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SIMBASE : A Decision Support System for Economic Justification of Automated Construction Technology

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Abstract

Methodology for the economic justification of automated technology has already been developed in the manufacturing arena. This paper discusses the modifications required for application of this methodology to the construction industry. Modifications are necessary due to the industry's conservative nature in adapting new technology, the fact that the construction process resembles more a job shop production system rather than a flow shop (more difficult to automate), and due to the fact that the majority of construction contractors, relatively speaking, are small in size and capital poor. An economic justification methodology appropriate for the construction industry is presented with four modules: Cost and Performance Information Module (CPIM), Cost and Performance Evaluation Module (CPEM), Project Bids Estimation Module (PBEM), and Total Expected Profit Module (TEPM).

1. INTRODUCTION

Since the early 1980's, the construction industry has been trying to adapt automated technologies, including robotics, in order to improve its decreasing productivity. It has been reported, in the manufacturing industry, that successfully applied automated technology can improve productivity by 20% to 30% [1]. However, the construction industry has been slow to adapt automated technology for the following reasons: a harsh working environment, dependence on a high degree of manual skill, minimal standardization, and frequent reconfiguration of the operation. Many researchers have broken the problem down systematically by working on the identification of tasks which have the most potential for automation, instead of trying to automate the entire construction process at once. Kangari and Halpin [2], Tucker, *et al.*[3], Fisher and O'Connor [4], and Rho *et al.* [5] have addressed issues of task identification for different construction processes using different criteria.

Unfortunately, none of the above models include an economic justification methodology appropriate for the construction industry. Contrary to the manufacturing industry's unified structure of large corporations, the construction industry is composed of several smaller participants (*i.e.*, owners, architects and engineers, and contractors). It is the contractors, among all the industry participants, that will introduce automated technologies into construction operations. Since contractors are, relatively speaking, small in size and poor in capital for research and development compared to their manufacturing counterparts, they are reluctant to adapt automated technology. Moreover, contractors in construction make profits based on each project's bids (*e.g.*, job shop production) unlike manufacturing which bases its profit on the number of products in the mass production system (*e.g.*, flow shop production).

Therefore, an economic justification methodology, the total expected profit (TEP) method, is developed in order to support a construction contractor's decision on incorporating and/or adapting new automated technology. This methodology is used in the development of software called SIMBASE. SIMBASE integrates digital simulation and a database system in order to estimate total expected profits accumulated from all projects over the user-defined time period.

2. TOTAL EXPECTED PROFIT (TEP) METHOD

The economic justification of replacing a conventional construction method with an automated method is becoming more complex as technology advances. Most of these automated technologies are expensive when considering only initial capital investments. Traditionally, automated technologies have been justified by applying a general expected savings analysis [6]. This analysis may be an appropriate method for the mass production system of the manufacturing industry. However, this expected savings methodology can not be directly adapted to the construction industry for the following reasons:

(1) The construction industry, in general, has been conservative in accepting new technologies. Therefore, automation in construction should be evolutionary, rather than revolutionary [2]. That is, it has to yield solid total expected profits over the initial investment cost and the life cycle operating cost.

(2) The construction process is characterized more as a job shop production in the sense that it is engaged in the production of low

quantities of various kinds of specialized products on a project basis [7]. In a job shop production system, it is more important to improve the probabilities of winning future project bids through improved credibility of the contractor by completing projects with reduced project duration and/or reduced rework than merely reducing the production cost per number of products. This is true even moreso today with the increased use of partnering arrangements for repeat business. With this strategy, contractors can increase the total expected profit and reduce the costs caused by being idle between projects.
(3) From the contractor's viewpoint, profits can be determined by the profit margin of the project bids. Since project bids include separate cost items for material, labor, and equipment, cost savings due to replaced laborers by the automated technology can not be considered as a direct benefit to the contractor even though it constitutes a major benefit in the economic justification for automation in the manufacturing industry.

For the above reasons, there needs to be an economic justification methodology which represents the job shop characteristics of the construction industry and focuses on the contractor's viewpoint. The total expected profit (TEP) method, modified from the net present value (NPV) method, was developed and implemented to calculate the total expected profit. TEP can be defined as the difference between the present value of total project bids and the present value of total costs, which represents the actual cash-flow of the contractor related to the technology being evaluated. TEP can be determined by the following equation;

$$TEP = \sum_{t=o}^{n} B_t (1+i)^{-t} - \left\{ \sum_{t=o}^{n} C_t (1+i)^{-t} + I.C \right\} \tag{1}$$

Total project bids is the summation of the yearly project bids, B_t, over the user-defined period, n, which has to be set equal to several economic life cycles of the evaluated technology. Total costs related to the automation technology can be composed of initial investment cost to adapt the technology, I.C., yearly operating costs, C_t, which include maintenance costs and labor costs required to operate the technology. Yearly costs and yearly project bids can be evaluated at the end of each year through digital simulation, and then adjusted to the present value with the user-defined minimum attractive rate of return, i.

Since the tôtal expected profit of each method is simulated under the same condition, the method with the greater total expected profit should be selected as the economical method. If the total expected profit of the automated method is greater than that of conventional method, the evaluated automated construction technology can be justified economically.

3. PRINCIPAL MODULES OF THE SYSTEM

The benefits for adapting automated technology are generally grouped into two categories, quantitative and qualitative benefits. Quantitative benefits are readily provable and quantifiable in the traditional economic justification methodologies, such as rate of return (ROR) analysis or cost-benefit analysis. Savings in labor cost, savings in project completion time, and tax benefits are some examples of the quantitative benefits. Other benefits areas are usually considered to be qualitative benefits and are frequently excluded from the formal economic justification calculations. Quality improvement, elimination of overtime charges, reduction in accident rates, and flexibility increases are some examples of qualitative benefits. Although these benefits are difficult to express in numerical values, the pervasive effect of these benefits are much greater than the quantitative benefits, in the sense that they can increase the contractor's credibility to customers for repeat business.

In order to express the qualitative benefits by numerical values as accurately as possible, SIMBASE integrates digital simulation and a database system with the economic justification methodology. Contractor's credibility can be represented by the probabilities of winning project bids, the probabilities of doing rework, and the probabilities of an accident. These probabilities are expressed as a factor and incorporated into the simulation procedure by storing these statistical parameters into the database for each construction method analyzed. These values will then be transferred to the simulation module when a project event arises. Therefore, automated technology will produce more expected profit than conventional methods due to more projects, higher utilization rate for equipment, less rework, and fewer accident claims. SIMBASE is composed of four modules; Cost and Performance Information Module (CPIM), Project Bids Estimation Module (PBEM), Cost and Performance Evaluation Module (CPEM), and Total Expected Profit Module (TEPM). The structure of SIMBASE is shown in Figure 1. Its functions and interaction between its modules are described in the following sections.

3.1 Cost and Performance Information Module (CPIM)

This module is a database file management program whose functions are as follows:

(1) To provide cost and performance information on the automation technology for the simulation process.

(2) To provide project type information to the PBEM.

(3) To store project bids and project operating costs, which will be provided to the TEPM.

Database files managed in this module are listed in Table 1.

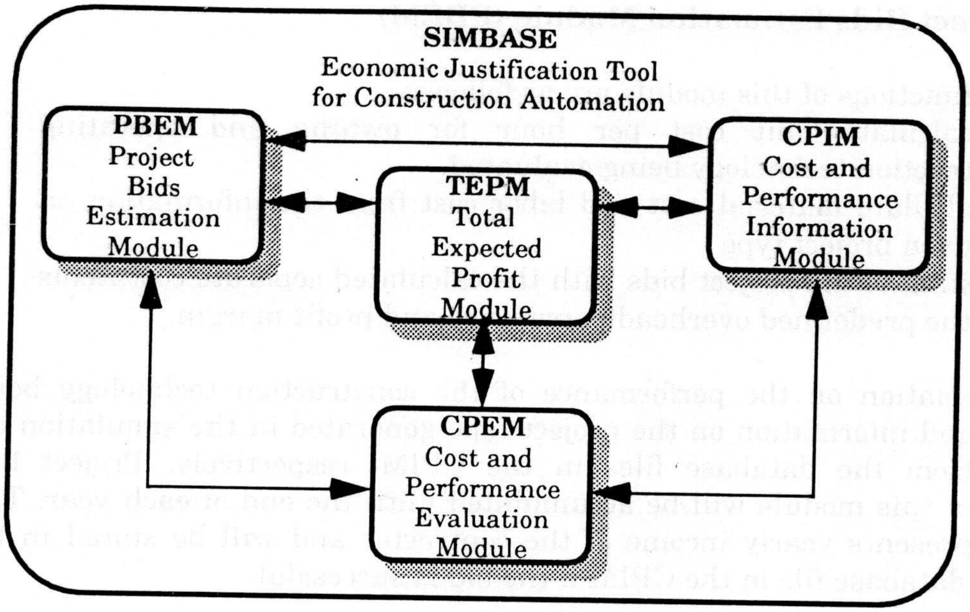

Figure 1. Overall structure of SIMBASE

The database system developed in this module can be used in many other applications later. First, all the files pertinent to the operating cost can be utilized in replacement analysis. Second, input of the project/equipment information can be automated by transfer from this database. Third, when combined with the design and engineering information, this will be the first step to computer integrated construction (CIC).

Table 1.
List of main file names and their interaction between modules.

File Name	Comments	Direction
ProjInfo	All information related to project type available in the simulation, such as project size, configuration, complexity, *etc*.	To PBEC To CPEM
ProjBids	Estimated project bids based on the project information and the technology performance if the bid is successful.	From PBEC To TEPM
PerfInfo	All information related to the performance of technology such as production rate, such as credibility factor, rework ratio, accident rate, *etc*.	To PBEC To CPEM
OpPara	Statistical parameters that each type of operation cost event will be occur during simulation process.	To CPEM
OpCost	Costs for each type of operating cost item, such as repair, downtime, maintenance, *etc*.	To CPEM

3.2 Project Bids Estimation Module (PBEM)

The functions of this module are as follows:

(1) To calculate unit cost per hour for owning and operating construction technology being evaluated.

(2) To calculate material cost and labor cost from the information on the given project type.

(3) To estimate the project bids with the calculated separate cost items and the predefined overhead percentage and profit margin.

Information on the performance of the construction technology being evaluated and information on the project type generated in the simulation are extracted from the database files in the CPIM, respectively. Project bids estimated in this module will be accumulated until the end of each year. This amount represents yearly income of the contractor and will be stored in the project bid database file in the CPIM if the bid is successful.

3.3 Cost and Performance Evaluation Module (CPEM)

This module is a digital simulation program, and its functions are as follows:

(1) To calculate project duration based on performance parameters of the technology for the given project information.

(2) To generate detailed annual project cost data for each project over the user-defined time periods.

(3) To convert contractor's credibility improvement from the qualitative benefit into numerical values by using statistical parameters.

CPEM performs simulation over the user-defined period that has to be set at several economic service lives of the automation technology in order to calculate its life cycle cost. CPEM will first schedule all the projects with the starting date and its type over the time period. Information related to each project type will be extracted from the project information file in the CPIM. (See Table 1.). Then PBEM will generate the project bids using information on the project and the technology. Finally, CPEM will decide whether the contractor will win the project or not by comparing the randomly generated number and the credibility factor of the technology. If its credibility factor is greater than the generated number, the contractor will win the project bids, and the calculated project bids will be stored in the project bids file in the CPIM. Project duration can be determined from the project information and the production rate of the technology. After completing the project, contractors will bid the next available project. The above procedures will be repeated until the end of the user-defined time period. During the simulation, CPEM will generate all events related to operating costs, such as repair, maintenance, downtime, rework, and accidents, based on their statistical parameters from the performance information file. Those operating costs will be accumulated to form yearly costs and then will be stored in the CPIM. CPEM will perform another simulation under the same project information for conventional methods. Due to the differences of the statistical parameters, total project bids and total costs will be different. The difference will be calculated in the TEPM.

Integrating digital simulation into the economic analysis can provide several advantages, one of which is the availability of sensitivity analysis. Sensitivity analysis involves repeated computations with different decision factors to compare results obtained from these substitutions with results from the original data. The sensitivity of any of the uncertain decision factors used in the economic justification calculation can be checked. Minimum attractive rate of return (MARR), time period for simulation, credibility factors, rework ratio, and accident rates are some examples of the decision factors in this module. Analysis can be displayed on graphs that show the effects of percentage variation for key factors.

3.4 Total Expected Profit Module (TEPM)

Yearly project bids and yearly operating costs, as well as the initial investment cost, will be provided to the user in tabular form, in order to indicate expected profit for each year. This table will show the above items for the conventional method and the automated method in two columns for the comparison purposes. The total expected profit can be calculated from equation (1), described earlier. If the total expected profit of the automated method is greater than that of conventional method, the evaluated automated construction technology can be justified economically.

4. CONCLUSION

This paper has provided an overview of the decision support system, SIMBASE, developed for the economic justification of automated construction technology, from the contractor's view point. Total expected profit (TEP) methodology has been developed by modifying the economic justification method for the manufacturing industry. The TEP method is appropriate for the project-oriented, capital poor contractors operating in the construction industry.

SIMBASE is composed of four modules. The Cost and Performance Information Module (CPIM) manages all the database files necessary for the other modules. The Project Bids Estimation Module (PBEM) estimates project bids based on the project information and the performance of the technology.

The Cost and Performance Evaluation Module (CPEM) simulates projects over the economic life cycle of the technology and generate project operating costs, which represents qualitative benefits of the technology. The Total Expected Profit Module (TEPM) calculates the present value of total expected profit and compares the results with those of conventional methods.

SIMBASE will be integrated into the software called "Drilled Shaft Decision Support" (DS^2), which is under development by the authors. DS^2, which is integrated software of an expert system, digital simulation, and database management system, can assist in decision making for construction of drilled foundations for bridges and other structures.

5. ACKNOWLEDGMENTS

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