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Major Factors in Robotization of Construction Operations

ABREGE:

La robotisation et l'automatisation de la construction d'un bâtiment nécessitent des méthodes techniques différentes de celles appliquées dans l'automatisation d'une usine. L'importance des opérations, leur mobilité, le genre de techniques utilisées et les conditions de travail ne sont pas les mêmes pour un chantier de construction et une usine. Une plus grande intelligence, une plage de charge et une plage de force plus importantes sont nécessaires pour un robot de construction. Les raisons principales pour lesquelles on utilise des robots dans la construction sont: l'amélioration de la sécurité des travailleurs et l'élimination de manoeuvres dangereuses; l'accroissement de la productivité et l'amélioration de la qualité du produit fini. Cet exposé présente une méthode d'étude systématique de la faisabilité de la robotique dans les manoeuvres de construction. Un système expert basé sur la connaissance et permettant aux entrepreneurs d'effectuer une étude préliminaire pour l'automatisation de la construction sera présenté. Ce modèle pourra servir de schéma pour évaluer les procédés de construction pouvant être automatisés.

ABSTRACT

Robotization and automation of a construction process requires engineering approaches different from those that are applicable in factory automation. Construction site differs from industrial plant in scale of operation, mobility, type of processes and the work environment. A greater intelligence, load, and force range is needed for a construction robot. The main reasons for using robots in construction operations are: to improve safety of workers and eliminate dangerous operations; to increase productivity; and to improve final quality. This paper presents a systematic approach to study the feasibility of robotics in construction operations. A knowledge-based expert system is introduced which allows the contractors to perform preliminary study for the automation. The model can be used as a guideline in evaluating potential construction operations for the automation.

INTRODUCTION

Although there still exist today differences of opinion about exactly what a robot is, there is a growing general concensus that robots will be increasingly adopted by construction industries throughout the world. Robot technology is not new, but many industries as construction are only just beginning to realize the impact that full automation could have in their production. Today, construction robots are still on the stage of research, and there are only few practical construction robots developed. However, among all these robots only one or two may be called real construction robots, and the rest are partially automated construction equipment (Paulson, 1985).

Robotization and automation of construction industry is an important step forward in the industry. For each construction process to be automated, it is necessary, on the basis of a detailed analysis, to determine the more important basic problems of automation and commence the solution of these problems by a systematic approach. With the wide-scale introduction of automation into industry, it is desirable, in the first stage, to do feasibility study for automation which is likely to give the best technical-economic effect. It is consequently of great importance to determine major factors affecting robotization which is rational from the socio-economic and technical viewpoints. The main objective of this paper is to identify major factors in robotization of construction operations, and to present a knowledge-based expert system for feasibility analysis.

MAJOR FACTORS IN ROBOTIZATION

A knowledge-based expert system modeling procedure is implemented to analyze the feasibility of robotics in construction operations. The following seven major variables are considered: Level of Repetitiveness; Cost Effectiveness; Technological Feasibility; Productivity Improvement; Level of Hazard; Union Resistance; Quality Improvement.

A repetitive routine operation is a desirable operation characteristic for the robotization. The amount and type of repetition in each of these work divisions should be analyzed. Relationship between number of units produced by robot and total cost can be shown as Figure 1. The total cost is divided into fixed and variable costs as shown in Equation 1.

$$\text{(Total Cost of Robot)} = a(\text{Number of Units Produced}) + b \tag{1}$$

in which a = variable cost; and b = fixed cost. If Equation 1 is divided by "Number of Units Produced", then Equation 2 can be shown as:

$$\frac{\text{Total Cost}}{\text{Number of Units}} = a + \frac{b}{\text{Number of Units}} \tag{2}$$

This equation can be shown graphically as Figure 2. Similar curves can be developed for conventional construction equipment, and fixed automation. These curves are presented in Figure 3. This figure shows the relation between unit cost and number of units produced. The intersection points

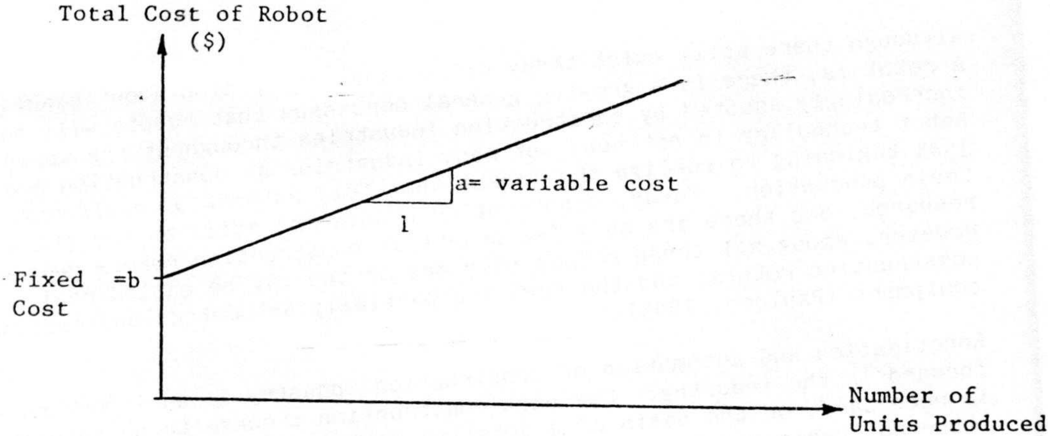

Figure 1. Total Cost Analysis

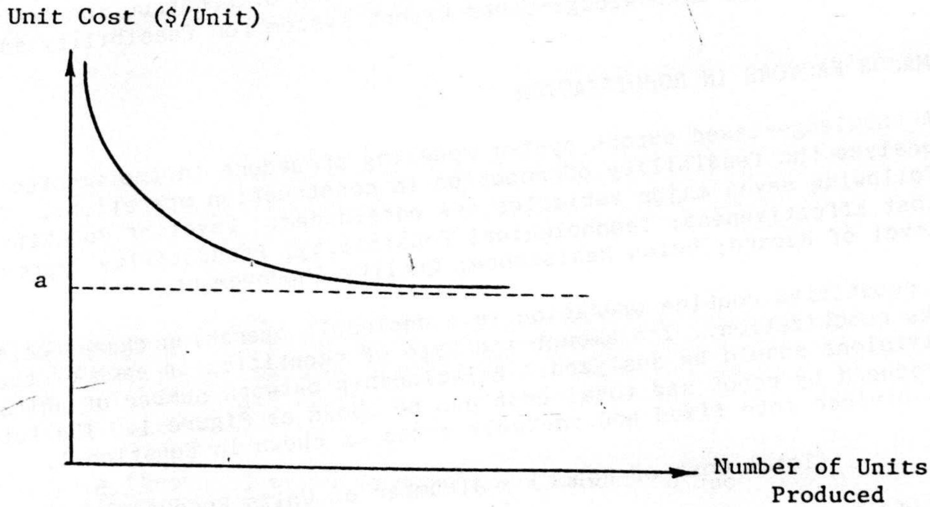

Figure 2. Unit Cost Analysis

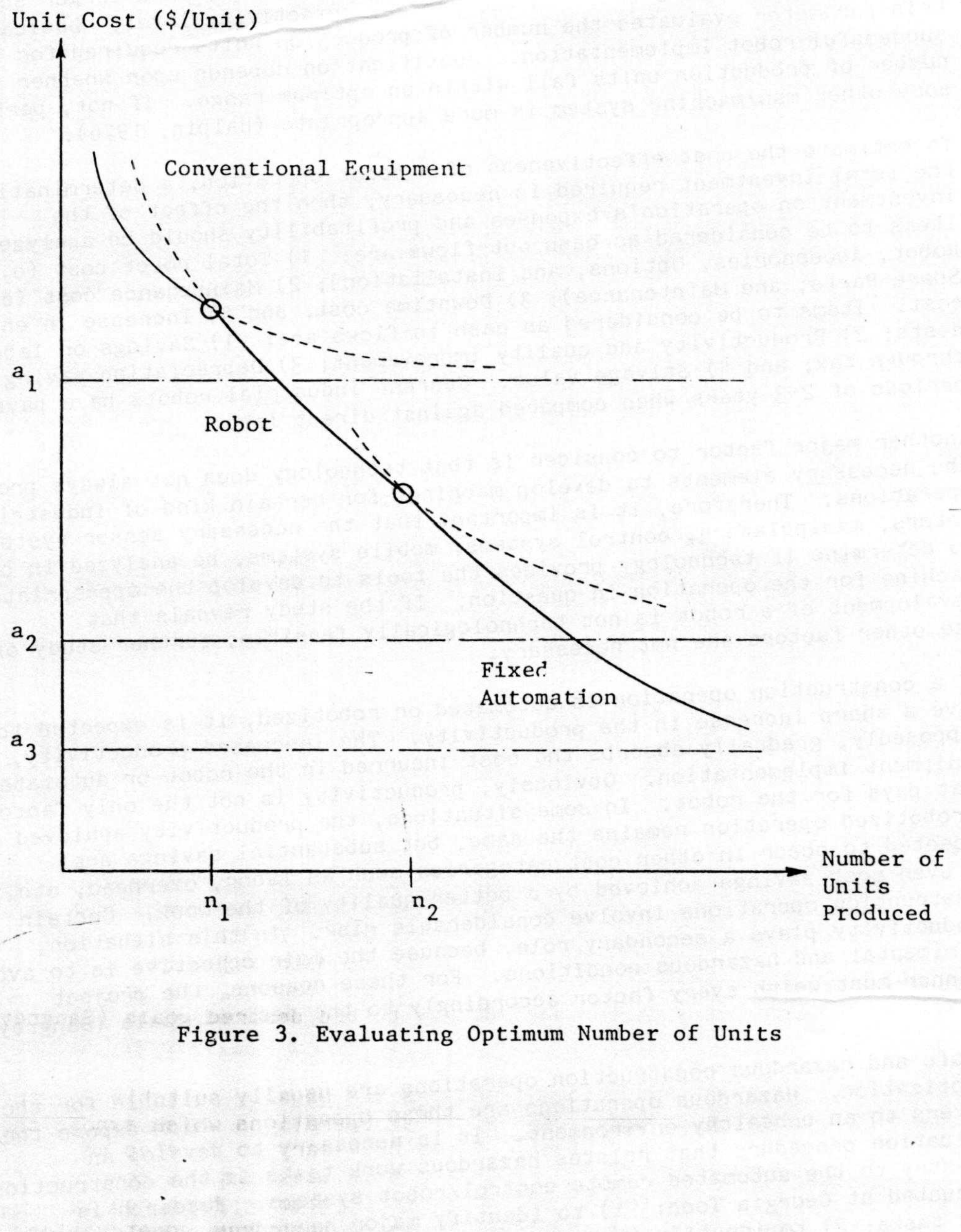

Figure 3. Evaluating Optimum Number of Units

(n_1, n_2) show that operation should change from conventional equipment to robot or fixed automation.

Standardization of design also involves repetition but on a larger scale. Here, repetition is studied on the project or activity level. Basically, this parameter evaluates the number of production units required for successful robot implementation. Justification depends upon whether the number of production units fall within an optimum range. If not, perhaps some other man/machine system is more appropriate (Halpin, 1976).

To estimate the cost effectiveness of a robot operation; a determination of the total investment required is necessary, then the effect of the investment on operation's expenses and profitability should be analyzed. Items to be considered as cash out-flows are: 1) Total robot cost (e.g., Robot, Accessories, Options, and Installation); 2) Maintenance cost (e.g., Spare Parts, and Maintenance); 3) Downtime cost; and 4) Increase in energy cost. Items to be considered as cash in-flows are: 1) Savings on labor costs; 2) Productivity and quality improvement; 3) Depreciation saving through tax; and 4) Salvage value. Current industrial robots have payback periods of 2-3 years when compared against direct labor.

Another major factor to consider is that technology does not always provide the necessary elements to develop machines for certain kind of industrial operations. Therefore, it is important that the necessary sensor systems, motors, manipulators, control systems, mobile systems, be analyzed in order to determine if technology provides the tools to develop the appropriate machine for the operation in question. If the study reveals that development of a robot is not technologically feasible, further study of the other factors are not necessary.

If a construction operation is automated or robotized, it is expected to have a sharp increase in the productivity. The increased productivity, supposedly, gradually absorbs the cost incurred in the robot or automated equipment implementation. Obviously, productivity is not the only factor that pays for the robot. In some situations, the productivity achieved by a robotized operation remains the same, but substantial savings are expected to occur in other cost categories such as labor, overhead, etc., or even cost savings achieved by a better quality of the work. Certain construction operations involve considerable risk. In this situation, productivity plays a secondary role, because the main objective is to avoid detrimental and hazardous conditions. For these reasons, the project planner must weigh every factor accordingly to the desired goals (Sangrey, 1984).

Unsafe and hazardous construction operations are usually suitable for the robotization. Hazardous operations are those operations which expose the workers to an unhealthy environment. It is necessary to develop an evaluation procedure that relates hazardous work tasks in the construction industry to the automated remote control/robot systems. Research is conducted at Georgia Tech: 1) to identify major hazardous construction work tasks; 2) to identify important hazardous factors involved in the applicable work tasks; 3) to evaluate the hazard, by using special instruments and permissible exposure limits; 4) to develop a series of work task diagrams in which all the work conditions are considered; and 5) to develop a rationale for replacing the worker in the hazardous environment, with a controlled remote equipment or a robot. Figure 4 shows a general spray painting work task. In this work task the application of different kinds of paint, with different solvents and additives, can create a possible hazard to the worker. From this figure, it can be determined when and where this hazard can occur, and if it is suitable to replace the workers by a robot.

At this time, the construction labor organizations are nominally interested in the potential use of robotics in the construction industry. This is fostered by the belief that the construction environment is too random and demanding to allow robots to function effectively for the foreseeable future. Thus, no formal policy has been developed towards robotization, and the cavalier statement that "the unions will not stand in the way of progress or the new technology to achieve this progress" can be made easily. However, the labor organizations need look no further than the recent experiences of the automobile and steel industry labor unions to achieve the needed hindsight with regard to what happens to labor when a shortsighted approach is taken toward robotic applications. Union resistance is considered to be somewhat dependent upon the following: number of workers being displaced; union strength in the area; policies of management (advance notice to union officials, placement programs for displaced workers, etc.). These parameters are more difficult to model because no definite measurement scale of union resistance exists.

Quality improvement is an important factor in developing robots. Generally, robot produces better quality than traditional systems. Quality can be measured by such characteristics as strength, dimension, color, and etc. Relationship between cost and the level of quality improved must be carefully analyzed by contractors.

KNOWLEDGE BASED FEASIBILITY ANALYSIS OF ROBOTIZATION

A model for robotics feasibility analysis in construction industry based on knowledge-based expert system was developed. Figure 5 shows an inference net for the developed model. The system considers the above seven important factors for its analysis. A microcomputer expert system shell program was implemented. Information is presented by production rules with many explanation modules (Kangari, 1985).

The model has utilized a confidence level for the analysis of the degree of repetitiveness. The economical analysis part consists of: 1) whether robotization is commercially economical; and 2) if it is economical to do research and build a new robot.

The final result of this model is a set of recommendations about a given construction operation which describes whether it should be robotized. A confidence level is associated with each outcome. The necessary suggestions to improve or further automate a construction process is provided. The model is designed to quantify qualitative judgements on the part of an expert group, and to combine that with the results of algorithmic model which estimates costs and production.

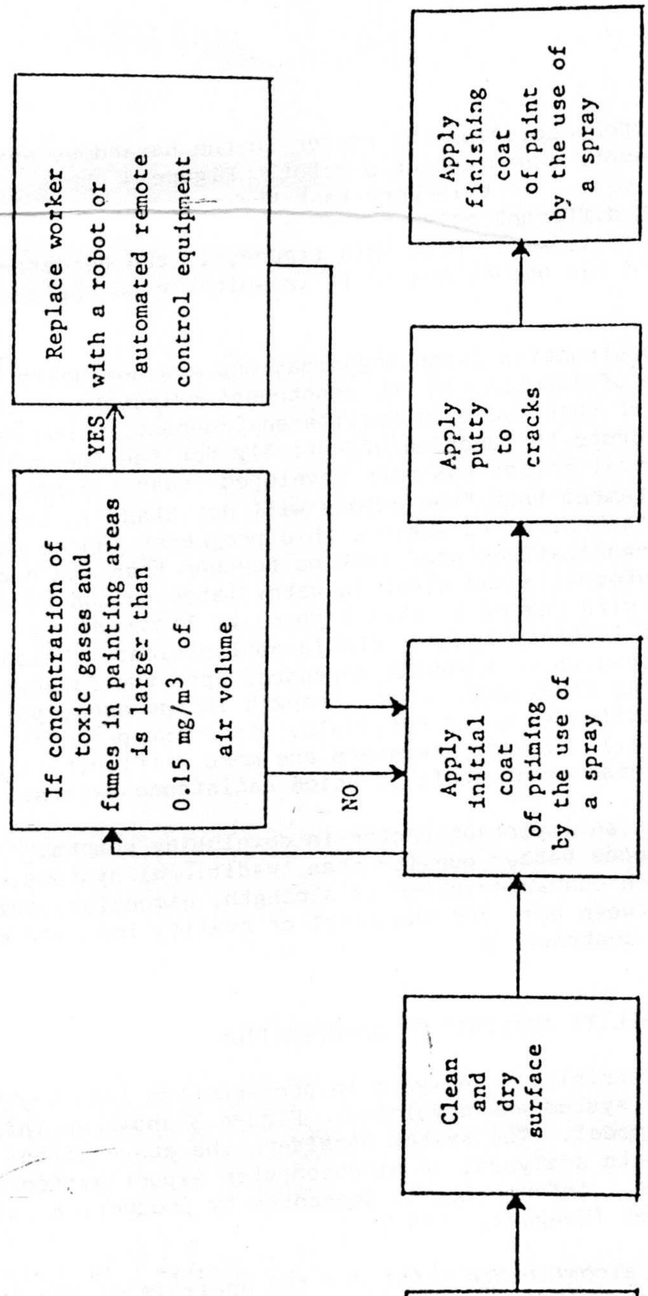

Figure 4. General Spray Painting Work Task Diagram

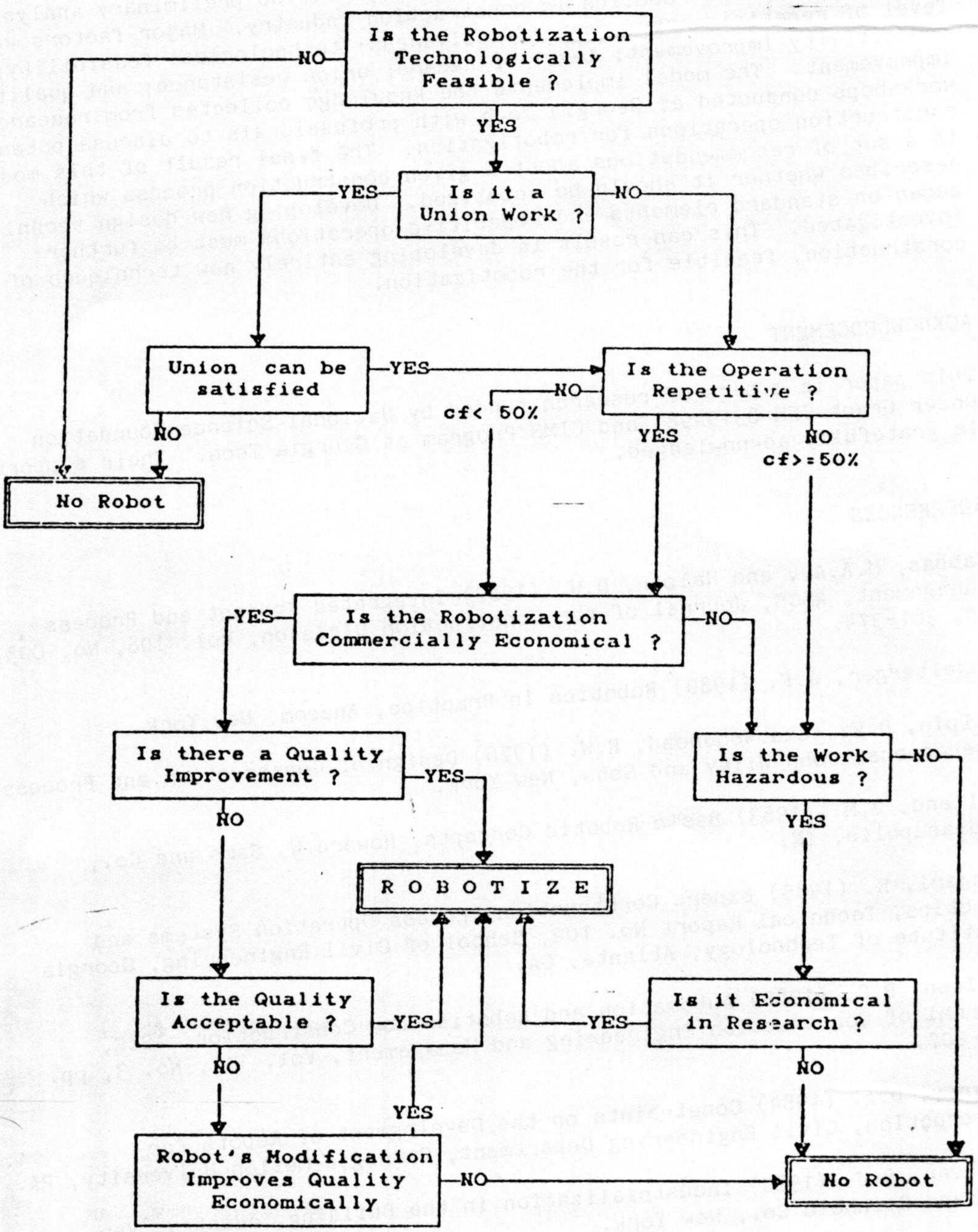

Figure 5. Knowledge Based Expert System Inference Net for Feasibility Analysis of Robotics in Construction

SUMMARY AND CONCLUSIONS

A knowledge-based expert system was developed to do preliminary analysis of feasibility of the robotics in construction industry. Major factors were: level of repetitiveness; cost effectiveness; technological feasibility; productivity improvement; level of hazard; union resistance; and quality improvement. The model implements the knowledge collected from research workshops conducted at Georgia Tech with professionals to discuss potential construction operations for robotization. The final result of this model is a set of recommendations about a given construction process which describes whether it should be robotized. Developing new design techniques based on standard elements and repetitive operations must be further investigated. This can result in developing entirely new techniques of construction, feasible for the robotization.

ACKNOWLEDGEMENT

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