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SIMBASE I & II: Project-Based Simulation for Economic Justification and Sensitivity Analysis of Automated Technology

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Abstract

One of the main reasons for the slow pace of implementation of automation technology in the construction industry, including construction robots, can be found in the fact that the construction industry has been following the automation development strategy of its predecessor, the manufacturing industry. The economic justification method developed for the mass production-oriented manufacturing industry is not appropriate for the project-oriented construction industry. Moreover, the financial situation of the specialty contractors is pretty much limited by the enormous initial investment costs of the automated technology, compared to manufacturing corporations. In order to resolve the above problems and to propose a more appropriate automation implementation strategy for the construction industry, a project-based simulation tool, called SIMBASE II, has been developed for sensitivity analysis of decision factors of a decision support system, SIMBASE I. SIMBASE I & II were applied to the drilled shaft construction process in the Texas Gulf Coast region. The results from SIMBASE I & II provide recommendations to the researchers, manufacturers, and developers regarding the direction of construction automation technology development strategy.

1. INTRODUCTION

Even though the development of automation technology in the construction industry, including construction robots, has already moved beyond the experimental stages, its practical implementation on the majority of job sites remains at a slow pace. One of the main reasons for the slow pace of implementation can be found in the fact that the construction industry has been following the automation implementation strategy of its predecessor, the manufacturing industry. Many problems have been revealed by utilizing the manufacturing industry's approach in the construction job site as follows: First of all, the traditional economic justification method for the mass production-oriented manufacturing industry, such as rate of return or return on investment method, is not appropriate for the project-oriented construction industry. Second, among many participants of the fragmented construction industry, it is the specialty contractors who will practically implement already developed automation technologies into the construction job sites. Their financial situation is pretty much limited by the enormous initial investment costs of the automated technology, compared to manufacturing corporations. Third, the level of automation technology developed for a flow-shop production system in the manufacturing industry is not suitable to be adopted directly by the job-shop type production system of the construction industry [Groover, 1987].

In order to resolve the above problems and to propose a more appropriate automation implementation strategy for the construction industry, the authors already have proposed a three-step Systems Engineering Model for Automation (SEMA) [Rho, Jan. 1993]. As a third analysis step, an economic justification method, Total Expected Profit (TEP) method, and a decision support system, SIMBASE I, were introduced at the 10th ISARC meeting in Houston [Rho, May 1993]. The TEP method calculates the total expected profit of the specialty contractor over several economic service lives, in order to include life-cycle cost analysis [Fabrycky, 1991]. Qualitative savings, such as accident reduction and quality improvement, are included, as well as quantitative savings, such as labor reduction and productivity improvement. SIMBASE I calculates the annual cash-flow of the contractor with respect to the projects winning ratio and historical operating cost databases.

A project-based simulation tool, called SIMBASE II, has now been developed in order to perform sensitivity analysis of decision factors for various projected future higher levels of automation technology implementation.

2. METHODOLOGY DESCRIPTION

SIMBASE II has been developed as a sensitivity analysis module of the project-based simulation program SIMBASE I which incorporated the TEP economic justification methodology.

2.1. Project-Based Simulation

Project-based simulation, when compared to activity-based simulation, can be defined as all of the events in the simulation being generated at the project level, rather than simulating microscopic activities. Since construction activities are mainly comprised of discrete projects, TEP can be calculated easily based on project bid income vs. project costs, as shown in the following equation:

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

where B_t = total project bids of t^{th} year
C_t = total operating costs of t^{th} year
$I.C$ = initial investment cost to adapt the technology
n = user - defined simulation period
i = minimum attractive rate of return

Total project bids are the summation of B_t, over the user-defined period 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 I.C.and C_t, which relats to operating the technology. B_t and C_t are then adjusted to the present value, using the user-defined minimum attractive rate of return.

Figure 1. shows the flow chart for project-based simulation. In the simulation, all of the income and costs occur relating to the project event, especially for the yearly cost calculation. Except for the regular maintenance and owning cost, all of the operating costs are generated during the project. These operating costs include consumables, downtime, and repair of the equipment. Costs due to accident and rework are also calculated during the project. All of the costs generated, as well as the utilization hour of the equipment, are stored in the database file, in order to calculate recovery cost for the year. Recovery cost can be calculated from the difference between the total costs and the total income from the equipment throughout the year. The total costs can be calculated by adding all of the costs recorded in the database file. The total income can be calculated by multiplying hourly unit operating cost by the total utilization hours for the year. This recovery cost, as well as owning and operating costs, is included in the unit cost calculation for the next year.

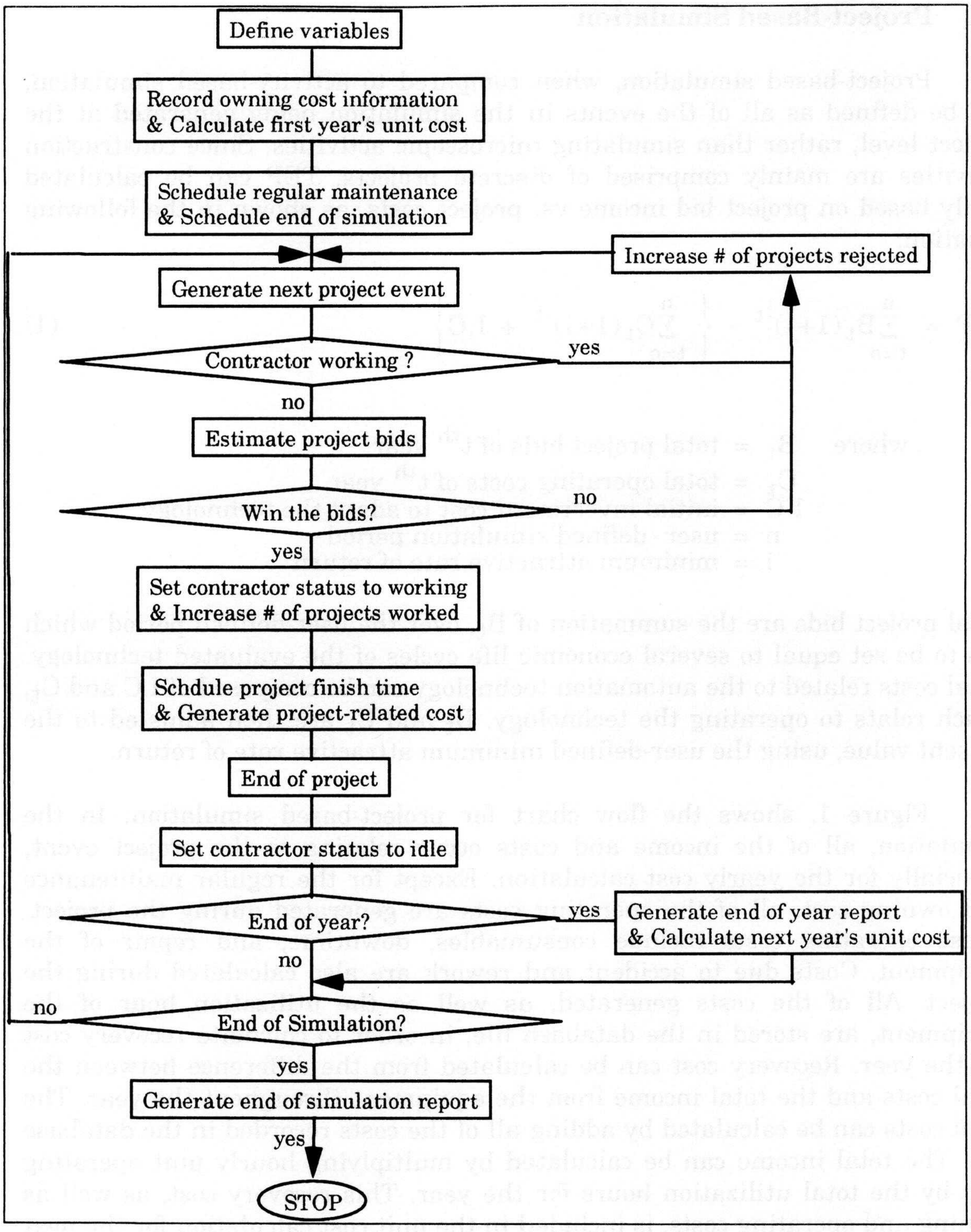

Figure 1. Flow chart for project-based simulation

2.2. Sensitivity Analysis

Implementing project-based simulation as the TEP economic analysis tool can provide several advantages, one of which is the availability of sensitivity analysis. Sensitivity analysis involves repeated computations with different values of decision factors in order to compare the results obtained from these substitutions with the results from the original value. Decision factors, included in SIMBASE II, are classified into two types; Variable Management Factors (VMF's) and Uncertain Technology Factors (UTF's). VMF's are factors that vary with respect to the user's decision on their technology management and UTF's are factors that are uncertain to the user prior to implementation. Table 1 lists the eleven decision factors selected in this research. Ratios for project bid winning, rework, and safety improvement are defined as the number representing the imprevement of respective categories, compare to the value of 1.0 of the conventional method. Sensitivity analysis is performed with incremental changes for the above decision factors from the base of the current technology's value or state. The results represent the changes of the TEP resulting from the incremental changes in the decision factors. Sensitivity analysis can determine the ranges of increment for each decision factor which guarantee a positive TEP.

Table 1.
Types of Decision Factors in Sensitivity Analysis

Type	Decision Factors
Variable Management Factor (VMF)	Minimum Attractive Rate of Return (MARR) Profit margin in project bids Annual utilization rate
Uncertain Technological Factor (UTF)	Project bid winning ratio Crew size/ hourly costs Productivity rate Repair frequency/costs Rework ratio Economic service life Safety improvement ratio Initial purchase price

3. SYSTEM INTEGRATION

Project-based simulation SIMBASE I & II are integrated with the database system, in order to manage project information and equipment cost information effectively. By utilizing more historical project information files of the contractors economic justification and sensitivity analysis produce more realistic results.

3.1. Selection of Hardware and Software

In order to minimize hardware investment and maximum convenience to specialty contractors, SIMBASE I & II are designed to operate in the commonly used DOS personal computer environment with a minimum 640 KB of RAM. Therefore, both the database management system and the simulation program are selected based on the DOS-compatibility. They are as follows:

(1) FoxPro Version 2.01 Database Management System - used for the management of owning and operating cost information of equipment/tools. It also manages the project information and default values.
(2) SIMPAK Simulation Program - used for the development of simulation and sensitivity analysis and for calculation of TEP. This program is written in QuickBASIC 4.5 and was developed at the University of Houston.
(3) MS-DOS Operating Environment - used as an interface and data transfer medium between FoxPro and SIMPAK environments.

3.2. Main Menu Structure of SIMBASE I & II

SIMBASE I & II are composed of a four main-menu system, as shown in Figure 2. In the 'Project Manager,' the system maintains all the information related to the project completed and estimates the project bids for the future projects to be bid. In the 'E/T Manager,' all of the information related to the owning and operating costs of the equipment/tools and unit cost per hour can be calculated based on the cost information. In the 'Simulation Tools,' TEP and sensitivity of decision factors can be calculated with the given project information and E/T cost information. Therefore, the first two menu items are included in the simulation tools as a submodule, respectively. In the 'System,' default values for the various modules can be updated and modified.

SIMBASE I & II are part of the software called "Drilled Shaft Decision Support" (DS^2), which has been developed by the authors. DS^2, which is an integrated expert system, digital simulation, and database management system, can assist in decision making for the construction of drilled shaft foundations for bridges and other deep foundation structures [Fisher, 1994].

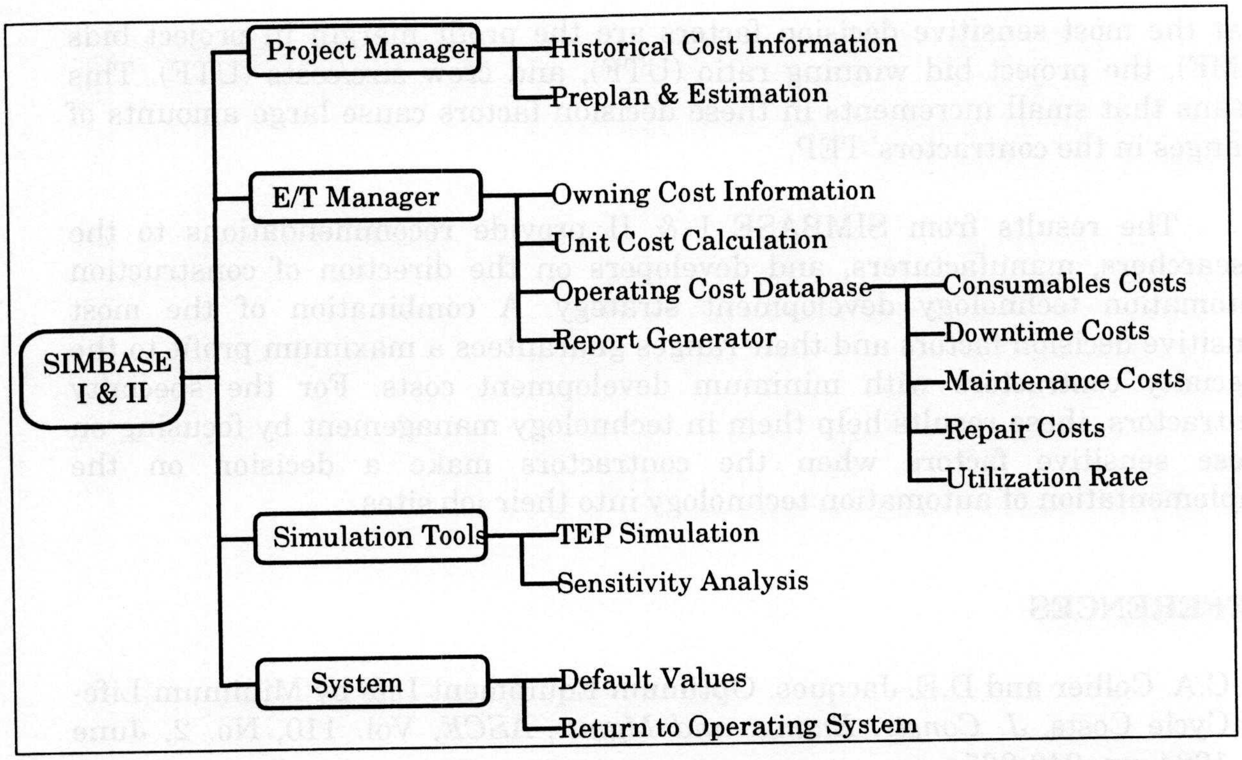

Figure 2. Main menu structure of SIMBASE I & II

4. CONCLUSIONS

SIMBASE I & II were applied to the drilled shaft construction process in the Texas Gulf Coast region. A total of thirty-two historical projects from the Texas Highway and Public Transportation were selected and provided to the system as project information [Roth, 1990]. Material and labor costs were extracted from the Means Building Construction Cost Data and conventional equipment cost information was gathered from manufactures and local contractors.

With SIMBASE I, several existing state-of-the-art pieces of equipment and technologies (equivalent to a semi-automated process) were combined and evaluated economically. This semi-automated simulated environment was then compared to conventional drilled shaft equipment and methods. Results from SIMBASE I indicate that the current level of existing automation technology can not be justified economically. There arises a need to develop a higher level of automation technology with greater returns on incrementally smaller investments.

With SIMBASE II, eleven decision factors for the development of future higher levels of automated equipment and technology, as listed in Table 1., were evaluated by the sensitivity analysis. Results from SIMBASE II indicate that the most sensitive decision factors are the profit margin in project bids (VMF), the project bid winning ratio (UTF), and crew size/costs (UTF). This means that small increments in these decision factors cause large amounts of changes in the contractors' TEP.

The results from SIMBASE I & II provide recommendations to the researchers, manufacturers, and developers on the direction of construction automation technology development strategy. A combination of the most sensitive decision factors and their ranges guarantees a maximum profit to the specialty contractors with minimum development costs. For the specialty contractors, these results help them in technology management by focusing on those sensitive factors when the contractors make a decision on the implementation of automation technology into their job sites.

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