AN INTEGRATED COST-TIME APPROACH TO RISK ANALYSIS FOR CONSTRUCTION PROJECTS

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Summary

This paper provides a framework for modelling and quantifying risks associated with time and cost emanating from construction projects. A methodology is proposed whereby time risk analysis and estimated cost risk analysis can be related thereby producing a time related cost risk analysis. By combining this development with a comprehensive scheduling system such as POEM, project risk can be managed in a structured way throughout the project life cycle.

Keywords

Risk Analysis, Risk Management, Project Management, Project Planning, Monte Carlo Simulation, PERT

Introduction

The uncertainty associated with construction projects has long been recognised. Despite the growing realisation of the importance of risk evaluation, the practical use of risk analysis techniques in construc tion management remains unpopular. This may be largely accounted for by problems associated with the increasingly complex nature of construction projects. The dynamic project environment and complicated project structure demands a specific approach to risk analysis. Project managers in search of strategies responding to various project risk scenarios require a full appreciation of risks. With the escalating amount of project information and changing circumstances, conventional techniques and manual approaches are deemed to be insufficient in producing sophisticated risk analyses in a speedy and meaningful manner.

This paper describes a methodology and approach to risk analysis for construction projects. The method is intended to form part of the risk management strategy within the construction management process. The intention is to make available to project managers full probability analysis which quan tifies composite risk within a determined envelope, thereby providing the ability to correlate outcomes and form a basis from which sound decisions and judgments can be made. The approach is intended to be utilized within a planning orientated evaluation method (POEM) which is a project evaluation system incorporating cost and time analysis. The whole concept has been implemented into a computerised management information system for project planning and control. This work is funded in the United Kingdom by the Science and Engineering Research Council, the Department of Trade and Industry, and E C Harris under a Teaching Company Programme.

The Risk Analysis Model

Risk analysis models, which consider risk generally and can be classified as non-project based techniques, often fail to account for the impact of a vast amount of risk variables and do not appreciate the interdependent nature of construction activities in terms of time and cost. The current practice of using a contingency sum set aside for the provision of risk is intuitive and subjective when used alone. Thus a project-based risk analysis approach which relates to time and cost is needed for construction management.

The proposed approach generalizes project uncertainty into three domains according to their impact on activity time and cost:

i) Time - uncertainty affects time only regardless of cost

ii) Cost - uncertainty affects cost only regardless of time

iii) Time related cost - uncertainty that affects cost depending on time taken

For individual project activities, risk is conceived by estimating the possible range of values and as signing a profile of probability. As time and cost are usually correlated among activities, several time/cost relationship curves have been introduced to model the interdependency of the two elements for project activities. Different types of risk analysis are then performed utilizing Monte-carlo simulation. A schematic diagram of the proposed approach is shown in Figure 1.

Risk Data Collection

Quantification of risk upon each activity is achieved by modelling the effect with the associated probability. Given the upper and lower bounds of the effect, a probability profile is assigned to the activity. An experience planner or manager usually makes reliable and coherent estimates for the minimum and maximum time or cost an activity may take. The subjective judgment in selecting an appropriate probability density function often leads to inaccuracy in risk information. Hence the methodology proposed is focussed on the knowledge and expertise of the user.

On the selection of appropriate probability functions, the expertise of planning management personnel was elicitated. Five pre-determined probability density functions were recognised and utilized to model risk elements of a project activity are Optimistic, Pessimistic, Normal, Regular `S', and Even. Each profile represents a different range of probabilistic outcomes. Details of the distributions are shown in the appendix.

The probability profiles presented in POEM are derived from statistical distributions that reflect the knowledge elicitated from in house expertise. Consequently, subjective risk data is calibrated and the elicitation of risk knowledge is achieved within a coherent framework.

Simulation

Devising an analytical solution to risk analysis for large project networks remains impractical although approximation techniques exist. Monte-Carlo simulation evaluates outcome by randomly assigning values to the variables according their probability density functions. Individual activity time and cost are selected within the specified range randomly with bias of uncertainty modelled and controlled by the activity probability profile. This stochastic process is repeated a number of times and possible outcome is evaluated in each iteration run. Data is accumulated and later retrieved to represent the risk statistics.

Although the accuracy of the analysis increases with the number of iterations, the time required also escalates. In the case of very large projects, intelligent simulation techniques suggested by Cook and Jennings offer significant speed improvement over the conventional approach. An alternative simulation technique under investigation is Latin Hypercube simulation. It is classified as a variance reduction technique and it replaces random sampling by stratified sampling. Initial study revealed the technique exhibits more efficient simulation than Monte-Carlo under certain conditions.

Levels of Risk Analysis

The proposed risk analysis approach evaluates risk at three levels depending on the risk classes contained within the project activities. Consider the preparation of the construction cost plan or estimate when the quantities and content of work packages have been identified. Due to fluctuating prices of materials, availability of labour, changing sub-contractor rates etc., the `price' of a work package varies and thus affects the cost estimate for a project. The proposed `estimated cost risk' model performs risk analysis with sole consideration of the cost aspect of work packages and develops cost distribution with the associated statistics. Such level of risk analysis evaluates risk in terms of cost only and is termed as `Estimated Cost Risk Analysis'.

The second level of analysis which compliments the previous level is `Time Risk Analysis'. As a result of the uncertainty presence in the time required to complete a project activity, a deterministic duration does not reflect the level of risk involved. Anticipating a project schedule with fixed activity durations often results in time overrun. The introduction of PERT addressed part of the problem by allowing three point activity estimates instead of one. This crude approach in modelling risk results in constant underestimation of project completion time. Furthermore, the inability to provide a comprehensive risk analysis also undermines the use of PERT.

The interdependencies between time and cost of project activities are modelled in the `Time Related Cost Risk Analysis'. Costs which are time dependent are not included in the first level of `estimated cost risk analysis'. To model the time/cost interdependencies and their implications, relationship curves have been proposed to provide an improvement over the current deficiencies in project modelling and risk analysis. Different relationships proposed are shown in Appendix.

Project activities which consist of multitude of risks will compose a combination of risk classes. Usage of different levels of risk analysis depending on the presence of the risk types is displayed in Figure 2.

(i) Time Risk Analysis

Risk associated with time is analysed by modelling the effect of the uncertainty associated with activity completion. Each activity demands an upper and lower estimate for the completion time, plus a curve profile which describes the chance occurence across the estimated time range. Full probability analysis can thus be obtained with confidence levels established. The analysis also tabulates an activity criticality index which indicates the probability of an activity being critical. Such data can be utilised as important management information. More monitoring and control is required to be dedicated to activities with high indices as delay in any of them could imply a high chance of an ultimate project overrun.

Another useful management tool is the `Hot-Path Analysis' which evaluates the likely critical paths. The phenomenon of random outcome relating to activity times yields a variation in the critical paths. Paths are compared according to their `hit-rate' which is the percentage of the frequency of a particular path becoming critical in a simulation. The five most dominant critical paths are shown graphically and minor insignificant paths are ignored. Interpretation can be carried out in two perspectives. The `Relative Hit-Rate' of a path is defined as the percentage of criticality with the five (or less) critical paths. A path with a high relative hit-rate may have a low overall hit-rate and thus its significance in the whole project should not be overstated. Such an analysis can provide management with a better appreciation of the sensitivity of the project network, and thus lead to better planning and use of resources.

(ii) Estimated Cost Risk Analysis

The risk analysis of cost disregards the time element of project activities and models solely the cost element. Similar to time risk analysis, project cost can be estimated at any intermediate point in the project. Individual activity costs are aggregated to form a project cost estimate. The range of selected activity costs should reflect the extent of risk in terms of amount and probability of occurrence under normal conditions. The analysis produces a distribution of results with statistical analysis. Confidence levels can be established for specific cost estimates.

(iii) Time-Related Cost Risk Analysis

While the cost risk analysis models the non time-related cost, time-related cost risk analysis takes an additional cost element into the project cost composite. For activities which consist of cost risk that varies with the time required to complete the activity, several Time/Cost relationship curves are proposed to model the influence of time on activity costs. Traditionally, activity costs are assumed to have linear relationships with activity times. Historical project data reveals that the influence of time on cost can exist in various forms. It appears that there are a few basic relationships which can be combined to form a variety of curves.

Beside uncertainty in a basic cost estimate, the time-related cost risk is an additional consideration. The extra time-related cost risk is quantified by amount anticipated in addition to the cost risk. The amount is expressed in either a fixed value, or as a percentage of the estimated cost, which is probabilistic. How the likely additional cost is incurred depends on the time/cost relationship as signed and the probabilistic outcome of the activity time.

A time-related cost risk analysis performs random sampling twice for every activity within each simulation run. Initially, an activity duration is selected randomly according to the time probability profile. The second random sampling subsequently determine a cost estimate depending on chosen cost profile. An additional time-related cost value is then modelled by utilising two controlling elements: the user anticipated maximum time-related cost as a fixed value or as a percentage of the initial estimate; together with a pre-determined time/cost correlation curve selected. The activity time simulated after the first random sampling is then directly referenced to a value on the correlation curve resulting in an additional cost. This additional value is then aggregated into the original estimate to arrive at an `all-in' forecast cost. A diagram illustrating the process is shown in Figure 3.

Utilisation of Software in Risk Management

The software developed in this paper establishes the proposed approach and enable three levels of risk analysis. As part POEM, it was written in C and Clipper under MSDOS for IBM compatible hardware. Emphasis has been given to speed, ease-of-use and presentation. Together with POEM, the proposed methodology produces a model which integrates risk analysis into the construction process.

Risk analysis forms an essential part of risk management. The proposed approach addresses the quantitative phase of risk management. Together with the implementation of the qualitative phase which encompasses risk identification, categorisation, and response management, the process represents a model that can manage project risk systematically.

Conclusion

The proposed risk analysis approach provides a framework for modelling and quantifying risks in construction projects. By classifying risks into time, cost, and time related cost, managers can assess risk flexibly and systematically. The time/cost relationship curves introduce a new dimension into project risk modelling by allowing correlation between activity time and cost to be fully annotated, thus overcoming the problem associated with time/cost interdependency. The approach enables risk to be quantified at different levels according to the nature and availability of risk data.

Utilising latest information technology, the simulation proposed represents a practical and reliable method to evaluate risk. The software written provides sophisticated risk analysis in a simple to use manner. By combining the software with a comprehensive scheduling system such as POEM, project risk can be managed in a structured way throughout the project life cycle.

Future research will be related to the risk data collection, categorisation, and profile selection. With the maturity of probabilistic expert system capabilities, currently proposed a knowledge-based system should improve the speed and the accuracy of the model.

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