A HYBRID NEURAL NETWORK METHODOLOGY FOR COST ESTIMATION

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ABSTRACT

This paper presents an integrated system approach, utilizing a hybrid methodology for the generation of practical cost and schedule baselines and for bid preparation under the prevailing competitive bidding environment. The system incorporates enhancements to the various functions that cover the quantitative aspects of estimate preparation, including: direct and indirect cost estimation, planning and scheduling, and resource utilization. For practicality, the system accounts for the qualitative aspects that strongly influence bid markup decision (e.g., competition, market conditions, and contractor keenness for the job). In order to provide a practical and efficient aid to such an experience-based decision, the system utilizes Neural Networks, an AI-based technique that emulates the human ability to learn from past experience and derive speedy solutions to new situations, based mainly on intuitive judgement (gut feeling) that is difficult to model by other AI-based techniques including expert systems. The paper emphasizes the conceptual and design stages of the system development, establishing a structured methodology for cost estimation and bid preparation in a competitive environment.

INTRODUCTION

Competitive bidding still represents the main vehicle for contractors to obtain jobs and secure their market share. A substantial proportion of the construction work is awarded based on this method (Clough 1986). Under the risky environment of competitive bidding, Contractors generally determine their bid price for the construction of a project by performing two distinct functions: (1) estimation of the project direct and indirect costs; and (2) determination of a markup value that maximizes the probability of winning the job with maximum profitability. In performing these two functions, the contractor needs to arrive at a bid value that is as "practically **low**" as possible to win the job, and yet, as "practically **high**" as possible to ensure maximum profit, with a minimum amount of money left on the table. Apparently, these are two conflicting goals that require an optimum balance to ensure success.

Cost and markup estimation functions vary a great deal regarding the nature of the decision problems frequently encountered and the type of tools needed for problems resolution. On one hand, cost estimation is mainly a quantitative process that lends itself to algorithmic solutions. Despite the difficulties generally associated with cost estimation of construction projects and the short time permitted to prepare bids, most of existing tools and methodologies, although lack integration, are highly structured and have considerably matured over the last two decades. In addition, there has been ample published cost data and computer software systems with comprehensive databases, that aid in the cost estimation function. On the other hand, the determination of the markup value is mainly a fuzzy, qualitative, and ill-structured process, frequently performed by contractors in a heuristic and intuitive fashion, based only on their experience and gut feeling. As such, markup decisions lend itself to heuristic and knowledge intensive solutions. Although several bidding models have been developed since the mid 1950's to estimate markup, their use has been very limited in the industry because of their algorithmic nature that hinder their ability to incorporate many qualitative factors that characterize the decision making process, including prevailing market conditions and contractor keenness for the job. Yet, there has been limited effort to develop adequate decision-aid regarding optimum markup estimation.

The inconsistency between the highly detailed and accurate performance of cost estimation tools, and the inadequate decision aids regarding markup estimation, have contributed to a lack of reliability of the final outcomes of existing estimating tools. This is because the high costs and large time associated with preparing detailed estimates, have not yet been recoverable by increase in the contractor's competitiveness and profitability. Consequently, estimates for bid proposals are more often based on less accurate methods and/or unadjusted cost data without proper consideration of time, resources, and cashflow constraints as well as the particular project conditions. The result of a recent survey seems to support this argument (Tavakoli and Riachi 1990). The survey investigated the use of the Critical Path Method (CPM) of planning and scheduling among the top 400 U.S. contractors. The survey revealed that only 28.6% of the respondents utilize CPM-based tools in the bidding phase, as compared with 94.6% using CPM in detailed planning of work prior to start of construction. Thus, estimates for cost and schedule baselines are most often performed after a contractor wins a job and is committed to a final cost and a total duration, irrespective of his actual expenditures and execution time. This has been translated into a high percentage of business failures, high potential for claims, and at best low profit margin in the industry (Kangari 1988).

This paper examines current cost estimation methodologies and identifies the deficiencies in current estimation tools. In an effort to overcome these deficiencies, the paper describes the nature of the main functions performed during the bid preparation process and proposes a most suitable tool pertaining to each of these functions. The paper thus proposes a framework for an integrated cost estimation environment, utilizing available tools (algorithms, database management systems, and AI-based techniques) that can benefit form current industry practice and provide an adequate decision aid during the bid preparation process.

LIMITATIONS OF CURRENT ESTIMATION TOOLS

Basically, the cost and time of construction are highly dependent on the quantity of work, cost of resources, date of execution, and productivity of working crews, pertaining to the method of construction adopted. Thus, cost estimation, planning and scheduling, and control operations are highly interrelated management functions, although usually treated as three distinct and isolated ones (Stephenson 1990). Most available tools are designed to perform one of the three functions, leading to high redundancy, time consuming processing operations, and higher probability of introducing errors. The main deficiencies of current estimation tools could be summarized as follows:

- Poorly structured estimating procedures and lack of generally accepted estimating guidelines (Carr 1990).

- Inability of to provide integration among the different efforts necessary for a general estimating methodology. Current tools may provide aid regarding cost breakdown and related calculations but, they do not assist decision making.

- Inefficient utilization of available information. Contractors often have information regarding their own organization, economic conditions, market volatility, project risks, and the bid competitors. However, available methods and tools are not designed to store, process, and benefit from such valuable experience-based information.

ARCHITECTURE OF AN EFFICIENT ESTIMATION SYSTEM

In order to overcome the aforementioned deficiencies, an efficient estimation system that produces practical baseline plans and aids the preparation of timely and practical bid proposals, would ideally be designed to have the following characteristics:

- Highly integrated; adopts a methodology that integrates different management functions that consider resource constraints and the impact of the schedule on estimated costs. Such methodology provides practical estimates, minimizing redundancy and work repetition.

- Practical; incorporates assessment to the quantitative as well the qualitative aspects, utilizing possible tools (algorithmic and AI-based) that provide adequate decision-aid.

- Have modular structure; allows future expansions and enhancements.

- Information-intensive; incorporate suitable means (e.g., databases, knowledge-bases, patterns) to store, process, and utilize available data and knowledge in order to improve the practicality of estimates.

- Efficient; user interactive and fast processing.

- Flexible; previous project estimates could be used as templates for new ones and databases are saved and downloaded with the project files for records.

- Transparent; changes in the databases are simply reflected on the estimate.

Such an estimation system encompasses the development of four main components (modules): a cost estimation module, a planning and scheduling module, a risk assessment module, and a bid preparation module. Those modules share common databases managed by a database management system that links the system four modules, forming a comprehensive management information system (MIS). Adrian (1987) identified that a common database is a major component of an integrated management system. The function of a database is to store data pertaining to the integrated management functions, such as the tasks and activities included in different work packages, costs of resources, and working crews productivity. Ideally, the contractor integrated system would interact with the common database(s) and provide timely, relevant, accurate, complete, and formatted data for the different management functions. Although many cost estimating systems have been developed incorporating resource databases, current literature is limited in describing a structure of contractor databases for estimation purposes. In general, however, researchers have reported that databases containing historical productivity data, in terms of manhours needed to perform a certain work, are more practical than those containing unit costs (Adrian 1987, and Rayburn 1989). This is because historical productivity data are not as sensitive to change over time as unit cost data are. Currently in construction, several published cost data describe combination of crews, average productivity data, different construction activities, and work packages (e.g., Means 1990). These data could readily be utilized in developing an integrated cost estimation methodology. Apart from the database management system core, the structure of the system four modules and the functions performed within each of them are discussed next.

Cost Estimating Module

Despite the proliferation of available estimating tools and their underlying methodologies, estimators develop procedures of their own to compile the cost of construction, based mainly on their experience and in an intuitive manner that suits their work environment (Peurifoy and Oberlender 1989). Two basic approaches have evolved in the literature, to organize work items for estimating. One approach is to identify work categories contained in the project's written specifications, such as those of the Construction Specifications Institute (CSI) for building construction projects, and are commonly utilized by commercial software systems. The other approach uses a work breakdown structure (WBS - US Department of Energy 1986) to identify work items by their location on the project. The use of the WBS has been strongly supported by researchers seeking integration among estimating, planning and scheduling, and control (e.g., Neil 1982; Meuller 1986; Adrian 1987; Keisk and Selby 1990; Riggs 1990; Al-Tabtabai and Diekman 1990). Despite the limited use of the WBS in the construction industry in general and the building sector in particular, it forms a sound basis for the integrated methodology, in addition to a proper design of a contractor code of accounts (Neil 1982 and Ho 1990).

In the process of performing detailed Cost estimates for bidding and control purposes, contractors need to come up with the direct costs attributed to the different work packages of the project. This is done by quantity take-off from complete drawings, specifications and subcontractors' quotations in consideration of the method of construction used. Contractor databases should provide data regarding crew combinations, productivity and pay rates used for direct cost calculations. Most of the estimating systems proposed for the industry (Arditi and Riad 1988) perform these calculations very efficiently.

Indirect costs need also to be estimated. These costs include project overheads and a part of the firm general overhead. Contractors usually have a list of possible items and estimated costs are assigned to those applicable to the project. Since indirect costs are mainly schedule-based, realistic costs are practically estimated based on cost and schedule calculations. When the total of the indirect costs is calculated, it cannot readily be attributed to a certain work pack-age or a certain contract item. This issue is covered in the bid preparation module.

Planning and Scheduling Module

In the integrated environment, the tasks and activities identified by adopting WBS in the cost estimation module are to be scheduled and the cost implications of such schedule addressed. The system should facilitate the link among the WBS elements, the activities and resources databases, and a proper planning and scheduling algorithm. Such algorithm should incorporate both calendar and working days in order to consider for pre-specified management decision activities (vacations, delays, etc.) or pre-specified time constraints. Complete and relevant information regarding the tasks and their interdependencies within an activity should be stored in the activities database. Accordingly, activities are assigned planned start and finish times, and critical activities are determined.

Following the initial schedule calculations, practical productivity factors are to be assigned to the activities to account for expected weather conditions at the scheduled times, trade congestion, over time, and other productivity-related factors. Also, the work load of owned resources is to be considered. Based on these considerations, a cycle of schedule updates may become necessary and resources may have to be reallocated, impacting the direct cost and the schedule. Accordingly, after cost and schedule refinements, various reports pertaining to the project activities, direct costs, schedule, and resource use, can be generated at the different management levels. Some of these reports, particularly those pertaining to accumulated resource use, provide a guide for indirect cost estimation.

A planning and scheduling algorithm, incorporating a comprehensive updating and resource management functions, is currently being developed. The algorithm integrates usual network techniques suited for projects comprising non-repetitive activities, and the Line of Balance technique (LOB) used mainly for planning, scheduling and control of linear projects comprising sequential and repetitive activities. Such algorithm provides a more suitable planning and scheduling model of high-rise buildings and a number of civil engineering projects (e.g., Johnston 1981; Lumsden 1968; O'Brien 1975).

Risk Assessment Module

The first two modules have discussed the procedures necessary to consider the quantitative aspects of bid estimation. The risk assessment module, on the other hand, presents an effort to incorporate the qualitative factors into the cost estimation methodology. Accordingly, optimum markup and the probability of winning the job could be more practically estimated. In order to identify the qualitative factors that characterize the bidding decision-making process, Ahmad and Minkarah (1988 b) have conducted a questionnaire survey among the top 400 U.S. general contractors. Table 1 lists the 10 top-ranked factors, out of an exhaustive 31-item list included in the survey, affecting percent-markup decisions. In practice, contractors depend on their "gut feeling" that is developed through accumulated experiences, to estimate a markup value in response to a group of qualitative factors representing a **project risk pattern**. Although several bidding strategy models have been developed since mid 1950's to provide assessment to the optimum markup problem, practically their application in the industry has been very limited due to the limitations described earlier.

Table 1: Factors affecting % markup decisions

Rank	Factor
1	Degree of hazard
2	Degree of difficulty
3	Type of job
4	Uncertainty in estimate
5	Historical profit
6	Current workload
7	Risk of investment
8	Rate of return
9	Owner
10	Location

Recently, some research efforts (e.g., Ahmad and Minkarah 1988 a) have investigated the application of Knowledge-Based Expert Systems to the problem. However, expert system applications for several of construction industry problems including the problem in hand, may prove inadequate. This is because the problem in hand, lends itself to more of an analogy-based solution which expert systems are ill-equipped to model. Also, this type of problem usually constitutes of a large number of attributes (i.e., qualitative factors) that have to be considered in parallel (as a pattern) and the knowledge needed for the problem resolution is mainly implicit and can hardly be modeled in the form of IF..THEN rules as utilized in most expert systems. This has been a major reason for the knowledge acquisition problem that faces the development of expert system applications in the industry and limits them to narrow domain problems where a large body of knowledge connecting situation to actions exists (Adeli 1988; Brandon 1990; Jackson 1986; Musen and Van Der Lei 1988 among others). Unlike the research in expert systems which mainly depends on reasoning, another AI-based research (Neural Networks) has recently provided powerful tools, performing complicated pattern recognition tasks. Since the problem in hand is of the latter type, neural networks could provide a more suitable and practical model of the optimum markup problem.

Recently in construction, Moselhi et al. (1991) have identified the characteristics of neural networks with respect to possible implementation in construction, and several potential applications outlined. An example network was developed to demonstrate the potential benefits of neural networks and illustrate the simple and efficient modelling of construction problems. The example presented a neural network designed to generalize the solution from a few training examples of input patterns and their outputs representing the desired decision or response. After training, the network could provide adequate responses to situations even not included in the training set. In a similar fashion, a model for the optimum markup problem is currently being developed. The contractor's past bids are utilized as a training set, having the inputs as the qualitative factors pertaining to those projects and the desired outputs as the optimum markup decided in those cases.

Bid Preparation Module

Bid preparation (unbalancing) constitutes the compilation of all the project costs (direct, indirect, and markup) into unit prices assigned to the different contract items, to be submitted to the owner as the contractor's bid for the project. A linear programming model (Stark and Mayer 1983) was developed to optimally unbalance the bid, minimizing the contractor's cash out-of-flow as an objective, under a set of constraints: limited cashflow, expected differences in bid quantities, and estimated upper and lower limits for the unit prices. Those constraints are mainly input to the model based on the contractor's expectation and experience. Simple heuristics could also be used, for example, the upper and lower limits for the unit prices of a particular contract item could be set as a function of the actual direct cost and the quantity of such item (e.g., 1.2 and 0.9 of item cost/item quantity, respectively). Such cashflow analysis requires data pertaining to the expected expense curve (S-curve) and the expected income profile, which could be obtained based on the project cost and schedule estimates.

BID PREPARATION METHODOLOGY

Based on the previous discussion, the elements included in the estimation system four modules are illustrated in Figure 1. Also, the methodology that effectively incorporates both the quantitative and qualitative assessments of bid preparation is outlined in the flow diagram of Figure 2. In the first step of this methodology, bid documents are received and decision to bid on the job is made. In the next step, work breakdown structure is performed, based on study of the project drawings and specifications. Each element in the WBS is automatically assigned a unique code of accounts and linked to the appropriate database(s) and an appropriate contract item. Direct costs associated with all WBS elements are then calculated based on the activities and tasks included and their resource type, cost, average productivity data from the appropriate databases, and the quantity of work estimated by the user. The output of this step is the labour costs, equipment hours and costs, total materials quantities and costs, subs costs, and total manhours used, in addition to the total of direct costs, for the different WBS levels and contract items.

In the next step, activities are to be scheduled and the cost implications of such a schedule addressed. After initial schedule calculations, practical productivity factors are assigned to the activities to account for expected weather conditions at the scheduled dates, trade congestion, over time, and other productivity-related factors. Those factors, in addition to the workload of owned resources, are considered through a cycle of cost, schedule, and resource updates. Accordingly, in the next step, reports pertaining to the project activities, direct costs, schedule, and resource use, can be generated at the different management levels. Some of these reports, particularly those pertaining to accumulated resource use, provide a guide for indirect cost estimation which is performed in the next step. These include the project overheads and a part of the firm general overhead, and the total cannot readily be attributed to a certain contract item. A list of possible indirect cost items could be utilized and estimated costs are assigned to those applicable to the project.

The following step is to identify the project expected competition and collect available information about the competitors and any other factors that contribute to a better classification of the project degree of risk including: project size, type, location, ownership, and prevailing market conditions. Accordingly, optimum markup and probability of winning the job are estimated, utilizing a neural network trained to provide a decision aid for the optimum markup problem. Once this is done, the bid could be prepared for submission to the owner. A suitable bid unbalancing procedure can then be utilized, such as that of Stark and Mayer, to provide the final unit prices for the different contract items. A possible strategy to be used with the linear programming algorithm is to utilize some heuristic rules as previously discussed. The last step in the methodology incorporates a feedback cycle to refine the information contained in the company databases and the neural network model, based on actual project outcomes (win/loose the job, actual profit, and actual productivity levels).

SUMMARY AND CONCLUDING REMARKS

An integrated system, utilizing a hybrid methodology is presented for the generation of practical cost and schedule baselines and for bid preparation under the prevailing competitive bidding environment. The system consists of four main modules: (1) an algorithmic work breakdown structure-based cost estimation module; (2) an algorithmic planning and scheduling module; (3) an Artificial Intelligence-based Neural Network module for risk assessment and optimum markup estimation; and (4) a combined heuristic and algorithmic bid preparation module for bid unbalancing. These individual modules are integrated through a database management system, incorporating a unified code of accounts, forming a comprehensive management information system (MIS). The first two modules cover the quantitative aspects of cost estimation, providing a feed back cycle to refine estimated costs and schedules, accounting for resource constraints. The risk assessment module utilizes a neural network designed to estimate an optimum markup value and predicts the probability of winning the job at such level of profit, in response to the project risk pattern. The system then optimally unbalances the final bid, in an effort to improve the contractor's cashflow while maintaining his competitiveness. The hybrid system facilitates decision making, allowing detailed pre-bid estimates of costs and durations to be performed with minimal redundancy and in a timely manner, improving the efficiency of the bid preparation process. The integrated system also contributes to current automation efforts in construction and the methodology used for solving analogy-based problems could readily be applied to other domains in construction management.

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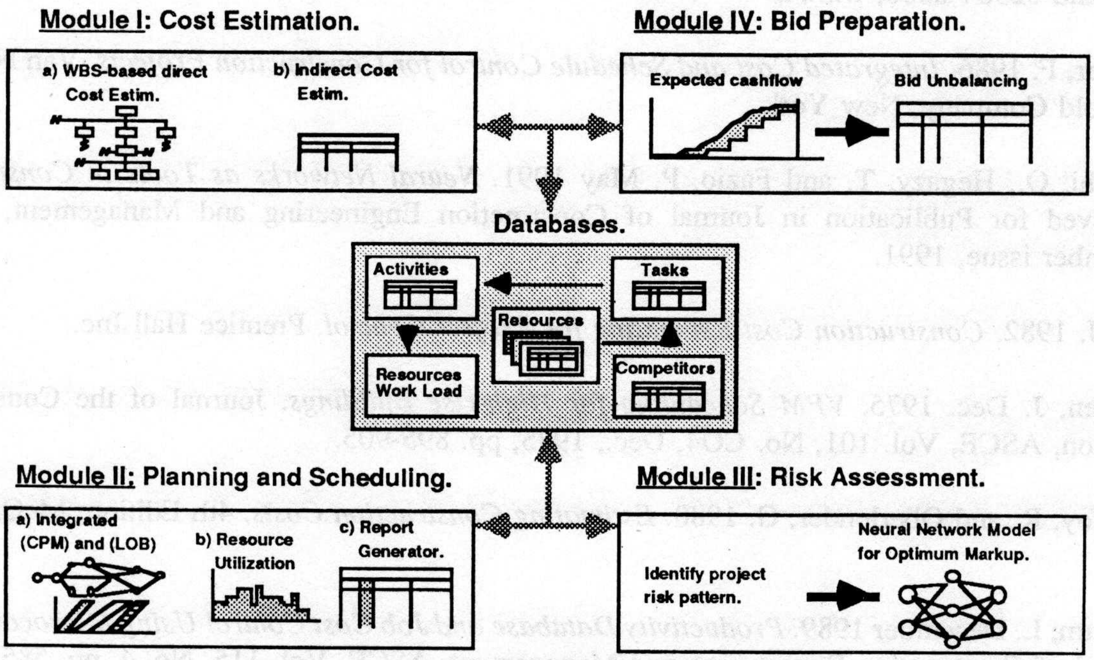

Fig. 1: Estimation system modules.

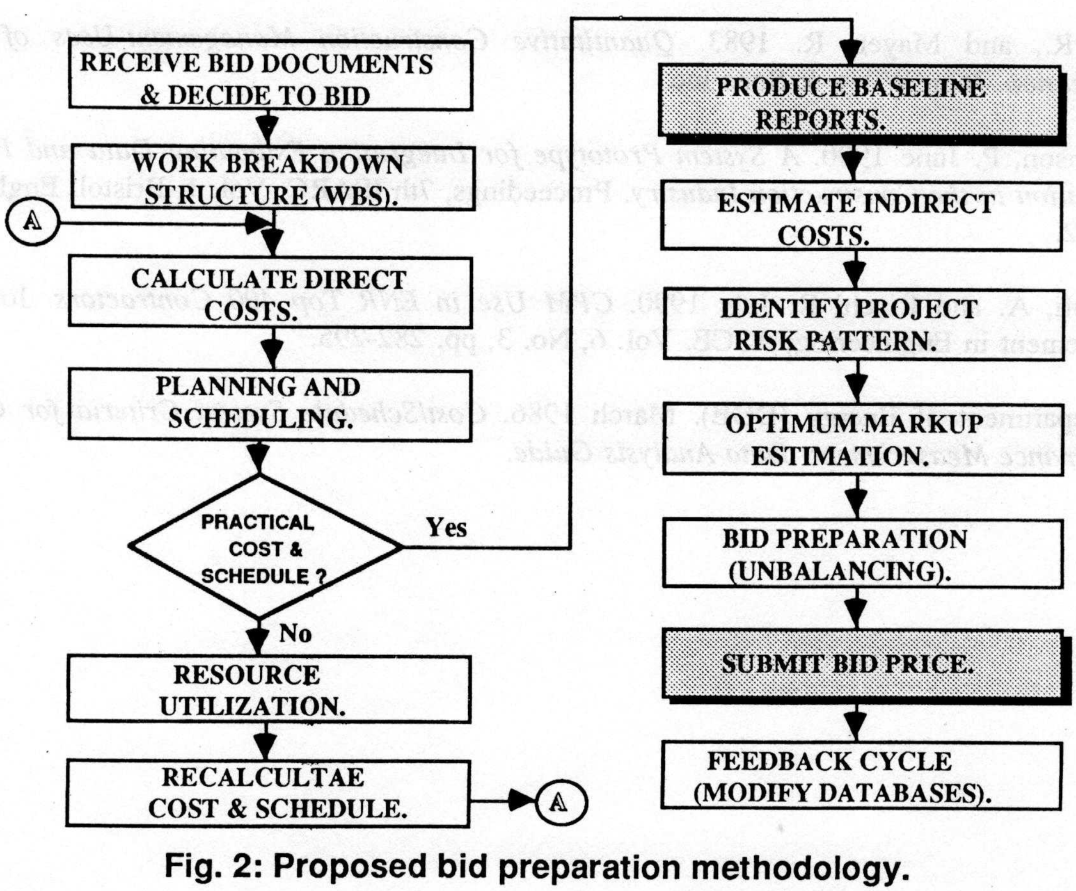

Fig. 2: Proposed bid preparation methodology.