

Cost-Performance Prediction Model of Construction Project using Bayesian Belief Networks Approach

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Abstract

Conditions of some construction projects are still experiencing cost overrun because of various uncertainty factors in the field. The uncertainty factors were interrelated. However, measurement method of cost performance such as Earned Value Analysis (EVA) didn't consider the interrelated among uncertainty factors. This paper proposes prediction method of cost performance with it consider cause-effect relationships among a set factors using Bayesian Belief Networks (BBNs) approach. To validate the model, two construction project of building were used as a case study. The results showed that prediction model can predict cost performance accurately. It provides high accuracy in cost performance prediction and the early warning for cost overruns of construction project.

Keywords: building project, probability, cost performance, prediction, Bayesian Belief Networks

Introduction

Cost is basic to successful completion of projects. Project cost and cost management are clearly two the most important management concerns in the greatly competitive environment of the construction industry. A project is considered 50% complete when one-half of the budget has been spent [1]. Cost control is the procedure of monitoring the position of the project budget and managing changes to the cost baseline. The survey result in relation to cost control techniques used in practice is Earned Value

Analysis (EVA) by 7% of contractors and 11% consultants [2]. Despite the wide application of cost control techniques, cost overruns are still quite common in construction projects.

Predicting project cost performance is very essential in tracking and controlling a construction project. Several methods have been proposed such as that based on earned value technique, fuzzy logic, social judgment theory and neural network. The EVA method currently used as a tool to evaluate the project status in terms of cost variances compared with planned value which is normally based on deterministic method [3]. In the real world, uncertainty factors such as labor productivity, equipment productivity, rework, availability of construction material, that cannot be allowed as input data to EVA method. However, a EVA method is useful to identify the variance between planned value and actual performance.

This research is intended to develop models to predict cost performance of building construction project during the construction stage. A BBNs was chosen to be a tool to develop the models so as to predict cost performance of building construction project during the construction stage more accurately than currently used method based on the EVA method. BBNs represented cause-effect relationship among uncertainty factors through graphical model [4-5]. Therefore, the result should be useful, not only for decision making, but also provides the early warning of cost overrun to the project manager of the building construction project.

Literature Review

Identify Top Uncertainty Factors

Prior to the survey, literature review helped to identify most of the significant factors that often lead to project cost overruns. In total more than 78 factors were initially identified from different studies. Some of these factors are related or overlapping each other. After an analysis from the survey with interview (expert opinion), questionnaire, and observation, 12 factors are the significant factors. These factors and their source are outlined in Table 1.

Table 1: Identified Uncertainty Factors Affecting Cost Performance

No	Uncertainty Factors	Sources
1.	Weather factors	[6-13]
2.	Quality of work	[8], [11], [14]
3.	Availability of construction materials	[14]
4.	Material price fluctuations	[6-10], [12-13], [15]
5.	Availability of construction equipment	[10], [13]
6.	The accuracy of construction material procurement	[6-11], [13]
7.	The accuracy of construction method	[6], [10], [14]
8.	Labor shortages	[6],[9-10],[12-13]
9.	Placement labor based on skill	[10]
10.	Rework	[8], [10-11], [14]
11.	Labor productivity	[7-10], [12-13]
12.	Construction equipment productivity	-

Bayesian Belief Networks (BBNs)

Bayesian Networks (BNs) or Bayesian Belief Networks (BBNs) are powerful technique for decision support under uncertainty that have attracted a lot of attention in different fields [16]. Bayesian Belief Network consist of quantitative and qualitative representation [4],[17]. The qualitative representation is the directed acyclic graph (DAG). The arcs represent direct influence or causal relationship between the variables [17-18]. The nodes in the graph are random variables. The quantitative representation is a Conditional Probability Table (CPT). The CPT represent likelihoods based on prior information or past experiences [19-20]. BBNs are probabilistic analysis methods based on the Bayes Theory [4], [17-18]. Bayes theory may be simply expressed as follows:

$$P(A|B) = \frac{P(B|A) * P(A)}{P(B)} \quad (1)$$

Prior probability P(A) dan posterior probability P(A|B). In general, the posterior probability is the product of prior probability and the likelihood. Schematically, Fig 1 represents a simple BBNs for cost performance in the building construction project.

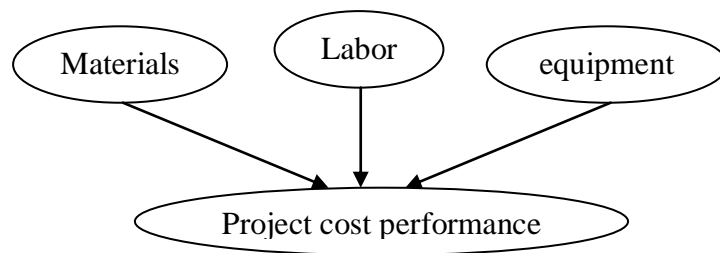


Figure 1: A simple BBNs structure in the project cost performance

Methodology

Building BBNs Models

Model building will proceed through a number of phases. Step 1: Identifying uncertainty factors that the most affecting the cost performance of construction project through the literature study, interview with construction experts and questionnaire. Step 2. The qualitative part. Identifying cause-effect relationship among the uncertainty factors through a questionnaire with a dependency matrix. The qualitative part of BBNs, the so called structure learning is the graphical representation of independence holding among uncertainty factors and has the form of a directed acyclic graph (DAG). Step 3. The quantative part. The quantitative part of BBNs, the so-called parameter learning, finds dependence relations as joinr conditional probability distributions among uncertainty factors using cause and consequence relationships from the qualitative part and data of uncertainty factors.

Prediction of Project Cost Performance

Steps to calculate prediction of project cost performance are 1) Determining the probability of the uncertainty factors that affect the project cost performance through prior input and fill CPT with secondary data, questionnaires and interviews construction expert, 2) Calculating the probability prediction of project cost performance from time to time with Bayes software, 3) Calculating prediction of project cost performance, by prior calculating the Expected (E) value. The formula is used to calculate prediction of project cost performance, namely:

$$E_n (\text{IDR}) = \text{BBNs probability}_n \times \text{Planned Value}_n(\text{IDR}) \quad (2)$$

$$\text{BBNs Prediction}_n (\text{IDR}) = \text{Planned Value}_n (\text{IDR}) \pm E_n (\text{IDR}) \quad (3)$$

n = time period (weeks)

Accuracy of Prediction Model

The accuracy of prediction models of project cost performance was calculated using statistical formulas Absolute Percentage Error (APE).

$$APE = \left| \frac{y_t - \hat{y}_t}{y_t} \right| \times 100 \quad (4)$$

where \hat{y}_t = prediction value in week t ,

y_t = actual value in week t ,

t = prediction period (weeks).

If the APE value ≤ 30 , the accurate prediction models to be used [21].

Model prediction process with "S" Curve is presented in Fig 2.

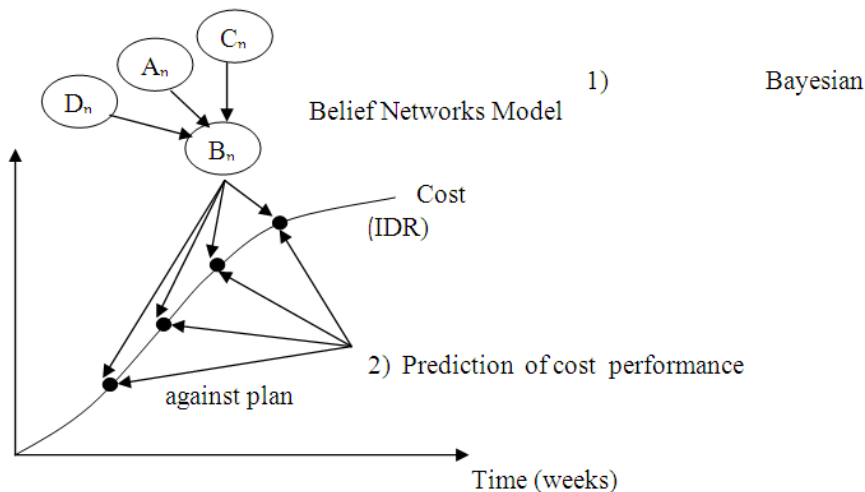


Figure 2: Prediction process of project cost performance using the BBNs approach

Model Implementation and Discussion

Model Structure

The identification of variables which is the first step of the development of a Belief Networks for affecting cost performance in construction project. The purpose of this research is composed of 12 variables that have a potential impact on the cost performance. The critical variable and their interrelationships were identified through a comprehensive literature review, questionnaire, and interview with expert from building construction projects. Table 1 provides list of the 12 variables included in the Belief Network. The cause-effect relationship among uncertainty factors as show in Figure 2, four uncertainty factors direct affecting cost performance in construction project. Other factors indirectly affecting cost performance in construction project.

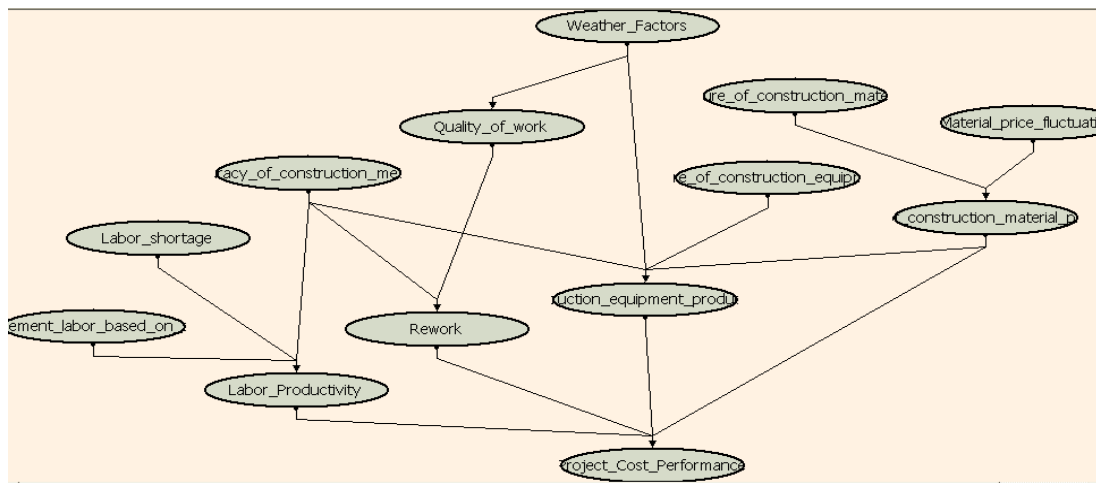


Figure 3: The cause-effect relationship model among uncertainty factors with *BBNs*

Case Studies Description

To validate prediction model based BBNs, two case studies of building construction project were used. A brief description of the building construction project is presented in table 2.

Table 2: A brief description of the construction project

Description	Project XXX	Project YYY
Project Type	Building	Building
Project Owner	Government	Government
Project Scope	12 floors	12 floors
Period of implementation		
based contract	27 weeks	26 weeks
Physical Contract Value	IDR. 58.580.000.000,-	IDR. 52.579.133.000,-

Source: Secondary Data, 2014

Prediction of Construction Project Cost Performance

Step of Bayesian Belief Networks

Based on the relationship between the uncertainty factors that affected cost performance is presented in Figure 3, each node factor (prior) and CPT filled with a probability value based on primary data (questionnaire) and secondary data. Example of data filling of probability (prior) to factor quality of work with state "high = 0.9" and "low = 0.1". The probabilities results of the cost performance simulation are presented in Fig 4 and 5. In the Figure 4, the probability result of cost performance simulation are state "overrun = 0,43" and "underrun = 0,57".

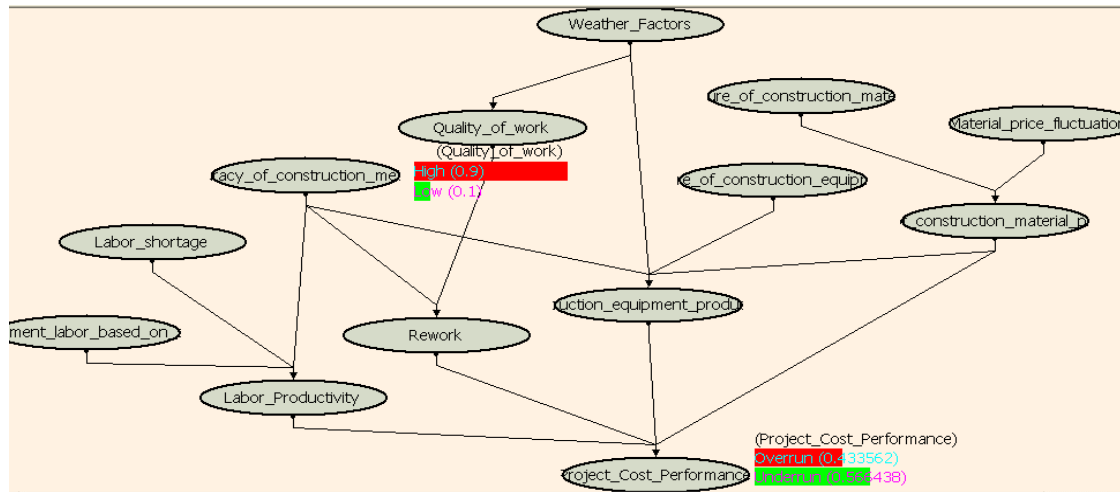


Figure 4: Probability (prior) of uncertainty factors state and simulation process in the project of building XXX with software BBNs

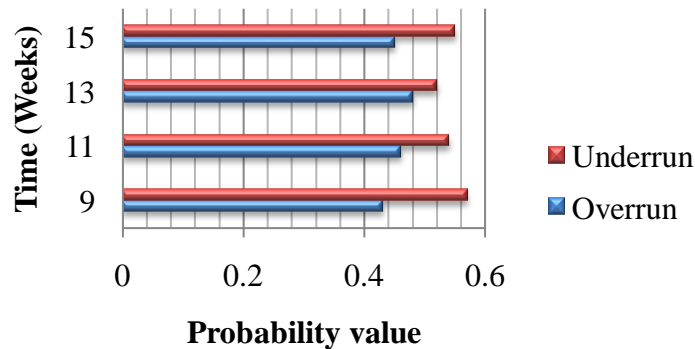


Figure 5: Probability results of cost performance in the project of building XXX

Step of Cost Performance Prediction

Based on the results of the output probability BBNs was presented in Figure 5, the next step is calculated the prediction value for 9 to 15 weeks by using the formula (2)

and (3). The calculation results of cost performance prediction in an "S" curve for the construction project of building XXX is presented in Fig 6.

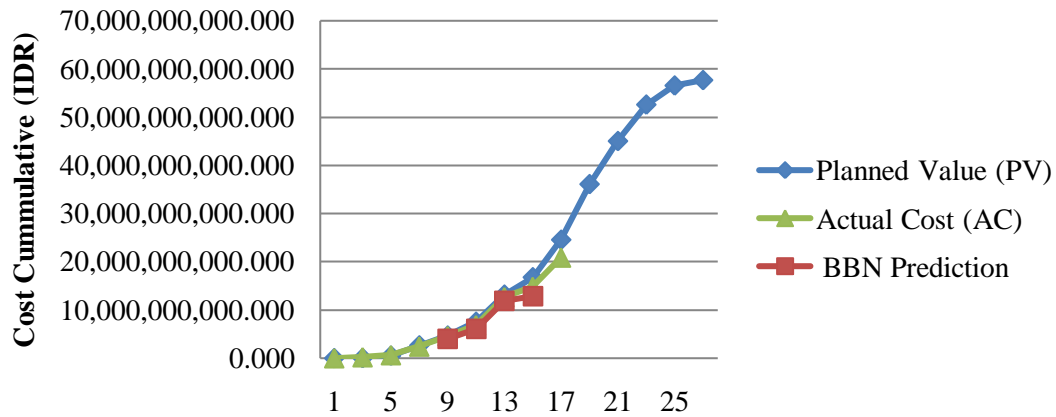


Figure 6: Prediction results of cost performance in the project of building XXX

Step of Prediction Model Accuracy

Accuracy measurement of the prediction model can be calculated using statistical formulas of APE, eqn (4). The APE value result in the project of building XXX is shown in Fig 7, where APE value from 9 to 15 week ≤ 30 .

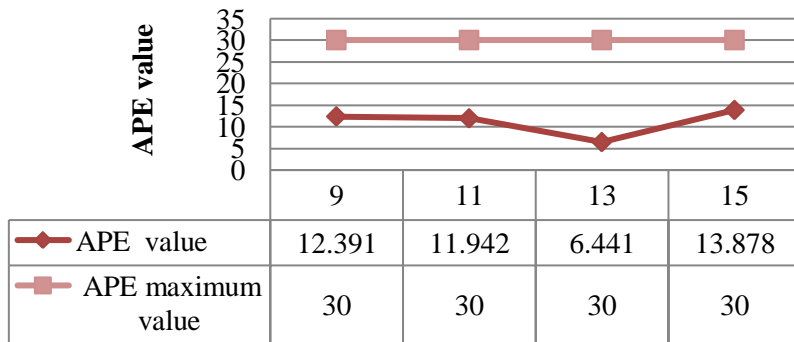


Figure7: APE value results in the project of building XXX

The validation results of the BBNs prediction model is accurate/feasible because APE values obtained for the two construction projects on cost performance meets the eligibility standards/accuracy APE value ≤ 30 . The complete the value of the average APE for both building construction projects are presented in table 3.

Table 3: Result of the APE mean for two buildings construction project

Time (Weeks)	Project of building XXX	Project of building YYY	APE mean
9	12,391	10,077	11,234
11	11,942	5,134	8,538
13	6,441	8,642	7,542
15	13,878	24,676	19,277
APE mean	11,163	12,132	11,648

The prediction model of cost performance using BBNs approach have the advantages such as: BBNs may be developed using expert opinion and historical data, the uncertainty factors that affect the cost performance can be added or removed in the model without significantly affecting the rest network, BBNs provides insight into the relationship between the uncertainty factors that affect the cost performance, the prediction model can predict the cost performance accurately. However, the prediction model also has disadvantages such as: the model can only predict the cost performance gradually over time, the model cannot predict the final cost performance of the project directly but it can predict gradually.

Conclusions

There are 12 uncertainty factors that have a potential impact on the cost performance. Four uncertainty factors direct affecting cost performance in construction project such as labor productivity, rework, construction equipment productivity and availability of construction materials. Other uncertainty factors indirectly affecting cost performance such as weather factors, quality of work, material price fluctuations, availability of construction equipment, the accuracy of construction material procurement, the accuracy of construction method, labor shortages, placement labor based on skill.

The cause-effect relationship among uncertainty factors have been described clearly. The results of model validation in the case study of building construction projects demonstrate that BBNs proposed models can predict and calculate the project cost performance accurately with value of APE mean ≤ 30 .

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