CONSTRUCTION AUTOMATION: DEMANDS AND SATISFIERS IN THE UNITED STATES AND JAPAN

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ABSTRACT: Automation and robotics are often proposed as solutions to problems in productivity, quality, safety, and skilled-labor availability in the United States and in Japan. In recent years, many prototype robots have been developed, but few practical examples can be found on construction sites today. Nevertheless, several large Japanese contractors are aggressively pursuing research and development (R&D) programs to introduce robots on construction sites. United States contractors exhibit little interest. This paper evaluates construction automation and robotics in the context of their ability to satisfy the often conflicting demands of managers and owners, workers, and society in the United States and in Japan. In the United States, there is weak demand for construction automation and robotics. In fact, there may be considerable resistance. In Japan, there is a great deal of demand for automation and robotics, much of it coming from workers and society in general. Differences in cultural, economic, and business practices help explain why construction automation and robotics are generating so much activity and investment in Japan and so little in the United States.

INTRODUCTION

The construction industries in the United States and Japan face problems in productivity, quality, safety, and skilled-labor availability. Automation and robotics are often proposed as solutions to some of these problems.

In recent years, many prototype field robots have been developed, but few practical examples can be found on construction sites today. Nevertheless, several large Japanese contractors are aggressively pursuing research and development (R&D) programs to introduce robots on construction sites. United States contractors exhibit relatively little interest.

Adoption of new technologies is driven by technology-push, by demand-pull, or by a combination of both mechanisms. Technology-push is the supply side of innovations and refers to new technologies that create new markets or offer improved methods for performing existing tasks. In this case technology guides or influences the nature of the problems posed. Construction automation and robotics technology available in the United States and Japan are similar, so it cannot be differences in technology-push that are creating such a disparity in interest between the United States and Japan.

Demand- or market-pull is the demand or "necessity is the mother of invention" side of innovation. Here the problem leads the solution (Nam and Tatum 1992; Rosenberg 1982).

To help understand the different motivation for robotics R&D between the United States and Japan, it may be useful to analyze the demands for construction automation and robotics by three different groups in each country: construction managers and owners; construction craft workers; and the construction industry in general and society at large. Each group's demands are different from and often in conflict with the demands of the other groups. The demands are also different in the United States than they are in Japan. By comparing the demands of the three groups to the potential for satisfying the demands, insight can be gained into opportunities and obstacles for promoting automation and robotics research, development, and implementation.

The objective of this paper is to compare the demands of the three groups to the potential for satisfying these demands offered by automation and robotics technology in the United States and Japan. The paper attempts to explain the apparent difference in attitude toward automation and robotics R&D and adoption. For each group in each country, the demands and potential satisfaction of the demands are rated on a three-point scale of weak, moderate, and strong.

MANAGERS'/OWNERS' DEMANDS

Construction managers and their clients, the owners, have been grouped together because they are both primarily interested in profitability and satisfactory business performance of specific construction projects. With respect to automation and robotics, managers' and owners' demands include increased productivity, increased speed of construction, improved quality, improved safety, constructibility, and project economy (Arditti et al. 1990). There is little difference in the types of demands between managers/owners in Japan and those in the United States, although the magnitudes may be different.

In Japan, managers and owners expect the same success story for automation and robotics in the construction industry that has occurred in the manufacturing industry. Moreover, competition to increase market share and project a positive corporate image drives Japanese contractors. Despite owners' demands for more cost-effective construction, U.S. managers traditionally have had less positive attitudes toward new technology than their Japanese counterparts. In the United States there are no leading companies like the Japanese "Big Five" who push the industry by their competition and leadership.

Tucker (unpublished paper, 1991) reports that U.S. construction industry leaders perceive robotics for off-site modular fabrication and linkage between computer-aided design

TABLE 1. Demands and Satisfiers for Construction Automation and Robotics in the United States and Japan

Group (1)	Demand or satisfier (2)	United States (3)	Japan (4)
Manager/owner	Demand	Weak	Moderate
	Satisfier	Weak	Weak
Workers	Demand	Weak	Moderate
	Satisfier	Weak	Strong
Social	Demand	Weak	Strong
	Satisfier	Weak	Strong

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(CAD) databases and shop robots to be important. At the same time, they do consider field robotics to be an important technology in addressing industry problems.

Table 1 indicates these attitudes by scoring the intensity of managers'/owners' demand for automation and robotics as weak in the United States and moderate in Japan.

WORKERS' DEMANDS

Generally, workers are primarily interested in job security, wages, safety, and decent work conditions and, particularly in construction, the reduction of heavy lifting and dirty, repetitive, and dangerous work.

Several years ago, "3K"—derived from *kitsui* (physically hard work), *kiken* (hazardous), and *kitanai* (dirty)—became a fashionable term in Japan. 3K implies an unattractive job for young people. Construction is said to be a typical 3K industry. In Japan, although workers enter the construction industry knowing that the work will be physical demanding, hazardous, and dirty, the desire to improve the current working conditions represented by 3K is becoming stronger because working conditions in other industries have improved rapidly. In the United States, not much attention is paid to 3K conditions. Poor working conditions and high injury and fatality rates are frequently considered to be part of the job.

In Japan, most construction workers belong to an enterprise union (company union) that represents both blue- and white-collar workers. Lifetime employment and the seniority system of enterprise unions creates a much different relationship between workers and management in Japan compared to the United States.

In the United States most construction workers belong to a craft or trade union or to no union. In either case, there is little job security and seniority. Workers move from employer to employer frequently, so there is little identification of worker with employer. In general, the relationship between workers and management is much more cooperative in Japan than in the United States, though this cooperative relationship sometimes makes union bargaining power weaker.

This cooperative relationship comes from unique union and business systems in Japan. The union shares its fate with its company under the enterprise union system, so the union's advantage in wages, working conditions, and job security depends heavily on the company's business condition and success. Because Japanese people hold strong negative images of labor disputes, good relationships with the unions are vital to management in maintaining a customer's and consumer's positive image of the company. Also, due to the lifetime employment and seniority system, most managers were members of the union in the past, so they have some sympathy toward the union. Enterprise union members have little fear of losing their jobs to machines. Japanese workers are generally positive in their attitude toward automation and robotics (Muro 1990).

In the United States, the building trade unions have generally been less than receptive toward new technology. Traditionally, the relationship between managers and unions has been adversarial. One of the principal goals of U.S. building trade unions and their members is job security. Labor-saving technologies are often greeted with strong institutional and individual resistance. "Labor agreements . . . have also delayed the use of new technology in some communities ("Technological" 1986). For example, the Washtenaw County (Michigan) Laborers' agreement states; "Use of new labor-saving devices and equipment shall . . . become a matter of economic interest to the union . . . ." (*1994–1997* 1994). Lane Kirkland, longtime president of the American Federation of Labor-Congress of Industrial Organizations (AFL-CIO) said; "So long as the quest for improved productivity is perceived as either a device to make workers toil harder and longer or simply a means for higher profit, then workers will resist. And we in the labor movement will be leading that fight," (Kirkland 1980).

It is expected that the introduction of robotics and automation in the construction industry will arouse considerable resistance among U.S. union workers despite potential benefits for workers, such as reducing accidents and improving working conditions. Navon et al. (1992) discuss several human barriers to the implementation of automation and robotics, including fear of unknown changes, perception of the threat of losing jobs or skills, fear of the inability to handle new requirements, and inadequate understanding of the need for change.

Table 1 indicates these attitudes by scoring the intensity of workers' demand for automation and robotics as weak in the United States and moderate in Japan.

SOCIAL DEMANDS

The biggest difference between the U.S. and Japanese demand for automation and robotics is seen in social demands.

In Japan, the 3K image of construction is not only perceived by the workers, but is also strongly felt by the industry in general, the government, and by the public. The negative image of construction has led to severe shortages of skilled workers, thereby increasing wages and the cost of construction. The Japanese policy of not allowing "guest" workers from other countries into Japan exacerbates the problem.

A Japanese Ministry of Construction (1990) white paper identifies skilled-labor shortages as one of construction's main problems requiring immediate action. The Ministry of Construction planned the Industrial Structure Reformation Program in 1989 to improve productivity and help recruit young construction workers (among other goals) (Ministry 1990). One would expect robotics and automation to be an essential theme in the improvement of productivity and production processes. However, automation and robotics is also viewed as an important component in the drive to improve working conditions and upgrade the industry identity to help attract young people.

To accomplish these goals, the government allows favorable treatment in taxation (e.g., a special depreciation method) to encourage the introduction of construction robots. Further, financial aid for R&D in construction automation and robotics was started by the Construction Development Foundation.

The federal government plays an important role, conducting its own R&D and coordinating private industry's research efforts with administration and legislation. Professional societies such as the Building Contractors Society, the Architectural Institute of Japan, and the Japanese Industrial Robot Association characterize R&D in Japan. They have been eager to commit to automation and robotics in construction because this topic seems to be indispensable for the industry's future. The societies have formed active research committees consisting of engineers and researchers from contractors, universities, and governmental laboratories. R&D topics focus mainly on needs, feasibility, and opportunity analysis, and evaluation of robot systems. Committees exchange information, form industrial consensuses, and establish future R&D directions.

However, most R&D is conducted in-house by large contractors. The Big Five contractors each invest more than $100,000,000 per year in R&D, although this is a relatively new trend. Their R&D investment started to increase sharply around 1980. Hasegawa and Shimizu Group FS (1988) explains this phenomenon with the following five reasons. First, the heated competition caused by the market slump after the second oil shock in 1979. Contractors were eager to develop low-cost organizational structures and cost-saving construction techniques. Second, the development of high-technology in-

dustries, such as electronics and precision machinery that required contractors to upgrade their technical capabilities (e.g., clean rooms). Third, the wide spread of high technology, especially information and communication systems, into society. This aroused the demand for high-tech facilities in construction (e.g., intelligent buildings). Fourth, the energy- and resource-saving demand. Clients became eager to save energy and resource costs after suffering two oil shocks. Fifth, the desire to meet the technological requirements for expected big projects such as the New Kansai International Airport and Trans Tokyo Bay Highway (Hasegawa and Shimizu Group FS 1988). These reasons continue to encourage R&D investment today.

Another reason comes from the industrial nature and structure: the difficulty of increasing market share in both public and private work. Japanese central and local governments and other affiliate organizations employ a prequalification and designated bid and tender system. Only a limited number of designated contractors are invited to the bidding. The ability of contractors compared to the scale and technical difficulty of the work is the main consideration for the contract award. Contractors' capabilities are evaluated based on the contractor's experience and accomplished work volume in the past in similar work. The chance of designation depends on past market share, making it difficult for a contractor to increase its market share in publicly funded construction.

In private construction, long-term client-builder relationships and strongly tied business groups with historical origins in the plutocracy before the Second World War exist in the Japanese business world. These groups impose barriers for outsiders, making it difficult for a contractor to find new clients.

It is not easy for contractors to increase their market share in either public or private work. However, if a contractor develops original new technology, it can attract new clients. Also, new technology can generate new construction demand and create a new market. Conversely, if a contractor falls behind in technology competition, it may mean loss of market share.

Levy (1990) pointed out another reason for large investment in R&D. Japanese contractors expected that the domestic market would be open to contractors from other countries and competition with foreign companies would be unavoidable. Japanese contractors wanted to bring their companies to the cutting edge of construction technology (Levy 1990).

Yamada (1992) explains that R&D is also used as a kind of corporate-image strategy. By appealing as a frontier of new technology, contractors try to polish their images. R&D plays a role in advertisement and public relations. This aspect is closely related to the "industry identity" and one of the forces to encourage robotization and automation. Yamada reported that the investment for R&D in construction is still strong in spite of the recent recession in Japan. Though some manufacturing, steel, electric, and chemical industries reduced their R&D investment in fiscal 1992, the construction industry increased its investment (Yamada 1992).

Corporate identity (CI) programs have become very popular in the past several years in Japan. CI seeks to represent and communicate corporate philosophy and culture with logos, trademarks, symbols, and slogans. A good corporate image helps influence people inside and outside the corporation to behave according to the corporate strategy (Yamada 1986). Some reasons for the introduction of CI are changes in management policies, diversified management expansion of the enterprise, the old-fashioned corporate image, and new sales and marketing strategies. CI also attempts to increase morale in the company by increasing an employee's motivation and loyalty to the company (Yamada 1986). Many leading companies in the construction industry implement CI programs. Some have removed the word "construction" from their trademark. For example, one of the Big Five, Kajima, changed its official name from Kajima Kensetsu (meaning construction) to Kajima. They appear to be trying to rid themselves of old-fashioned images of construction. Many contractors have launched new businesses such as hotels, restaurants, golf clubs, sports-club operation, and sales of construction software.

Leading companies also invest in advertising to improve their images. Some major contractors such as Shimizu, Taisei, Hazama, Ohbayashi, and Nishimatsu run commercials on television, and Kajima sponsored a race car (Korman et al. 1992).

While social demand for construction automation is strong in Japan, it is weak or nonexistent in the United States. Labor saving is not a strong social demand because skilled-labor shortages are limited to certain trades in certain geographical regions. In the United States, the usual suggestion to reduce skilled-labor shortages is to train the abundant supply of unemployed workers, instead of building expensive machines that will only put more people out of work. The U.S. construction labor force has traditionally been composed of white males. Minorities and women represent a huge untapped pool of potential construction workers. This is in contrast to the Japanese situation of not having enough people to fill the positions without going outside the country.

The U.S. construction industry has no unified voice in public policy and has no organized industry-image-improvement program. Although the U.S. domestic market is steadily being penetrated by foreign firms, the industry as a whole does not seem to pay much attention. The U.S. government is generally not eager to conduct R&D in robotics and automation, because these technologies are perceived as being the concern of private industry. Providing job opportunities is far more valuable politically than investing in technology that may be perceived as a threat to constituents' jobs.

A few samples of social demand for construction automation and robotics do exist in the United States. The hazardous environments of the Three Mile Island nuclear power plant prompted the only example of well-organized R&D efforts by the government, private sectors, and university community. The government (Department of Energy), Electric Power Research Institute, and General Public Utilities Corporation funded the recovery work robot development performed at Carnegie Mellon University ("Japan" 1983). The Carnegie Mellon University researchers developed the remote work vehicle for the cleanup, treatment, and transport of materials for structural surface decontamination.

In addition to nuclear power plant recovery and demolition work, underwater and outer-space work, and hazardous-waste cleanup have gained the attention of the U.S. government. Demand for outer-space construction is currently limited to the federal space program. Cleanup of hazardous waste promises to be a growth industry and will likely include increased emphasis on machines rather than on human workers.

Table 1 indicates these attitudes by scoring the intensity of social demand for automation and robotics as weak in the United States and strong in Japan.

DEMANDS VERSUS SATISFIERS

Demand for automation and robotics in construction represents only half of the picture. To gain acceptance in the workplace, the new technologies must somehow satisfy the demands for them. Technology-push alone has not led to significant adoption of automation and robotics technology in construction.

The emphasis in studies of automation and robotics has been on identifying opportunities, assessing the technological and economic feasibility of automation and robots, and developing

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prototype hardware and software. Most of the robots and highly automated machines developed to date have been designed to perform tasks that are physically demanding, where labor shortages are critical, where high accident rates are expected, and where the required performance functions cannot be met by current technology.

Few practical or cost-effective examples of construction robots can be found today, yet there remains a substantial interest in the U.S. research community, and tremendous R&D activity by the large Japanese contractors. There must be other drivers keeping all this activity and investment alive.

By analyzing the ability of automation and robotics to satisfy various groups' demands, it becomes clear why automation and robotics is such a hot topic among the large Japanese contractors and of so little interest to U.S. contractors and government.

MANAGERS'/OWNERS' SATISFIERS

For both U.S. and Japanese managers, the important issues are improved productivity, improved speed of construction and, possibly, improved quality and safety. Owners seek "a facility that is safe and meets economic, functional, and aesthetic criteria," (Nam and Tatum 1989). Despite the introduction of many well-publicized prototype robots, there have been very few examples of robots that can compete favorably with human workers. In both the United States and Japan, the ability of automation and robotics to satisfy owners' and managers' demands has been weak.

"From the managerial viewpoint, the goal is not to robotize, but to reduce cost and increase value produced," (Koskela 1992). There are alternative or competing technologies and strategies to automation and robotics to improve safety, quality, productivity, and labor shortages. One could argue that, at least in the United States, these alternative strategies have received limited application as well.

WORKERS' SATISFIERS

In the United States, workers' demands are primarily job security and wages, with working conditions being secondary. Automation and robotics are a perceived threat to job security and wages, even if they help improve work conditions, so workers' satisfiers are given a weak rating.

In Japan, improved working conditions are considered very important, while job security and wages are less important. Even management feels that working conditions for the craft workers are important. "At present, leading contractors have been actively engaged in the development of robots designed to free human workers from unpleasant work, rather than to raise productivity," (Hasegawa et al. 1988). Automation and robotics are perceived to be of great benefit to workers and there is little resistance to their introduction, so Japanese workers' satisfiers are given a strong rating.

SOCIAL SATISFIERS

In the United States, there is little social demand for robots. Neither the government nor the construction industry appears to have much interest in supporting R&D or helping promote new construction technologies, except for the few highly specialized examples mentioned earlier. United States social satisfiers are given a weak rating.

In Japan, there is a great deal of social demand for automation and robots in construction. R&D is perceived to attract workers to construction, improve individual corporate images as well as the industry identity, and create new markets for construction. Even if no practical robots are developed, the impression that contractors are conducting R&D satisfies social demands. Japanese social satisfiers are given a strong rating.

SUMMARY

The results summarized in Table 1 offer an explanation of why automation and robotics are such a hot topic in Japan. Despite the relatively weak ability of automation and robotics to satisfy owners' and managers' demands of higher productivity, improved speed, quality, and safety, the strong ability of these new technologies to satisfy workers' and social demands more than compensates for current economic and technological shortcomings.

In the United States, there is little demand for automation and robotics. In fact, there may be considerable resistance. Workers' and social demands are quite different from those in Japan, and automation and robotics do not satisfy what demands do exist in the United States.

A recent example of new construction technology incorporating automation and robotics illustrates the cultural and economic differences in construction between the United States and Japan. The automatic building construction system aims to turn the construction site into a factory for the assembly of prefabricated components (Skibniewski and Wooldridge 1992). Similar systems have been developed by the Japanese firms of Takenaka, Taisei, Shimizu, Ohbayashi, Toda, Maeda and Kumagai-gumi.

This system has been developed to save labor, shorten construction time, and create a factory-like working environment. Normile (1993) reported that the Smart system by Shimizu will cut by 30% the number of man-hours required to complete a 20-story building, and the T-up system by Taisei will cut the construction time of a 33-story building from 30 to 24 months. With an indoor construction environment, quality improvement is easier, and stable and regular schedules for workers are possible. The ultimate aim of this system is to automate the entire system.

No one claims that these systems have lowered contract prices for owners, but immediate cost savings are not necessarily the highest priority. Shimizu's Yasuyoshi Miyatake is quoted in *Engineering News Record* as saying, "The biggest problem the industry faces is the labor shortage," and "Eventually, cost savings will flow from manpower and time reductions," (Normile 1993). Japanese contractors, with the support of owners, are willing and able to invest in full-scale experiments because the bottom line on the current project is only one aspect of their business. In the U.S. construction culture, it is difficult to imagine an owner willing to subsidize such experimentation, or a contractor willing to invest/gamble so heavily on new technology.

CONCLUSION AND RECOMMENDATIONS

This paper has evaluated construction automation and robotics in the context of their ability to satisfy the often conflicting demands of managers and owners, workers, and society. The technology available to U.S. and Japanese construction managers and owners is similar, so it cannot be differences in technology-push that are creating such a disparity in interest between the United States and Japan.

In the United States, there is little demand for construction automation and robotics from any of the three groups, and it is not surprising that technological developments have had difficulty gaining acceptance at the worksite. In Japan, there is a great deal of demand-pull for automation and robotics, much of it coming from workers and society in general. Technological developments have shown a strong ability to satisfy workers' and social demands, even if managers' and owners' demands have not been well-satisfied. Differences in cultural,

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economic, and business practices explain why automation and robotics are generating so much interest, activity, and investment in Japan and so little in the United States.

It is hoped that this paper will encourage discussion on what, if anything, should be done to promote an increased interest in construction automation and robotics in the United States.

If and when automation and robotics can perform faster, or at a lower cost, or at a higher quality than current means and methods, construction managers and owners will adopt the new technology. They will have to in order to remain competitive.

In the meantime, researchers and developers who want to promote automation and robotics in the United States should also address the concerns and demands of workers and society. As long as any new technology is seen to increase productivity and profits at the expense of the craft workers, then workers and influential elements of society will oppose the technology. If automation and robotics is perceived to improve job security, wages, safety, and work conditions, then workers and society will be more likely to demand automation and robotics.

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