DEVELOPMENT OF A RISK ALLOCATION STRATEGY FOR CONSTRUCTION IN THE PROCESS INDUSTRY: A KNOWLEDGE APPROACH

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The lack of structured cost escalation models for construction activities in the process industry has lead to the development of this paper, which looks into the development of a methodology for improving cost management for construction works in the process industry, through the addition of a cost escalation factor. This paper reviews and discusses a knowledge based model for applying a risk / refinement allocation. The refinement allocation forms part of an overall cost escalation factor that derives out-turn costs from initial base estimates. Development of the knowledge for the refinement allocation strategy required three forms of elicitation; questionnaires, interviews and workshops. The deliverables, produced using these approaches, came in the form of influences and there affect on project cost escalation. The knowledge engineering process also showed the need for a two level contingency allocation related to the industry generically and the project specifically. The model is not intended to improve the initial cost estimate but insure improved management of the project throughout its life. Therefore, the accuracy of this escalation is imperative for client assurance and improved control of project costs.

Keywords: Knowledge, out-turn cost, project influences, risk allocation.

INTRODUCTION

The overall research looks into the development of a structured cost escalation model for improved estimating management and control in the process industry. As part of this research, the axiomatic goal of this paper is to introduce and discuss an applicable risk allowance, in the form of a refinement allocation index and strategy used to formulate this index. The model is based on knowledge provided by expert personnel from the process industry. Furthermore, as part of the refinement allocation strategy, this paper will show how a two level contingency Figure can be applied as part of an overall cost escalation model for the development of out-turn costs from an initial base estimate. The two levels of contingency are related to the general industry in which the estimate is being made and the project specifically. The entire cost escalation model developed by Bates (1997) is summarised, before concentrating on the refinement allocation strategy.

As part of the refinement allocation model, the paper will look at the way in which we can apply a two tiered contingency allocation. Ranasinghe (1994) and Yeo (1990) developed two tier structures for contingency based on quantifying uncertainties in the cost of particular items. Our case is fairly similar in as much as we have a two tired approach. However, our allowances are added in relation to the industry in which the estimate is to be made and the project specific influences, which will be explained in a ensuing section. Furthermore, company additions, such as profits, are kept separate

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from contingency, whereas, it seems to be included in the Ranasinghe (1994) model. Obviously, this may be due to the different approaches utilised by the building industry as opposed to the process industry. We feel that this component is a higher management level discussion issue and depends on the present status of the firm. Whereas, contingency and our refinement allocation are project driven.

A contingency plan is defined as a reaction to a possible future event. In the case of project management, contingency tends to be referred to as an addition to project costs based on the estimator's 'gut feeling' or a risk analysis process. There is no understandable structure or explanation with either approach. Therefore, as part of a change in thinking we will refer to the reaction against future risks as a Refinement Allocation Index (RAI). This will be the factor provided by our risk / refinement allocation strategy

As with all management procedures there are analytical and subjective techniques. (Spooner 1974) showed in his paper a mathematical approach for contingency allocation. However, contingency additions within the process industry, tend to be formed using managerial opinion. This is based on interviews with industry personnel (Bates 1997). Contingency in our opinion is a set of influences related to the overall industry in which the estimate is made and the specific project being dealt with. The allocation for this component is a science all of its own.

We feel, and the literature agrees, that contingency should be broken into a two tiered factor. Ranasinghe (1994) concluded that estimators in the first instance tend to underestimate the project cost and therefore an engineering contingency should be added to bring the cost up to the even chance position. This is dealt with our overall cost escalation model as a bias factor within the company additions element (Figure 2). The second constituent is a management contingency. This relates to the specific risks that may appear in a project life. As it says, it is management based and depends on the risk attitude of the firm.

In the case of our model the engineering contingency relates to the general industry and management to project specific influences. The first section of the paper will deal with the Work Breakdown Structure proposed by the authors to suit the proposed escalation model. The second section looks into the out-turn cost breakdown and gives a brief explanation of the components involved. It will also highlight a high level escalation model related to project cost as opposed to component costs. Moreover, the escalation model will be broken down to provide the refinement allocation model introduced in this paper. The final section uses example values to provide full understanding of the model. In addition to this, it provides conclusion of the findings and usefulness of the model within the process industry.

WORK BREAKDOWN STRUCTURE

The most important element within a process industry project is the Main Plant Item (MPI). These are items such as pressure vessels, reactors and heat exchangers and form the bulk of the cost within such a project. The work breakdown structure should therefore be developed around such items as shown in Figure 1.

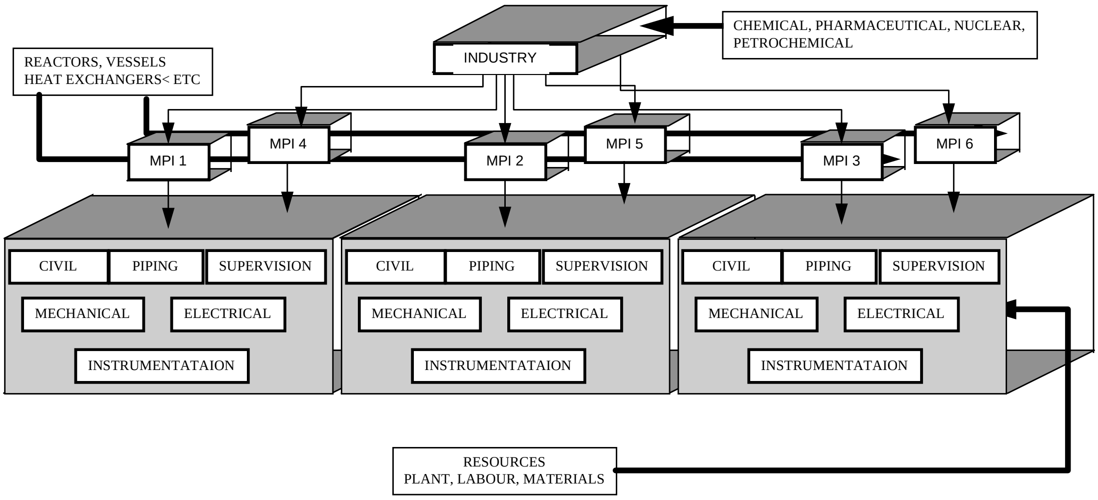

Figure 1: Possible work breakdown structure

The cost escalation model should concentrate on the main plant items. The following paragraph describes the knowledge stages within a project, utilising different levels of the work breakdown structure, to form an initial cost estimate. Then, applying an overall cost escalation factor to formulate an out-turn cost estimate.

There are five distinct knowledge / estimating stages found from knowledge elicitation of personnel from within the process industry. These are:

1. Outset Estimate }PRE- DESIGN
2. Process Estimate }MODELS
3. Detailed Design Estimate
4. Control Estimate
5. Final Analysis

The final analysis may not be an estimate, however, it is used to develop a measurement for the previous estimates and provide a bias factor to be included in future projects (Bates 1997).

There are several modelling techniques for providing a base (deflated) estimate for each of these knowledge stages. The following section looks into the breakdown of an out-turn cost in terms of escalation and a base estimate. The base estimate modelling techniques are also outlined.

OUT-TURN COST BREAKDOWN

What this paper is concerned with is the development of a refinement allocation model to be attached to the researchers overall cost escalation model. As pointed out earlier, we will be looking at a simplified cost breakdown of out-turn cost, in the process industry, and showing how the refinement allocation model fits into the scheme of things. This is represented in Figure 2.

Fitting escalation to the out-turn cost model

The out-turn cost as you can see is made up of four fundamental components, Refinement Allocation (RAI), Index Variation (IV), Company Additions (CA) and the Base Estimate. Each of these elements has equal importance.

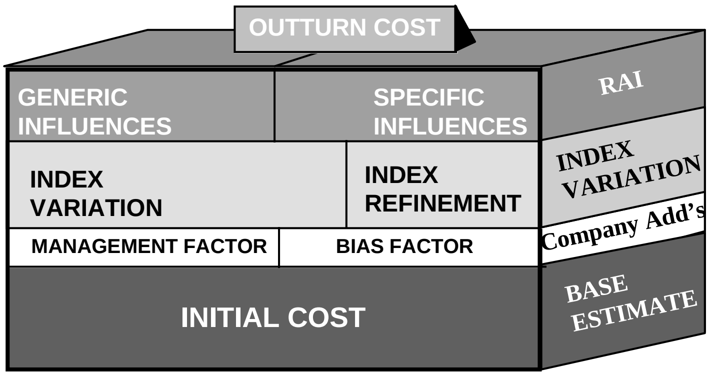

Figure 2: Out-turn cost breakdown

However, how do we get from the initial estimate to out-turn cost. Our initial estimate can be representative of any level of data from the general project cost to the detailed component cost and relates to the knowledge stage and the derived Work Breakdown Structure (Figure 1). However, at any level there are basically three matrices:

1. The Initial Cost Matrix (IC)
2. The Out-turn Cost Matrix (OC)
3. The Escalation Matrix (ESC)

The above matrices are related as in the generic case of Equation 1, which represents overall project cost. The initial cost matrix can again itself be broken into further matrices relating unit rates, times and quantities. However, as the paper is concerned with the refinement allocation strategy, we will continue at this high level of detail.

$$\left[\mathbf{OC}_{\mathbf{PI}}\right]_S = \left[\mathbf{ESC}_{\mathbf{PI}}\right]_S \times \left[\mathbf{IC}_{\mathbf{PI}}\right]_S$$

Equation 1

P represents the project level cost
I representing the number of cost items
S representing the knowledge stage

Figure 2 reveals three components involved in the development of the cost escalation factor no matter what level of cost breakdown. The relationship is assumed to be that of Equation 2:

$$\left[ESC_{PI}\right]_S = [1] + \left\{\left[CA_{PI}\right]_S + \left[IV_{PI}\right]_S + \left[RAI_{PI}\right]_S\right\}$$

Equation 2

1. IV is an index variation throughout the project life predicted using some of the approaches reviewed in Bates (1996).
2. RAI is an allocated percentage based on the model outlined later. This is the focus of the paper.
3. CA, which is a constant, based on the company set-up at that time or determined via a company bidding strategy. This also includes a bias factor based on previous project estimates.

The unity value represents the initial estimate as 100%. The procedures for developing a Figure for the initial estimate are outlined below. Computerised models, such as ICARUS are providing more detailed estimates. However, the ICARUS model still lacks the provision for escalation.

Cost models in the process industry

Mentioned above was the fact that costing models increase in complexity as a project progresses. This is due to the increased information the estimator has at hand when developing the estimate. No matter what the level of detail, the escalation model is the same, only the base estimate will change.

Stage 1, where there is no information about the foreseen project, the estimator may have to utilise past project information about the mass production per year on a similar project.

Stage 2 again may have limited information. This maybe in the form of a simple process drawing showing the possible MPIs involved in the project. Then by utilising preliminary models, also referred to as factorial models, initially developed by Lang, Chilton and Hand (more recently by Kharbanda and Stallworthy) a capital cost estimate can be provided. However, again lacking an escalation amount.

Stage 3 assumes a complete design therefore a fairly detailed estimate of capital cost can be made. The cost estimate should still however revolve around the creation of the MPI. This means that the cost headings should be broken down into the MPIs and there related costs such as civil works, electrical works, instrumentation and so on, that go into producing the MPI. Yet again this model lacks an escalation structure.

Stage 4 is a control estimate. There maybe several of these within a project life. However, again they should be related to the percentage completion of both the project as a whole and each MPI. Escalation is still required.

Stage 5 is the final analysis, which acts as a benchmarking facility for the rest of the estimates and provides a factor for bias that can be related to new estimates.

We have highlighted the components within the overall cost escalation model. Further to this some insight into the different cost models was provided. Computerised models, in the form of ICARUS, have provided further accuracy in the early stages. Nevertheless, escalation and the provision for risk are still missing. The axiomatic goal of this paper is to provide a contingency plan in the form of a Refinement Allocation Index. This is explained and discussed in the ensuing section.

Contingency addition through a refinement allocation index (RAI)

The Refinement Allocation Index is based on the surroundings of a particular project and also on a generic relationship applied to the industry in which the project belongs (pharmaceutical, petrochemical, nuclear…). Some of the factors that may influence the RAI generally (which maybe considered as risks) are:

- Duration (Long Term)
- Duration (Variable)
- Duration (Set Date)
- Project Complexity
- Choice Of Contractor
- Design Variations
- “Brief” Detail
- Client Experience Of Construction
- Flood
- Earthquake
- Landslide
- Bad Weather
- Fire
- Wind

Knowledge elicitation with expert personnel, from the process industry, has already been done and will continue in an attempt to continually update the effective list of influences. Some of the approaches applied as part of the research team’s elicitation process are reviewed in a subsequent section.

The RAI may be considered as a qualitative supplement to the quantitative components of Equation 2. However, this factor has its own defined structure and although not as statistically sound, has its confidence supplied by the experts whose knowledge we are employing.

There are no definitive changes, as the project progresses, in the RAI as with the costing models and index variation. However, the RAI has an assumed exponential degradation (Figure 3) throughout the project. This is based on the premise that there is less chance of the risks involved in the project actually occurring as the project progresses.

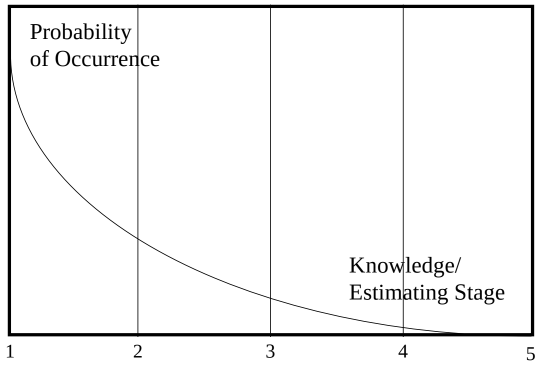

Figure 3: Decreasing effect of influences throughout project

KNOWLEDGE ACQUISITION

Several processes were used in the development of knowledge from the process industry. The methods utilised came from the relevant literature (Aouad *et al.* 1994, Boud and Walker 1994, Boose 1986, Moore and Miles 1991). This included:

- Questionnaires
- Semi-Structured Interviews
- Workshops
- Seminars

The process of knowledge acquisition has taken several turns. Nevertheless, the stages follow the next series of paragraphs. This is expanded in Bates (1997).

Stage 1 involved the development of a questionnaire to extract information on all of the influences that could possibly exist in a project’s progression, general and project specific.

Stage 2 used interviews, workshops and seminars to develop the information from the first questionnaire.

The final stage saw the revamping of the initial questionnaire to elicit useful knowledge in a structured form that could be utilised in our model, detailed later. In the first instance it was proposed that the team would utilise a process introduced by Russell and Ranasinghe (1992). However, this was obviously going to be difficult, as the knowledge required would have to be of a high quality and did not relate to different stages in the project progression. Therefore, the model had to be simplified to fall in line with the knowledge that could be acquired. The next section introduces the simplified model derived from the knowledge extracted from expert personnel within the process industry.

REFINEMENT ALLOCATION STRATEGY AND FACTOR PRODUCTION

The knowledge engineering stage caused a change in the way the RAI could be modelled. The probabilistic process introduced by (Russell and Ranasinghe 1992) was ideal for supplying variations in work package costs but not so for escalation additions. The model also fell down on the knowledge stages. Therefore, based on the knowledge attained, a simpler model was derived.

The refinement allocation index consists of two levels related simply by Equation 3.

$$\mathbf{RAI = IR + PR}$$

Equation 2

The simple model required to produce the Industry Relationship (IR) and Project Relationship (PR) factors, relates directly to the knowledge acquired and is shown in Equation 4.

$$\mathbf{(IRorPR)_S = \sum_{K=1}^{M} \phi_{KS} \times E[INF]_K}$$

Equation 4

ϕ_{KS} Represents the weightings of each of the K influences at knowledge stage S, provided by expert opinion. They represent a 'Probability of Occurrence'

$\mathbf{E[INF]_K}$ Represents the expected escalation percentage addition value for each of the K influencing factors found through the knowledge engineering processes.

Each of the influences involved are distributed according to the estimating/knowledge stage of the project. Earlier in the paper, we mentioned five distinct estimating stages found by discussion with expert personnel. The factors for IR and PR will decrease as the project progresses. This is due to the weighting factor. This weighting factor is provided by the experts in the form of a probability of occurrence ϕ_{KS}. This means, what is the probability this influence will affect the project at this particular estimating stage and in the future.

The knowledge acquired from the experts was an expected addition for the particular influence and its probability of occurrence at each of the knowledge stages. As an example, in the initial stages some account would be made for incomplete design. However, at the detailed design stage there would be no need to account for this and the probability of occurrence would be zero. This presented us with the required distributed factor for each influence. Then by utilising the model and the knowledge supplied, a factor could be developed for IR and PR and finally RAI. This is shown by example in the following sub-section.

RAI Example

Estimates at each Stage of a project's progression are given below. Also tabulated is some knowledge factors for:

- Pharmaceutical industry generally
- Project Specific

A factor is also given for company additions that include Management Additions and the bias factors for each stage based on previous projects. The Index Variation throughout the project is already calculated and is shown in the estimates table along with company additions. For further insight into the use of the forecasting methods to provide the index variation, refer to Bates (1996).

Table 1: General Project Information

	ESTIMATING STAGE				
	1	2	3	4	5
Company Additions	0.08	0.06	0.04	0.02	0
Index Variation	0.1	0.08	0.05	0.03	0
Initial Estimate	10000000	12000000	15000000	18000000	20000000

Table 2: General Industry Influences

	Probability of occurrence					
INFLUENCE	1	2	3	4	5	**Addition**
Incomplete Design**	1.0	0.6	0.2	0	0	0.2
Location	0.6	0.4	0.3	0.2	0	0.15

Table 3: Project Specific Influences

	Probability of occurrence					
INFLUENCE	1	2	3	4	5	**Addition**
Bad weather	1.0	1.0	1.0	1.0	0	0.05
Fire	0.5	0.5	0.5	0.3	0	0.05
Flood	0.2	0.2	0.2	0.1	0	0.02

RAI Factors (based on tabulated values and use of the authors' model)
RAI_1 = 1*0.2+0.6*0.15+1*0.05+0.5*0.05+0.2*0.02 = 0.37
RAI_2 = 0.6*0.2+0.4*0.15+1*0.05+0.5*0.05+0.2*0.02 = 0.26
RAI_3 = 0.2*0.15+1*0.05+0.5*0.05+0.2*0.02 = 0.11
RAI_4 = 1*0.05+0.3*0.05+0.1*0.02 = 0.07
RAI_5 = 0
Out-turn Cost Estimates
EST_1 = 10000000*(1+0.1+0.08+0.37)=15500000
EST_2 = 12000000*(1+0.08+0.06+0.26)=16800000
EST_3 = 15000000*(1+0.05+0.04+0.11)=18000000
EST_4 = 18000000*(1+0.03+0.02+0.07)=20160000
EST_5 = 20000000
Analysis of the final out-turn cost in relation to the previous estimates can provide insight into the factors that were allowed for and those that were not. The analysis will then be used to update the knowledge for use in future projects.

CONCLUSIONS

In conclusion of this paper the Refinement Allocation model, used in conjunction with the overall cost escalation model, will provide improvements in the cost management and control of process industry projects. Furthermore, client assurance in the estimates will be increased due to the explanation for each influence addition.

The simplicity of this model can easily be seen. It is quick, yet effective, especially in the early stages. Probabilistic analysis is an ideal form of modelling risk. However, attaining the distribution for each influence is difficult. Therefore, this model provides a simpler approach to risk appraisal utilising more attainable knowledge.

Finally, it is proposed that this model is utilised within the boundaries of a knowledge based system for early project estimation. Currently, provision is being made within TAROT© (A Cost Escalation Knowledge Base) for the authors' model. Further publications will highlight the model's development and the use of TAROT© within the process industry.

REFERENCES

Ahmed, I., U., and S.T. Rahman (1994) Refinement of cost estimates with artificial neural networks. *Computing in Civil Engineering - ASCE*. **2**, 1373-1380.

Aouad, G.F., S.R. Ford, J.A. Kirkham, P.S. Brandon, F.E. Brown, T. Child, G.S. Cooper, R.E. Oxman, and B. Young (1994) Knowledge elicitation using protocol analysis in a workshop environment. *Construction Management and Economics*, **12**(3), 271-278.

Bates, W. (1996) Internal report on statistical forecasting methods and their application to the heavy civil engineering, University of Teesside.

Bates, W. (1997) Internal report on cost modelling for the process industry, University of Teesside.

Boose, J.H. (1986) Rapid acquisition and combination of knowledge from multiple experts in the same domain. *Future Computer Systems*, **1**, 191-216.

Boud, D. and D. Walker (1990) Making the most of experience. *Studies in Continuing Education*, **12**, 61-80.

Farid, F. and L.T. Boyer (1985) Fair and reasonable markup (FARM) pricing model. *Journal of Construction Engineering and Management ASCE*, **111**(4), 374-390.

Grice, D.R. (1998) Potential project cost savings using principles similar to those recommended by CRINE and ACTIVE. *The Cost Engineer*. **36**(2), 5-10.

Moore, C.J. and J.C. Miles (1991) Knowledge elicitation using more than one expert to cover the same domain. *Artificial Intelligence Review*. **5**(4), 255-271.

Paek, J.H. *et al*. (1993) Pricing construction risk: fuzzy set application. *Journal of Construction Engineering and Management ASCE.* **119**(4).

Ranasinghe, M. (1994) Contingency allocation and management for building projects. *Construction Management and Economics.* **12**(3), 233-243.

Russell, A.D. and M. Ranasinghe (1992) Analytical approach for economic risk quantification of large engineering projects. *Construction Management and Economics*. **10**(4), 277-301.

Spooner, J.E. (1974) A mathematical model for contingency. *Transactions of AACE*. 81-88.

Yeo, K.T. (1990) Risks classification of estimates and contingency management. *Journal of Management in Engineering ASCE*, **6**(4), 458-470.

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