AN EXPERT SYSTEM FOR QUANTIFYING THE IMPACT OF CHANGE ORDERS ON PROJECT PERFORMANCE

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ABSTRACT

Changes at different phases of a construction project are inevitable due to a multitude of reasons such as design changes, design errors, additions to scope, or unknown conditions that may arise due to resource limitations and the uniqueness of the project. For each change, contractors are entitled to an equitable adjustment to the base contract price and schedule. It is commonly accepted that change orders can have adverse effects on project performance, but these effects are difficult to quantify and manage, and they frequently lead to disputes. Most work in change order management focuses on labor productivity and does not pay as much attention to the quantification and management of the impact of change orders in regard to overall project performance in terms of time and cost. This paper describes a prototype expert system named QUICOPP that implements these ideas. The knowledge used in the system was acquired through a questionnaire survey administered to the contractors in North Cyprus construction industry. A list of factors that describe the adverse effects of change orders on project performance have been identified based on the survey, and this list of factors was used to develop a quantitative model of how different change orders affect the time and cost of a project. Our system provides a cost-effective means for handling change orders through all phases of a project such that construction operations can continue with the least amount of interruption that usually results from of disputes between different parties involved in a project.

KEYWORDS

Expert systems, change orders, project performance, construction industry, North Cyprus.

INTRODUCTION

Most construction projects today undergo changes at different phases due to the uniqueness of each project and limitations of time and money. A change may occur in a project due to a number of reasons such as design errors, design changes, additions to scope, or unknown

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conditions. Since contractors expect an equitable adjustment to the base contract price and schedule for each change, change orders may lead to disputes. Therefore, successful quantification and management of change orders is a must so that construction operations can continue with the least possible amount of interruption and disputes that may arise between different parties involved in a project can either be avoided or resolved efficiently.

Change orders have long been identified to have negative impact on construction productivity. They are known to lead to decline in labor efficiency and, in some cases, sizable loss of man hours (Barrie and Paulson 1996; Moselhi 1998). Therefore, change orders pose a serious challenge for both owners and contractors, and they frequently lead to disputes because of cost overruns. On the other hand, however, change orders provide an essential mechanism for (i) satisfying the construction needs of owners throughout a project and (ii) responding effectively to errors and/or omissions in design, construction methods, and contract documents. This is particularly true of fast-track construction, where construction starts prior to design completion and the scope of work is adjusted as work progresses.

Most work in quantifying the impact of change orders focuses on labor productivity, which remains to be a challenging task. Existing studies can be grouped into two broad categories: (i) Studies that cover the construction stage (Leonard 1988; Moselhi et al. 1991a; Moselhi 1998; Abdo 1999) or both the design and construction stages (Ibbs 1997), and (ii) studies that are trade-specific, covering mechanical (Hanna et al. 1999a) and electrical (Bruggink 1997; Hanna et al. 1999b) work. Thomas and Napolitan (1995) analyzed, in quantitative terms, the effects of changes and change orders on labor productivity and efficiency. Hanna et al. (1999a) developed a statistical model that estimates the actual amount of labor efficiency loss due to change orders in mechanical construction projects. Similarly, Hanna and Gunduz (2004) developed a statistical model that estimates the amount of labor efficiency lost due to change orders for small projects. Hanna et al. (1999b) conducted a study to quantify the impact of change orders on labor efficiency in electrical construction. Charoenngam et al. (2003) developed a web-based change order management system that supports documentation, communication, and integration between different team members in the change order work flow. Change orders issued during the construction of the second national highway in Taiwan have been categorized depending on whether they originate from the owner, design consultant, on-site contractor unit, or external parties (Wu et al. 2004).

In contrast to this body of work, the aim of our research is to exclusively focus on the quantification and the management of the impact of change orders on overall project performance in terms of time and cost, such that disputes that arise between different parties involved in a project can either be avoided or resolved as quickly as possible in order to reduce the interruption in the work flow. A prototype named QUICOPP (an expert system for Quantifying the Impact of Change Orders on Project Performance) has been developed to implement our approach.

QUANTIFYING THE IMPACT OF CHANGE ORDERS ON PROJECT PERFORMANCE

As first step to achieve our research objectives, a review of background literature has been conducted to identify a commonly accepted list of factors that describe the adverse effects of change orders on overall project performance. Second, using a questionnaire, a survey of private construction companies in North Cyprus has been conducted to determine which of the factors mentioned in the literature are of greatest importance in the context of North Cyprus. Finally a quantitative model of the impact of change orders has been developed, and this model has been used to implement a prototype expert system called QUICOPP. The system is to be used by managers working on behalf of both the contractor and owner to help resolve conflicts arising from having to handle change orders during all phases of a construction project.

SURVEY FOR DETERMINING THE IMPORTANCE INDEX OF DIFFERENT ISSUES OF CHANGE

The literature review resulted in the identification of 41 types of changes and five (5) responsible parties that form the *Action Group* in a project as Table 1 shows. Based on this list of possible issues of change, a questionnaire survey was designed using a nominal scale for the real values of the independent variables. To evaluate the dependent variables, a scale of 4 integer intervals (‘0’ meaning no effect and ‘4’ meaning maximum effect) was used. The respondents were asked to check a number on the scale reflecting their assessment of different factors.

A list of all 35 contractor organizations was obtained from the Association of Building Contractors in North Cyprus. During the survey, 30 organizations were contacted, and 20 (66%) replies were received. The personnel contacted for the questionnaire survey at each company was either from top management or senior management in their respective departments. Therefore, because of their expertise, the responses they provided were deemed acceptable for the validity of the survey results.

FINDINGS OF THE SURVEY

The participating contractors numerically scored their opinions on the significance of each variable in identifying the quantitative impact of change orders on project performance. The weighted average for each factor was calculated, and then it was divided by the upper scale of the measurements in what is referred to as *importance index*. The level of importance of the 41 types of changes during during construction project phases were computed using the Kish formula (Kish, 1965).

Table 1 shows the importance indices of 41 types of changes or influence factors during four project phases versus the responsible parties contributing to adverse effects of change orders on project performance. The table also includes the mean values and the rank orders of all the influence factors listed with their index values.

Three influence factors have been found to have significantly higher levels of importance than the remaining factors. In descending order, these factors are *Late Procurement Activities, Late Receipt of Equipment, Schedule Change, and Cost Reduction Change.*

Table 1: Importance indices of different types of changes during four project phases versus the responsible party contirbuting to adverse effects of change orders on project performance

				PHASES				IMPORTANT INDEX VALUES RESPONSIBLE PARTIES				
	MEAN IMP. INDEX	**RANK**	**TYPES OF CHANGES**	**Planning (P)**	**Design (D)**	**Procurement (PR)**	**Construction (C)**	**Outside**	**Engineer**	**Owner**	**Contractor**	**Vendor**
1	**2,85**	10	Omissions	☑	☑	☑	☑	0	14,25	0	0	0
2	**8,55**	8	Engineering Errors		☑		☑	0	42,75	0	0	0
3	**11,40**	6	Design Changes		☑		☑	0	57	0	0	0
4	**8,55**	8	Unforeseen Conditions				☑	42,75	0	0	0	0
5	**22,80**	4	Change in Work Sequence			☑	☑	0	28,5	42,75	42,75	0
6	**31,35**	**2**	Schedule Change			☑	☑	0	42,75	57	57	0
7	**8,55**	8	Specification Change		☑	☑	☑	0	42,75	0	0	0
8	**5,70**	9	Vendor Change				☑	0	28,5	0	0	0
9	**17,10**	5	Process Change	☑	☑	☑	☑	0	42,75	42,75	0	0
10	**11,40**	7	Asthetic Change	☑	☑		☑	0	0	57	0	0
11	**8,55**	8	Operation Directed Change				☑	0	0	42,75	0	0
12	**14,25**	6	Value Engineering				☑	0	28,5	0	0	42,75
13	**28,50**	**3**	Cost Reduction Change	☑	☑		☑	0	28,5	57	57	0
14	**11,40**	7	Constructibility Change		☑		☑	0	28,5		28,5	0
15	**17,10**	5	Intended Use Change	☑	☑	☑	☑	0	28,5	57	0	0
16	**8,55**	8	Regulatory Change			☑		42,75	0	0	0	0
17	**17,10**	5	Concept Change	☑	☑	☑	☑	0	42,75	42,75	0	0
18	**8,55**	8	Scope Change	☑	☑	☑	☑	0	0	42,75	0	0
19	**5,70**	9	Design Evolution Change		☑			0	28,5	0	0	0
20	**11,40**	7	Design Coordination Change		☑			0	57	0	0	0
21	**2,85**	10	Safety/Insurance Change(Design)		☑			0	14,25	0	0	0
22	**11,40**	7	Change in Available Resources		☑	☑		57	0	0	0	0
23	**5,70**	9	Force Majeure				☑	28,5	0	0	0	0
24	**5,70**	9	Mobilization Delay				☑	0	0	28,5	0	0
25	**11,40**	7	Quantity Change			☑	☑	0	57	0	0	0
26	**2,85**	10	Code Change		☑	☑	☑	14,25	0	0	0	0
27	**11,40**	7	Material Availability	☑		☑	☑	57	0	0	0	0
28	**5,70**	9	Seasonal Work Change				☑	0	14,25	14,25	0	0
29	**2,85**	10	Accident-Change in Safety Approach(Construction)				☑	14,25	0	0	0	0
30	**8,55**	8	Work Rules(Labor)				☑	0	0	0	42,75	0
31	**2,85**	10	Work Rules(Operations)				☑	0	0	14,25	0	0
32	**17,10**	5	Failure to perform(Owner-Engineer-Contractor-Vendor)	☑	☑	☑	☑	0	14,25	14,25	28,5	28,5
33	**5,70**	9	Late Issue of Design		☑			0	28,5	0	0	0
34	**31,35**	**2**	Late Receipt of Equipment				☑	0	28,5	28,5	42,75	57
35	**11,40**	7	Change in Timing of Vendor Drawing Approval				☑	0	28,5	28,5	0	0
36	**42,75**	**1**	Late Procurement Activities			☑	☑	0	57	57	57	42,75
37	**2,85**	10	Change in Access to Work Area				☑	0	0	0	14,25	0
38	**14,25**	6	Change in Basic Data Requirements	☑	☑	☑	☑	0	42,75	28,5	0	0
39	**8,55**	8	Change in Raw Materials		☑	☑	☑	0	0	42,75	0	0
40	**5,70**	9	As-builts Used for Design were Incorrect		☑			0	0	28,5	0	0
41	**5,70**	9	Change in Engineering Support to Construction		☑			0	28,5	0	0	0
			RANK					5	**1**	**2**	**3**	4
			MEAN IMP. INDEX					6,256	**20,854**	**17,726**	**9,037**	4,171

Influence factor *Late Procurement Activities* ranked first, both *Late Receipt of Equipment* and *Schedule Change* ranked second, and *Cost Reduction Change* ranked third. These factors are perceived by survey respondents to have adverse effects of change orders on project performance with the same value of importance (57). The interviews and observations highlighted that the emphasis should be on these input factors since crew output decreases when materials are not available. Thus the lack of materials reduces performance. Congestion and lack of tools and equipment also showed negative effect on project performance. Changes cause disruptions, and the disruptions become the de facto cause of loss of efficiency. Thefore, it is critical to avoid disruptions.

SYSTEM ARCHITECTURE AND OPERATION

Figure 3 shows the architecture of our system. The user enters information about each change order via the user interface of the system. Using this input data and information from the bill of quantities database and the project schedule database, the expert system computes the change in time and/or change in cost that is required for each change order. In addition, referring to the contract document for a given project, the system outputs recommendations about what contract clauses are of issue regarding the work item associated with the change order being processed in order to help resolve disputes.

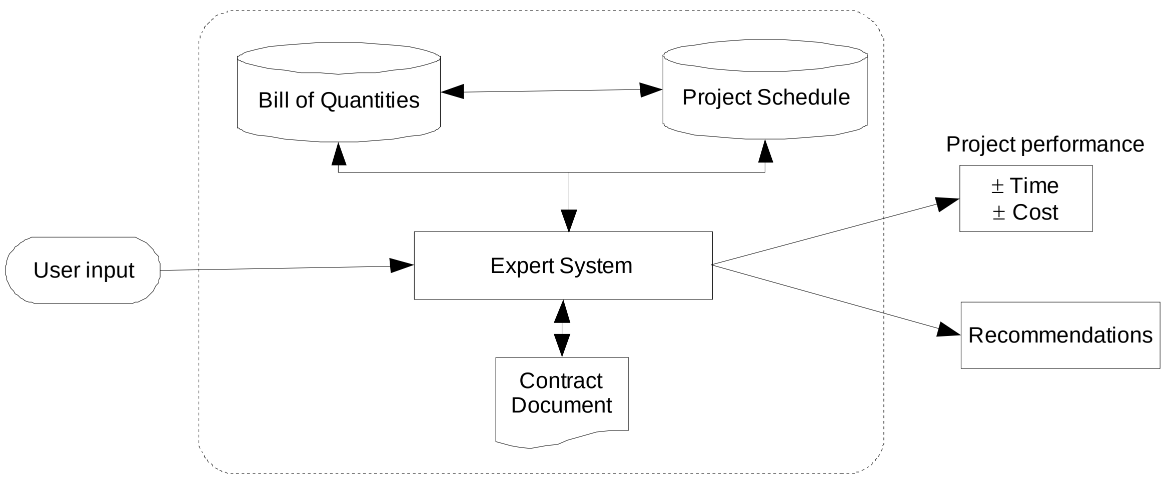

Figure 1: System architecture

Figure 2 shows the process model for our expert system, QUICOPP. There are five major stages to this model. First is information collection, which involves obtaining general information about the current project from the user. In the second stage, the user specifies the phase(s) of the project in which a change has occurred or is likely to occur. The third stage of the model is the identification of the change order type affecting project performance in terms of cost and time. In the fourth stage of the model, the impact of change order is quantified based on the issue of change.

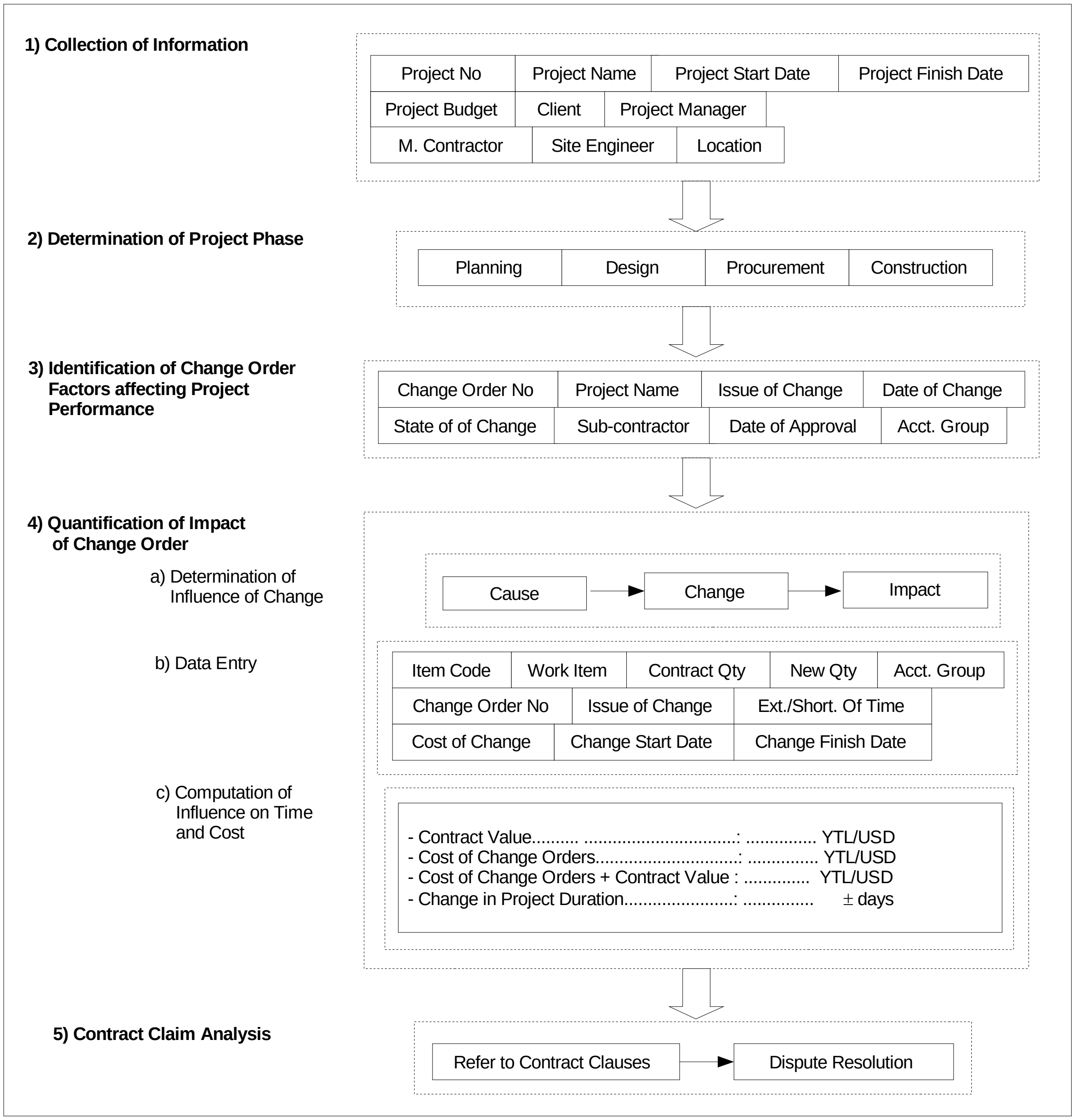

Figure 2: Process model of the QUICOPP expert system

This fourth stage involves firstly the determination of the influence of each change order using *cause-change-impact* relationship according to the influence roadmap shown in Figure 3. This influence roadmap depicts how each change type given in Table 1 is related to intermediary factors that ultimately affect project performance in terms of time and cost. The change types in Figure 3 are shown in rectangular boxes listed with their index values given in Table 1.

Considering the relationships between successive changes, in the fifth stage, the system will quantify the expected impact of those changes on project performance in terms cost and time and present the results to the user. In addition, the system will present recommendations for contract claim analysis by referring to clauses related to the type of change in question so that probable disputes may be avoided or resolved.

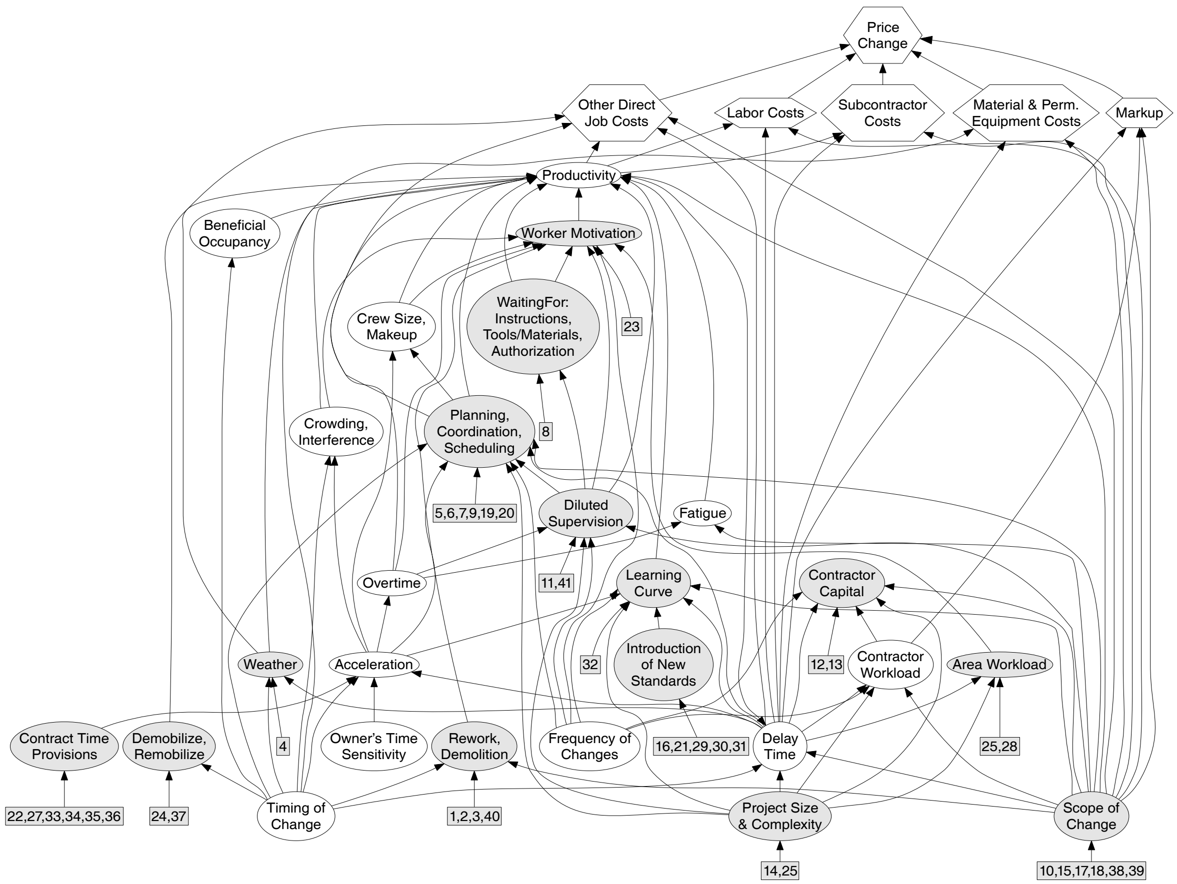

Figure 3: Influence roadmap of how each type of change is related to factors that affect project performance in terms of time and cost (Figure modified from Thomas and Napolitan (1994))

AN EXAMPLE PROBLEM SCENARIO

Suppose there is a *Schedule Change* (Table 1, index 6), and the responsible parties are the *Owner* and *Contractor*. Let us assume that the *Contractor* proposes the change and will therefore using the system. As Figure 3 shows, any change in schedule will directly affect *Planning, Coordination, Scheduling*. This factor, in turn, affects intermediary factors *Crew Size--Makeup*, *Worker Motivation*, and *Productivity*, which are a function of time. These factors then influence three types of direct costs, *Subcontractor Costs*, *Labor Costs*, and *Other Direct Job Costs* (See Table 1), which help determine the change in price associated with the work items involved in the project schedule. Hence the work item in question and other related successor work items involving the schedule will be influenced by this change. Considering the influence relationships in Figure 3, the system will display information about the influenced work items regarding the updated schedule and projected cost. If the change order is approved by both parties (*Owner* and *Contractor*) in the contract, then the system will compute the influence of changes considering the updated quantities, productivity rates, and unit costs. Since the new results are the source of probable claims inevitably arising during that phase of the project, the system will directly refer to the related contract clauses stressing the necessity for the resolution of the disputes as soon as possible. Therefore, the system may be considered as an early warning system for both parties managing the changes and dealing with the contract.

CONCLUSIONS

This paper presents an expert system named QUICOPP that quantifies the impact of change orders on project performance in terms of cost and time. The system analyzes the factors contributing to adverse effects of change orders and provides recommendations to all parties associated with a project in resolving claims regarding those changes at any stage of a project. According to the findings of our research, the emphasis should be on change types *Late Procurement Activities*, *Late Receipt of Equipment*, and *Cost Reduction Change* in managing the change orders and resolving the probable disputes that may arise between the parties involved in a project. The expert system provides a cost-effective means for resolving changes that inevitably arise during a construction project. Hence managing change orders will result in less interruption to construction operations. Moreover, this management will facilitate consensus on the final project cost and duration.

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