieved tremendous advance both in building materials and building structures. Although the pace of technical change has been slow, technological changes and innovations have been continuously taking place in this industry. Project-orientedness previously mentioned is one of the unique and important nature of the construction industry to be considered. Because of this nature of this industry, technological development has been taking place as the project-oriented fashion that is to say: "Necessity is the mother of invention." This notion is most applicable to construction process innovation. As long as construction can be carried out safely and bring considerable amount of profit by conventional process, there is little incentive to innovate the processes which several involve risks. When it turns out to be impossible or difficult to achieve this goal, necessity of innovation arises and people will try to solve the specific problem by modifying conventional methods or creating new methods gathering information from those who have similar experience or by contracting another firm or consultant. The important thing to consider is that many of those innovations are project specific and not applicable to every project directly in many cases because of the one-of-a-kind nature of construction projects and not intentionally developed for future use. Furthermore, firms in the construction industry are not used to formalize those innovative knowledge and technology that are generated in each project from specific needs. As the result, in many cases, those knowledge are stored as the individuals' knowledge or know-how and make systematic development of innovation difficult.

Concerning the materials, pace of innovation has been faster than process innovation and most of the case innovations occur from supplier side. As science and technology develop, numerous kinds of new materials have been developed and many of those new materials can be applied to construction aside from economic feasibility. Material suppliers have enough incentives to seek and develop prospective new materials from the

economic point of view. The size of the construction market is so big that the expected future profit is enormous if widely usable materials are developed.

Given those background, both in Europe and United States, high proportion of construction research is state funded and performed in universities and research institutes. The private sector makes little investment. As the result, European and American construction industries including contractors and designers have chosen to compete with each other not on the basis of superiority of technology but on the price. In both Europe and the United States, results of construction research are openly published in journals and are freely available to everyone. Researchers have a personal incentive to contribute to international knowledge by publishing their results and construction research is rarely considered proprietary and subject to commercial confidentiality. This is very different in Japan where construction related researches are concentrated in industry rather than in university or research institutes. Increasingly, major Japanese engineering and construction (E&C) firms are shifting their perception of technology from project-oriented one to market-oriented one. This different situation in the Japanese construction industry will be discussed in chapter IV.

Source of Technology

As noted above, in both Europe and United States, large proportion of construction related research is state funded and performed in universities and research institutes and freely available to everyone through various media such as professional journals and conferences. Since construction requires wide range of expertise, it is almost impossible to own every necessary knowledge and technology internally, those knowledge and technologies are widely spread among various participants in construction. Generally, construction firms rely on the following sources to acquire technology and knowledge: publication, universities, research institutions, consultants, conferences, acquisition of firms, joint venture, alliances, licensing, subcontractors, suppliers and internal research

and development. Among those, portion of internal R&D is little if any in the U.S. construction industry since virtually no construction firm is conducting formal research and development internally in the United States. Strategic implication of internal research and development is the main issue of this thesis and will be discussed in chapter V.

Future Prospects of Technology Development

Information Technology

Information technology (IT) is the current hottest issue in every industry. IT has a tremendous potential to improve productivity and quality, and even it can change the structure of industry itself.

Information technology has important general-purpose power to manipulate symbols used in all classes of work, and therefore, as an "information engine," it can do for business what the steam engine did in the days of the Industrial Revolution. It goes beyond this, however, as a technology that permits one to manipulate models of reality, to step back one pace from the physical reality. Such an ability lies at the heart of IT's capability to alter work fundamentally.⁶

The construction industry is sometimes regarded like an information industry. One reason for this is the lack of standardization in information processing compared with manufacturing industry. Construction projects themselves progress according to somehow normalized procedures but people who are engaged in production process and the dealing information are vary from project to project basis and varieties of information processings are required. The other reason is that, in construction, there always be preceding information and investigation, understanding, evaluation, selection, processing and transmissions of those information have crucial effects on succeeding production processes. Those preceding information vary from project to project and there are quite a few unpredictable factors. Therefore, it is necessary to gather and properly process new

⁶ Norton, Michael S. S., *The Corporation of the 1990s*, 1991

information each time. The quality of preceding information and the following information processing has significant impact on productivity, quality and cost of each project. Firms who involve in construction projects are first required to deal with those uncertain information and then producing their products by conducting variety of information processing and negotiation throughout various phases of construction. Those characteristics make the construction industry like information industry.

There is another important characteristic of this industry in terms of its information flow. The main media of information in the construction industry are people and inter communication between those people is fundamental of construction. The amount of information and the complexity of information have been increasing rapidly along with the evolution of whole society and optimal processing of the abundant information is increasingly difficult. Considering the information intensive nature of the construction industry, improvement of information processing which supports the construction activity itself is crucial not only for each firm but also for entire industry.

Information technology has a potential to overcome the inefficiency caused by fragmentation of AEC industry by building information linkage between those fragmented segments. One of the most important advantage of information linkage is the vertical integration of data, design decisions and knowledge through all phases of facility development to improve the efficiency and quality of design and construction, so that facilities can better meet the cost, schedule, and technical performance objectives of their users. At the same time, enhanced integration and automation of decision making in all phases of the process can create a machine-readable and machine-usable knowledge environment in which automation of the physical construction processes can be achieved more easily. Thus, inter-corporate information linkage, once it is achieved effectively, could improve the productivity of the construction industry and could reduce the cost of construction and design which would be beneficial for both designer, contractor and owner. It could also improve the quality of constructed facility and manageability of the

facility. Combing the advantage of vertical integration, it could largely diminish the inefficiency of fragmentation of the construction industry preserving the flexibility.

Computer Integrated Construction

In construction management field computers have been used primarily as the means of improving the process of office work. As the result, the main usage of computers at construction sites are still for office work such as accounting and cost management, and computers have not been widely used as the tools for construction planning and construction management.

As the price of personal computer has been fallen down, installation of personal computers to construction sites has been increasing rapidly. However, most of those software which are used at construction sites are relatively small systems or commercial software and they have not devoted to the computer integrated construction management yet. Although recent development of computer science and software development made it plausible to computerize many of construction management work such as construction planning, scheduling and human resource management, there still be plenty of problems to be solved technically and those tools are not perceived as truly productive and helpful ones for construction management especially in case of small and medium size of projects. The obstacles which prevent computer integrated construction management are as follows.

1. Immaturity of computer technology both on hardware and software.
2. Inefficiency to input large amount of data to achieve intended results.
3. Difficulty of sharing and transferring data between different software.
4. Difficulty of common system which is suitable for every manager because of the lack of common schema for planning and management and the different way of project planning and management or variety of procedure.

The benefit of computerization of construction management is optimization of construction as well as economization of management. Optimization of construction is the

primary goal for management. Therefore, if the computerization can help the optimization of the construction management and construction process, the adoption of computers as the management tool would rapidly diffuse.

In manufacturing industry, production has been going toward automation and reduction of direct labor and rationalization of indirect operations such as sales and financial division. To embody those objectives, CIM (Computer-Integrated-Manufacturing) has been developed and aside from the degree of integration, most of the firms from giant manufacturers to small ones have been trying to apply it and have been achieving great success in certain industry such as electronics and automobile industry.

In the construction industry, however, the notion of CIM cannot be applied directly because of the several fundamental differences from manufacturing industry. First, production process from project planning to construction is divided into several specialties: project planning, design, engineering, construction, and maintenance. Second, nearly all of the products are custom-made and site specific. Third, production conditions and complexity vary from project to project because of on-the-site production derived from the immobility of the products and the necessity to be specifically suitable for each site. Fourth, components to handle are relatively bulky and heavy. Fifth, it relies most of the necessary materials on suppliers and subcontractors. Therefore, in construction, this notion is being applied as a CIC (Computer-Integrated-Construction) which put importance on site automation as well as the integration of production information between interfaces in each specialized production phase.

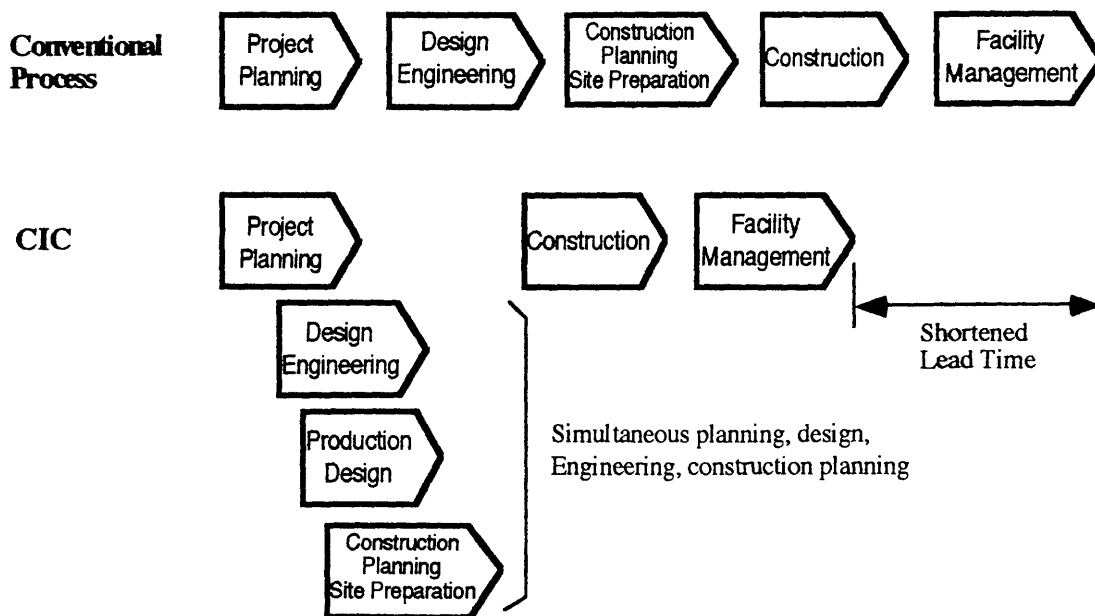
The notion of CIC is becoming popular to solve the various problems the construction industry is facing. Recent trend toward CIC is to tackle this issue from the point of view that put importance on the issue of management of information throughout production process rather than automation of each production process itself, and automation of production process is considered as a part of CIC. In the present construction process, transmission of data between each construction phase as well as

within the phase rely heavily on human, and the concept of CIC is to integrate and manage those information flow more effectively using computers. There seem to be four main objectives of CIC:

1. Effective and quick proposal to customers that well reflects the design and technological capability and the customer needs.
2. Rationalization of design, engineering and construction through the integration of production and information.
3. To shorten the development cycle and improve the efficiency
4. To enable effective strategic management which can respond quickly to the change in external environment.

As the result of effective use of CIC, there are tremendous possibility for the construction industry such as improvement of quality, reduction of cost, increase of flexibility in production system and shortening of lead time before construction by simultaneous progress of design, engineering and construction planning (See Figure 2-1).

Figure 2.1: Conventional Process, CIC Comparison



Two approaches toward CIC from both hardware and software are going on presently in building construction research. On the hardware side, application of automation technology such as CAD/CAM (Computer-Aided-Design/Computer-Aided-Manufacturing) is being applied. On the software side, application of information technology and planning and management technology which utilize the information about design, engineering and construction through communication network and database management systems is taking place. Among the software side, there are two movements toward integration: one is to enrich each application in each construction phase or specialty and integrate those applications, the other is to integrate production functionality using unification of database systems as a core. Followings show the current trend toward CIC.

1. Application of CAD/CAM on pre-cast concrete production and reinforcing bars and forms work.
2. Integration of systems' function such as computer-aided engineering system and total construction management support system
3. Exchange of data and information about design and production between designers, engineers, contractors, subcontractors, material suppliers and vendors.
4. Integrated database (use of upstream information in down stream)

To realize CIC, it would be necessary to establish flexible production system which could deal with the variety of needs based on the intellectual activity of human along with the normalization and standardization from both hardware side and software side. CIC would promote the formation of new open systems which correspond to the highly information-oriented global trend. CIC would also bring the change in functional division between planners, designers, contractors, subcontractors, suppliers and vendors.

Computer-aided design and engineering

Computer-Aided-Design (CAD) and Computer-Aided-Engineering (CAE) are rapidly becoming popular and useful tool along with the development of software and

hardware as well as the tendency to become increasingly advanced and complex design and engineering. In the near future, it would become impossible to do those tasks without computer. Most of the current CAD systems are based on the two-dimensional drafting type systems and little help for integrated construction. However, quite a few research are going on to make three-dimensional CAD system which can make it possible to share data electrically between different phases of project from planning through facility management and capture the image more intuitively so that even people who have little knowledge about construction could understand the presented finished products visually. It also prevents each specialist from possible errors because the errors are immediately reflected to the final image. Therefore, the use of three-dimensional design would tremendously contribute to the improvement of the design, engineering and construction process.

Knowledge-based project planning and management systems

In the project planning and management field, learning curve is quite gentle and usually it takes quite a few years to become expert in this field. One reason is that managers have to deal with various kinds of subject such as scheduling, site planning, safety control, quality control, cost management, procurement, negotiation with customers, subcontractors and suppliers, etc. They usually gain knowledge about those subjects from variety of sources and experiences. Among those, experience is quite important for managers to develop the ability to deal with the various kinds of unpredictable problems which usually occur in the construction process and respond correctly to those problems. The most important benefit of knowledge-based project planning and management in conjunction with the development of computer technology would be the shortening of learning time. To develop truly useful knowledge-based project planning and management systems, it is necessary to solve the problem which the construction industry has internally. That is the lack of formalized knowledge. This lack of formalized knowledge in the construction

industry is analyzed by Brach⁷. She argued that the knowledge in construction is "contextual knowledge" that is so tied to the context(s) in which it is learned that it is difficult to apply in wholly new contexts and it is difficult to transmit to people who have not experienced the same contexts. Therefore, further research efforts to formalize and conceptualize the knowledge in construction would be necessary to develop truly useful knowledge-based project planning and management systems.

Artificial intelligence

Artificial Intelligence (AI) is the current hottest issue in computer science field and numerous researches are going on in many universities and research institutes. Although there seems to be a long way for AI to become truly applicable to industry field, it has been gradually applied to some industry like electronics industry. For the construction industry, AI would be one of the key technologies for CIC. Combining electronics with mechatronics and sensor technologies, artificial intelligence is expected to handle wide variety of work such as selection of construction methods and project planning as well as to do highly complicated control on automated equipment and robots.

It would be necessary to incorporate AI into CIC in conjunction with database management systems, object-oriented modeling applications, real-time simulation systems and three dimensional CAD/CAM systems which integrate design, engineering, and construction information.

Graphic and non-graphic databases

Database management systems are the fundamentals of information technology and CIC. Once properly established, database management systems can be used throughout every project phase from planning through facility management in conjunction with other systems such as CAD/CAM. For example, project data produced in the design phase can be

⁷ Brach, Ann M., "Contextual Knowledge and the Diffusion of Technology in Construction," 1991

accessed from construction sites, subcontractors, suppliers and vendors and used and additional data are added by each specialist and sent to construction sites and used for construction planning, scheduling and cost management. Some data would be used for controlling automation system. Site data can be accessed from headquarters of through communication network and stored and used for centralized management and further implementation of the systems or after service. To optimize the usage of database management systems, normalization of the data throughout the construction industry would be necessary.

Robotics

Brilliant success of industrial robots in manufacturing industries such as electronics and automobile industry inspired the introduction of robotics to the construction industry. Those robots in electronics and automobile industry have played quite important role for solving the labor shortage problems, improving the productivity, improving the workers' safety, and product variation. In the construction industry, robots were introduced in heavy construction area where there more merits against manual labor exist compared with building construction, and various kinds of automated earth moving equipment such as tunneling moles and laser-guided graders have been commercially successful.

Followings are the main incentives for using robots in the construction industry.

1. To free human workers from risky and heavy tasks, protect human workers from exposure to hazardous environment, and improve the working condition.
2. To solve the labor shortage problem.
3. Cost reduction, productivity and quality improvement.

Certainly, as many construction works are performed outside, those works are weather sensitive and noise and vibration sometime cause physical problems on workers. Materials they handle are relatively large and heavy. Therefore; it is necessary to introduce

robots which can perform those risky and heavy tasks on behalf of human workers and improve the working condition.

The number of young workers coming in the construction industry has been decreasing and shortage of labors is becoming problem especially among the types of job which involve risk and heavy work. As the result, aging of workforce and decrease in technical level has been happening, and keeping production volume may become difficult. Therefore, robots are expected as a mean of reducing the portion of human labor and required skill as well as keeping and improving quality of construction.

Although it usually takes time for innovative technology to be widely accepted and applied, the development and application of robots in the construction industry seem to be relatively slow compared with manufacturing industry because of several reasons. Those reasons can be divided into two categories: technological factors and managerial factors. First, as a technological factor, insufficient performance of robots which comes from the immaturity of elemental technology which satisfy the requirement of construction work can be pointed out. Second, as a managerial factor, low utilization rate, high cost, complicated and troublesome operation and management, and a passive attitude toward practical usage could be pointed out.

To promote the application of robots in construction, first it is essential to improve the performance of robots. Since following conditions should be satisfied for construction robots, they have to be more technologically sophisticated than ordinary industrial robots.

1. Flexibility and compatibility for dealing with various complex conditions
2. Mobility and transportability
3. Solidity and Durability against shock, water, dust, etc.
4. Ability to handle bulky and heavy materials
5. Safety measures and reliability when working with human workers
6. Ease of operation and judgment
7. Ease of maintenance and repair

Especially, to develop robots to substitute the function of skilled workers who can perform their job making proper judgment against and dealing effectively with the circumstances that design varies from project to project and working conditions and environment are always changing, highly sophisticated and advanced elemental technology is necessary. To fulfill those requirements, leaning ability and judging ability would be most important, and then self mobility and accommodation of visual, auditory and touch sensor would also be important. To develop those highly intelligent robots and introduce to construction, compound and cooperative research in the field of mechanical engineering, electronics, bioengineering, cognitive science, computer science and civil engineering would be essential.

Second important issue to be considered is the establishment of the system to support the operation and utilization of robots in conjunction with the technological development of robot to accomplish cost reduction and productivity improvement. It would be necessary to reorganize entire construction process from design, engineering through construction management as a production process that is more suitable for robotics. To establish the production system suitable for robots, reexamination of every element of production and research and development of technologies which optimize the overall construction process. Followings are the issues to be examined and solved.

1. Design and engineering which take constructibility into consideration and the feedback from contractors to support the design and engineering.
2. Normalization and conceptualization of construction process
3. Establishment of design and design method of the robotized construction system
4. Planning and management of computer support systems which support the application of robots and on site operation.
5. Allocation of function between human workers and robots based on the analysis of qualitative aspect of construction work and human factor and education of workers.
6. Establishment of maintenance system

7. Technological measures and reexamination of law and regulation to keep safety and reliability.

Automated construction system

Automated construction system would be the ultimate style of rationalized construction system which requires broad range of technologies and process engineering. To improve the productivity dramatically, automation by individual robots has limitation and the necessity to establish the total system including design, engineering and construction which could enable automated construction arose. In this category, Japanese E&C firms are well ahead in terms of the development of the system. Major Japanese E&C firms are eagerly conducting research and development in this area and published their conceptual model of automated construction systems. Among those, Shimizu Corporation, the leading Japanese E&C firm, is now constructing a 20-story steel-frame office building in Nagoya, Japan using an automated construction floor system. This system automates many construction processes by using prefabricated components. Although this system is primitive in terms of the ratio of automated process in entire construction process, it is surely the progress of construction technology and will bring tremendous impact on the construction industry. To realize this system, further development of CAD/CAM system and management technology which makes full use of knowledge engineering, development of database systems and communication network, development and diffusion of intelligent construction robots and automated equipment, and reorganization of production process and project organization would be necessary to proceed simultaneously.

There are two possible directions to develop automated construction system. One is to advance automation at the construction level based on the industrialized and systematized construction methods. Advantage of this approach would be the relatively short development time compared with the other approach. Drawback of this approach is the limitation of the applicable projects for each system. The other is to advance automation

based on the conventional construction methods, that is to use different functional robots and automated equipment in combination depends on the project. This system would be able to be applied to broader range of projects, but the degree of automation might be limited to operational level. In either direction, unlike factory automation which aims to unmanned operation, automated construction system would likely to be developed toward cooperation work with human workers.

Innovation of Materials

Quite a few kinds of materials are used in construction. Various kinds of new materials have been developed and begun to be used in the construction industry such as carbon fiber, aramid fiber, ceramics, new type of paint, new metals which have high durability and strength, etc. There are two ways of innovation of material in construction. One is the innovation correspond to the requirement from design, structural engineering and construction method. This kind of innovation often appears as the result of development effort to overcome the weak point or improve the quality of currently used materials. The other is the independent innovation of materials. Generally, construction materials are relatively cheap and widely being distributed and available. However, if we ignore the current price, we can find new materials which are not presently used for construction. Aside from construction, technological progress in this area is quite rapid and there would be potential materials among those. There are possibilities that new materials would change the construction process or structure itself like steel did in the past.

Research and Development in Construction Industry

Construction Industry and R&D

Historically, the design and construction industry have conducted limited formal research, unlike the automotive, electronics and pharmaceutical industries. Although construction related research and development is active and well advanced in university or institutional level in the United States, private construction sectors are investing little on research and development compared with other industries as well as foreign competitors. The National Research Council's Building Research Board (BRB) estimated the aggregate R&D expenditure by U.S. design and construction industries to be roughly \$1.2 billion in 1984 that was 0.4 percent of sales in the industry. Although this figure might not be accurate, it can be said that the design and construction are spending less than other mature industries such as automotive, electronics, appliances where R&D expenditures are more than 1 percent. Recent study by Business Week⁸ does not even show the design and construction industry on the comparison table. According to the survey, industries such as automotive, electronics and appliances are spending 3.7, 5.3 and 1.6 percent on R&D respectively. Compared with the construction industry in other countries, the R&D 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 spending in the United States at well below half the rate in Japan, and just over 20 percent of the spending rates in Sweden and Denmark, the nations seemingly most committed to building research. Among the leading industrialized nations, only Germany seems to spend at a lower rate for building research⁹. Since the construction industry has not been technology intensive so far, this difference might not immediately affect the competitiveness of the industry. However in the long run, considering the rapid

⁸ Business Week: R&D Statistics (1991 Bonus Issue), Data: Standard & Poor's Compustat Services Inc.

⁹ Lemer, Andrew C., "Construction for the 21st Century," *Construction Business Review*, July/August 1991.

technological change in other industries as well as the recent trend toward increasingly sophisticated and complex demand toward construction, this could make a great difference on the competitiveness of the industry.

Given the importance of technology and research and development for the construction industry as well as for the entire nation as discussed in chapter I, this reluctant attitude of the construction industry toward research and development might cause serious problems in the future. The construction industry has already been experiencing the continuous decline in productivity and international competitiveness and many researchers have claimed that the main reason for this trend is due to the lack of commitment to research and development by the industry. Many researchers also claim that the other important reason is the inefficiency of technology transfer between basic research conducted in university or research institutions and the private sector.

Basic Research and Practical Development

As mentioned above, although construction related research is active and well advanced in the United States, much new knowledge is generated in research centers and universities, not in the private sector. Those new knowledge and inventions generated in research centers and universities can lead to improved productivity, better quality only when these new ideas are put into practice. Since these researches are usually basic researches, some of the technologies and ideas yielded by these researches may be directly applicable to practical construction projects, but most of these especially technologies relating to physical systems and methods require further development efforts in the practical field to become commercially usable and effective.

One of the studies published in 1987 by the Office of Technology Assessment (OTA) indicated that in the area of engineering and construction the U.S. is strong in data intensive technologies (OTA, 1987). However, most of the innovative technology that has shaped physical systems and methods of design and construction over the past 20 years has

its roots in Europe and more recently Japan.¹⁰ Engineering and construction management is related to data intensive technologies and construction methods, equipment and materials are related to latter category of technologies. This finding strikingly corresponds to the declining tendency of productivity since the late 1960's (See Chapter 1, Figure 1-1). Since those technologies related to physical systems and methods directly affect the performance of the projects, it seems not far from reality to assume that there is a strong correlation between the declining productivity and declining competitiveness on the technologies related to physical systems and methods.

Japanese E&C firms on the contrary have been achieving success in developing innovative construction products and processes. The Japanese firms seem to be quite good at transferring new technologies and methods into practice whether they are discovered internally or not. One of the fundamental difference between U.S. construction firms and the Japanese construction firms is their degree of commitment to research and development. According to the National Research Council of the National Academy of Sciences and a Japanese Government R&D Survey for 1987, Japanese construction firms spent over \$800 million in R&D that year, spending more than 15 times as much as their U.S. counterparts. Meanwhile, the ratio of the investment in construction to the gross national product in Japan is 18 versus only 8.5 for the U.S.¹¹ Besides, every major Japanese E&C firm has its own research and development institutes and the large number of researchers.

These findings also suggest the importance of the commitment to research and development by the private sector to smoothly transfer research results into practice. Since it is quite important for the new technologies and methods to be tested in the practical field to become truly useful ones, the lack of those systems that can effectively transfer

¹⁰ Halpin, Daniel W., "The International Challenge in Design and Construction," *Construction Business Review*, January/February 1992.

¹¹ Bernstein, Harvey M., "Forget the Bottom Line; Invest in R&D," *Construction Business Review*, January 1992.

technologies and knowledge from basic research into practice in the United States is the serious disadvantage.

Obstacles to R&D

When we consider the importance of research and development and innovation for the construction industry as well as for entire nation, it is quite important to identify and analyze the obstacles that prevent the construction industry from committing research and development and innovation. Many researchers have pointed out the followings as obstacles: uncertainty of the payoff, risk evasion, short time horizon, government policy and regulation, and cost based bidding system.

Uncertainty of the Payoff

Probably the most challenging obstacle for research and development would be the uncertainty of the payoff that is inherent to the innovation.

One reason for not spending on research is that one cannot know in advance what the payoffs are likely to be. This is true especially if the research is aimed at improving aspects of building performance such as comfort or appeal to potential buyers, that are themselves subjective or otherwise difficult to describe. Would-be researchers often have a tough time competing for funding when they have to show how their work contributes to bottom line profits or, in public agencies, when their programs are compared to other ways of using scarce tax dollars¹².

Most economists agree to distinguish two types of uncertainty: *measurable uncertainty* and *unmeasurable uncertainty*.¹³ The first type of uncertainty can be calculated by statistical probability and thus less risky although there still remain uncertainty. The second type of uncertainty usually cannot be calculated statistically and

¹² Lemer, Andrew C., "Construction for the 21st Century," *Construction Business Review*, July/August 1991.

¹³ Knight F. H. (1965), "*Risk, Uncertainty and Profit*"

thus more risky. Technological innovation is usually classified with the second category. Among those technological innovations some innovations are recognized less uncertain than others. Freeman classified degree of uncertainty associated with various types of innovation into 6 categories (Table 2.1).¹⁴

Table 2.1 Degree of Uncertainty Associated with Various Types of Innovation

1 True uncertainty	fundamental research fundamental invention
2 Very high degree of uncertainty	radical product innovations radical process innovations outside firm
3 High degree of uncertainty	major product innovations radical process innovations in own establishment of system
4 Moderate uncertainty	new 'generations' of established products
5 Little uncertainty	licensed innovation imitation of product innovation modification of products and processes early adoption of established process
6 Very little uncertainty	new 'model' product differentiation agency for established product innovation late adoption of established process innovation in own establishments

He also pointed out that even in the lowest category of uncertainty very small portion of R&D is financed directly by the capital market and internally generated cash flow predominates. Given those uncertainties of the innovation, most of the firms are not willing to invest in research and development especially when they are categorized in the higher uncertainty level.

¹⁴ Christopher Freeman, *"The Economics of Industrial Innovation (second Edition)"*

It will be argued that the nature of the uncertainty associated with innovation is such that most firms have a powerful incentive most of the time not to undertake the more radical type of product innovation and to concentrate their industrial R&D on defensive, imitative innovations, product differentiation and process innovation. ... Product innovation involves both technical and market uncertainty. Process innovation may involve only technical uncertainty if it is for in-house application, and, as Hollander has pointed out, this can be minimal for minor technical improvements.¹⁵

Along with the one-of-a-kind and custom-made nature of construction, the effect of uncertainty of the payoff to the reluctant attitude of management toward research and development seems to be even greater in the construction industry.

Risk Evasion

Perhaps the most challenging problem that prevents the construction industry from development of new technology and innovation is the possible risks to workers as well as users from trying to apply new technologies or ideas to practical construction. Designers, owners, and construction firms are understandably reluctant to try new technology that may lead to expensive litigation if an accident occurs or the technology fails to perform adequately during construction as well as after the completion. Besides, built facilities are not merely commodities which individuals own but public assets and production cost of each facility is much higher than commodities and product life cycles are much longer than them. Those factors make management obliged to be cautious to apply new methods or technologies to practice.

¹⁵ Christopher Freeman, *"The Economics of Industrial Innovation (second Edition)"*

Short Time Horizon

Seeking short-term profit

Most people agree that, in general, there is a tendency for American business to be preoccupied with short-term results. One reason for this short-sightedness is frequently asserted to come from investors and financial institutions that are driven by short-term expectations and require short-term return on investment and have little interest in, or understanding of, the long-term vision or needs of the firms they invest in. Another reason would be the higher cost of capital which pushes U.S. firms irresistible in the direction of a shorter time horizon. As the result, managers in U.S. firms tend to focus heavily on short-term financial objectives and unwilling to invest in research and development which does not show any sign of bringing immediate profits to the company or its shareholders.

Project-oriented nature of the industry

Short time horizon of the construction industry also comes from the project-oriented nature of the industry. As noted earlier, for designers and contractors, technologies have been mainly perceived as the means of executing each project fulfilling each project specific requirement. Therefore, as long as they can solve those project specific problems by using conventional methods and technologies or employing external sources, they do not have to conduct any research and development internally. Most of the technological information and information about construction process can be acquired through various kinds of sources such as technical journals, conferences, magazines, consultants and informal sources such as personal contact with people within or outside own company. Designers and contractors try to solve specific problems and optimize the performance of their projects by gathering the available information and somehow modifying them so that they fit to the specific situation of the projects. Even when the necessity to develop some innovative methods or technologies for the projects arise, they rarely try to use those data and knowledge acquired during the development process for the further development. The

completion of the project is usually the completion of the development. Besides, many of those project specific methods and processes are not directly applicable to other projects. Those factors also make management reluctant to invest in research and development.

Fragmentation

As mentioned earlier, the construction industry especially in the U.S. is highly fragmented both vertically and horizontally and the majority of firms are highly specialized small or medium-sized firms which are ill-equipped and have weak financial base. Although small firms may have some advantage over larger firms because of their relative flexibility and speed of reaction, generally speaking, larger firms have advantage over small firms in terms of research and development because even though larger firms invest smaller portion of their revenue in research and development, the amount of the capital is likely to be larger than small firms in absolute term. Besides, the number of researchers available is also larger than the small firms. The advantages of large firms become even greater when the costs of R&D become higher. "It is essential to realize that the higher the development and associated innovation costs, the greater the advantage to larger scale producer.⁶" "The development, design and test costs are very high for new generations of equipment and they are absolute threshold, which must be met by any firm which wishes to compete, irrespective of its sales volume.¹⁶"

Cost-based Bidding System

Although the traditional design-bid-construct approach contributes to the lowest cost construction at least in theory, it has often caused many problems such as the long delays which lead to increase in overall costs, adversarial relationship between owners, designers and contractors or decline in quality and reliability. Given those drawbacks, alternative project delivery methods such as turnkey construction and BOT (Build-Operate-

¹⁶ Christopher Freeman, *"The Economics of Industrial Innovation (Second Edition) "*

Transfer) are gradually increasing. However, majorities of construction are still carried out by traditional method. To compete on price firms have traditionally tried to reduce every possible cost associated with the projects and have been reluctant to use new methods or technologies which increase the costs in that projects even though the new methods or technologies might bring the firms benefit in the future. Since research and development would increase the overhead costs and rarely bring visible profits to each project, the management especially in small firms where the increase in R&D would largely affect the overhead costs is likely to become reluctant to invest in R&D.

Government and Social Environment

Another important factor to consider is the role of government. Under the current system, the U.S. government is not offering tax incentives or low interest rate loans to those firms who are conducting research and development. Therefore even those firms who are committing research and development tend to invest in those which are likely to yield some immediate return rather than the researches which has tremendous potential but requires long term commitment and also has uncertainty, and most of the firms are reluctant to invest on the research and development which are likely to bring benefit to entire industry or nation not to individual firms.

The lack of the system to evaluate the firms' commitment to R&D or technological capability is also pointed out by many researchers. In Japan, for example, there is a "pre-qualification" or eligibility system to participate in public works projects. To participate in public works projects, firms have to be pre-qualified their technological capability. This status assured by government also leads to the credibility by private customers and helps those firms to acquire private contracts. This is one of the important reason why the Japanese firms are heavily invest in research and development.

The lack of the system to effectively reduce the risk of applying new technologies, methods or materials is another important obstacle to consider. The system that can

neutralize those risks by certifying the new technologies or methods before practical application would reduce the individual risks and help firms to become more active to develop new technologies and become more innovative.

Chapter III

CONSTRUCTION INDUSTRY AND AUTOMOBILE INDUSTRY

Comparison with Manufacturing Industry

The construction industry is not categorized in manufacturing industry because it differs from manufacturing industry on several aspects. First, it does not sell products based on production planning but produces based on order. Second, products are immobile. Therefore, it seems to be few similarities between the construction industry and manufacturing industry. However, there certainly exist many similarities between them in terms of their structures and production process. Concerning their attitudes toward research and development, there is a fundamental difference between them. While strategic management of technology and research and development perceived as the critical factors of success and executives are paying close attention to the strategic decision making in these issues in manufacturing firms, they are perceived as mainly the means of executing projects successfully, even nothing more than that in construction firms. In this chapter, I would like to compare the construction industry and the automobile industry because this comparison gives us many insights on would-be and should-be directions of the construction industry. Since the objective of this thesis is the role of research and

development in construction firms, I would like to put importance on the comparison of R&D and product development between two industries.

The Automobile Industry

Three Production Systems

International Motor Vehicle Program (IMVP) at MIT conducted the intensive research on automobile industry and its production systems and published its findings and analysis¹⁷. They largely divided the automobile manufacturers into three categories: craft producers, mass-producers and lean producers. They defined these three categories as follows:

Craft producer: The craft producer uses highly skilled workers and simple but flexible tools to make exactly what the consumer asks for—one item at a time.

Mass-producer: The mass-producer uses narrowly skilled professionals to design products made by unskilled or semiskilled workers tending expensive, single-purpose machines.

Lean producers: The lean producer employs teams of multiskilled workers at all levels of the organization and uses highly flexible, increasingly automated machines to produce volumes of products in enormous variety.

These definitions may not be directly applicable to the construction industry. However, when we make a comparison between two industries, it would be helpful to use these definitions. When we try to categorize construction firms according to these criteria, given the characteristics of the industry such as one-of-a-kind and custom-made nature of the products, they seem to be very close to craft producers.

Craft Production

IMVP also described the characteristics of craft production as follows:

¹⁷ Jones, Daniel T., Roos, Daniel, Womack, James P., *The Machine that Change the World*, 1991

1. A work force that was highly skilled in design, machine operations, and fitting. Most workers progressed through an apprenticeship to a full set of craft skills. Many could hope to run their own machine shops, becoming self-employed contractors to assembler firms.
2. Organizations that were extremely decentralized, although concentrated within a single city. Most parts and much of the vehicle's design came from small machine shops. The system was coordinated by an owner/entrepreneur in direct contact with everyone involved—customers, employers, and suppliers.
3. The use of general-purpose machine tools to perform drilling, grinding, and other operations on metal and wood.
4. A very low production volume—1,000 or fewer automobiles a year, only a few of which (fifty or fewer) were built to the same design. And even among those fifty, no two were exactly alike since craft techniques inherently produced variations.

There were hundreds of companies in Western Europe and North America because of the low entry barriers and the industry became highly fragmented as today's construction industry. After World War I, mass production was introduced, but a number of these craft producers have survived focusing on small niche markets: luxury end of the market where customers were willing to pay extra money to possess unique products.

When we compare these characteristics with the construction industry, we will notice that most of these characteristics of craft production are applicable to the construction industry. Although craft producers could offer products which exactly the customer wanted, they had fatal problems inherent to craft production. First, production costs were high and did not drop with volume because there were virtually no economies of scale. Second, quality was not consistent and reliability was low because each product was essentially a prototype. Third, because of the small size of those craft producers, they couldn't afford to conduct systematic technological development which was required for real technological advance. As the result, those craft producers were easily overwhelmed

by mass producers. These problems which the craft producers had are also resemble to the problems the construction industry have.

Mass Production

Henry Ford introduced the revolutionary way of production to automobile industry: *mass production*. This new production system enabled to overcome the problems inherent in craft production described above, and brought the revolutionary change to the automobile industry. "The key to mass production wasn't—as many people then and now believe—the moving, or continuous, assembly line. Rather, it was the complete and consistent interchangeability of parts and the simplicity of attaching them to each other.... Taken together, interchangeability, simplicity, and ease of attachment gave Ford tremendous advantage over his competition. For one, he could eliminate the skilled fitters who had always formed the bulk of every assembler's labor force.¹⁸" Not only Ford could eliminate the skilled fitters but also could reduce the entire human effort itself. Furthermore, the more production volume increased, the more the cost per vehicle decreased. This effect which is well known as economies of scale was the tremendous competitive advantage for Ford. After the Ford's success, many firms followed and adopt this system. The early stage of mass production which was represented by Ford tried to accomplish vertical integration as much as possible to maximize the economies of scale and accomplish the tighter delivery schedule to ensure the continuous production. Ford eventually failed to internalize every operation as business expanded because of the difficulty of managing organization and inefficiency of keeping everything internally to deal with the cyclical and variety of demand in international market.

General Motors (GM) completed mass production from the different approach. GM consisted of a dozen car companies and there were a high degree of product overlap between those companies and it was hard to manage the entire organization. GM solved its management problem by creating decentralized divisions which were managed from small

¹⁸ Jones, Daniel T., Roos, Daniel, Womack, James P., *The Machine that Change the World*, 1991

corporate head quarters that acted as the profit centers. Those profit centers were overseen by senior executives of GM. To serve the broad range of market, GM developed five product ranges from cheap one to expensive one. GM also developed the interchangeability of parts further across the entire product range.

It is hard to imagine that the mass production system is applied for construction in the same way auto mobile industry applied even if technologies become more advanced because of the several fundamental differences between two industries. First, every built facility is site specific and must be specifically suitable and tied to the site. Therefore, even though every component is fabricated in a factory, earth moving, foundation, assembly and gardening work will remain as site work. Second, every built facility is custom made according to the specific needs and tastes of the customer rather than customers choose ready-made products according to their needs and tastes. Because of these fundamental differences, mass production system is not applicable to entire construction project. Concept of this system is partially applicable to certain aspects of construction such as pre-cast concrete, aluminum curtain wall. However, the usage of those components has been limited to the parts of building where complicated adjustment is not necessary or other elements can be adjusted easily. Furthermore, although those prefabricated components certainly have contributed to reduce the labor force on site and to shorten the period of construction work, in most case they have not contributed to reduce the cost of construction as a whole. The reason of this is that those components are fabricated based on the design which is specific to the project and the usage is usually limited to the project, therefore, fabricators can not achieve cost reduction significantly by economies of scale except in case of large projects. Even in case of large projects, the degree of cost reduction is far from comparable to the case of automobile. Besides, the cost reduction is limited to the project and fabricators can not achieve continuous cost reduction. Furthermore, most of the

projects in the construction market are medium size or small size. Those factors make the construction industry difficult to apply mass production technique.

Although the application of mass production system to construction has many difficulties, the possibilities still exist and many researches are going on. The first approach is the standardization of components which can be used in many projects. By standardizing the prefabricated component, fabricators can achieve economies of scale and can reduce the cost of production. The second approach is the flexible manufacturing which is well known in manufacturing industry recently. By using highly flexible machinery and computers, fabricators can also achieve scale economy in a relatively small volume. By the way, flexible manufacturing is a little different from mass production in its concept. The basic concept of mass production is to standardize components as much as possible and produce the same kind of products as many as possible in one assembly line so that it can achieve maximum scale economy. The third approach is the combination of the first and the second approach. In any of these cases, cooperative research and development between designers, engineers, general contractors and specialty contractors would be essential.

Lean Production

What makes lean production different from mass production is literally its leanness throughout the system from organization, product development to final assembly line. The main objective of the lean production is to become as lean as possible that is to eliminate every possible useless part of operation which add little value on products or business. Lean production system was originally developed by Toyota. After World War II, during Japan's postwar reconstruction, Japanese auto makers tried to introduce mass production system in Japan. Toyota studied Ford's Rouge plant carefully in Detroit in 1950 and concluded that mass production could never work in Japan and tried to develop its own version of production system which Toyota called Toyota Production System which eventually became the production system IMVP called lean production. The Japanese

domestic market was small and fragmented from luxury cars to small cars as well as from large trucks to small trucks. Therefore, Toyota perceived that high-volume production and vertical integration were not feasible in Japan. Besides, it became increasingly difficult to deal with the cyclical demand by firing and re-hiring production workers.

To solve those problems, car makers had to develop more effective ways to produce in low volume. To deal with the variation of products more efficiently the Japanese carmakers developed flexible machinery that could be switched from one product to another. One good example is the die-change technique developed through endless experiment by Toyota which could eventually shorten the time to change each die to only three minutes which typically required a full day in western mass production system. Besides, because the die-change technique was easy, Toyota could eliminate the need for specialists to change dies. Furthermore, Toyota also found that the cost of stampings per part was less than the traditional stamping methods.

Another innovation was the human resource management. Because Toyota acknowledged the difficulty to handle its workers as variable costs like mass producers in the U.S., it tried to get the most out of its workers. Instead of allocating its workforce into highly subdivided production process, it grouped workers into teams with a team leader and gave those teams a set of assembly steps. Those teams were told to work together and solve any problems they encountered as a team and try to improve their assigned steps of production. Leaders were supposed to work with other workers in the assembly line as well as to coordinate the team rather than work as a foreman. This system eliminated the need of many supervisors required in typical mass production system. Furthermore, Toyota allowed any workers to stop the assembly line when they found any problem which they could not fix themselves in the process, and the whole team was supposed to work on the problem. This was not feasible in mass production where stopping the assembly line cost tremendously. Toyota succeeded to reduce the amount of rework while achieving virtually no assembly line stop.

The roles of suppliers are also quite important in lean production system. Toyota organized its suppliers into functional tiers. The first-tier suppliers were given the responsibility to participate in the production from the product development stage. They developed parts according to the performance specifications set by Toyota. Toyota did not specify every detail like materials, rather those suppliers were supposed to develop every detailed design of the parts in harmony with other parts suppliers who were in charge of other parts. Those first-tier suppliers assigned the job of producing individual parts to the second-tier suppliers. Unlike mass production system, suppliers among each tier were not competing on the same parts, the information exchange about advanced techniques were relatively smooth. Lean producers also have tried to reduce the amount of inventory by requiring just-in-time delivery to suppliers. Toyota developed this new way called *Kanban* at Toyota to coordinate the flow of parts within the supply system by dictating that parts would only be produced at each previous step to supply the immediate demand of the next step. The mechanism was the containers carrying parts to the next step. As each container was used up, it was sent back to the previous step, and this became the automatic signal to make more parts.¹⁹ This was extremely difficult to implement in practice because even a failure of the small part of the production caused the stop of entire production line, and indeed it took Toyota more than 20 years to fully implement this system.

Research and Development in Automobile Industry

Product Development

The managerial challenge for development of new product is the effective coordination of a number of functional departments from marketing, power train engineering through factory operations. To be successful, those functional departments must collaborate intensively. Most automotive companies adopted some kind of matrix

¹⁹ Jones, Daniel T., Roos, Daniel, Womack, James P., *The Machine that Change the World*, 1991

consists of employees from each functional department. The difficulties lay on the effective management of the matrix to satisfy both development project and functional departments.

International Motor Vehicle Program (IMVP) pointed out that there are four basic differences in design and development methods employed by mass and lean producers. These are differences in leadership, teamwork, communication, and simultaneous development.

Leadership

In lean production, each development team has a leader who is fully in charge of entire development process from design to production and has great authority over any other members as well as other department. Since the leader's decision is the top priority in the company, coordination of the team is smooth. Besides, there is a carrier path from project leader to top executive and, in many cases, post of project leader is the previous step to top executive, therefore, those project leaders are eager to pursue projects successfully and members of the projects respect their leaders as the prospective executives of the company. Western mass producers also have development team leaders but they have relatively weak power and usually there is no carrier path to top executives. These factors make the coordination of the projects difficult for team leaders.

Teamwork

In lean production, each development team consists of small members from every necessary functional department from marketing to factory operation. This development team continues to exist through the product life. Although the members of the project team retain ties with their department, they are under control of project leader during the project life. In case of mass producers, each development project consists of the temporary members borrowed from each department. Those members tend to think themselves as temporary workers for the project and their commitment to the project is relatively weak compared with the case of lean production. Besides, each development phase is conducted by different development team rather than a single development team throughout the

development process. This also makes the commitment of members weak and also makes development inefficient.

Communication

Since a development team in lean production consists of every necessary department, effective communication between each member makes it easy to find any conflict between each aspect of product and those conflicts can be found in the very early stage of development. Development team in mass production, by contrast, can not find any conflict between different aspect of the product in the early stage because of the lack of communication between different project teams in different development phases.

Simultaneous Development

Each phase of product development is conducted simultaneously in lean production rather than to develop one phase to another. This is made possible by the composition of the development team and close communication between team members.

Effects of those differences are enormous in terms of development time, product development cycle, development cost, production cost, quality and required engineering hours.

Research and Development

Generally it takes longer time for mass producers to put the new ideas generated in research into practice mainly because of the lack of communication between researchers and practitioners. For example, GM established its technical center outside Detroit and isolated scientists and engineers who were conducting advanced pre-production research from daily operation. As the result, although GM made a number of fundamental discoveries, those discoveries were transferred quite slowly from technical center to the market. In contrast, lean producers' approach toward research and development is quite different.

In most of Japanese lean producers, newly hired engineers are usually assigned to assembly line. After they spend a certain period in assembly line, they are transferred to different division and spend a certain period in the division. This job rotation continues

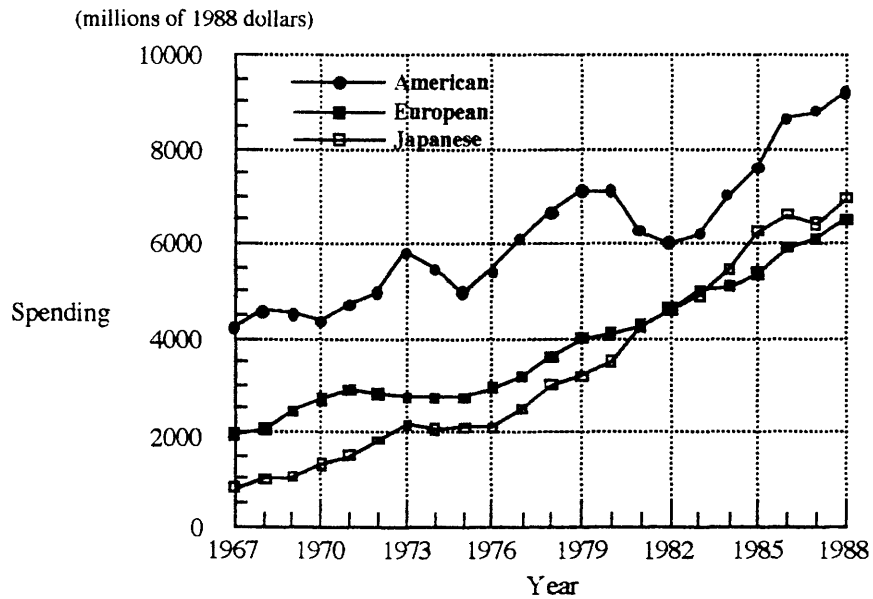
until those engineers have experienced every activity for making a car. Then they are assigned to engineering department. Even in engineering department, they are not involved in fundamental long term research immediately. They usually step up from practical development such as new product development to long-term and more advanced fundamental research and development gaining experience in each step. Through those experiences, engineers gain much knowledge about practical aspect of car making. As the result, those engineers become sensitive to practicality of development and eventually technology transfers become smooth and faster than mass producers. This system also improves the inter-departmental communication between each department and R&D department since engineers in R&D department have spent certain time in virtually every department.

The consequence of these different approaches toward research and development is apparent when we compare Figure 3.1 and Figure 3.2. American mass producers are spending more money than Japanese lean producers but Japanese lean producers are outperforming American mass producers in terms of the number of patents. Furthermore, Japanese producers are bringing those patented innovation into practice more quickly than American producers and European producers.

Learning from Automobile Industry

When we compare the design and construction industry with three types of production systems in automobile industry, we can find some similarities in each system. For instance, as described earlier, highly fragmented structure, low production volume, lack of economies of scale, inconsistent quality and lack of systematic research and development in craft production are common in the construction industry. In terms of production system, construction itself is far from mass production. However, as mass production consists of many highly specialized divisions and suppliers, the construction

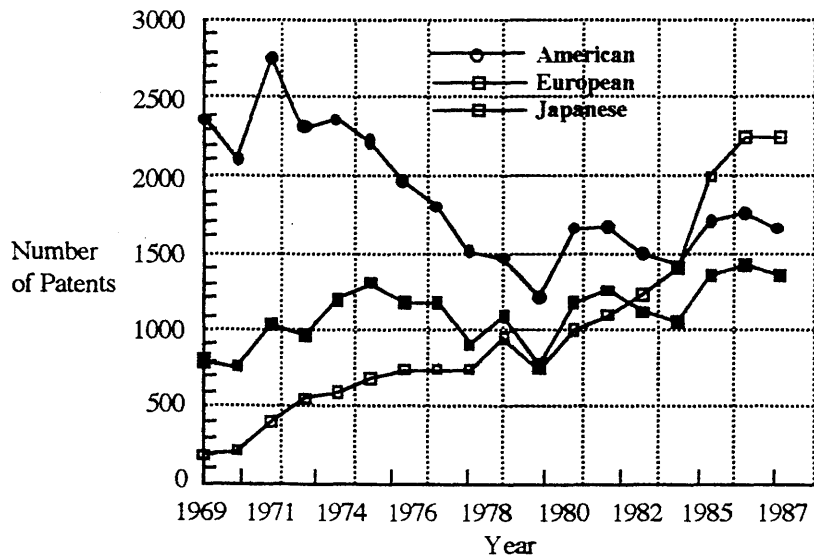
Figure 3.1 Annual Spending on Motor Vehicle Research and Development, by Region



Source: James P. Womack, Daniel T. Jones, and Daniel Roos - *"The Machine That Change the World"*

Original source: Estimated by Daniel Jones from the Organization for Economic Cooperation and Development's annual "Compilation of Surveys of R&D by Member Governments"

Figure 3.2 Motor Vehicle Industry Patenting, 1969 - 1986



Source: James P. Womack, Daniel T. Jones, and Daniel Roos - *"The Machine That Change the World"*

Original source: Estimated by the Science Policy Research Unit of the University of Sussex from data supplied by the United States Office of Technology Assessment, Washington, D.C.

industry is also consists of highly specialized firms. Besides, the lack of effective communication between specialties in different aspects of construction as well as between specialties within the same aspect of construction is commonly taking place in the construction industry although collaboration work is essential to successfully complete construction projects. This problem is quite similar to which mass producers have. Concerning lean production, we can also find some similarity at least on the surface. For example, just-in-time delivery of materials and components are quite common in construction projects especially in congested area like center of city. Simultaneous development is also taking place in construction and gradually increasing to shorten the periods of construction.

The construction industry as a whole seems like a mixture of those three types of production systems. Depend on the type and the size, a construction project comes closer to one of those types. In case of automobile industry, production systems has evolved from craft production to lean production and lean production seems to be gradually dominating the entire automobile industry. However, other production systems would remain in the industry to serve niche market. In case of construction, it is difficult to predict the future but it seems that the industry is going toward closer to lean production. One reason for this is that the effectiveness of lean production especially for small volume of production has been proved over the decade. The other reason is that the characteristics of lean production such as just-in-time delivery, team approach, and simultaneous development are quite suitable for construction. Although not quite successful yet, Japanese major E&C firms seem to have been fumbling to implement the lean production system in construction inspired by the success of Japanese lean producers in automobile industry. Major Japanese E&C firms have been investing considerable amount in research and development to develop the best possible production system for the future such as automated construction

systems, computer integrated construction, and robotics. Those technologies would be quite important to become truly lean producers in the construction industry.

Given the fact that even Toyota took more than two decades to fully implement lean production technique and mass producers have been losing market share and struggling to catch up with the lean producers with great difficulties, it would be quite important for U.S. design and construction firms to conduct research and development on this issue and quickly develop the necessary techniques.

Chapter IV

CONSTRUCTION INDUSTRY IN JAPAN

Background

While U.S. construction firms have difficulties in transferring knowledge and technologies generated in basic research into practice and have been suffering from losing competitiveness both in domestic and international marketplace, Japanese engineering and construction (E&C) firms seem to increase their competitiveness and market share steadily. The percentage of the dollar value of the foreign contracts awarded to U.S. contractors decreased from 38 percent in 1984 to 36 percent in 1990 while the percentage awarded to their European competitors increased from 38 percent to 43 percent and to their Japanese competitors from 9 percent to 14 percent in the same period²⁰. In the domestic market, foreign firms have been winning a growing share. According to an article in the Wall Street Journal (April 5, 1991), "foreign-owned firms (primarily from Japan and Europe) controlled 6 percent of U.S. building contracts in 1989, compared with about 2 percent in 1982."

As is the case in manufacturing industry, Japanese major E&C firms have developed strong technological capability by eagerly conducting research and development, and this technological strength seems to be one of the main driving factors which enabled Japanese E&C firms to increase their market share in the global market. As noted earlier,

²⁰ Engineering News Record, July 22, 1991

Japanese major E&C firms have been heavily investing in research and development in comparison with the U.S. counterparts. According to the National Research Council of the National Academy of Sciences and a Japanese Government R&D Survey for 1987, Japanese construction firms spent over \$800 million in R&D that year which was more than 15 times as much as their U.S. counterparts. Besides, the Japanese Ministry of Construction reports that the top 30 E&C contractors in Japan maintain their own research institutes and ten of them have more than 100 researchers each. The U.S., on the other hand, only five such firms have their own research institutes, each employing approximately six personnel. Although this difference has not made critical difference in terms of overall sales and market share, it could make great difference in the future.

The purpose of this chapter is to investigate the Japanese construction industry and find out why and how the Japanese E&C firms invest heavily in R&D, and to study the role of research and development in E&C firms.

Industry Structure

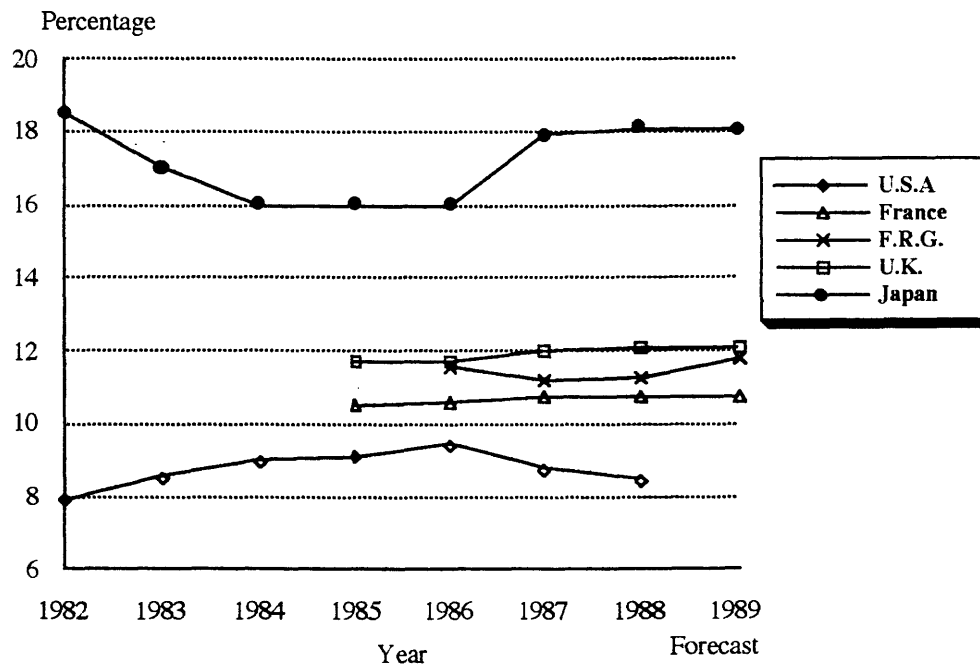
The construction industry is the largest industry in Japan as is in the United States. Its market size is about \$590 billion dollars in 1990 (1\$=¥140)²¹. This is bigger than U.S. construction market in terms of the simple dollar value (U.S. is \$434.9 in 1990). This figure is quite impressive when we consider the small size of the land and a population which is nearly half of the United States. Figure 4.1 shows comparison of the ration of construction investment to gross national product. This figure also indicates the relatively heavy construction investment in Japan.

The Japanese construction industry is no exception in terms of its highly fragmented nature of the industry although it is less fragmented than U.S. counterpart. There are approximately 510,000 firms in 1991 and 99% of them are medium sized and small sized firms that have less than 300 employees or capitalized at less than 720,000

²¹ Shueisha, Japan - "Imidas 1992"

U.S. dollars.²² The total market share of the ten major E&C firms is only about 15% of the entire market. The total number of employees in the construction industry is about 6,060,000 which is 9.7% of the entire industries.

Figure 4.1 Ratio of Construction Investment to Gross National Product



Source: Civil Engineering Research Foundation - "TRANSFERRING RESEARCH INTO PRACTICE: LESSONS FROM JAPAN'S CONSTRUCTION INDUSTRY"
 Original Sources: Ministry of Construction - "Estimate on Construction Investment"
 Bank of Japan - "Comparative Economic and Financial Statistics"
 U.S. Department of Commerce - "Construction Review"
 Data from EURO-CONSTRUCT Conference

E&C (Engineering and Construction) Firms

Japanese Engineering and Construction (E&C) firms are called "ZENECON" in Japan. "ZENECON" is the Japanese pronunciation of abbreviated words "General Contractor". One of the characteristics of Japanese E&C firms is vertical integration. As the

²² Shueisha, Japan - "Imidas 1992"

word "ZENECON" shows, the original businesses of those firms were that of general contractors. As Japanese economy grew and so did the construction industry, those firms especially major ones have expanded their business into other categories partly to increase their sales volume and partly to maintain their organizations in a cyclical construction market. Those firms are doing not only construction but also project development, design, engineering, financing, and research and development. This broad range of business makes Japanese E&C firms quite unique among the international E&C firms. Major Japanese E&C firm perceives the limitation of traditional style of construction business that is to design and build facilities to ensure steady growth. They are trying to change their sales strategy from traditional defensive one to more offensive one that is to create market themselves rather than respond the market by offering attractive projects to their potential customers. Golf course developments and resort developments are good examples.

Since the late 1980s, Japanese construction demand has increased so rapidly that every Japanese E&C firm as well as design firms have tried very hard to keep up with the pace and increase their sales. They were eager to increase their sales and kept trying to obtain new orders sometimes beyond their capacity. Those firms have tried to digest the obtained huge orders by increasing employees, working hours and by attempting to improve their productivity in every aspect of construction. During that process, the Japanese E&C firms have increasingly acknowledged the limitation to leap their productivity by incremental improvement of their operation. Besides, they have encountered the new problem, that is the shortage of skilled and unskilled labor as well as their own employees. Although Japanese major E&C firms have been conducting research and development on robotics for many years, they began to take the necessity of robotics in the construction industry quite seriously.

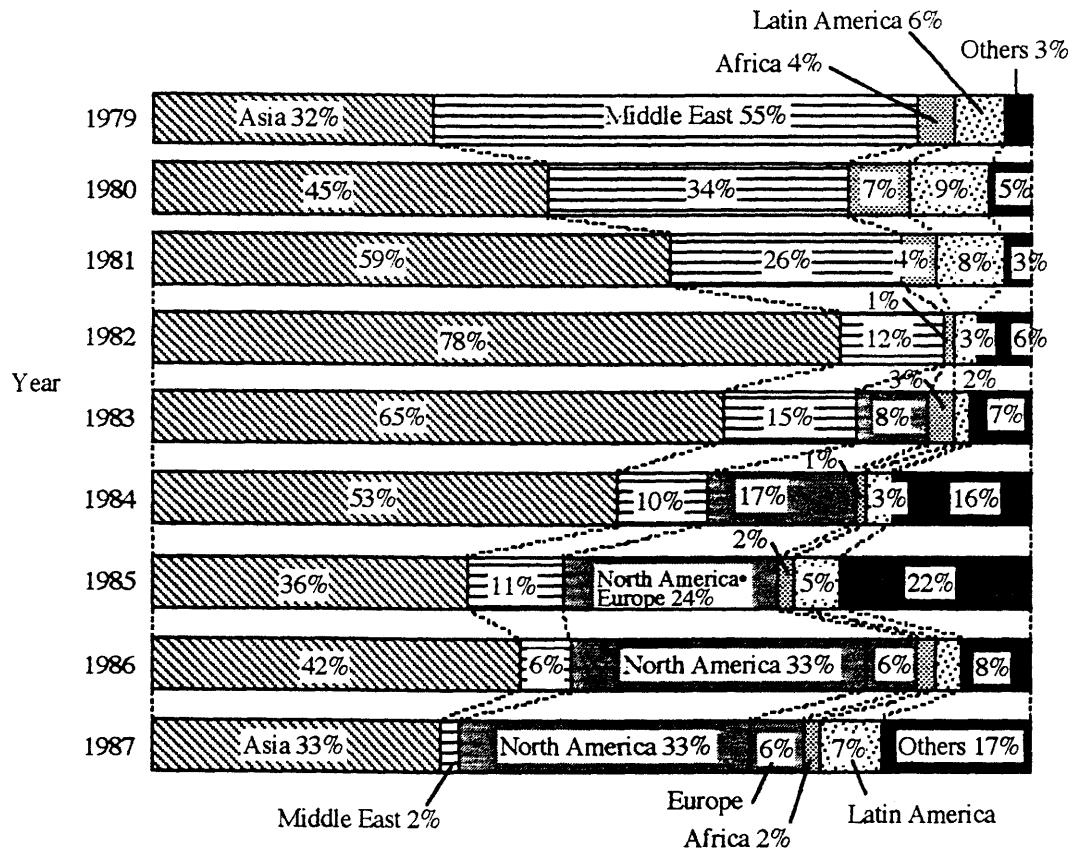
E&C firms and Globalization

Originally, internationalization of the Japanese construction industry started from compensation projects and economic cooperation and development projects based on the peace treaty after World War II, but basically the construction industry was no more than a typical domestic market dependent industry. This situation changed when the first oil crisis hit the Japanese economy in 1973. According to the government policy to repress the entire demand, big public project plans were frozen and the domestic construction market became stagnant. This situation had continued until the middle of 1990s and called "winter era of the construction industry", and the Japanese construction industry was called "eternally depressed industry". To break the unpleasant situation, major E&C firms began to enter into the international market. First target market was Middle-East market rich in oil dollars. When the middle east market became unfavorable because of the Iran-Iraq war and the unstable political situation, the target was gradually shifted to the Southeast Asia. And since the middle of 1980s the target has been gradually shifted to Europe and the United States (Figure 4.2).

Since 1984 the United States has been the biggest overseas market as an individual nation for Japanese contractors. However, 80 percent of the projects were ordered by Japanese manufacturers or developers and only 20 percent of them by American firms and public sectors. This shows the difficulty of penetration in the relatively mature highly competitive market like the United States. Although this figure seems small, Japanese major E&C firms have been trying to expand their market share in the United States based on several strategies. The most popular strategy is to establish a branch office in the United States as a foothold to penetrate the market by gathering information about the U.S. market and participating bidding. Several major Japanese E&C firms have followed this strategy and some of them have established subsidiaries to strengthen the tie with the market and customers. However, in reality, the operations of those branches have been far from

profitable because of the intense competition and unfamiliarity of the market except the business with Japanese based firms.

Figure 4.2 Ratio of Regional Sales of Japanese Contractors in the Overseas Market (include Japanese own foreign firms)



Source: Ministry of Construction "Oversea Construction Sales Investigation (1987)"

Another popular strategy is to form a joint venture with local firms that are familiar with the local market and have relatively weak financial capability. For those firms Japanese E&C firms' financial and technological capability is quite helpful to win the bids. For Japanese firms forming a joint venture is a good way to become familiar with the local market as well as establish some relationship with local suppliers and subcontractors that are essential to perform projects. Although forming a joint venture is relatively easy way to enter

into the market, the relationship is basically one-time basis and it isn't easy to increase their sales volume steadily.

Acquisition of U.S. E&C firms has also become popular strategy for Japanese E&C firms to increase their market share in short term. This strategy has been especially common for European E&C firms to penetrate in the U.S. market. Although the number of takeover by Japanese E&C firms

In either case, Japanese E&C firms seem to perceive the U.S. construction market as quite important one in the long run and continue to struggle in the market even though it is not profitable for them compared with the Japanese market. One of the main motivation toward globalization is to minimize the risk arise from the cyclical nature of the construction industry. Although Japanese construction market is relatively stable compared with the U.S. counterpart because of the government policy that increase public work when the industry is down turn, it is still cyclical and largely influenced by other industries' behavior. Since it is difficult to adjust the operational cost internally according to the business cycle by firing employees or hiring experienced employees because of the lifetime employment system which became the traditional practice and the overhead of those large firms is larger than small firms they have to maintain large market and sales. Given the cyclical nature of the construction industry, it is difficult to maintain their sales volume in only one country since they cannot export their products; constructed facilities.

Construction friction between Japan and the United States and the pressure to open Japanese construction market to foreign contractors further strengthened their perception toward the necessity to become globally competitive E&C firms. Besides, Japanese E&C firms have increased their organizational capacities to catch up with the rapidly grown domestic construction demand since the late 1990s being helped by so called "bubble economy". During this period, the expansion of overseas market became moderate and some firms even decided to withdraw from certain markets to deal with the rapidly growing domestic demand. However, the Japanese economy seems to be slowing down recently

and those E&C firms seem to put more importance on overseas market to neutralize the negative effect of the downturn economy.

General Contractors and Subcontractors

One of the characteristics of the construction industry in Japan is the relationship between original contractors and the subcontractors. Given the nature of construction, the existence of these relationships is quite common and not special in Japan. What makes the Japanese construction industry peculiar is the strongly colored ruler-ruled relationship between original contractors and subcontractors and the multiple-layered subcontracts. Historically, repetitive business between general contractors and specialty contractors has developed peculiar relationship between them. General contractors have increasingly rely on specific specialty contractors by continuously subletting some part of the work to them and the specialty contractors have increasingly belonged to the general contractors and many of them have become the exclusive subcontractors. These specialty contractors became to deal with the fluctuation of the work volume by further subcontracting. General contractors' site managers have become to select subcontractors based on the familiarity of the subcontractors and their ability rather than based on the competition between subcontractors. Under these circumstances, allotment of the role of general contractors and subcontractors has been formed.

Originally, when the specialty contractors were organizationally, financially and technically weak, they were providing only work force to general contractors and procurement of materials, provisions of construction machinery, shop drawings and construction planning for every job were general contractors' responsibilities. This situation has been changing as specialty contractors have gained enough knowledge and capabilities. Allotments of those jobs vary from specialty to specialty, but generally they have been gradually shifting toward subcontractors from general contractors and general

contractors are shifting their attention toward upstream jobs such as development, planning, design, engineering and construction management.

Suppliers and Vendors

Material suppliers and vendors are relatively free from traditional relationship between general contractors and subcontractors since they are usually targeting entire market including other industries rather than specific general contractors or projects. As technologies advance in material field, they have perceived the potential benefit to apply of new materials to construction and conducting research and development eagerly. Major E&C firms also have been conducting research and development in this field and they are usually conducting joint research with those material suppliers (manufacturers). Those manufactures need the opportunity to test new materials and the knowledge about construction while E&C firms need advanced technological knowledge about new materials and the facilities to produce those prospective new materials or enough fund for those research. These joint researches sometimes produce materials proprietary to those firms.

Role of Government

Japan International Research Task Force (JTF) led by Civil Engineering Research Foundation conducted the extensive research on the Japanese construction industry through a trip to Japan. JTF's major findings about the role of government to encourage technological developments are as follows:

1. Pre-qualification or eligibility system to participate in public works projects.

To participate in public works projects, construction firms have to be pre-qualified as the eligible candidates for the projects before bidding. This pre-qualification is based on the sales volume, technological capabilities, financial status, and so on depending on the type and the size of projects. To be pre-qualified, construction firms have to prove

that it has conducted research in the area of technology required to do the projects. This is extremely important to participate in large projects which are usually challenging both technologically and managerially. To be eligible to participate in public works projects is quite important for construction firms because it provides them relatively stable job opportunities as well as the status that indicate their ability and lead to the recognition by private owners, ultimately to the sales.

2. To provide financial assistance through tax incentives.

The Japanese government provides four tax incentives relevant to construction (Table 4.1).

Table 4.1 Japanese Government Tax Incentives

-
- a. When firm acquires, produces or constructs qualified plant and equipment, (more energy efficient or more electronic), and uses them within one business year, there is an investment tax credit of 7% of unit's cost or 20% of firm's income tax, whichever is less.
 - b. If amount of experimental and research expense incurred during a business year exceeds the largest of such amounts during each of preceding business years, there is a tax credit of 20% of such excess or 10% of corporation tax before tax credits (typically 30-40% of taxable income), whichever is less.
 - c. Shorter depreciation lives for assets contributing to prevention of disasters caused by earthquakes (15%); qualified high rises in specified city planning zones (24%); qualified assets for research and development located in designated areas (30%).
 - d. Tax free reserve for construction companies to provide against additional costs for repairing defective portions of their work (based on actual costs for two preceding years or 0.5% of construction cost).
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Source: Civil Engineering Research Foundation - *"TRANSFERRING RESEARCH INTO PRACTICE: LESSONS FROM JAPAN'S CONSTRUCTION INDUSTRY November 1991"*

3. To provide financial assistance through offering low interest loans by following ways²³.

- a. directing the Japan Development Bank to offer low interest loans (at about 9% in 1990) for the underwriting of practical experiment on newly developed construction technologies.
- b. directing the Sasakawa Foundation (the recipient of funds from legalized gambling on motor boat racing) to provide low interest loans for transportation related product development purposes approved by the Ministry of Transport.

Those government policies which U.S. government lacks are quite important to understand the reason why the Japanese E&C firms are heavily investing in research and development.

Another important issue is the role of Ministry of Construction (MOC). The MOC procedures governing use of new technology require extensive laboratory and field testing and an approval recommendation from an independent technical examination committee, organized by public agency, prior to introduction of the innovation. The Building Research Institute (BRI) plays a pivotal role in authorizing new technologies for building and the Public Works Research Institute (PWRI), over the release of new infrastructure development.²⁴ To use innovative new technologies in actual construction, construction firms must obtain approval from those institutes. They must conduct laboratory research as well as field experiment on those new technologies and submit data acquired by those researches and experiments to prove the effectiveness and safety of the technologies. Therefore, if they want to use new technologies, it is essential to have their own research laboratory.

²³ Civil Engineering Research Foundation, "TRANSFERRING RESEARCH INTO PRACTICE: LESSONS FROM JAPAN'S CONSTRUCTION INDUSTRY November 1991"

²⁴ Civil Engineering Research Foundation, "TRANSFERRING RESEARCH INTO PRACTICE: LESSONS FROM JAPAN'S CONSTRUCTION INDUSTRY November 1991"

Research Institutions

Compared with the United States, research activities of universities in Japan are quite modest and their focus is mainly fundamental researches in the fields of design, structural analysis, construction related materials, environment, etc. Besides, public regulations have made it difficult for private companies to commission research projects to universities and public research institutes. This is one of the reasons why many Japanese E&C firms maintain their own research laboratories and research staff internally.

Although their own research and development activities are modest compared with the U.S. counterparts, they are playing quite important role in the form of cooperative research with private sectors. According to the guidance advocated by MOC, those institutes are supposed to conduct joint research with private sectors. MOC identifies a desirable research theme in accordance with the policy of MITI (Ministry of International Trade and Industry). To participate the projects using technologies related to those researches, it is quite important to make a commitment to those joint researches. These cooperative joint researches help the smooth technology transfer between basic research and practical development.

Societal Environment

Historically, many construction related technologies have been developed because of the necessities derived from the environment peculiar to Japan. For example, frequent threats from earthquake have generated the necessity to develop structures tolerable to those seismic vibrations. Japanese small land and consequent high land price have generated the necessity to develop technologies to excavate deep into underground or high rise building which can withstand the extreme seismic vibration. The mountainous land has generated the necessity to develop tunneling technologies. The evolution of computer has generated the necessity to develop clean rooms which can reduce dust or technologies to control and

reduce seismic vibration more thoroughly because of the sensitivities of computers. More recently, shortage of skilled labor and aging workers has generated the necessity to develop more effective way of construction, construction robots and site automation. Environmental concern is also becoming increasingly important in Japan. To satisfy those societal demands is the minimum requirement for E&C firms to survive in the competitive environment.

Perception of R&D

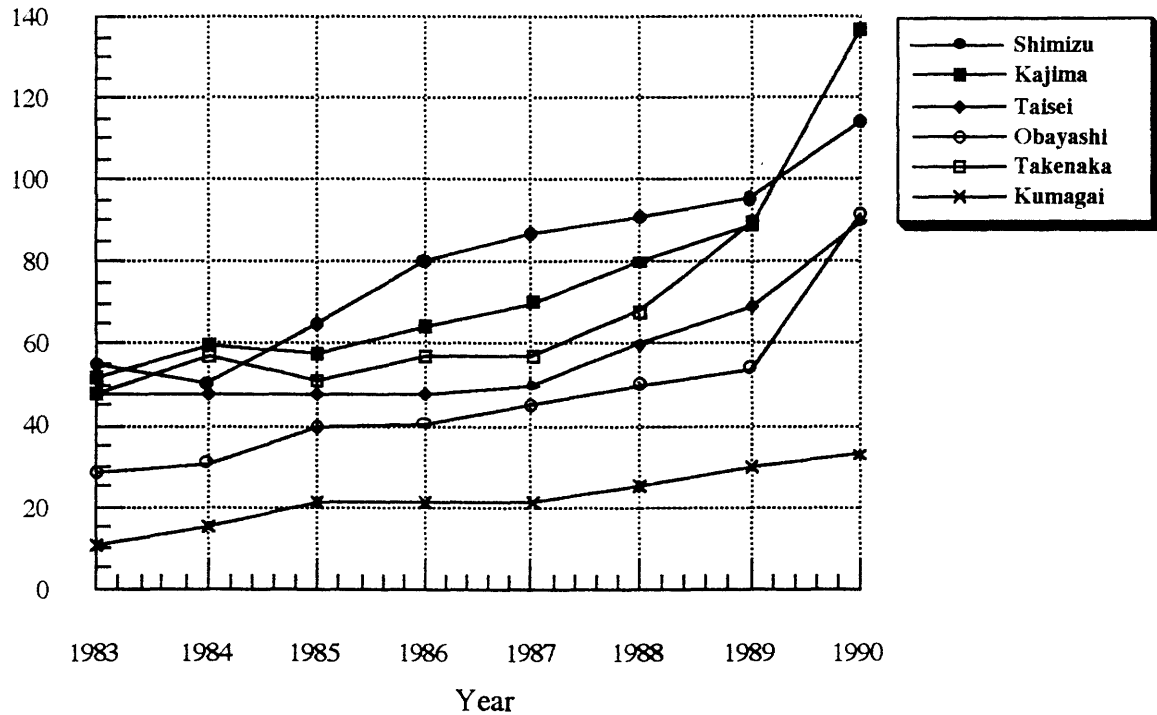
Major Japanese E&C firms have been heavily investing their capital and resources in their research and development which covers vast areas such as new materials, construction process innovation, robotics, space development, software development, etc. Many of those researches show no sign of bringing immediate profits to the company of its shareholders. As mentioned earlier, they are spending more than 15 times as much as their U.S. counterparts. Figure 4.3 shows the level of R&D expenditure by six major E&C firms in Japan. The Japanese ministry of Construction reports that the top 30 E&C firms in Japan maintain their own research institutes and ten of them have more than 100 researchers each.

Those major Japanese firms are now perceiving technology from different point of view that is to see technology not only as the means of improving productivity or reducing costs of construction but also increasingly as the essential part of long-term competitive strategy.

The pre-qualification system, tax incentives and low interest loan associated with the technological development mentioned earlier have strengthened the commitment of E&C firms to research and development.

Figure 4.3 Level of R&D Expenditure by "Big 6" in Japan

(Millions of U.S. Dollars)



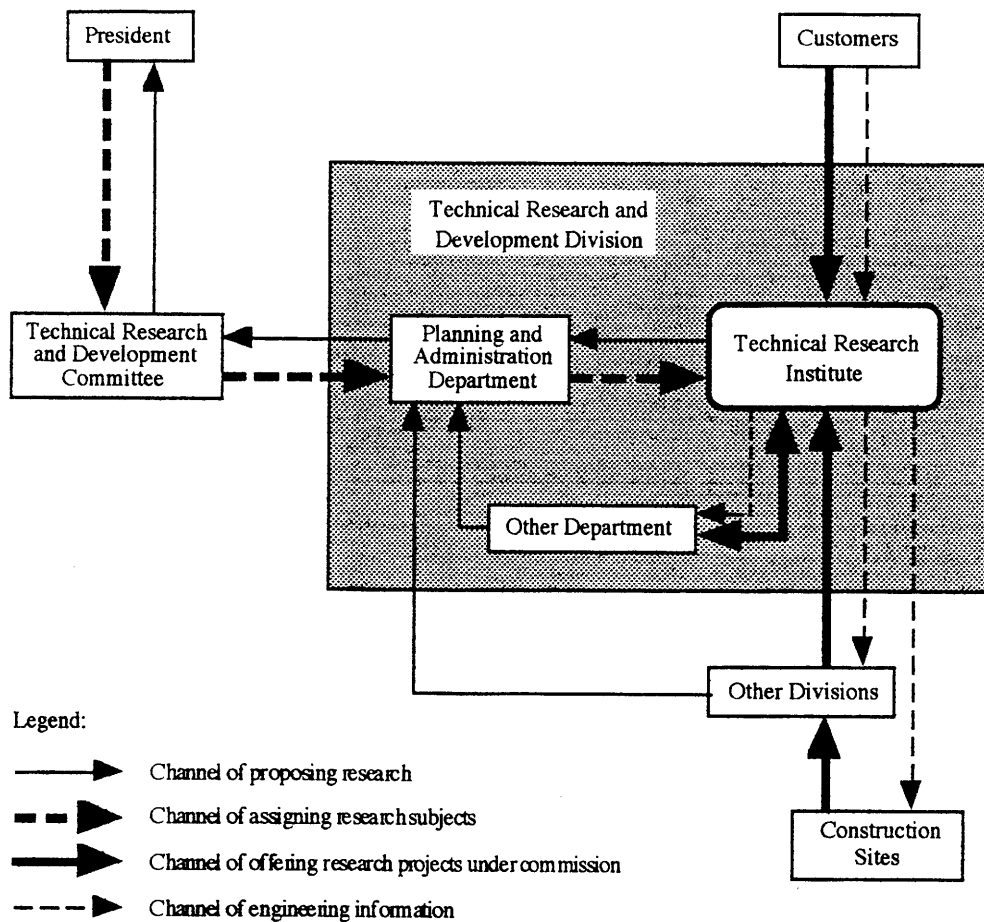
Source: 1983-1989 Data: Civil Engineering Research Foundation - "TRANSFERRING RESEARCH INTO PRACTICE: LESSONS FROM JAPAN'S CONSTRUCTION INDUSTRY"
 1990 Data: Tokyo Keizai - "Kaisha Shikibo 1991-Fall"

R&D Organization in E&C

Organization of R&D is highly centralized in Japanese E&C firms. Technology research center or technical research institute is usually a part of technical research and development division and the technical research center is usually apart from headquarters, but other part of technical research and development division is usually in the head quarters in order to maintain close tie with other functional departments.

Figure 4.4 shows the organizational structure of R&D in a typical Japanese E&C firm.

Figure 4.4 Organization of R&D in a Typical Japanese E&C Firm



Source: Civil Engineering Research Foundation - "TRANSFERRING RESEARCH INTO PRACTICE: LESSONS FROM JAPAN'S CONSTRUCTION INDUSTRY"
 Original Source: Japan Technical Evaluation Center - "JTEC Report, 1991"

Research and development activities in Japanese E&C firms are largely grouped into three: product innovation, process innovation, and business innovation. Technologies needed to incorporate an agreed function into an existing project receive top priority followed by processes which are likely to increase productivity and make construction more worker-attractive (i.e., robotics and automation); and innovations for establishing new markets (i.e., Bio-degradable plastics manufactured from sludge). Lower priority is

assigned to projects aimed at transferring know technologies into future projects, for long-term basic research, and for monitoring and evaluating R&D activities.²⁵

Marketing and R&D

Every Japanese E&C firm has experienced the difficulty of dealing with the cyclically changing demand. Especially in down turn economy, it is quite difficult for major E&C firms to keep minimum sales to maintain their large organization. It also had become difficult to increase orders merely by building facilities according to the given design and time schedule demanded by client. Consequently, they became aware of the importance of creating market by offering attractive projects to potential customers rather than waiting for the opportunities to receive orders from customers. To make attractive proposal to customers, they have increasingly put importance on technological development which can add value to customers' business. Thus they became to perceive that only those construction companies capable of offering new technologies and services through research and development would continue to exist.

R&D and Practice

Many researchers claim that the Japanese E&C firms are faster in bringing research results into practice. One of the reason of this is that many researches are conducted base on the specific needs of actual construction projects whether they are ongoing or planed in the immediate future.

Second reason is the human resource management. Basically, major Japanese E&C firms have followed the practice of automobile industry. They put importance on practicability when they conduct research and development and most actual development projects are usually conducted by project teams consists of members from every functional

²⁵ Civil Engineering Research Foundation, "*TRANSFERRING RESEARCH INTO PRACTICE: LESSONS FROM JAPAN'S CONSTRUCTION INDUSTRY November 1991*"

department, and team leader has strong authority. Although this approach is not as complete as lean producers, the ease of communication between different functional department helps the technology transfer.

Third reason is the vertical integration. Unlike design and construction firms in the United States, Japanese major E&C firms are vertically integrated and it is relatively easy for those vertically integrated firms to transfer information between different functional divisions and coordinate entire project so that the total results become optimal. Forth reason is the cooperation with subcontractors and suppliers.

Fifth reason is the intense competition on technological development between major E&C firms. This situation is quite interesting in Japan. Major six E&C firms are competing head-to-head and every firm is afraid to fall behind and try to overtake others. Since technological capability became perceived as one of the most important factor of success, they have tried to identify themselves as technological leaders. As technology advanced and diversified, however, it has become increasingly difficult to keep lead in every field which every major firm is competing in because of the rising development cost. Besides, to choose specific areas as the target and concentrate the research and development on the area is risky because of the uncertainty of the market response. Therefore researchers in E&C firms are spending considerable amount of effort to keep eyes on the movement of other companies' research and development. Then once one firm shows the intention to develop some prospective research, other firms swiftly follow in order not to fall behind. A good example is the research and development on automated-building-construction systems. Currently available models of this system developed by major E&C firms are based on the same basic concept and quite similar to each other. This tendency seems to have brought multiplier effect on quick technology transfer.

Chapter V

EVALUATION OF INTERNAL R&D

Introduction

According to current economic theory, individual firms act in their own self-interest. When we consider the various obstacles to research and development discussed in Chapter II, the low investment in research and development by individual engineering and construction firms and their reluctance to apply innovative technologies can be attributed to rational decisions based on their own self-interest. However, when aggregated, those individual rational decisions may not produce favorable results for the entire industry or nation. Furthermore, those decisions might turn out to be no longer rational ones if the situation surrounding the construction industry changes. External pressure such as increasing challenge by foreign competitors can change industry structure. Change in government policy, technological change, change in demand can also affect the industry structure. If such changes occur, those firms who adhere to the current technology strategy, which is to invest little in research and development, might not be able to survive because the competitive advantage they believed they had might not be a competitive advantage any more. They even might be forced to invest in research and development if the technological know-how becomes less easy to imitate than before. However, this would take both time and capital before getting some results from R&D. In addition, it

might take an even longer time to put the research results into practice successfully. This time delay can be a fatal disadvantage for those firms. Therefore, it is quite important to pay close attention to the industry's structural change and to factors which might change the industry structure in the near future. Thus strategic decisions should put importance not on how to gain short-term profit, but on how to achieve a long-term sustainable competitive advantage.

The objectives of this chapter are to discuss the structure of the construction industry from a strategic point of view; to analyze the effect of technological change on the industry structure as well as on the competitive strategy of construction firms; and to analyze how internal research and development affects the competitive advantage of construction firms.

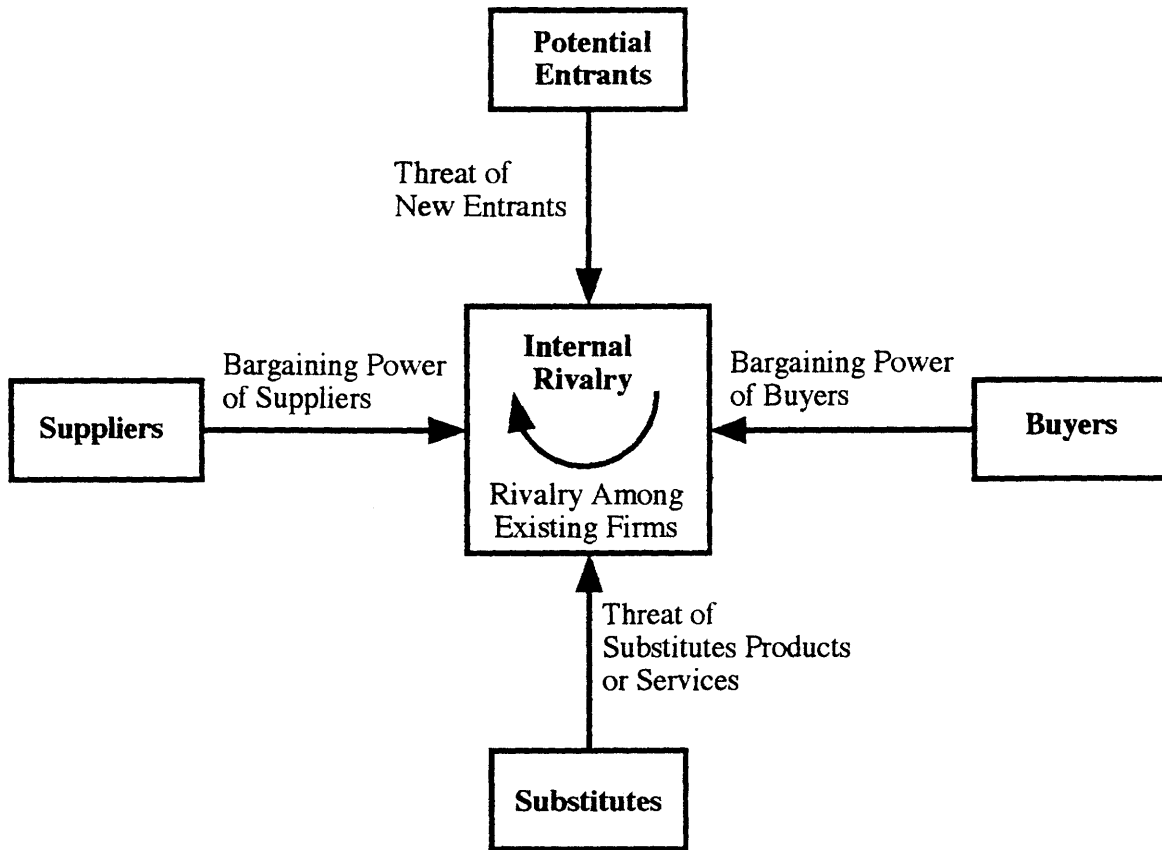
Structural Analysis of Construction Industry

Industry Structure

Firms should deal with industry structure from a strategic point of view which means that they should understand the current industry structure as well as the changing direction of that structure. To analyze industry structure, it is very useful to use the market framework introduced by Porter [1985].²⁶ According to this market framework, there are five competitive forces in an industry structure: 1) rivalry among existing firms, 2) threat of new entrants, 3) bargaining power of buyers, 4) bargaining power of suppliers, and 5) threat of substitute products or services. It is quite important to capture the overall picture of competition to understand what's going on in the industry from the strategic point of view. Figure 5.1 shows the elements of industry structure.

²⁶ Porter, Michael E., "Competitive Strategy," 1990

Figure 5.1 Elements of Industry Structure



(Source: Michael E. Porter - "Competitive Strategy")

1) Rivalry Among Existing Firms

As we have seen, internal competition among existing firms in the U.S. construction industry is quite fierce. The focus of this competition is not placed on quality of construction facilities but is rather placed mainly on construction cost. This emphasis on construction cost favors the relatively small size firms because of their relatively low overhead costs and organizational flexibility in comparison with larger firms. This assumes of course that the smaller firms can employ appropriate technologies for pursuing construction projects successfully. This is one of the main reasons why the construction industry in the U.S. is so fragmented.

Technological change can alter this situation however, by enabling large firms to reduce their construction cost significantly by employing more effective technology which

cannot be imitated by small firms. For example, automated construction systems could have such an impact on the industry if they successfully come into practice.

2) Threat of New Entrants

As described in Chapter II, foreign competitors have been increasing their market share in the U.S. construction market. Those foreign firms who have already penetrated the U.S. market can be considered as "internal rivalry" in a sense. However, if those firms have different strategies for their operation in the U.S. market, they can change the rules of competition or industry structure itself. Internal competition among existing firms in the U.S. construction industry is mainly based on cost. A construction firm who can offer the lowest price usually wins a contract in the case of open bidding. However, this situation is already changing. For example, design-build contracting is gradually increasing. This system favors a firm or group of firms who can offer technological and managerial capabilities which enhance overall project performance such as shorter construction time or superior quality. If there is an increase in the use of alternative project delivery methods which put importance on project performance rather than simply on project cost, those firms who have technologies which other firms in the industry do not possess, will have competitive advantage over other firms. The use of those alternative methods will also bring significant change in the industry structure.

3) Bargaining Power of Buyers

Bargaining power of buyers has been extremely strong in the construction industry. There are several reasons for this. First, since investment in construction projects usually represents a significant fraction of the buyer's cost of doing business, buyers are extremely sensitive to construction cost, order selectively and place great emphasis on obtaining the lowest and most favorable price. Second, since it is difficult for a construction firm to differentiate its products from those built by other construction firms, it is possible for

buyers to find alternative construction firms to pursue a project. A design firm, in contrast, can differentiate itself from others and thus can diminish the buyers bargaining power. Third, in many cases, the relationships between contractors and owners are often one-time relationships and there are few switching costs. Fourth, in many cases, the quality of built facilities does not affect the quality of the buyer's products or services directly. In such cases, buyers have strong incentives to reduce construction costs rather than paying extra money for better quality if the minimum quality of the constructed facility is acceptable. Finally, buyers have become quite knowledgeable about costs of construction especially about material costs and standardized components, because of the available information from many publications and from past experiences. As a result, it is quite difficult for contractors to ask premium prices from their customers even if they can offer better quality than their competitors.

Technological change can shift the bargaining relationship between construction firms and their customers. For example, if using a certain technology can shorten construction time significantly and the technology is available to only one firm, this construction firm will have strong bargaining power with buyers especially with those buyers where construction time significantly affect sales or production schedules.

4) Bargaining Power of Suppliers

In the construction industry, material suppliers have relatively modest bargaining power with construction firms as long as there are enough suppliers for the industry. If a certain kind of material market is dominated by a few suppliers or there are few alternative materials, they have strong bargaining power with construction firms. This is the case with sheet roofing. If those materials account for a large portion of construction costs, contractors have particularly strong incentives to cut the price. They do this by seeking out cheaper materials which satisfy the specifications or seeking out cheaper suppliers.

Specialty contractors such as carpenters and steel fabricators can be considered as suppliers. These contractors can also have strong bargaining power with general contractors. For example, since the late 1980's in Japan, construction demand rapidly increased beyond expectation and shortages of these specialty contractors occurred. As a result, many specialty contractors increased their bargaining power and general contractors were obliged to pay premium price to pursue construction projects.

Technological change can shift the bargaining relationships between an industry and its suppliers. Technological change can also provide a number of substitute inputs which can be used on a firm's construction projects, creating bargaining leverage against suppliers.

5) Threat of Substitutes

Threat of substitutes is relatively weak in the construction industry since construction has a long traditional preference of applying technologies, structures, and materials which are proven safe by long usage. This is because constructed facilities are directly related to the safety of large numbers of people and the product life is extremely long compared with commodities. In addition, it is extremely difficult and costly to reconstruct the facilities. Therefore owners are reluctant to use newly developed materials or structures if there is any possibility of their failure.

Because of these characteristics, most of innovations in the construction industry have been incremental and make use of well known materials or technologies. However, there are possibilities for substitutes in construction industry through technological development. For example, if fully automated construction systems can be brought into practice, they can substitute for specialty contractors as well as many general contractors who do not possess the technology. This kind of innovative construction technology can be considered as a substitute in a broad sense. Another example is the prefabricated building

systems developed by other industry players such as steel manufacturing companies. These building systems can be considered as substitutes as well as potential entrants.

Generic Strategies

To keep their relative position above the average level in the industry, firms seek sustainable competitive advantage against their competitors. There are two basic types of competitive advantage firms can possess: low cost and differentiation. The significance of any strength or weakness a firm possesses is ultimately a function of its impact on relative cost or differentiation. The two basic types of competitive advantage combined with the scope of activities for which a firm seeks to achieve them lead to three generic strategies for achieving above-average performance in an industry: cost leadership, differentiation, and focus.²⁷ Figure 5.2 shows these generic strategies.

Figure 5.2 Three Generic Strategies

		COMPETITIVE ADVANTAGE	
		Lower Cost	Differentiation
COMPETITIVE SCOPE	Broad Target	1. Cost Leadership	2. Differentiation
	Narrow Target	3A. Cost Focus	3B. Differentiation Focus

(Source: Michael E. Porter - "Competitive Advantage")

²⁷ Porter, Michael E., "Competitive Strategy," 1990

Cost Leadership

Low cost is one of the two types of competitive advantage firms can possess. Achieving overall industry-wide cost leadership is one of the three generic strategies and is quite common in the construction industry. In the construction industry especially in the United States, in most cases, cost is the most critical determinant of success in acquiring jobs from customers. This is because of the cost based open bidding system and the relatively strong buyer power in the industry. To achieve overall cost leadership, it is quite important to distinguish cost drivers which are playing significant roles in determining the overall cost of projects.

In the construction industry, one of the important cost drivers is manual labor. Although the construction industry has advanced in terms of its technologies compared with the past, it still largely relies on manual labor as craft producers do in the automobile industry. The high dependence on manual labor, especially on skilled labor, is causing various problems in the construction industry such as declining productivity, declining quality, rising construction cost, construction time delay, and increasing shortages of skilled labor due to aging workers. Furthermore, it is quite difficult to reduce construction cost because of this dependency on manual labor. Therefore, if technologies such as robotics and automated construction systems can substitute for skilled labor such as it happened in the manufacturing industry, productivity would increase dramatically and construction cost would decrease as well. Japanese major E&C firms are actively conducting research and development in this field. If those firms are able to successfully implement these technologies, they would gain significant competitive advantage over other firms. It would also significantly affect the industry structure not only in Japan but also in the world, since those firms have been increasing their presence in the international marketplace.

It is important to note that this strategy can also bring disastrous result when more than one firm tries to be the cost leader because the resulting fierce cost based competition

leads to sacrifice of profitability in order to gain market share. This can be prevented only if one firm can gain a cost lead and can convince others not to compete on price or if one firm possesses superior technologies which can significantly reduce cost below that of its competitors. Cost based competition also leads to decline in product quality because each firm tries to reduce its cost by sacrificing product quality to the minimum acceptable level.

Differentiation

Differentiation is another type of competitive advantage a firm can possess and it is also one of the three generic competitive strategies. Uniqueness of products or services does not always lead to successful differentiation unless it is valuable to the buyers. By differentiating its products or services from competitors, and if the uniqueness is perceived by its buyers as valuable to them, a firm can reduce the bargaining power of buyers and can require premium price from its buyers or gain greater buyer loyalty. To be successful with this strategy, the premium price the firm can impose on its products should not exceed the extra cost which is necessary to differentiate the products from its competitors'.

It is relatively difficult to achieve and maintain differentiation of the products themselves in the construction industry, especially by the construction firm. The construction firm usually constructs facilities that are designed by other firms and thus there are few possibilities to show any uniqueness in them. In the case of architects, where artistic factors play an important role, there can be uniqueness of design which is apparent to their customers. Architects can also achieve differentiation by offering more functionally superior design than their competitors. Thus they can achieve differentiation by showing it in the products themselves. Although it is difficult for construction firms to differentiate their products physically, it is possible for them to differentiate themselves from competitors through other factors such as product quality, service quality, or shortening of construction time by superior management or technology.

Focus

Focus is the third generic strategy. This strategy differs from the other two strategies in a fundamental way. It chooses a segment or several segments in the industry as targets and produce products or offer services specifically suited to those segments. As shown in Figure 5.2, there are two variants in focus strategy. One is to focus on cost advantage in a firm's target segment and the other is to focus on differentiation in its target segment.

Focus strategy commonly takes place in the construction industry. Local firms usually focus on their regional customers. Those firms can differentiate themselves from broadly targeted competitors by offering more convenient and closely tied service to their customers during construction as well as after construction, or they can offer lower cost because of the familiarity with suppliers and subcontractors, or with local site conditions. In contrast, broadly targeted firms may offer more than enough quality to their customers whose quality requirement may be lower than the average level of the entire market because of the unfamiliarity of the specific needs of their customers.

Another common focus strategy is to focus on specific product segments - that is to focus on specific type of construction projects such as hospitals, factories and so forth. By focusing on specific type of projects, those firms can build up thorough knowledge about the functional and quality requirement of those facilities and thus can offer differentiated service or facilities which are closer to the specific needs of customers than broadly targeted competitors.

Technology and Competitive Advantage

Technology development is important to competitive advantage in all industries, and it holds the key to success in some industries. Technological change is one of the most important drivers of competition. It can change the rules of competition as well as industry structure itself by altering the balance of the five competitive forces. Technological change

itself is not important if it does not affect competitive advantage or industry structure. Technological change is not always strategically beneficial and it may worsen a firm's competitive position or industry attractiveness. Technology affects competitive advantage if it plays a significant role in determining the firm's relative cost position or differentiation. Technology varies from industry to industry or within the industry. Since every activity involves some kind of technology, and some of these technologies such as information technology and communication technology, are playing quite important roles in achieving linkages among activities. Thus technology can be a powerful determinant of both cost and differentiation. Therefore, it is quite important to understand which technologies influences the cost drivers or drivers of uniqueness of products and services. A firm can use technological development to alter those drivers so that it can gain competitive advantage from those changes.

Technology and the Value Chain

To understand the role of technology in competitive advantage, it is useful to use the value chain concept which was introduced by Porter.²⁸ Figure 5.3 illustrates a value chain of a construction firm and various kinds of technologies which are used in each value activity. As we can see in the figure, technology is embodied in every value activity in a firm. Therefore, technological change can affect any activity and consequently, can affect competitive advantage.

"In competitive terms, value is the amount buyers are willing to pay for what a firm provides them. A firm is profitable if the value it commands exceeds the costs involved in creating the product. Creating value for buyers that exceeds the cost of doing so is the goal of any generic strategy. The value chain disaggregates a firm into its strategically relevant activities in order to understand the behavior of costs and the existing and potential sources of differentiation. A firm gains competitive advantage by these strategically important

²⁸ Porter, Michael E., *Competitive Advantage: Creating and Sustaining Superior Performance*, 1985

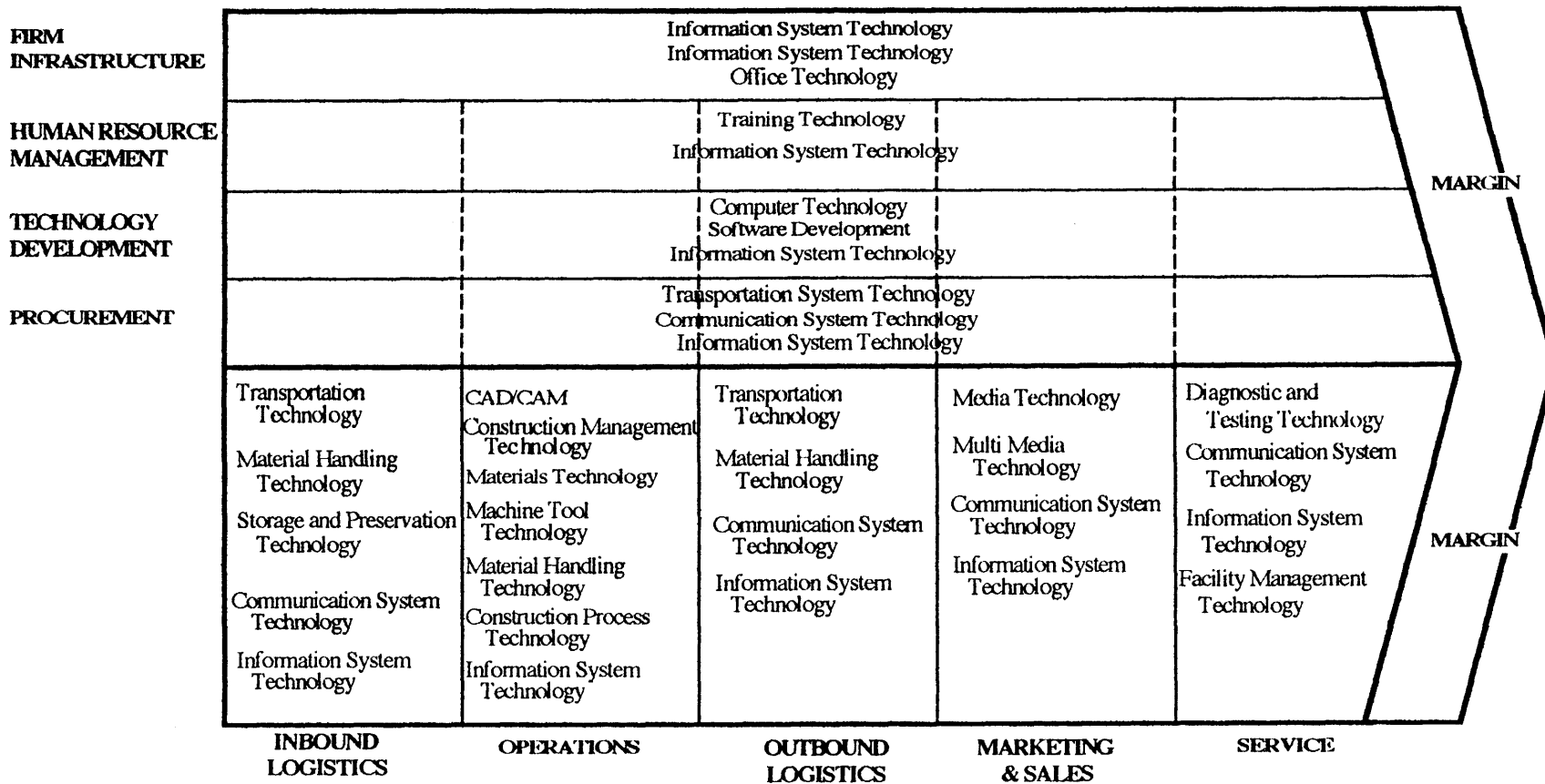


Figure 5.3 Representative Technologies in a Construction Firm's Value Chain
 (Based on the figure presented by Porter [1985])

activities more cheaply or better than its competitors."²⁹ The fundamental basis for differentiation is a firm and its product's role in the buyer's value chain. It is essential to understand not only a firm's value chain but how the firm's products or services affect the buyer's value chain.

Thus a firm can gain competitive advantage by technology development if it can either reduce the cost of a firm's activities or add some value to those activities such as quality improvement. It is quite important to understand that even though a firm can succeed to improve its product quality, or produce unique products through technology development, it cannot gain competitive advantage over its competitors unless the technology can bring cost reduction to its customers activities or can add value to them. Conversely, even though the price of the products or services a firm offers to its customers is higher than its competitors, customers are likely to pay extra money as long as the products or service can reduce overall cost of activities of customers or can add significant value to those activities. Therefore, to successfully differentiate a firm's products or services by technology development, it is essential to understand the effect of its technology development not only on its own activities but also on its customers' activities.

Among many technologies involved in value activities, information system technology is playing a preeminent role because every activity has to deal with various kinds of information and thus information system technology affects every value activity. Especially in the construction industry, information system technology has a great potential not only to improve the productivity of each value activity, but also to overcome the inefficiency caused by fragmentation of AEC industry by building information linkage between those fragmented segments. If it is properly developed and used, it can make inter-organizational information linkages more efficient and help solve the various problems that arise from fragmented decision making. It can change the structure of construction industry itself. Thus information system technology has great potential and few firms can remain

²⁹ Porter, Michael E., *Competitive Advantage: Creating and Sustaining Superior Performance*, 1985

competitive without taking advantage of this technology in the future. However, there still remain many problems to fully take advantage of this technology and to improve the productivity of the construction industry.

For example, it is quite difficult to achieve standardization of data and information which enable information sharing between different functional participants. To improve productivity by reducing inefficiency caused by fragmentation, it is necessary to achieve truly effective information linkages between different stages of a construction project which means information sharing between different organizational divisions as well as between different firms whose involvement in the project is necessary.

Although it is quite difficult and takes time to achieve truly effective management of the interdependencies between different organizations or functional divisions, development and effective usage of information technology will become a critical factor of future success.

Technological Change and Sustainable Competitive Advantage

Technological change by a firm will lead to sustainable competitive advantage under the following circumstances:³⁰

1. *The technological change itself lowers cost or enhances differentiation and the firm's technological lead is sustainable.* A technological change enhances competitive advantage if it leads to lower cost or differentiation and can be protected from imitation.

2. *The technological change shifts cost or uniqueness drivers in favor of a firm.* Changing the technology of a value activity, or changing the product in ways that affect a value activity, can influence the drivers of cost or uniqueness in that activity. Even if the technological change is imitated, therefore, it will lead to a competitive advantage for a firm if it skews drivers in the firm's value favor.

³⁰ Porter, Michael E., *Competitive Advantage: Creating and Sustaining Superior Performance*, 1985

3. *Pioneering the technological change translates into first-mover advantages besides those inherent in the technology itself.* Even if an innovator is imitated, pioneering may lead to a variety of potential first-mover advantages in cost or differentiation that remain after its technological lead is gone.

4. *The technological change improves overall industry structure.* A technological change that improve overall industry structure is desirable even if it is easily copied.

Even though technological change is quite innovative and technologically successful, it will not lead to a firm's sustainable competitive advantage if the technological change does not meet those conditions described above. Technological change can even worsen the a firm's competitive advantage if it produces the opposite conditions.

First-mover Advantages

Seeking technological leadership is strategically desirable when first-mover advantages exist. In many case first-mover advantages make it possible for a leader to sustain competitive advantage even when technological lead itself vanishes. Some of the most important considerable first-mover advantages are as follows.

First, a firm that moves first may be able to gain a reputation as the pioneer. Once this image is established, it is difficult for competitors to overcome this image. Although to keep this image require continuous development effort, reputation is an extremely strong competitive advantage. Second, a first mover may be able to gain loyalty from its customers since it is likely to be the first firm to serve its customers in the field. Third, a first mover may be able to gain cost advantage or quality advantage if there is a significant learning curve effect. Forth, a first mover may be able to define the standard which favors the firm and force the followers to adopt the standard. Finally, a first mover may be able to protect its technological advantage from imitation by patenting.

First-mover Disadvantages

It is also quite important to consider first-mover disadvantages. First movers often encounter disadvantages as well as advantages. The most significant one is the cost of developing new products or technologies. To become a first-mover especially technologically, a firm has to invest significant capital and human resource in research and development. This is one of the main reason many entrepreneurs fail to succeed. Another important one is the risk arise from market uncertainty. It is quite difficult to predict future needs of buyers.

Technology Diffusion

Technology diffusion is quite important to consider when discussing the sustainability of competitive advantage gained by technology development. Advantages gained by technology development are canceled or diminished if competitors can easily imitate the technologies a firm develops. There are several factors which make technology diffusion possible. First, competitors can imitate a firm's technologies by directly observing its products or operations. This is quite common in the construction industry. Usually construction projects are pursued in the open air and it is rather difficult to conceal their operation. Second, competitors can gain knowledge about the technologies through suppliers, vendors and subcontractors. This is also quite common in the construction industry. Information about construction process, methods, materials and machines easily travel through the firms involve in projects. Since those firms are not working only with a specific firm, it is quite difficult to keep technological secrets. Third, competitors can gain knowledge about new technologies through publications, conferences and consultants. Newly developed technologies are usually quickly introduced by trade magazines, conferences, and other related publications. Competitors can easily gain knowledge about those technologies by gathering information from these media. Fourth, technologies can be transferred through personnel transfer. This is common not only in the construction

industry but also in other industries especially in the United States where changing jobs is a normal and acceptable practice.

Technology diffusion itself is favorable for the industry as a whole because it can improve the technological capabilities of the entire industry. However, if it is extremely difficult to keep a technological advantage over other firms, few firms are willing to invest their precious capital and human resources in research and development. Therefore, to seek competitive advantage through technology development, it is important to find ways to maintain the advantage by slowing down the rate of technology diffusion.

There are several possible ways to slow down the rate of technology diffusion. First, patenting of the technology is a typical method in every industry. Although this is possible in the construction industry as well, most of construction related technologies, other than materials, are usually combinations of already existing technologies and are relatively easy to apply without violating patent right by slightly modifying them. Second, keeping the technological know-how secret from competitors is also possible. To do this, it is quite important to develop key technologies in-house and to prevent their leakage through employees. Therefore, effective personnel policies designed to retain employees are essential.

Technology Strategy

Technology is one of the most important determinants of overall industry structure if specific new technologies become wide-spread throughout the industry. Technological change can potentially affect each of the five competitive forces. Thus even if technology does not yield competitive advantage to any one firm, it may improve the profitability or productivity of all firms in the industry. Therefore, it is important to consider the impact of technology to the entire industry when a firm sets its technology strategy.

Technology strategy has to be consistent with the firm's generic strategy. Inconsistency between technology strategy and generic strategy will result in lack of

commitment in every value activity toward either technological or generic strategic directions or both. As a result, a firm may lose its corporate identity and the attractiveness which appeals to its customers, and can neither gain nor sustain competitive advantage. Therefore, what kind of technology to pursue or develop should be determined based on the generic strategy of the firm and should be consistent with that strategy. In many firms, R&D programs are driven more by scientific interests than by the intention to seek competitive advantage. However, it is clear that the primary focus of a firm's R&D programs should be closely tied with the practical operation of the firm as seen in the case of lean producers.

In formulating its technological policy, the firm must make choices in at least the following six areas: ³¹

Selection, specialization and embodiment: what technologies to invest in? What technologies are promising from the perspective of the existing product line, or for new or related products? What technologies provide opportunities for improved product performance or lower product cost? What performance parameters should dominate? how should proposals for new technologies/products be evaluated?

Level of competence: how proficient to become in understanding and applying the technology? How close to the state of the art should the firm be in this technology to achieve its objectives in its products and markets, given the competitive environment? How much emphasis should be placed on advancing knowledge of the technology through basic or applied research, as opposed to straightforward applications of the technology through product development engineering?

³¹ Maidique, Modesto A., Patch, Peter, "Corporate Strategy and Technology Policy," 1978

Source of Technology: to what extent should external sources be relied upon, including contract research and licensing from individual inventors, research and engineering firms, or competitors? To what extent should we rely on internal development?

R&D investment level: how much to invest in these technologies? What level of internal staffing or external expenditure is appropriate? Do we let R&D investment or profit oscillate?

Competitive timing: should we lead or lag competitors in new product introduction? Does the benefit from leading competitors outweigh the risk of uncertain market acceptance of a new product? Are there benefits in allowing a competitor to go first, evaluating market acceptance of that product, and developing an improved product if market conditions warrant? What response is appropriate to a competitive product introduction?

R&D organization and policies: should there be a central R&D lab? How should it be structured? Should there be a separate career track for scientists? Should we use project teams? Or a matrix organization arrangement to allow sharing of scarce technical resources? Should we reward scientists and engineers with a level that is compatible with our industry? Or should we be leaders in compensation? How closely should top management be involved in technological decisions? What decision rules will we use to allocate funds to R&D projects? How should we protect our technological know-how? What should be our patent policy? Our publication policy?

Since technologies are becoming more and more diversified and advanced, it is virtually impossible to gain an unrivaled bargaining power from ordinary technological development efforts. Therefore, it is important to formulate specific technology strategy which is consonant with the firm's generic strategy. Although the majority of R&D

activities have been aimed at ways to reduce construction costs or improve productivity, it seems better for contractors to reverse their way of thinking and aim their R&D efforts at increasing the cost performance, or the added value, or adding value to their clients' value chain so that the profitability can be improved and overall competitiveness of U.S. construction industry will improve.

Internal R&D and Competitive Advantage

As discussed earlier, technological status is a very important determinant of competitive advantage for a firm against competitors, and research and development is essential to maintain or improve the firm's technological status. R&D is not limited to technology development. Service quality can also be enhanced through R&D. Although technology is essential to stay competitive, it is quite difficult to determine which technology to invest in and which research and development projects to pursue internally because of the uncertainty of the payoff inherent in the research and development or innovation. Research and development is an important part of support activities. In a broad sense, research and development is related to all primary activities as well as to other support activities and can enhance the performance of those activities. To understand the benefit of internal research and development, a firm must consider the role of R&D in the value chain of a firm as well as the impact of R&D on the buyers value chain.

Benefits of Internal R&D

Differentiation A firm cannot differentiate itself from competitors without conducting some research and development whether it is formal or not. As described earlier, this is the main reason why U.S. construction firms have become competitive on the basis of price and not on the basis of technology. In the United States, most of the construction related technologies have been developed in universities, research institutions, or outside of US. Since those technologies and knowledge are equally available to every

construction firm, it is extremely difficult to differentiate products or services technologically. As long as technological capability is not critical factor of competitive advantage, a strategy for not conducting R&D is not a wrong strategy. However, as construction projects become more complex and difficult, technological capability becomes critical in certain projects. Therefore, it is essential to invest in internal R&D if a firm seek differentiation.

Not to be differentiated by competitors This may not be a benefit of R&D but this is quite important from a strategic point of view. Being differentiated is worse than failing to differentiate because it means losing relative competitiveness compared with competitors rather than keeping the same level of competitiveness. This is extremely important determinant of committing R&D if a firm is competing with these competitors directly in the same market segment. It has been relatively easy not to be differentiated technologically by competitors since most of construction related technologies are widely available to anyone who wants through various media. However, this situation is gradually changing along with the advance of technologies, not only in construction industry itself but in other industries. Technologies are getting more and more complex and technological requirements are becoming more and more severe, and individual basis technical knowledge is becoming insufficient to keep up with the technological changes especially when a firm competes in a broad market. Being differentiated technologically will ultimately leads to the lose of market share especially in the market segments where highly advanced technologies are required. This tendency will be strengthened if some firms increase their commitments to R&D to differentiate themselves by technologically. For example, the heavy investment in research and development by Japanese major E&C firms may make it difficult for other firms to keep up with them technologically. Aside from appropriateness of applying their R&D strategies in U.S. construction industry, the speed of technology development of those Japanese firms seems to be faster than the American

counterparts. Therefore, if construction firms in the United States do not increase in their commitment to R&D, they will be differentiated technologically by those firms and will continue to lose their market share.

Fast technology transfer from basic research into practical application. One main reason why U.S. construction firms are lagging behind transferring research results into practice compared with Japanese competitors, is the absence of formal research and development within U.S. construction firms. Extensive development and testing are necessary for innovative research results to become practical. However, most of the research results in the U.S. are generated in universities and research institutes, and those institutes do not have strong incentives or the opportunities or facilities to conduct further development to apply those technologies to practical construction. Therefore, most of the practical developments must rely on industry level efforts. Japanese major E&C firms, on the contrary, heavily invest in the practical development of their research results. The consequence is apparent. Those who conduct research and development are faster in transferring research results into practice whether or not the basic research results are generated internally.

Fast response to problems. Another strength of firms who have an internal R&D function, is that they can respond to various kinds of technical problems faster than those who do not have. They can draw an state-of-the-art technological knowledge in their R&D division quickly and solve problems. This capability can enhance service quality, gain credit from customers, and differentiate the firm from its competitors.

Avoidance of duplicate efforts to solve problems. A firm can avoid duplicate efforts or redundant work to solve problems which arise during project execution, by using its R&D division as a integrated knowledge base which can suggest optimum solution to

the problems. Because of the project-oriented nature of the construction industry and the lack of formalization of knowledge, to execute each project and how to solve problems which arise, has largely relied on individuals' knowledge. This knowledge concerning solving problems and making incremental improvement in construction process technologies is generally in the mind of individuals. Close linkage between each project and an R&D division however, can help to collect and store this knowledge systematically and facilitate the more effective use of the knowledge on future projects.

Sensitive to technological change. The faster technological change occurs, greater becomes the need to be sensitive to technological change. Even if there are many prospective new technologies available, firms who are not conducting R&D are likely to be slower to implement those technologies in actual operation than their competitors who have R&D functional divisions internally. As long as projects can be completed using conventional technologies, there is little incentive to use new technologies which have risks and might fail. Thus many who do not conduct R&D may not be aware of the potential of new technologies. By the time they see the importance and the potential of new technologies, it is often too late to make use of them to gain a competitive advantage.

New market opportunity Sometimes during the process of research and development, researchers happen to come up with the idea of applying their findings to areas of business other than conventional construction projects. This creates a new business opportunity for a firm. For example, some firms are selling CAD applications or construction management applications which were developed internally, and some of these have become commercially successful. Although many of them are not yet commercially successful, construction robots are another possible example. Information technology would also create new market opportunities such as construction related database or usage of databases for facility management.

Reap first mover advantage A firm who is conducting research and development internally is likely to reap first mover advantages if it can successfully develop new technologies, new products, or new services. To keep these first mover advantages longer, continuous effort must be made to improve newly developed technologies, products, or services, otherwise, competitors will easily catch up and those first mover advantages will not become sustainable competitive advantages.

Reputation or recognition By conducting research and development internally, a firm may be able to gain reputation and recognition for its superior technological capability and can thus attract superior researchers and engineers. Those researchers would further strengthen the firm's technological capability throughout its operation and ultimately lead to differentiation.

Drawbacks of Internal R&D

The most significant drawback to internal R&D which is extremely difficult to handle, is the risk which arise from uncertainty. Firms can neither be sure whether they can succeed in developing new technologies or products nor whether those technologies or products will be paid off even if the development itself becomes successful. Since research and development require significant amount of capital investment as well as human resources, failure in research and development can be lead to disastrous results especially for small firms. Therefore, the increase in overhead cost, combined with the risks associated with R&D will significantly affect management decision making on the desirability of conducting R&D internally.

Another drawback of internal R&D is the possibility to lock into developing technologies that rapidly become obsolete. Firms who do not conduct internal R&D are relatively free to change from one technology to another, while those who do develop technologies or products are likely to adhere to their products and methods, and thus can

miss the the opportunity to adopt new and improved technology that has been generated elsewhere.

Chapter VI

CONCLUSION

Importance of Research and Development

The construction industry in the United States is losing its technological lead to European firms and Japanese firms and losing its market share in the international construction market as well as its own domestic market. The main reason for this trend is the lack of the industry's commitment to research and development. Because of this, U.S. firms are slower in transferring research results into practice. As technology advances and construction projects become more and more complex, industry-wide commitment to extensive research and development becomes necessary to remain competitive against foreign based firms. To continue to rely largely on university or research institutes to develop technological know-how, as has been quite common in the past will no longer work effectively to compete with foreign competitors. This is because of the slowness of technology transfer from basic research to practical application and the necessity of further development efforts to implement those research results into practice. Therefore, to prevent the U.S. construction industry from further loss in its competitiveness and market share, and to regain its technological leadership in the international construction market, it is essential that individual firms understand the necessity and benefits of internal research and

development and establish effective technology strategies which are consonant with their generic strategies.

Benefit of Internal Research and Development

The following major benefits can be gained from internal research and development.

Differentiation A firm cannot differentiate itself from competitors without conducting some research and development. As construction projects become complex and difficult, technological capability becomes critical in certain projects. Therefore, it is essential to invest in internal R&D if a firm seeks differentiation.

Defense against differentiation by competitors This may not be a benefit of R&D but this is quite important from a strategic point of view. Being differentiated is worse than failing to differentiate because it means losing relative competitiveness compared with competitors rather than keeping the same level of competitiveness. This is extremely important determinant of committing R&D if a firm is competing with these competitors directly in the same market segment. It has been relatively easy not to be differentiated technologically by competitors since most of construction related technologies are widely available to anyone who wants through various media. However, this situation is gradually changing along with the advance of technologies, not only in construction industry itself but in other industries. Technologies are getting more and more complex and technological requirements are becoming more and more severe, and individual basis technical knowledge is becoming insufficient to keep up with the technological changes especially when a firm competes in a broad market. Being differentiated technologically will ultimately leads to the lose of market share especially in the market segments where highly advanced technologies are required. This tendency will be strengthened if some firms

increase their commitments to R&D to differentiate themselves by technologically. For example, the heavy investment in research and development by Japanese major E&C firms may make it difficult for other firms to keep up with them technologically. Aside from appropriateness of applying their R&D strategies in U.S. construction industry, the speed of technology development of those Japanese firms seems to be faster than the American counterparts. Therefore, if construction firms in the United States do not increase in their commitment to R&D, they will be differentiated technologically by those firms and will continue to lose their market share. Increase in commitment to R&D can reverse this situation.

Fast technology transfer from basic research into practical application. Those who conduct research and development are faster in transferring research results into practice whether or not the basic research results are generated internally. One of the main reasons why U.S. construction firms are lagging behind in transferring research results into practice compared with Japanese competitors is due to the absence of formal research and development within U.S. construction firms. Extensive development and testing are necessary for innovative research results to become practical. However, most of the research results in the U.S. are generated in universities and research institutes, and those institutes do not have strong incentives or the opportunities or facilities to conduct further development to apply those technologies to practical construction. Therefore, most of the practical developments must rely on industry level efforts.

Fast response to problems. Another strength of firms who have an internal R&D function is that they can respond to and solve various kinds of technical problems faster than those who do not have. They can draw an state-of-the-art technological knowledge in their R&D division quickly. This capability can enhance service quality, gain credit from customers, and differentiate the firm from its competitors.

Avoidance of duplicate efforts to solve problems. A firm can avoid duplicate efforts or redundant work to solve problems which arise during projects execution, by using its R&D division as a integrated knowledge base which can suggest optimum solution to the problems. Because of the project-oriented nature of the construction industry and the lack of formalization of knowledge, to execute each project and how to solve problems which arise, has largely rely on individuals' knowledge. This knowledge concerning solving problems and making incremental improvements in construction process technologies is generally retained in the mind of individuals. Close linkage between each project and an R&D division however, can help to collect and store this knowledge systematically, and facilitate the more effective use of the knowledge on future projects.

Sensitive to technological change. The faster technological change occurs, greater becomes the need to be sensitive to technological change. Even if there are many prospective new technologies available, firms who are not conducting R&D are likely to be slower to implement those technologies in actual operation than their competitors who have R&D functional divisions internally. As long as projects can be completed using conventional technologies, there is little incentive to use new technologies which have risks and might fail. Thus many who do not conduct R&D may not be aware of the potential of new technologies. By the time they see the importance and the potential of new technologies, it is often too late to make use of them to gain a competitive advantage.

New market opportunity Sometimes during the process of research and development, researchers happen to come up with the idea of applying their findings to areas of business other than conventional construction projects.

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Reputation or recognition By conducting research and development internally, a firm may be able to gain reputation and recognition for its superior technological capability and can thus attract superior researchers and engineers. Those researchers would further strengthen the firm's technological capability throughout its operation and ultimately lead to differentiation.

Recommendation

It is obvious that construction firms in the United States will continue to lose their competitiveness against foreign competitors if the commitment of the industry to research and development remains at its present level. Therefore, it is essential for construction firms to increase their commitment to R&D. Based on this observation and the results of this thesis research, the following strategies are recommended in order to improve the technological competitiveness of U.S. construction firms.

1. Construction firms should identify the most critical technologies and increase the commitment to research and development in that fields.
2. Construction firms should strengthen their financial capability to conduct research and development by merger or technological alliances.
3. The U.S. construction industry should strengthen the relationships with universities and research institutes so that technology transfer from basic research to practical application becomes much smoother and faster.

4. Construction firms should conduct research and development programs closely tied with practical operations in the firm's entire value chain.
5. Alternative project delivery methods such as design-build contract should be encouraged.
6. Government should encourage industry level research and development by providing financial assistance such as tax incentives and low interest loan to those firms who conduct research and development.
7. Government should implement a technology approval system or other effective methods which can reduce the risks associated with the application of new technologies and innovative construction methods, or it should provide the opportunities to test new technologies and methods.
8. The pre-qualification system which the Japanese government is using for public work projects would also be helpful to encourage research and development.

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