# AUTOMATION INDEX FOR EVALUATION OF ROBOTICS IMPLEMENTATION IN CONSTRUCTION

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Abstract

The Canadian construction industry must carefully consider the use of robotics if it is to meet its changing needs. This paper presents an approach for evaluating the implementation of robotics in construction activities. Each activity is considered in terms of strategic, tactical and operating needs. Since these needs may vary among different countries and regions, priorities are assigned based on social, economic, and political considerations. An example application is presented to illustrate the methodology.

## INTRODUCTION

The application of robotics in construction activities is a necessary response to the changing needs of one of Canada's largest industries. Recent international efforts have shown that such applications are not only technically feasible but also economically desirable. However, because the construction industry has no experience with robotics, there is no consensus regarding its potential role. Consequently, a method for evaluating robot implementation is required if a common language for consistent decision making is to be developed.

The approach presented in this paper provides the basic elements needed in a decision making process, that could be undertaken by manufacturer-suppliers, government, and academic institutions, for evaluating areas of promising robotic implementation. Since a more refined analysis of the actual work tasks would follow, a simple methodology, incorporating readily available factual information, supplemented by industry experience obtained through surveys, was considered to be important at this stage.

First, characteristics of the Canadian construction industry that have a direct bearing on robot implementation are outlined. An automation index for evaluating robotics implementation is then formulated, and its use is demonstrated by considering robotization in cement floor finishing operations. Emphasis is placed on the identification of those robotic applications which, when linked to national and/or regional priorities, can best meet future requirements.

## INDUSTRY CHARACTERISTICS

### Labor Shortages

Presently the Canadian construction industry is experiencing faster employment growth than other industries, a typical phenomenon during recovery periods. Significant changes, some underway and others expected, will create even greater demand for labor. The Canada-U.S. free trade deal for instance is expected to generate an additional 49,000 jobs in construction by 1995, representing approximately an 8% growth [12]. An increase in the number of large-scale projects being planned throughout Canada will also add to the drain on the skilled labor force. This concern was recently addressed at a seminar in Montreal entitled 'The revival of megaprojects in Quebec- Will we have sufficient manpower?'. In addition, changing labor force demographics are expected to adversely affect certain provinces, most notably Ontario, where half the skilled labor force is expected to retire within the next ten years [8].

Concerned over future labor supplies, the Canadian Construction Association, a national industrywide employer organization, has established programs aimed at informing women and students about careers in construction. It has been estimated however that the potential supply of Canadians age 18 to 24 available for entry into apprenticeships will decline from a high of approximately 3.3M in 1980 to 2.6M in 1992 [7].

Business Constraints

In 1985, 90% of the 110,000 Canadian construction firms had 20 employees or less, and 95% had annual operating revenues of less than $1M [3]. In Quebec in 1987, 79% of construction employers had total wage disbursements of $100,000 or less [1]. Two key features of these firms are a high degree of leverage and a lower than average working capital ratio, resulting from the use of short term debt as the main source of financing for both operating capital and equipment purchases. As a matter of fact, liabilities due to short term debt represent a larger proportion in construction than in manufacturing and wholesale trade [2].

Construction is a also notoriously unstable, exhibiting both cyclical and seasonal instability. When both are combined, year to year employment is 4 times as unstable as in manufacturing [2]. Zanasi suggests a 16 to 20 year cycle for construction in Canada and a 10 year cycle in Quebec [23]. As for seasonality, different trades have different employment cycles depending on the nature of their work and the construction sector in which they operate. On an aggregate level however, in 1987, 70% of the total number of hours registered by all trades in Quebec were registered between May and November, corresponding on average to 6 months of full employment per person [1].

The Economic Council of Canada has linked instability with higher costs due to inefficiency, wasted effort and skills, and retraining expenditures [2]. Additionally, the use of robots year round in Canada is expected to be a major advantage because winter construction costs in the city are approximately 25% greater than in summer, and productivity of many trades drops by at least 20-30% when temperatures fall below 0°C or rise above 32°C [22]. Construction robots are also seen as important to the development of Canada's north, where it is estimated that 27% of the value of large energy-related projects will be spent, making it the second most important region in Canada in this respect [7].

The portrait of the average construction firm which is painted is one of a small and highly leveraged firm, operating in a seasonal and cyclical industry, which due to the functionally segregated delivery and production systems, is highly specialized and has short term, project specific needs. Consequently, for the average contractor to introduce robotic equipment it will have to be proven that its use will result in decreased costs, improved delivery time, and increased profits. It is believed that robots "whose primary justification is quality improvement without increase in productivity need to overcome inherent disincentives in the building delivery process [14]".

### Labor Relations

Collective bargaining and institutionalized labor relations affect only a portion of each province's construction industry because union membership, apart from Quebec, is concentrated in certain sectors. In Quebec, the construction industry is the most regulated industry in all of North America. Since 1968, all construction workers must belong to one of 5 recognized trade unions and all employers must belong to the Association of Building Contractors of Quebec. In the event these two groups cannot reach an agreement, and they have not in over 15 years, the provincial government imposes a wage settlement by decree on all workers in 22 officially recognized qualified trades.

Total employee benefits, including safety premiums, health and unemployment insurance, pension funds, seniority and other fringe benefits, cost employers on average 27% of the employee's gross salary. The main effects of the decree system have been identified by a provincial study on deregulation as 1) restricting access of skilled workers and 2) impeding technological change and innovation [4]. Within such an entrenched system, it is believed that the use of labor reducing/replacing robots will be accepted foremost in activities that are recognized as dangerous or where working conditions are unpleasant.

## MODEL FORMULATION

Several approaches have appeared in the literature concerning the identification of promising robotic applications. Knowledge based expert systems have been suggested by Skibniewski [18], for the evaluation of robotic implementation based on engineering considerations, external considerations, and costs and benefits, and by Kangari [5], for robotic feasibility analysis based on level of repetitiveness, cost effectiveness, technological feasibility, productivity improvement, level of hazard, union resistance, and quality improvement. A traditional feasibility analysis has been proposed by Kangari and Halpin [6], based on the evaluation of need, technological feasibility, and economical feasibility.

In this paper, the implementation process is viewed as being motivated by 4 fundamental considerations, requiring:

1- The identification of those robotic applications which, when linked to national or regional priorities, will best meet future requirements.
2- The evaluation of the technological complexity associated with automating the task.
3- The identification of institutional resistance, either by building codes or trade unions, to the application being considered.
4- The evaluation of economic benefits incurred from robot use.

Generally, technological considerations have been well addressed in the literature, as studies have identified major technological parameters [6], technological requirements for various activities [22], and robot performance requirements [19]. Similarly, economic consideration have been identified [6], economic evaluation models proposed [22 and 17], and various economic models have been compared [11]. Thus for our purposes, emphasis is placed on the identification of those applications where the overall need for robotics is greatest.

The automation index model used in evaluating overall need is depicted in Figure 1. Each activity is considered in terms of strategic, tactical and operating needs, called 2nd level needs. Strategic needs reflect industry-wide or societal concerns. Tactical needs are determined at the firm level and typically include business concerns. Operating needs are determined at the task level and deal with performance considerations. Each 2nd level need is characterized by 3rd level parameters which must be evaluated for each activity.

Clearly, the need for robotics in construction activities will vary among different countries, regions, and sectors. The importance of the 2nd level needs must be determined based on national or regional, social, economic, and political priorities. The importance of the 3rd level parameters are established based on the extent to which they support or impact their related 2nd level need. After the needs and parameters have been prioritized, various activities can be analyzed and compared.

An important criteria in developing the automation index was that it should benefit from the attractive features of the highly regulated construction industry in Quebec. Consequently, safety related information was obtained from the C.S.S.T., the agency which regulates safety and security in the workplace. Business information was obtained from the C.C.Q., the agency to which all hours worked and wages paid must be registered. Information not available from these sources, concerning task requirements, was obtained from surveys of specialized subcontractors.

In order to perform a preliminary investigation into the implementation of robotics in construction, the use of the automation index is demonstrated by evaluating the need for robotics in cement floor finishing operations. The evaluation of the 3rd level parameters identified in Figure 1 is explained below. The first 5 parameters, summarized in Table 1, are evaluated for each of the 22 official trades in Quebec based on historical information. The maximum values for each parameter are identified in bold type, and are used to compare individual scores. The remaining 6 parameters are obtained from a survey of cement floor finishers in the Montreal area.

1) Safety

Dangerous activities are prime candidates for robotization. The safety record and the associated costs of prevention and accidents in construction have been reported in [10]. A measure of the level of danger associated with different trades has been obtained by combining the frequency of accidents (number of accidents per man-hour) with their gravity (number of days lost per accident) [13]. The results are presented in column 1 of Table 1.

2) Labor shortages

Shortages occur when supply does not meet demand. A major function of the agency regulating the construction industry is to precisely determine the number of men to be 'supplied', based on its own forecast of demand. Consequently, the identification of any real labor shortages is very difficult. For the purpose of this paper, it was assumed that if the composition of demand remains constant (i.e. relative importance of residential, industrial, engineering ...), then the greatest potential for labor shortage is in those activities where the attrition rate is high. The attrition rates shown in column 2 of Table 1, represents the combined rates of attrition for experienced tradesmen and apprentices.

3) Seasonality

The use of robots is expected to be beneficial in highly seasonal trades, improving the firm's ability to react quickly and efficiently to increased volumes of work, and ensuring consistent output regardless of the weather. The value for seasonality expresses the maximum spread between the monthly hours registered in a year, as a percentage of the maximum number of monthly hours for that year. Seasonality is summarized in Column 3 of Table 1.

4) Overtime

Trades that regularly register large amounts of overtime usually suffer from reduced labor productivity [20], and may also reflect a shortage of labor. A measure of overtime, expressed by the ratio of total to regular number of yearly hours registered, is given in column 4 of Table 1.

5) Volume of work

A robot is of more importance, in support of business needs, to a trade representing a large volume of work, than it is to a trade representing a small volume of work, depending of course on the cost of labor for that trade. By combining the total number of registered hours and hourly wages for each trade, the importance of the trade in terms of salaries paid, is obtained. Column 5 of Table 1 summarizes the proportion each one of the 22 trades represents with respect to the total value of salaries paid in the construction industry.

6) Quality

The need for a robot based on improvements in quality can be determined by estimating the frequency of rework. In tasks which require the application of materials, such as painting, spray fireproofing, etc.., material wastage is also an important indicator. For cement floor finishing, the frequency of rework was established by the survey at 10%. (In this case frequency of rework indicates the number of times owners were dissatisfied with the quality of their floor)

7) Experience

Tasks which require highly experienced workers are prime candidates for robotization. The length of time required for an inexperienced person to acquire the basic skills for the job of cement floor finishing was determined by the survey to be on average 2.5 years.

8) Work context

Tasks that are noisy, cramped, dusty/dirty, where the lighting is poor, where vibrations are high, or where work is frequently carried out at night, are also prime candidates for robotization. From the survey, a combined index for these attributes, for cement floor finishing, rates 6 out of 10.

9) Work content

This parameter identifies tasks that are boring, repetitive, unpleasant, and uncomfortable. From the questionnaire, a combined index for these attributes, for cement floor finishing, rates 4.3 out of 10.

10) Labor utilization

Some tasks reflect a less efficient use of labor than others. Results from the survey indicate the proportion of ineffective time spent at work by cement floor finishers is approximately 20%.

11) Exploitation degree

The term exploitation degree, first defined for regular construction equipment [16], seeks to determine how the expected increase in productivity will affect the construction task, with respect to time, labor, and material. Will the robot work in conjunction with man, such as the ceiling panel positioning robot described in [21], and thus be limited by him, or will it work by itself, such as the floor finishing robot, also described in [21]. In the latter case, a high score of 8 out of 10 was determined.

In order to arrive at a value for the automation index, the parameters and overall needs must first be prioritized. The structure of the automation index permits the use of formal methods of prioritizing, such as the Multiple Binary-Decision Method [9] or the Analytic Hierarchy Method [15]. However, for demonstrative purposes, weights were assigned by the authors, considering the Canadian priorities which have been previously identified. Strategic, tactical and operating needs were respectively rated 0.4, 0.3 and 0.3, and all 2$^{nd}$ level parameters were given equal ratings within their specific groups. This yields an automation index for cement floor finishing of 1.9 on a scale with a maximum scoring of 3.4, indicating only a medium strength need.

Combining this 'need' score with the remaining major considerations of the implementation process, technological complexity, institutional resistance, and economic benefits, results in a measure of the implementation of robots in a particular activity. Repeating this process for several activities will help determine which activity should receive resources for automation.

CONCLUSION

The use of robotics is an important development in Canada's evolving construction industry. The approach presented in this paper provides the basic elements for evaluating robot implementation in construction activities. Overall need is considered in terms of strategic, tactical and operating requirements. Which, when combined with technical, institutional and economic considerations, will guide in the efficient allocation of scarce resources and will help meet future needs.

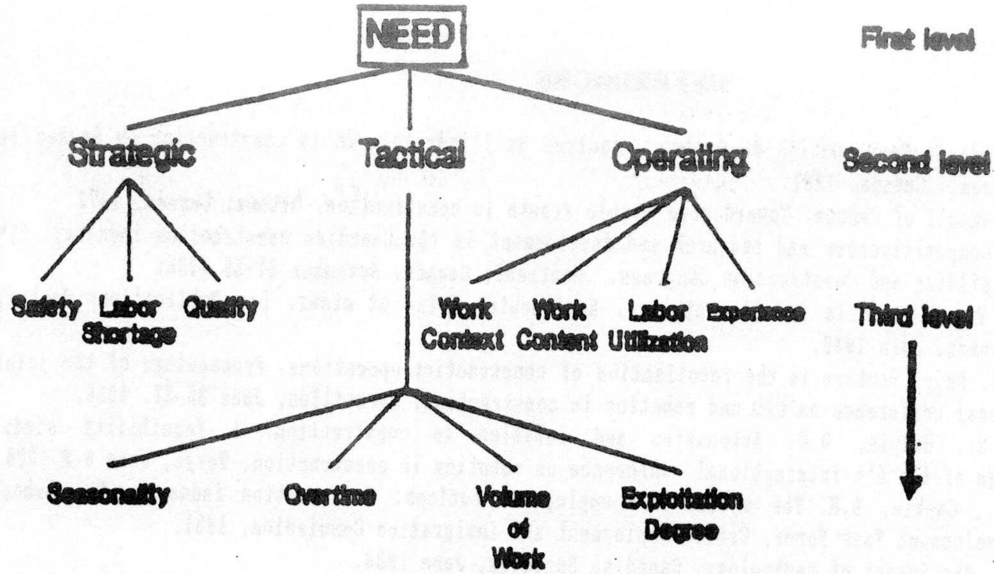


**Figure 1: Automation index model**

| Trade | Safety[1 3] | Labor shortage[2 3] | Seasonality[4] | Overtime[4] | Volume of work[4] |
|---|---|---|---|---|---|
| Heavy equipment operator | 0.90 | 0.35 | 0.85 | 1.05 | 0.05 |
| Roofer | 1.75 | 0.30 | 0.79 | 1.01 | 0.01 |
| Shovel operator | 0.91 | 0.35 | 0.79 | 1.05 | 0.02 |
| Bricklayer | 1.13 | 0.25 | 0.78 | 1.01 | 0.03 |
| Cement floor finisher | 0.97 | 0.30 | 0.74 | 1.05 | 0.01 |
| Reinforcing steel placer | 1.59 | 0.25 | 0.72 | 1.04 | 0.01 |
| Painter | 0.96 | 0.35 | 0.64 | 1.01 | 0.03 |
| Boilermaker | 1.25 | 0.15 | 0.62 | 1.15 | 0.01 |
| Heavy equipment mechanic | 0.99 | 0.40 | 0.59 | 1.22 | 0.01 |
| Carpenter | 1.04 | 0.25 | 0.58 | 1.02 | 0.19 |
| Plasterer | 0.65 | 0.35 | 0.56 | 1.01 | 0.01 |
| Insulator | 0.88 | 0.15 | 0.52 | 1.04 | 0.01 |
| Crane operator | 1.20 | 0.35 | 0.52 | 1.16 | 0.01 |
| Vinyl tile layer | 0.34 | 0.40 | 0.49 | 1.01 | 0.01 |
| Ceramic tile setter | 1.03 | 0.30 | 0.47 | 1.01 | 0.01 |
| Millwright | 1.26 | 0.15 | 0.46 | 1.14 | 0.01 |
| Structural steel erector | 2.54 | 0.25 | 0.43 | 1.08 | 0.02 |
| Interior systems installer | 1.16 | 0.35 | 0.42 | 1.01 | 0.01 |
| Sheet metal worker | 0.91 | 0.20 | 0.39 | 1.02 | 0.03 |
| Ornamental steel worker | 1.75 | 0.30 | 0.38 | 1.02 | 0.01 |
| Plumber | 0.89 | 0.20 | 0.36 | 1.05 | 0.10 |
| Electrician | 0.71 | 0.15 | 0.35 | 1.03 | 0.12 |
| Elevator mechanic | 0.57 | 0.30 | 0.24 | 1.06 | 0.01 |

**Table 1: Summary of different need parameters**

1 Construction industry average 1 2 Represented by attrition rate
3 Based on 3 year average 4 Based on 7 year average

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