Quality and Reliability as Motivation for Construction Robotics

Dwight A. Sangrey
Carnegie-Mellon University

Abstract

Introduction

The concept of developing highly automated tools and techniques for applications in construction, including construction robots, is maturing. Along with more experience, the motivation which justifies this application is becoming clearer. Some preconceptions from the recent past are being supported by current experience - some are not. One motivating factor which is emerging as even more significant than was anticipated is the issue of reliability and quality of the construction.

Japan is often used as a model in discussions of reliability and quality, especially in manufacturing. These issues are also important in Japanese construction. A recent issue of *Engineering News Record* (2) illustrates the motivation for Japanese constructors with its title "Japan: World Marketers of Construction Quality and Innovation". The Japanese Ministry of International Trade (MITI) strongly encourages Japanese industries, including construction industries, to take advantage of the real and perceived image of high quality Japanese products. Another common example is the extensive program of quality assurance - the TQC programs - being used in Japanese industry (4).

In recent visits to Japanese construction companies, the author has found that these same factors are operating. The Japanese Union of Scientists and Engineers (JUSE) awards an extremely prestigious prize for implementing effective TQC programs in Japan. The Deming prize was first awarded to a construction company five years ago and is now much sought after as a prestigious recognition for construction companies.

In personal meetings and interviews with Japanese constructors, the close tie between quality and robotics was obvious. Kajima Corporation's President, Dr. Rokuro Ishikawa, a frequent spokesman for Japanese construction industries, was specific in noting that "robotics is one way to achieve high quality and reliability". A senior official of Taisei Corporation explained that for his company, "higher quality and lower cost meant advantages for owners, prime and subcontractors, through use of robotics".

The ultimate expression of this Japanese attitute toward robotics and quality is the perceived comparative advantage of providing a high quality product. As an example, many Japanese companies offer impressive warranties on their construction work. Sekisui Chemical uses robotics and other quality improvement techniques to manufacture residential housing. These housing units carry a 100%-10 year warranty. This principle extends beyond domestic manufactured housing, however, and is most impressive in international construction. Several major Japanese companies described their policy of offering major construction (especially for international markets) with complete warranty up to 30 years. They see this warranty, and its associated high quality, as a principal advantage for their company in international competition.

The objective of this paper is to systematically examine the attitudes and experiences relating to quality and reliability as a motivation for construction robotics.

The Importance of Quality in Manufacturing with Robots

Quality as an issue in manufacturing automation, including manufacturing with robots, has been with us for a long period of time. Examples from this history are relevant to construction robotics. Programs to improve the quality of manufactured products have long been recognized as an important part of successful manufacturing. Simon in *The Shape of Automation* (6) intimately links the principle of comparative advantage with the role of quality and reliability in manufacturing. More recently in the popular book by Peters and Waterman, *In Search of Excellence*, the theme of high quality is woven throughout their arguments. They highlight this principle in their conclusion that "one of the basic tenets of excellent companies is a belief in superior quality and service". They have a delightful example of this in a discussion of the reliability of Maytag washing machines in "the man who keeps those Maytag repairmen lonely".

How to achieve quality in manufacturing, however, has not been a simple issue. There have been significant changes in thinking during the past two decades. The traditional approach is quality control. As described by Hagan in *The Management Role for Quality Control* (3) "the keystone is inspection". However, he goes on to note in this 1968 publication that "no inspection system was ever designed to check every quality characteristic of every product. Any attempt to do so would be not only economically unfeasible, but also foolish and, in many instances, physically impossible." Hagan's 1968 technology required that conclusion, but innovation during the past years has made this principle invalid for the 1980's.

A definitive study of robotics and manufacturing is *Robotics: Applications and Social Implications* by Ayres and Miller (1). In this 1983 book, the authors report on an extensive and well designed survey of applications of robotics in manufacturing, principally in the United States. The impact of this new technology has brought about significant changes in the way users conceive the principle of quality and reliability.

Part of their book is based on the detailed survey of 40 major U.S. manufacturers. Among the questions in this survey was a request to rank the factors which motivated the use of robots in manufacturing by these 40 companies. The results of this survey are presented in Table 1. It is important to note that these data were collected for two populations. Some of the companies had been involved only with the retrofit of existing manufacturing facilities through the addition of automated and robotic equipment, the other group was applying robots in new factory applications.

An analysis of the motivation for applying robots in new factories is somewhat different from the general conclusion, Table 2.

Ayres and Miller reached several conclusions which are highlighted in Table 1 and Table 2. They noted that:

- product quality is highly ranked as a motivating factor for applications to robotics

- some respondants indicated that "arguments about improving product quality or increasing production flexibility are nebulous" and difficult to quantify

- all companies who rank quality among the top 3 factors noted improvement in the quality of their products through use of robots. Interestingly, more than one-half of the companies who ranked quality lower than number 3 also had significant quality improvements.

The extent to which these impressions and experiences from the use of robots in manufacturing can be applied to construction has not been explored in any formal way. However, there is a strong indication that quality is at least as important in the construction domain.

A final interesting conclusion from current studies of industrial manufacturing in Japan is that quality circles only spend 20% of their time on issues directly related to the quality of the manufactured product (4). It is noteworthy that the TQC programs in Japanese construction companies spend much more than 20% of their time focused on quality issues. (This paragraph goes somewhere else.)

The Importance of Quality in Construction Robotics

It was noted in the introduction to this paper that quality and reliability appear to be important motivations in construction, at least in Japan. In an attempt to quantify this attitude, we have attempted to ascertain the relative significance of various factors in motivating the development of construction robotics. The base for collecting such information is weak, however, because so few companies have become involved with construction robots. It is also important to note that the data are dominated by Japanese experience. There is certainly an important bias because of the disproportionate representation from this source.

Table 1: Motivating Factors for Use of Robots in Manufacturing
(all responses)

reduce labor costs

relieve workers of tedious or dangerous jobs

increase output rate

improve product quality

increase flexibility to change products or designs

reduce material waste

increase compliance with safety regulation

remedy labor turnover problems

reduce capital costs

from Ayres and Miller (1982)

Table 2: Motivating Factors for Use of Robots in New Manufacturing Plants

reduce labor costs
improve product quality
relieve workers of tedious or dangerous jobs
increase output rate

from Ayres and Miller (1982)

One source of information concerning the importance of reliability and quality in construction robotics is a 1981 (?) survey conducted by the Japanese General Contractors General Trade Association. This information was supplied by Mr. Takashi Hara, Associate General Manager of Takanaka Komuten. The results of this survey are presented in Table 3. Note that quality was not a specific option available to the survey respondants, nevertheless, the factor of "higher accuracy" did rank fourth.

Table 3: Motivation for Using Automated Equipment in Japanese Construction (a survey of Japanese General Contractor Trade Assoc.)

labor savings	25%
higher efficiency	20%
higher operativity	19%
higher accuracy	18%
avoid dangerous jobs	14%
other	4%

per communication T. Hara (1984)

In an attempt to combine all available data and survey opinion to indicate the ranking of motivating factors for application of construction robots, the information in Table 4 was collected. This table presents the ranking of motivating factors for developing construction robots based on the opinion, in contrast to experience, of constructors and researchers from all parts of the world. Not surprisingly, cost reduction and productivity increase rank first on this survey as they did with others including the Japanese General Contractor Trade Association survey. Hazardous tasks and environments is a strong second in this 1985 survey. This probably reflects the successful development of robots for work in a variety of hazardous environments including nuclear reactors, toxic waste environments, and others. Superhuman tasks is a description of applications where the physical limitations of a human being are overcome by the robot. For example, robots to work inside of small diameter pipes is a classic superhuman task. Others include magnetic supported robots for working on steel bridge superstructures and robots working in small underground excavations.

Table 4 presented the ranking of motivating factors based on opinion. By 1985 we have a sufficient base of experience with robots in construction and similar applications to allow an analysis of this factual experience. Table 5 presents a summary of the motivating factors which contributed to the development of all robots which have actually been designed and/or built for applications in construction. The data represent a worldwide set and include research as well as practical robots. The conclusion from this table indicates that we are building robots for very different reasons than we think.

The principal motivation for developing robots for application in construction and similar environments has been the application to hazardous tasks and environments. Approximately half of our experience to date is in this area. Quality has emerged as the second most important reason. New computational and sensing techniques, when coupled with high precision robotic manipulators, permit higher quality and higher reliability in the construction process. Hagan's 1968 statement (3) that checking "every quality characteristic of every product... would be not only economically unfeasible, but also foolish.." is no longer true, even in construction. A major contribution of modern robotic technology has been the ability to measure almost any characteristic of a manufactured or constructed product and to act on that information in real time. This techological evolution now permits the design and construction of tools which can do work with "zero defects" (3). Zero defects in construction has the same economic potential that zero defects provides to manufacturing.

The significance of quality and reliabity in construction robotics is best shown through some examples. Several Japanese construction companies have made their initial excursion into robotic construction equipment by modifying rock drilling equipment. Kumagai-Gumi is typical in their modification of a conventional drilling jumbo to incorporate sensing, feedback and computer control of mechanical manipulators supporting the drills. Their development began with simple modification of the manual drill through sensors and servo-control to optimize drilling efficiency. Their next step was to focus on increased accuracy in the location of drill holes on a rock face. This increased accuracy included improved control over the location of the hole within the rock mass. After several years of development and prototype applications, the company reports that they are able to achieve these improvements over conventional manual drilling:

- approximately 10% savings on the cost of drilling
- approximately 10% reduction in the cost of explosives because of higher accuracy in the location of the hole

Table 4: Motivation for Construction Robots; Survey of Opinion

cost reduction/productivity increase

hazardous tasks/environments

superhuman tasks

quality

Table 5: Motivation for Construction Robots; Survey of Experience

hazardous tasks/environments

quality

superhuman tasks

cost reduction/productivity increase

- a reduced labor force (3 persons reduced to 2 persons)
- approximately 50% reduction in the amount of concrete needed in the construction of liners for underground tunnels drilled using this equipment.

While all of these savings are important, the most significant by far is the reduction in the amount of concrete needed to line the tunnels. This reduction in concrete is directly related to the fact that the drilling and blasting operation produces a more accurate tunnel. There is less overbreak in the rock and fewer instances when manual techniques must be used to remove extra rock materials. This improved accuracy is, in turn, a direct consequence of the robotic construction equipment and is ultimately responsible for the significant cost savings on this job.

Other typical examples from the Japanese experience involve the use of task control sensors to reduce the amount of material used in various coating operations. The Shimizu SSR robots, for example, have been developed to operate with uniformity of coating as a primary work objective. Task control sensors and operating procedures have significantly reduced the amount of materials needed.

The typical target for reduced material consumption by Shimizu is 50%. Kajimi and Taisei have a similar objective, 50% reduction in material consumption, for their shotcrete robots. These targets are being achieved because of the higher quality of work which is possible using task control sensors and robots.

Conclusions

Quality and reliability are important factors in motivating the development and use of robots in construction. The importance of quality and reliability in construction may be under-recognized until the time of actual development and application of robots. The direct result of improved quality and reliability in construction work is often cost reduction. These reduced costs may be associated with both reduction in labor needs and in reduction of materials consumed. In addition to direct cost reduction, the improvement of quality in the constructed product provides a distinct competitive advantage for construction companies. This is being recognized and exploited by companies who have been involved in early development of robotic construction techniques. They perceive the advantages to be especially important in international construction competition.

The motivations for developing construction robots may be somewhat different from the motivations which lead to the application of robots in manufacturing.

References

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