The 9th International Symposium on Automation and Robotics in Construction June 3-5, 1992 Tokyo, Japan

ECONOMIC EVALUATION OF ROBOTS IN CONSTRUCTION

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ABSTRACT

The purpose of this paper is to introduce the potential application of robotics in the field of construction. Recent applications of robotic technology have been explored in light of its economic viability. The decision to introduce a robot into the construction work place must be carefully analyzed since the potential cost of introduction goes far beyond the initial capital purchase. Some of the elements of robot costs include the capital cost, the costs of transportation, installation, operation and maintenance, insurance, staff training and awareness, etc. Other socio-economic concerns are also discussed. A justification for introducing robots in light of reduction in health hazards, increase in work productivity, labor cost savings is presented. There is a great potential for using robots in certain construction activities which will result in higher productivity. Furthermore, it is economical to use robots in a series of simple and repetitive work tasks.

INTRODUCTION

The purpose of this paper is to present the potential economics of the application of robots in relevant construction-related activities. The paper will further detail the status of robots in Japan, as well as the United States.

In the U.S., there are future potential markets for robot application in construction work. The costs of construction in terms of human-related accidents are very high, and construction liabilities are a growing problem in the United States. There is enough medical- and safety-related evidence to support the assertion that certain construction-related activities pose substantial human health and safety problems. Some examples are the sandblasting process, excavating deep trenches, deep-sea work, desert work during sandstorms, mining, some cleaning operations, and framing steel high in the air in the cold of winter in such places as Chicago, Tokyo, New York, etc.

There are many other areas where robots could play major roles in reducing human hazard and increasing safety, e.g., robots could assist in cleaning toxic waste dumps, repair work at nuclear power plants, removal of sunken nuclear warheads from the sea bottom, etc. Recently, the President of the United States called for an 11 percent increase in funding to $2.25 billion for the space station in order to promote robotic missions in paving the way to man's return to the moon and he urged support of a hefty spending increase to develop the $30 billion station, Freedom.

Also in this paper, an example of the benefit-cost justification of introducing robots is presented along with an analysis of the effect of robot application on labor costs.

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LITERATURE SEARCH

The term "robot" was coined in 1923, and since that time the number of robots has grown. The concept of substituting robots for human labor in certain construction activities has been around for many years. Today, on more than 50 construction sites in Japan, robots are used for the final troweling of concrete floors[6]. Most of Japan's robot research was begun at Waseda University System Science Institute in 1978 under a program known as WASCOR and is supported by private and public funding. Japan's Ministry of International Trade and Industry and another organization named JIRA (Japan Industrial Robot Association) specifically separates and supports construction-related activities that can be performed by robots. The first true robot produced through this program was the SSR developed by Shimizu in 1983. It was designed to spray fireproofing material on steel beams[6].

Japan has recognized the importance of the application of robots in construction activities. The Japanese are aggressively looking at the long-range future benefits of robots in the construction field. Their imagination and foresight in the area of robotics is similar to that of their computerization of the world's automobile industry. Their products are well-tested and of high quality, and have captured the world market. The Japanese recognize that more than 15 percent of the gross national products of the U.S. are produced with construction-related activities. For instance, in 1991 overall construction activities in residential, non-residential and government spending totaled a seasonally adjusted annual rate of $404.9 billion according to the Commerce Department report[2].

Japanese industry is on the right track in striving to develop robots that can complete many tasks. Shimizu has now developed a multipurpose vehicle named MTV1. It includes a powered mobile-control module, sensors, navigation devices and controllers, and it performs various floor-finishing operations[6]. The long-range 25-year research and development plan of the Japanese will definitely benefit the world's construction industry and will undoubtedly capture the world market in robotics just as their auto industry did.

In the United States, the number of robots grew from 200 in 1970 to more than 100,000 at the present. There are 20 to 25 academic research centers and government science laboratories, along with a similar number of commercial enterprises, that experiment with robots. The volume of government-sponsored research in robotics in the U.S. was about $20 million in 1982[3]. According to a January 1992 CBS Evening News report, the U.S. lags behind Japan, Germany and Sweden in related research and development activities. The high cost of labor in the United States is part of the cause, compounded by construction safety, the legal aspects of construction liability, and decreasing productivity. The United States must recognize increasing foreign competition, improve quality control, increase productivity, and deal with the high cost of insurance liability and safety.

In the U.S. robotic development efforts are focused on new technologies such as artificial intelligence, robotic vision and parallel processing computer architecture[8]. Currently, there are three levels of robots in the U.S.: 1) tele-operated which are controlled from a remote site; 2) programmed robots with a program installed in the machine; and 3) cognitive robots that have the ability to sense, interpret, and evaluate their surroundings[8]. An example of the latter, is the John Deere 690C Excavator used by the U.S. Air Force to repair runways during bombing raids. Use of the 690C in earth-moving operations in combat areas, handling of hazardous materials and clearing of mines has been studied[8].

Carnegie-Melon has developed REX which is used to unearth pipelines, especially in areas where explosive gases are present[8]. Carnegie-Melon has identified other potential utilization of REX such as spray washing, wall finishing, material application and sandblasting[8]. ICADM (Investigating Construction Automation Design Methodology) of the Massachusetts Institute of Technology is a robot first applied in the construction of interior wall partitions which represents about 10% of the cost of commercial building[8].

The task of building the interior wall partitions was divided between two separate robots, "the trackbot and the studbot. The trackbot is separated into two parallel working stations, an upper station for the ceiling track and a lower one for the floor track, and is guided by a laser beacon aligned by a worker. Detectors are mounted on the ends of the effector arms to ensure the laser guidance achieves the necessary precision. The placement of the track is made in four steps: The effector arm grabs a piece of track and positions it. Two pneumatic nail guns fasten the track, and then the trackbot moves forward, stopping twice to add additional fasteners. Once the trackbot has completed a run of track, the studbot can place studs. Location assessment is made by following the track and employing an encoding wheel or electronic distance measuring instrument. The studbot then references a previously stored floor plan to ascertain locations of studs to be placed. The positioning arm then spotwelds the stud into place.

The total cost for building the two machines is $40,000; the combined maintenance is $20,000 per year. Each machine has an operative life of five years, and each operates at 2 ft/min. Each operates only 16 hours/week, and each requires 40 man-hours/week for operation and maintenance. It has been determined that walbots can save more than a dollar per lineal foot, and can complete approximately <u>four times</u> the length of hallway that a two-man crew can in a 40-hour week.

MIT researchers are also developing the blockbot, which is designed to complete the repetitions and labor-intensive work in constructing masonry walls. It is currently envisioned that the complete wall assembly system will consist of four major components:

- A six-axis "head" that will actually place blocks in the wall;
- A 20-30 ft hydraulic scissor lift used to coarse position the placement head both vertically and longitudinally;
- A large-scale meteorology system, sensors, and other related computer control equipment; and
- A block feeding system/conveyor belt to continually supply the placement head"[8].

It is essential for the American construction industry to increase robotics research and development to be able to compete with the Japanese and Europeans.

JUSTIFICATION FOR USING ROBOTS

Integration of robotics into the manufacturing industries, particularly in the automotive industry, is widespread. Construction applications of robots are still in the preliminary research stage. The application of robotics into the construction industry will be influenced by technical, financial and cultural considerations[10].

Application of robotics in construction can reduce construction labor costs and increase productivity. Construction work is strenuous and often performed under harsh and hazardous conditions, which require high wages, high insurance rates and large economic losses due to work accidents[4]. On the other hand, the shortage of skilled workers is a problem[10]. A robot is capable of working in foul weather, darkness, hazardous areas, and without problems of motivation and administration which affect the efficiency of humans.

Robotized construction can expand the scope of construction operation to very difficult environments[4,6]. For instance, safety will be the primary reason for developing construction robots to work in harsh environments, high and deep places, undersea, radiation zones and nuclear plant construction.

Construction robots can perform many tasks of a repetitive and monotonous nature. The traditional work force is aging and new entrants choose jobs which are more suitable to their interests. This is a prime reason for future robotics to replace certain parts of the human work force.

COST AND BENEFIT OF USING ROBOTS

The success of robotics in the construction industry depends on their value to the construction contractors and the cost of using robots. From the contractor's viewpoint, economic evaluation is performed by comparing a cost analysis of nonrobotic versus robotic work alternatives[7].

The cost of the robotic approach in performing a construction task includes all cost components necessary to perform the task with use of the robots, such as labor, material, robot setup, dismantling and operation. Robot cost can be divided into two categories: capital costs and operating and maintenance costs.

Major capital cost items include the purchase of hardware and software, initial training of the operating personnel, changes in the physical environment of the worksite necessary for robot implementation, special work tools, accessories, monitoring and control equipment fees.

Robots, like other equipment, will exhibit a useful life and it is ordinary practice to depreciate the investment over this useful life. The anticipated economic life of 5-10 years for industrial robots may be somewhat shorter for construction robots operating under rugged environmental conditions. In most instances, straight-line depreciation is used.

The operating and maintenance costs of the robotic equipment will depend on the exact characteristics of the machinery and of the maintenance performed during operation. The items on the list of these costs include the robot setup, operation, dismantling and transferring fees.

For the economic evaluation of using robots in building construction versus conventional nonrobotic methods, we must use the same standard. To compare costs, we must convert costs into unit costs of a given building task performed by both robotic and nonrobotic methods.

ECONOMIC EVALUATION EXAMPLE

Economic evaluation of robotic use is illustrated in an example of construction of interior wall partitions.

Costs using conventional, nonrobotic method.

From Means Construction Cost and Data (1991), we can find the standard costs[5]:

Crew:	2 carpenters
Wage:	$21.60/hr
Output:	5 L.F./hr
Material cost:	$30/L.F.
Equipment cost:	$0/L.F.
Total Unit Cost =	$38.65/L.F.

Costs using the robotic approach.

Robot is taken as on kind of equipment[5,8].

Robot name:	Walbots (developed by MIT)
Investment cost:	$40,000
Maintenance:	$20,000/year
Interest rate:	10%
Useful life:	5 years
Annual work hours:	800 hr/year
Output:	20 L.F./hr
Crew:	2 workers
Wage:	$17.5/hr
Material cost:	$30/L.F.
Assumed salvage value:	$0

Capital cost = depreciation cost + investment cost = $13/hr
Operating cost = maintenance cost + power cost + labor wage
= $61/hr
Total unit cost = $33.7/L.F.

Comparing the total unit costs of robotic and nonrobotic alternatives, we find that the robotic approach is more economic.

CONCLUSIONS

This paper discussed the necessities of development and application robotics in the construction industry. The financial benefits, the shortage of a skilled work force, the need for an increase in construction productivity and the safety and health requirements are the main considerations for developing construction robots. An example of performing the construction of interior wall partitions using both robotic and nonrobotic approaches is presented and evaluated, with the finding that the robotic approach was more economic in performing the task. It is concluded that robotics have a potential for higher productivity and are more economic in a series of simple or repetitive tasks.

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