



Project cost risk analysis: A Bayesian networks approach for modeling dependencies between cost items

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Abstract

Uncertainty of cost items is an important aspect of complex projects. Cost uncertainty analysis aims to help decision makers to understand and model different factors affecting funding exposure and ultimately estimate the cost of project. The common practice in cost uncertainty analysis includes breaking the project into cost items and probabilistically capturing the uncertainty of each item. Dependencies between these items are important and if not considered properly may influence the accuracy of cost estimation. However these dependencies are seldom examined and there are theoretical and practical obstacles in modeling them.

This paper proposes a quantitative assessment framework integrating the inference process of Bayesian networks (BN) to the traditional probabilistic risk analysis. BNs provide a framework for presenting causal relationships and enable probabilistic inference among a set of variables. The new approach explicitly quantifies uncertainty in project cost and also provides an appropriate method for modeling complex relationships in a project, such as common causal factors, formal use of experts' judgments, and learning from data to update previous beliefs and probabilities. The capabilities of the proposed approach are explained by a simple example.

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1. Introduction

To make cost estimates, project managers use cost analysis; a discipline that attempts to forecast the ultimate cost of a project. The difficulty about this analysis, especially for complex projects, is that there are a lot of uncertainties about cost items such as technology, productivity of human resources, economic conditions, market conditions, prices, inflation and other future risks and events. In general uncertainty occurs for a number of reasons:

- Uniqueness (no similar experience)

- Variability (trade-off between performance measure like time, cost, and quality)
- Ambiguity (lack of clarity, data, structure, and bias in estimates)

Cost uncertainty analysis is an important aspect of cost estimation that helps decision makers to understand not only the potential funding exposure but also the nature of risks for a particular project or program and possible responses to them. Without considering the uncertainty involved, there is a high risk that the actual cost of a project exceeds what it was originally anticipated, which in turn causes several other risks such as delays and performance problems (Elkjaer, 2000; Lai et al., 2008).

Several techniques including Regression modeling, Artificial Neural Networks (ANNs), feature-based method (FBM) and case-based reasoning (CBR) are proposed for modeling risk and uncertainty in project cost analysis. Section 2 briefly reviews a number of notable techniques. However none of

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these techniques capture the dependencies between project cost items consistent to real world conditions.

Simulation-based techniques are the state-of-the-art approach that are adopted by many project management software tools and are arguably the best practice available (Arena et al., 2006; Chapman and Ward, 2011; Chou et al., 2009; Cooper et al., 2005). Monte Carlo simulations (MCSs) treat cost uncertainty with the input distributions derived from elicitation sessions with technical experts or, occasionally, from historical data. In particular, the ultimate goal is to estimate a cumulative distribution function (equivalently, a probability distribution function) for the final cost, which in principle contains all of the uncertainty information and allows the computation and comparison of different project riskiness.

Steadily improving software and the wide availability of powerful desktop computers make this approach straightforward to be implemented in practice. It is also attractive to analysts because of its conceptual simplicity and the widespread use of simulation technology elsewhere in the business world (Cooper et al., 2005).

However, a debate continues over the inclusion of explicit correlation in simulated quantities. The cost items may not be independent—that is, the high cost of one element may affect the cost of another because of shared technology or manufacturing resources. Such correlation—if it exists—must be captured, or the final distribution will not accurately represent the uncertainty in the final cost (Book and Young, 1997; Vose, 2000). The difficulty of doing so is an obstacle to applying quantitative risk methods. However, modeling this correlation is known to be much more difficult for human subjects to do without using various conditioning arrangements (Kadane and Wolfson, 1998). This problem is compounded by the fact that correlations between random variables, which can only take positive values (as duration and cost can), are not unconstrained. Unlike normal distributions, where the correlations between unlimited sets of normal random variables can be arbitrarily specified, subject to an overall condition of a positive definite correlation matrix, the constraints on correlated positive random variables are stronger and far less intuitive.

As is the common practice of combining probability distribution, MCS employs a correlation coefficient matrix to model dependencies between distributions of cost items (Chapman and Ward, 2011). Usually, the same project participants that estimated the cost ranges will estimate the correlation. It ranges between +1 and -1 . A correlation coefficient of +1 signifies a perfect positive relationship, while -1 shows a perfect negative one. Practically, it is difficult to estimate these correlation coefficients because the estimator has to specify all the joint distributions among cost items, which is highly impractical when the number of items is large (Yang, 2011). Moreover, matrix theory implies that a correlation matrix will not have any negative determinants in real life. Yet, with several people sitting around in a room, the correlation matrix that results may not be feasible. Adjusting the coefficients allows the user to ensure that the correlation matrix is at least not demonstrably impossible. This is a minimal test and does

not ensure us that the correlation coefficients are “right” in any sense.

The dependencies between project cost items have seldom been examined (Chou et al., 2009). In order to consider the dependencies and correlations between the cost items, this paper proposes a quantitative assessment framework integrating the inference process of a Bayesian network to the traditional probabilistic risk analysis. Bayesian networks (BNs) are a framework that presents probabilistic relationships and enables probabilistic inference among a set of variables (Heckerman et al., 1995). BNs provide an intuitively compelling approach for handling causal relationships and external influences. The application of BNs as a tool for mapping causal dependencies between frequencies and severities of risk events is demonstrated for modeling financial institutions’ operational risk (Mittnik and Starobinskaya, 2010).

The proposed model of this paper handles the correlation problem by modeling the uncertainty of common characteristics and performance indicators which affect cost items. The motivation behind this paper is derived from the fact that despite a causal relationship between uncertainty sources and cost items; this causality is not modeled in current state-of-the-art project cost risk analysis techniques (such as simulation techniques).

The purpose of the proposed approach is to improve the assessment of likelihood distribution of project cost. The new approach explicitly quantifies uncertainty in project cost and also provides an appropriate method for modeling complex relationships and factors in project, such as: causal relation between variables, common causal factors, formal use of expert’s judgments, and learning from data to update previous beliefs and probabilities.

The remainder of this paper is organized as follows. In Section 2, we briefly review previous approaches for project cost estimating. Section 3 describes the concept of correlation and dependency between cost items. An overview of BN methodology and its application to modeling dependency, and developing the proposed model is covered in Section 4. For clarification purposes, a simple example is studied in Section 5. The paper ends with the conclusion.

2. Advanced techniques for project cost estimating: a review

Several techniques and models have been developed to support better project cost estimating. Cost estimates can be provided as probabilistic or deterministic values. As each cost item is a random variable representing an unknown future cost, a deterministic value should be applied only when detailed or specific cost estimates are available from a reliable source. Deterministic values can be achieved through definitive formulation, linear programming, and optimization approaches. On the other hand, probabilistic cost estimating should be utilized during the early project development stages, especially when the reliability of information is questionable. Probabilistic models treat the future final cost of a project as a random variable and use formal probability methods to quantify its uncertainty.

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