

STANCE OF MACHINERY MANUFACTURERS AND LEASING COMPANIES
FOR DEVELOPMENT AND APPLICATION OF CONSTRUCTION ROBOTS

TATSUYA WAKISAKA, DR.EIJI MURO, KAZUHIKO ARAI, PROF.NOBUYASU MIURA
CONSTRUCTION ROBOTICS COMMITTEE BUILDING CONTRACTORS SOCIETY
5-1 HACHOBORI 2-CHOME CHUO-KU TOKYO 104, JAPAN

ABSTRACT

The Building Contractors Society conducted a questionnaire of manufacturers and leasing companies concerning construction robots in 1989. The questionnaire items included predictions on the future of the circumstances surrounding the construction industry, the situation surrounding production and leasing of construction machinery and the attitudes of the respondent firms to development and spread of construction robots. The results indicate that though faced with a number of problems, the respondents are generally positive. A large number of opinions were also given and these will be useful in promoting development and application of construction robots in future.

1. Introduction

Thanks to the policy of expanding internal demand, the demand for construction work has increased dramatically in recent years in Japan. The construction industry, on the other hand, is beset by a number of problems, such as the shortage and aging of skilled workers and lowering of skills and sense of responsibility on the part of the workers, together with the rising standards in the quality of work being required. These changes in the circumstances surrounding the construction industry have greatly affected the way in which the industry responds to the demand. While over 60 types of construction robots have been developed to date for the purpose of overcoming these problems by raising work efficiency, only a few of them have been put to practical use and a large number of problems remain as regards their development and application. One of the causes for this is to be found in the way in which these robots have been developed without paying much attention to the opinions of the workers who actually use the robots on the construction sites and the wishes of those who develop, manufacture, sell and operate the robots.

The Construction Robotics Committee at the Building Contractors Society, which is composed of 80 representative general contractors in Japan, has decided that there is a need to clarify the needs and views of the subcontractors, manufacturers and leasing companies in order to promote efficient development and spread of construction robots and has been making a survey of the situation in a three-year study project which began in 1988. The results of the survey of subcontractors have already been reported¹⁾. The present report is concerned with the questionnaire surveys conducted on manufacturers and leasing companies.

2. Survey Method

Questionnaires were sent out between October and November 1989 to 120 machinery makers and 78 leasing companies who were or had the potential of becoming involved in the development and leasing of construction robots. Answers were returned by 60 makers and 30 leasing companies. Table 1 ranks the respondent firms according to their capital.

Table 1: Respondents

Capital (billion yen)	~0.01	0.01 ~0.05	0.05 ~0.1	0.1 ~0.5	0.5~1	1~5	5~10	10~	Total	Recovery Rate (%)
Manufacturers	1	13	7	10	3	4	5	17	60	50.0
Leasing Companies	3	13	4	4	5	1	0	0	30	38.4

The questions were concerned with a wide range of items from forecasts on the future of the circumstances surrounding the construction industry to the situation surrounding production and leasing of construction machinery and the attitudes of the respondent firms to development, application and spread of construction robots. 24 questions and 16 questions were put to the makers and leasing companies, respectively.

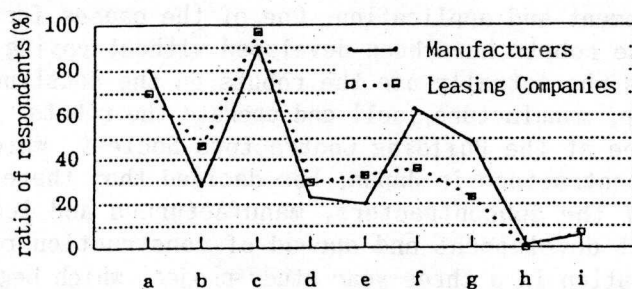
For multiple-choice questions, the percentage of respondents selecting each answer was calculated for evaluation of the importance of each choice. For questions where the respondents were asked to write freely on their views, after the answers were rearranged according to their contents, evaluation was made on the correlation between the answers by the members of the Construction Robotics Committee and cluster analysis was conducted on the basis of this. The views given in the responses were classified according to categories and evaluation was made on the importance of each category.

3. Survey Results and Discussion

3.1 Forecasts on Mechanization of Construction Industry

The answers to the question on the future of mechanization in the construction industry are given in Figure 1. Makers replied that mechanization was "indispensable for solving the problem of labour shortage" (90%), that it would become "increasingly necessary in order to reduce dangerous work" (80%), that "a new concept of construction planning and management for mechanized construction will be a prerequisite condition for mechanization" (62%) and that "mechanization will need to be promoted while making considerations for division of work between the workers and machines" (48%).

The answers from the makers and leasing companies showed similar tendencies but there was the difference that while the makers attached importance to establishment of a new concept for construction management as a prerequisite to promotion of mechanization and considerations for cooperation between workers and machines, the leasing companies were looking at the future of mechanization from a more practical point of view, with considerations for shortening of construction period, improvement of quality and reduction of costs.



- a. Mechanization will be needed in order to reduce dangerous work
 b. Use of machines will be effective in shortening construction period

- c. Use of machines will be indispensable in solving the problem of labour shortage
 d. Mechanization is meaningless if it does not lead to cost reduction
 e. Machines are needed in order to cope with the demand for higher quality and precision
 f. Establishment of a new concept for planning and implementation for mechanized construction is a prerequisite condition for introduction of robots
 g. Mechanization should be promoted making considerations for division of work between workers and machines
 h. The increasing complexity of design will hinder mechanization
 i. Mechanical power far greater than human power may lead to unthought-of accidents

Figure 1: Forecasts on Mechanization of Construction Industry

3.2 Development and Leasing of Construction Robots at Present

Thirty-eight makers (63%) replied "yes" to the question "Have you either planned, developed or actually produced construction robots?". Of these, 70% had actually developed such machines or were in the process of doing so. Of the 22 makers who answered "no" to the question, a total of 73% were positive about the possibility of their being involved in development of robots in future, with 14% saying that they "would like to make positive efforts" and 59% that they "would consider developing robots given the right circumstances" in reply to the question on whether they would consider developing robots in future. Reasons given by those "not thinking of developing robots at present" included "lack of engineers" required for the purpose.

Only three (10%) of the leasing companies actually had construction robots to lease. The reason for an overwhelming majority not dealing in robots included the "lack of robots that are profitable as rental machines" and "lack of time and resources to deal in robots". As regards the possibility of their dealing in construction robots in future, 63% replied that there was a possibility, 22% did not know and 15% said they were not very hopeful about the prospect. Leasing companies are less enthusiastic than the makers but they too may be said on the whole to be positive about dealing in construction robots.

3.3 Expectations on Introduction of Construction Robots

For the questions as to how hopeful the respondents were about various benefits that might be derived from the introduction of robots, the choice "unhopeful" (A) was given 0 points, "not very hopeful" (B) 0.5 points, "slightly hopeful" (C) 1 point, "hopeful" (D) 1.5 points and "very hopeful" (E) 2 points, and the level of expectation was calculated using the following formula. The results are given in Figure 2.

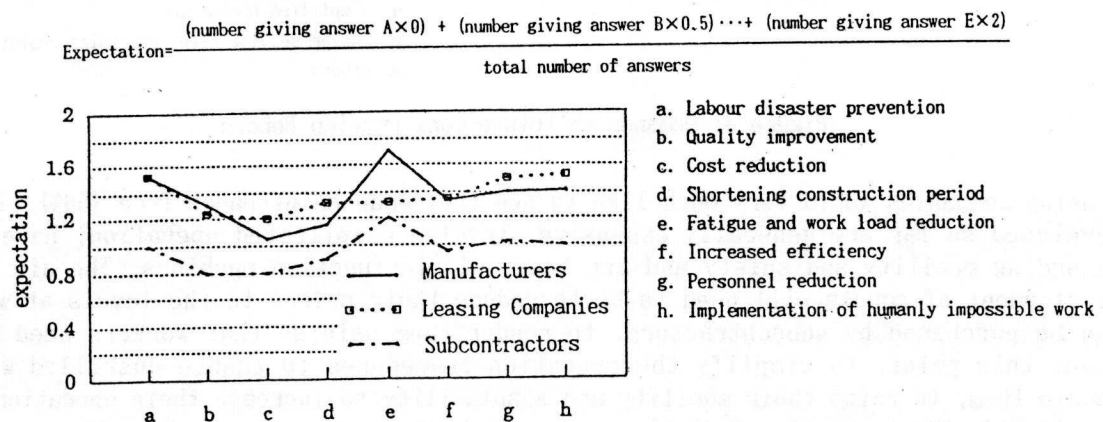


Figure 2: Expectations Placed on Introduction of Construction Robots

Whereas the expectations from the makers ranged widely between 1.0 and 1.7 points according to items, the level of expectation on the part of the leasing companies showed a narrower range from 1.2 to 1.5. Although one cannot make a direct comparison with the results of the survey on subcontractors¹¹, since a different three-choice evaluation system was used for the latter, it can be seen that the views of the makers and subcontractors show a very similar distribution.

Makers were hopeful about the "reduction of fatigue and work load" (1.7 points), "prevention of labour accidents" (1.5), "implementation of work that is impossible for humans" and "personnel reduction" (1.4). There was a relatively low level of hope for "shortening of construction period", "improvement of quality" and "cost reduction". The respondents in both parts were more hopeful about the improvement of working conditions and environments resulting from the introduction of robots than about increased productivity.

The reason for the high level of expectation placed on "reduction of fatigue and work load" is to be found in the misgivings that much physical and mental load is placed on the aging workers by the heavy physical work such as carrying around construction materials, continuous work that has to be carried out in awkward postures and repetition of monotonous work. As regards the "prevention of labour accidents", the line of thought is that the accidents, which are still far more frequent in the construction industry than in others, may be reduced by having the robots carry out work in dangerous situations in place of the workers.

3.4 Demands on Construction Robots

The answers to the question on the demands the respondents would make on future robots are given in Figure 3. The answers that were given by over 30% of the makers are "cost reduction," "simplified operation" (48%), "mobility," "increased safety" (40%), development of "multi-function robots," "adaptability" (33%) and "weight reduction" (31%).

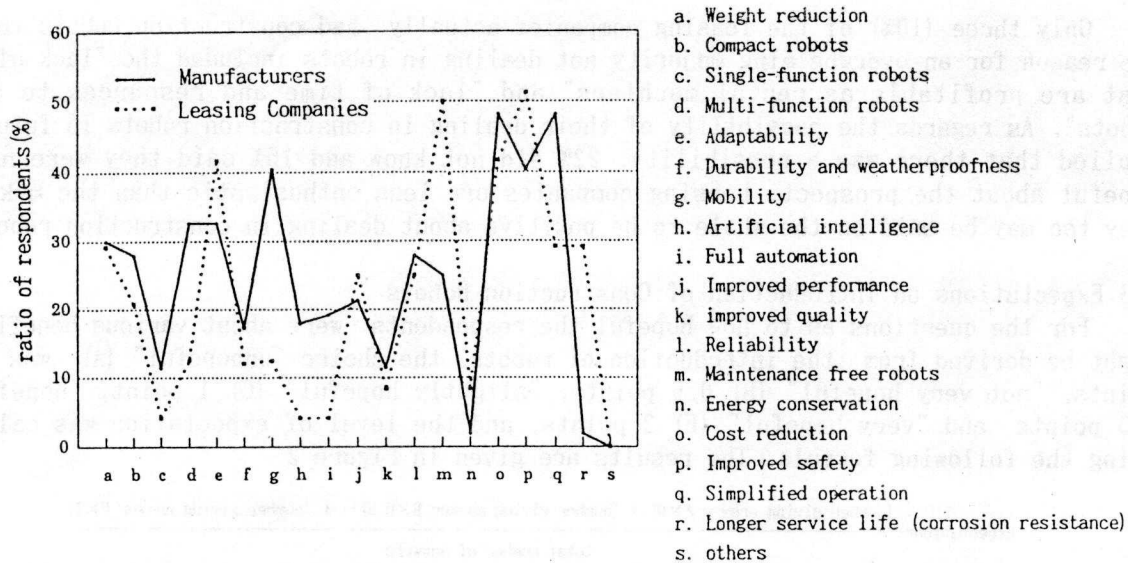


Figure 3: Demands on Future Construction Robots

Leasing companies would very much like to see them made maintenance free (50%). The robots developed so far are generally expensive, involve complicated operation, have problems regarding mobility and safety and are heavy single-function machines. The aim in future development of robots will need to be to reduce their prices to the levels at which they can be purchased by subcontractors, to render them safe so that workers need not worry about this point, to simplify the operation procedures to enable unskilled workers to handle them, to raise their mobility and adaptability to increase their operation rate and to simplify the inspection and maintenance procedures.

3.5 Obstacles in Development of Construction Robots

The answers to the question on obstacles to the development of construction robots are given in Figure 4. The most prominent answers were "high R & D costs" (62%) and "low hope of there being enough buyers to justify the development efforts" (60%). These were followed by "lack of preparation at construction sites for acceptance of robots" (43%), "inadequacy of exchange of information between makers and users" (33%) and "underdevelopment of component technologies" (28%).

The obstacles, in other words, are to be found in the two managerial aspects of development costs and the state of the market. Construction robots are required to have

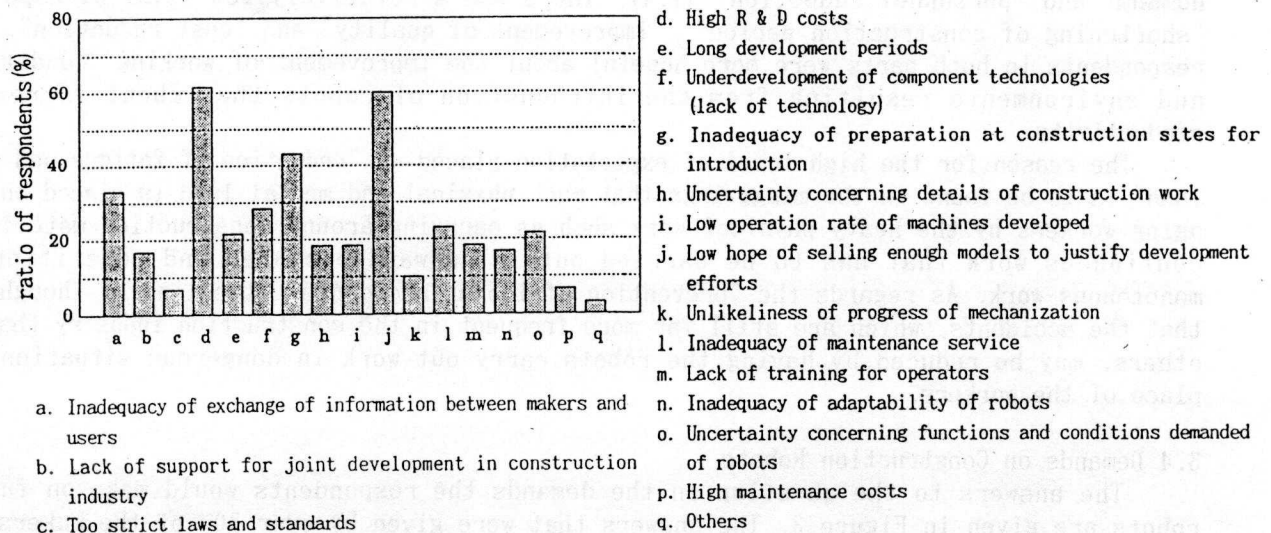


Figure 4: Obstacles to Development of Construction Robots

higher performances than normal industrial robots because of the need for them to handle heavy and varied materials and to carry out complex work while changing their positions, under severe and unstable environmental conditions. Since many of the technologies for their component elements have as yet to be established, there is a need to make continuous investment in research and development and the R & D costs inevitably mount up. At the same time, it is difficult for the makers to have a clear view of the needs, and consequently of the size of the market and the number of prospective buyers, and the makers as a result cannot hope to sell enough models to justify the efforts required in their development and production. It is hoped, however, that makers will be willing to adopt an attitude of expanding into new fields in spite of the risks involved.

The "lack of preparation at construction sites for acceptance of robots" is a problem that has to be faced by general contractors. The conditions at construction sites differ from site to site and full-scale use of robots is still difficult at this stage in view of the levels of their performance and safety at present, but efforts need to be made by general contractors for establishment of conditions suited to introduction of robots, while providing situations and opportunities for test operation.

A number of respondents mentioned the "inadequacy of the exchange of information between makers and users". It is thought that there has been a certain amount of progress in exchange of information between makers and users during the past tens years or so since the development of robots began in earnest. Exchange of information is indispensable in production of construction robots, the methods for which are quite different from those for robots used in the manufacturing industry. In any case, this is a problem, for the solution of which positive efforts need to be made by both parties.

As regards the "underdevelopment of component technologies", it is not enough to apply the technology developed for industrial robots to the field of construction robots without modification, since there are differences in the actual details and methods of the work they are to perform, as well as in the environmental conditions under which they operate. Since the robots will often need to coexist and cooperate with workers at the sites, a higher degree of safety and reliability are required of them.

There is a need to promote the development and spread of construction robots by solving the five major obstacles described above.

3.6 Price of Construction Robots

The free answers to the question on "factors involved in determining prices of construction robots" were classified into 8 categories through cluster analysis. The numbers of answers fitting into each category are given in Figure 5. The answers given by the largest number of respondents were "production costs", "expected sales" and "labour cost". These were followed by "R & D costs" and "valuation by users". While pointing to manufacturing costs, expected number of robots sold and R & D costs as major factors in determination of costs, the makers also attach importance to valuation by the users. The prices of the robots must be acceptable for the users in view of the equivalent labour costs in conventional construction methods and the benefits derived from the introduction of the robots.

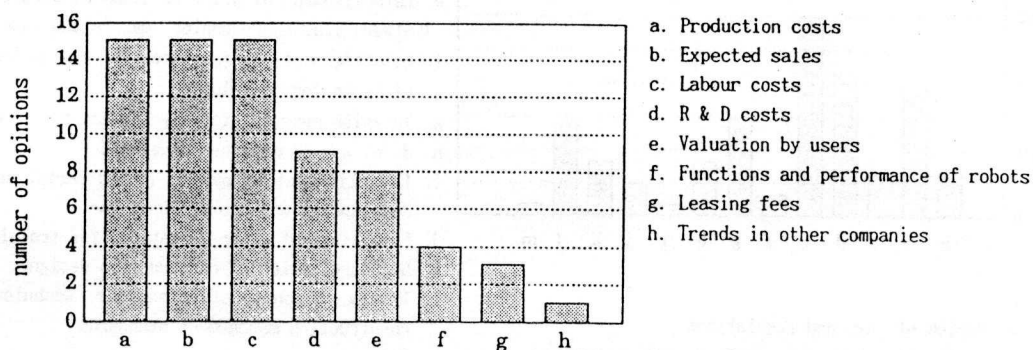


Figure 5: Factors Involved in Determination of Robot Prices

The makers were asked to give estimates for the R & D costs for a construction machine worth about ¥ 10 million to provide an idea of the R & D costs, which is one of the major factors involved in determination of robot prices. The answers are given in Figure 6. The largest number said "3 to 5 times the sales price of the machine" (39%) and this was followed by "1 to 3 times the sales price" (23%). It seems that the R & D costs for robots will normally be around 3 to 5 times their prices, although they may be even higher because of the element of automation involved.

The answers the leasing companies gave to the question on the prices they would pay for robots in the event of their deciding to deal in construction robots are given in Figure 7. 80% of the leasing companies would pay less than ¥ 10 million for a robot.

3.7 Measures for Promoting Use of Construction Robots

The answers to the question on measures for promoting use of construction robots are given in Figure 8. These included "establishment of structures for joint

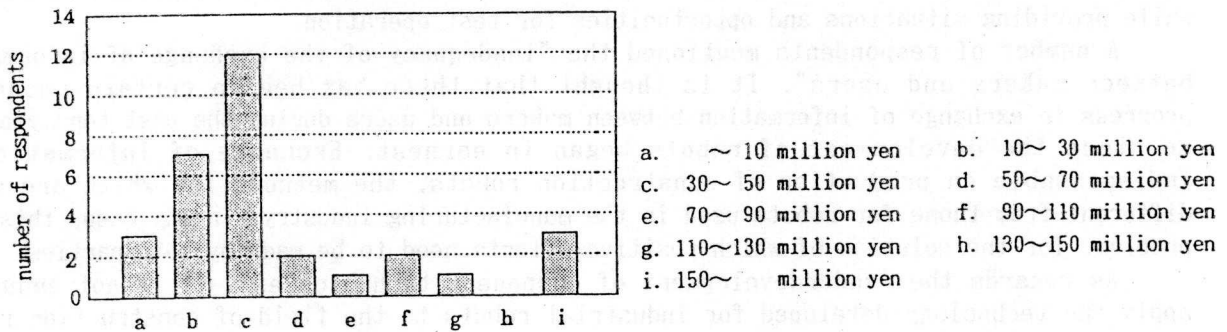


Figure 6: R & D Costs for ¥ 10 Million Construction Machine

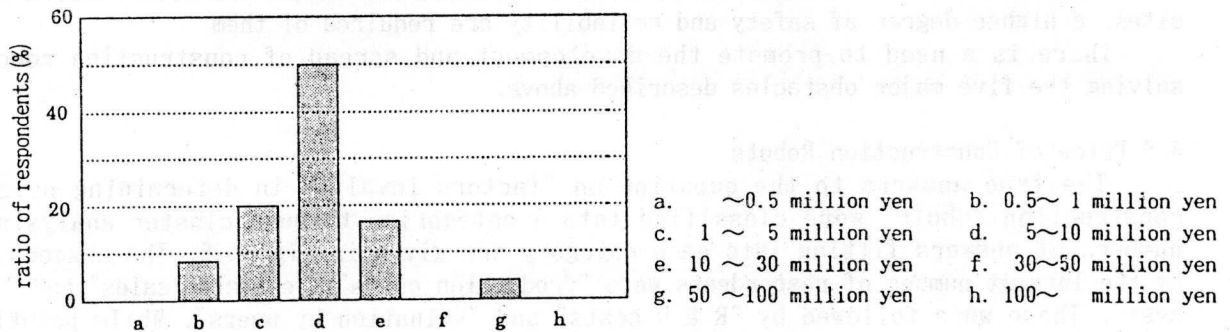


Figure 7: Purchasing Prices for Construction Robots

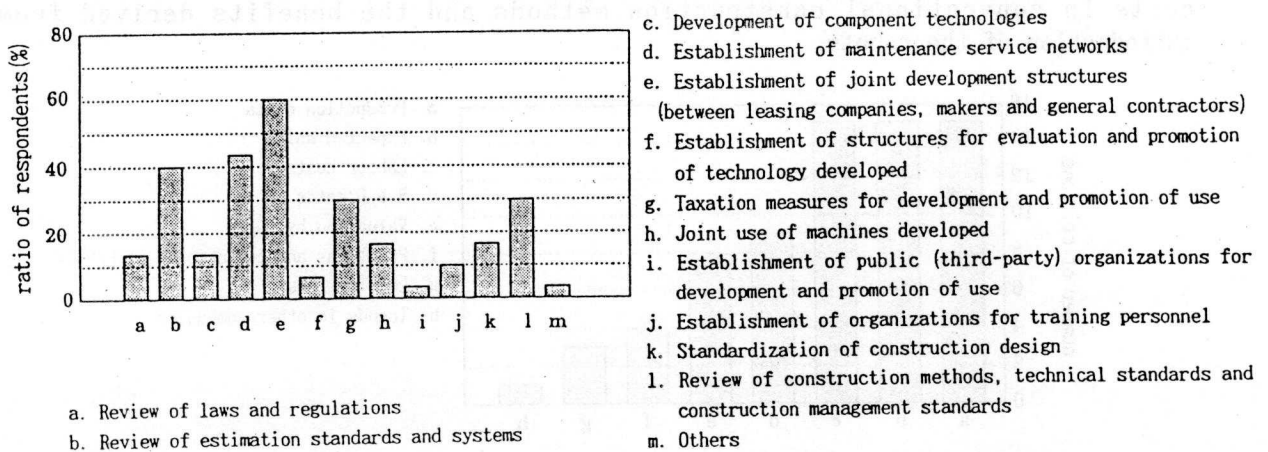


Figure 8: Measures for Promotion of Construction Robots

development" (60%), "improvement of maintenance service networks" (43%), "review of estimation standards and systems" (40%), "taxation measures for R & D and promotion of use" and "review of construction methods, technical standards and construction management standards" (30%). Importance is attached to the cooperation between the organizations involved in establishing a structure for the series of work from the development of robots to their application to use, in reviewing various standards and in preparing the ground for the spread of their use.

3.8 Role of General and Subcontractors

The results of the cluster analysis on the free answers given by the makers to the question concerning what they "would most like to ask of the general and subcontractors" are shown in Figure 9. The demands can be classified into the following 6 categories.

- ① On needs and specifications for robots
Provision of more specific needs and clearer specifications and information on work to be robotized, on the basis of which to develop practical robots
- ② On construction methods
Improvement in construction methods to render them better suited to robotization and standardization and preparation of the construction sites to facilitate introduction of robots
- ③ On attitude to development of construction robots
General contractors have in the past one-sidedly forced their demands on the makers. They must adopt a more cooperative and positive attitude to development of robots based on a better understanding of the position of the makers.
- ④ On understanding towards introduction of robots
Cooperation of general and subcontractors is indispensable in introducing robots to construction sites. Contractors must clarify the structure for acceptance of the robots and strengthen their cooperation. Repeated test construction on site is necessary for development of practical robots.
- ⑤ On ordering and costs
Establishment of a system for making orders and rectification of systems for cost estimation are items related to ④ above and are prerequisite conditions for full-scale use of robots at construction sites. These, however, are problems that cannot be solved by individual general contractors but must be solved in consultation between the construction industry and the administration.
- ⑥ On allotment of R & D costs
Shouldering of R & D costs by general contractors is earnestly desired by makers, since construction robots are more expensive to develop than industrial robots.

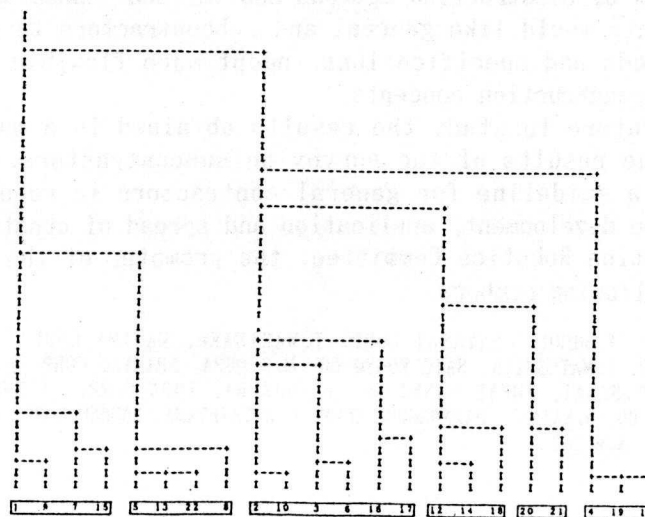


Figure 9: Most Important Demands on General and Sub-contractors (Dendrogram)

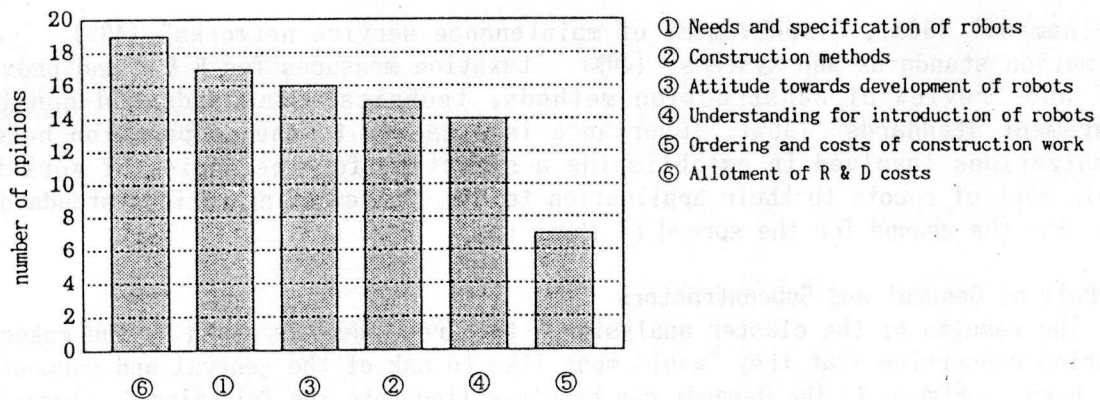


Figure 10: Most Important Demands on General and Sub-contractors

The statistics on the views included in the above items are given in Figure 10. As expected, the makers would like above all to have assistance for the R & D costs. Establishment of structures for cooperation in R & D is another important issue.

4. Conclusions

A questionnaire survey was conducted on machinery makers and leasing companies concerning their views and attitudes to construction robots and what they would ask of general contractors. The results of the survey may be summarized as follows.

The makers and leasing companies have a positive attitude to construction robots and place their expectations on improvement of working conditions and environments rather than increased productivity as benefits of the introduction of construction robots. Demands were made for robots that are cheap, easy to operate, safe and highly adaptable and mobile, as well as being maintenance free. Obstacles to development mentioned include high R & D costs, lack of clarity concerning the market, lack of preparation for acceptance of robots at the construction sites, inadequacy of exchange of information and underdevelopment of component technology. The respondents recognised the need for joint development and were particularly keen to see participation by general contractors.

The factors involved in determining the prices of the robots include production costs, expected sales, labour costs, R & D costs and valuation by users. Leasing companies would expect to pay less than ¥ 10 million for a robot. As measures for promoting the use of robots, establishment of joint development structures, improvement of maintenance services and review of construction methods and various standards were pointed out.

The respondents would like general and subcontractors to take a share in financing R & D, clarify needs and specifications, adopt more flexible attitudes to development and establish new construction concepts.

We hope in future to study the results obtained in a more comprehensive manner, taking in also the results of the survey on subcontractors, and on the basis such a study to prepare a guideline for general contractors in robotization of construction work and to promote development, application and spread of construction robots.

The Construction Robotics Committee, the promoter of the survey reported here, is composed of the following members.

TAKENAKA CORP. E.MURO, OBAYASHI CORP. T.WAKISAKA, KAJIMA CORP. K.ARAI,
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KOKUSHIKAN UNIV. N.MIURA

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