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A Progress-based Expert System for Quantitative Assessments of Project Delay

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Abstract

Construction projects have frequently exceeded their schedule despite reliable estimates at the start of a project. This problem was attributed to unpredictable causes at the beginning and to shortage of proper tools to accurately predict project completion date. To supplement this difficulty, project managers need a comprehensive system that can be employed to monitor the progress of an ongoing project and to evaluate potential delay for achieving the goal on time. This paper proposed a progressive-based expert system for quantitative assessments of project delay at the early stages of the execution. Furthermore, the system is used to inspect the change of the uncertainty on completion date and its magnitude. The proposed expert system is helpful for furnishing project managers a warning signal as a project is going behind schedule and for tracking the changed uncertainty at a desired confidence level. The main objectives of this paper are to offer a new system to overcome the difficulties of conventional forecasting tools and to apply a construction project into the system to illustrate its effectiveness. This paper focuses on construction phase of project development and is intended for the use by project managers.

Keywords : Change of the Uncertainty, Progress-based Expert System, Project Delay, Quantitative Assessments, Warning Signal

1. INTRODUCTION

Reliable predictions of completion date and efficient assessments of project delay present continuing challenges to project managers because there is no perfectly systematized forecasting tool for the future possible outcomes. Thus, project managers pursue an effective expert system to diminish the uncertainty in forecasting completion date, such that they can manage the possibility of potential delay with a quantitative indicator. If the expert system is well-organized and properly operated at the early stages of project execution, this is valuable in evaluating project progress and avoiding schedule delays in achieving incomeplete project (Joglekar and Ford, 2005). Such an expert system provides a good forecast of completion date. Furthermore, satisfactory predictions made at the beginning stages considerably help project managers have an opportunity to effectively re-arrange resources when a construction project is behind schedule.

Probabilistic forecasting tools have been widely employed to assess and quantify the variation of the uncertainties. Conventional approaches are commonly based upon the index-based model. In estimating the schedule, a single-point deterministic tool is unsafe because of the unforeseen changes of the uncertainty caused by project's complications. Applied statistical techniques, such as regression analysis and Monte Carlo simulation are also useful to analyze and range the amount of the uncertainty when historical information of previous projects was systematically recorded; however, they are difficult to update its behavior over time (Pugh and Soden, 1986; Rad, 2003). As deterministic prediction models are still used at the middle of project execution, the changeable uncertainty is unconsidered, and it is difficult to reflect the impacts of a new reported data on the future outcomes (Alkass, et al., 1996). In spite of many logical approaches, conventional models tend to neglect the effects of an informed data of a progressive project to the behavior of the uncertainties (Jung and Kang, 2007). Fleming and Koppelman (2002) have asserted that Earned Value (EV) system has efficiently evaluated the performance of an ongoing project and predicted completion date in monetary terms. Hence, this system provides one way to assess project delay. However, the EV system has still limitations to represent the impacts of past performance on the incomplete execution.

Construction projects are susceptible to schedule delays. Variations from the planned schedule result in large financial losses for owners and contractors. In a specific case, the viability of the project itself is jeopardized by the variations from baseline plans (Al-Tabtabai, et al., 1997). Thus, new techniques and expert systems that assist project managers in forecasting the schedule variance need to be developed. This paper proposes a progress-based expert system to identify schedule variances from a baseline plan of construction projects. The proposed system adopts the Information-based Forecasting Model (IFM) to capture the decision-making procedure in monitoring and assessing the current progress. To overcome the shortcomings of deterministic prediction models, the IFM with the mathematically derived function has satisfactorily accomplished the reliable estimate of project completion date, based upon Bayesian Inference and three types of S-shaped growth curves (Yoo and Hadipriono, 2007). Bayesian approach has been widely employed for predicting and updating the uncertainty on an expected outcome with information collected during short-term period. This is technically functional for the long-term forecasts with limited information at the early stage and has been applied to the cost-expensive experiments, such as medical research and diagnosis of animal growth. In this way, Bayesian approach is used to build and operate an expert system introduced in this paper due to its cost-effective capability. In other words, information from an ongoing project absorbs affirmatively the unconstructive outcomes, such as the potential of project delay and its quantitative magnitude, for effective management strategies against them. The system developed in this paper is applied to a multistory building project to demonstrate the capability and practice in construction industry. The advantages and limitations of the system operation in predicting the variance of completion date are discussed in the latter. The system is built by an existing computer program (Visual Basic 6.0) for the convenient generation of the forecasts and their revisions.

2. OBJECTIVES AND SCOPE

The main goals of this paper are to construct a progress-based expert system for a more strategic decision support and to improve the deterministic approaches in assessing project delay, based upon experienced engineers' knowledge, historical database, and informed data of an ongoing project. The paper, using the proposed system, explores ways of quantifying the changes of the uncertainty on completion date.

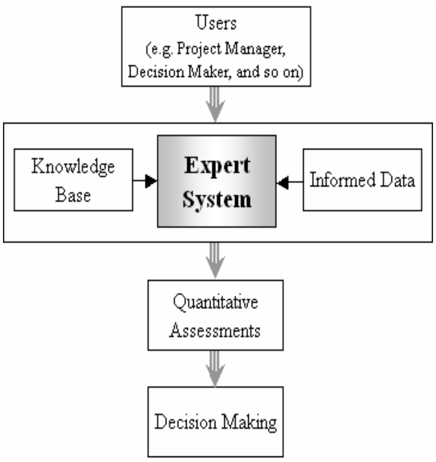

Figure 1. Operation process of the proposed progress-based expert system

This paper focuses on the development of a mathematical tool into the prototype of an expert system for quantitatively assessing project delay at the early stages. Operations of the system are concerned with a construction project in which actual progress is timely reported and objectively evaluated. Also, they are accomplished during construction phase of the said project and intended for the implementations by project managers in evaluating the current project status and aiding in the successful completion on time. The progressive-based expert system introduced in this paper is preliminary; it will need substantial refinement and improvement. The professional development of this prototype is required for practical applications in construction industry.

3. QUANTITATIVE ASSESSMENTS OF PROJECT COMPLETION DATE AND DELAY

The failures of achieving a project within the planned duration and schedule delays have been costly problem encountered on construction projects. During project execution, project managers have been constantly pursuing to look for reliable decision making support to provide them an early warning signal and to assist in avoiding potential delay. Hence, they have been looking forward to concretely assessing how well the projects are executing. When dealing with the uncertainty on completion date, it is important that the system employed is viable and practical. Although there is the maximum use of information generated by the project itself, conventional approaches, such as Critical Path Method (CPM), Earned Value (EV) analysis, statistical simulation, and so on, are deterministic, and accordingly, they rarely reflect the impacts of progress performance of an ongoing project on the future status. However, delays of current progress can be a cause that results in poor performance of the incomplete execution.

The models constructed on the deterministic knowledge or information have frequently neglected the behavior of the uncertainty on completion date and failed to satisfactorily assess project delay (McGartland and Hendrickson, 1985). Bayesian approach, which is a root of the proposed progress-based expert system, provides the confidence intervals on the forecasted completion date. Furthermore, this approach modifies such intervals considering the effect of reported progress data to the re-predicted completion date. In this paper, such an effect is quantified by the change of the uncertainties resulted from an informed data. In this manner, the progress-based expert system quantitatively computes the potential of project delay during the early stages of the execution. In planning project development, the budgeted cost of work scheduled (BCWS) is distributed over time and determined by the resource-allocation scheme under the sufficient considerations. Construction projects have often progressed like the S-shaped curve, but there is no universal growth curve function to accurately represent all types of the projects. As one of the ways to describe the progress of the planned development, it is efficient to approximate the set of the planned values (BCWS plan) by fitting any growth function to the points. If a growth curve function fits the BCWS plan to an acceptable degree, the budgeted cost of work performed (BCWP) follows the same functional group of the BCWS plan with different parameters, which are important elements in the introduced S-shaped growth curves, depended on the degree to which an actual progress matches the plan. Information of the BCWP at each time period is defined as a reported input data to the proposed system. The process for operating the system is cost-effective because data of the BCWS and BCWP are obtained at the beginning and during the execution. The changes of parameter values in

S-shaped growth function are essential to modify the fitted progress curve comparing to the BCWS plan. The characteristics of three S-shaped curves (Logistic, Gompertz, and Reverse-Gompertz functions) and parameters in each growth function are explained in the next section.

When actual progress deviates from the BCWS plan, project managers try to restore the current progress to the planned condition. However, it is a challenge how they quantify the changes of the uncertainty on completion date, based on such a reported data. Supposing that any progress data on the BCWP is collected at a specific period, it is used to modify the estimates of parameters in the fitted S-shaped growth function. However, their values are constant over a specific time period. A deviation from the plan is defined as a deviation of the forecasted BCWP curve from the planned BCWS. This deviation is used to predict the estimated date at completion (EDAC) from the original schedule. The following section describes the technical fragments consisting of the proposed expert system and provides the operation instruction in the application of a construction project.

4. EXPERT SYSTEM

Since the concept of expert system was first introduced around 1940, the system has been developed rapidly along with computer science and it handles more complex than conventional system (Wentworth, 1990). McGartland and Hendrickson (1985) described that expert system is one part of the areas of Artificial Intelligent (AI), which is a specialized area of computer science that attempts to make computers imitate logical human behavior. The most significant feature is that it involves the ability to repeatedly simulate an expert's reasoning process, which is difficult to be represented in mathematical functions. Occasionally, expert system is defined as a computer program that efforts to embody the subjective knowledge based on experts' experience. Such a program offers a means to capture this knowledge to be used as assistants or decision aids for other less experienced people. This section discusses the fragmented process of the proposed expert system operation, its contributions to the quantitative assessments of project delay, and the application of a case study. Based upon the validation of the system, expert system provides reliable predictions of project duration. Consequently, the progress-based expert system presented in this paper is helpful in assisting project managers to support more efficient management strategies for project progress deviated from the plan.

(1) Inference Engine

Because it is difficult to perfectly estimate the uncertainty on completion date at the start, project managers consider the possibility or likelihood that an unexpected delay is occurred during the execution. However, there is no uncertainty as a project is entirely completed due to the decreases of the uncertainty associated with completion date resulted from the increasing progress information. Bayesian approach illustrated in this section is a core method to construct the Inference Engine of the proposed expert system. This method appropriately describes a common fact that more available information reduces continuously an uncertainty until the completion of an ongoing project (Ramgopal, 2003). In this paper, project progress growth curve is shown by one of S-shaped curves (Logistic, Gompertz, and Reverse-Gompertz functions), which has been widely used for technological growth forecasts during a short-term period (Franses, 1994; Meade, 1985). The progress-based expert system is an extensive model on the basis of the IFM introduced in earlier papers by the authors (Yoo and Hadipriono, 2007). They have employed noninformative prior distribution for parameters in developing the S-shaped function. However, the author in this paper extends to the applications of other prior information (informative prior and subjective judgments) of parameters, and focuses on building an expert system. The numerical data of a construction project is used to illustrate system's efficiency and capability. This system enables project managers to analyze time variation at completion date during the execution and to approximately quantify its magnitude. The below equations provides three types of mathematical functions of S-shaped growth curves to represent a construction project progress.

a. Logistic function: $BCWP(t) = S/1 + a \times e^{-bt}$

b. Gompertz function: $BCWP(t) = S \times e^{-a \times e^{-bt}}$

c. Reverse-Gompertz function: $BCWP(t) = S \times (1 - e^{-a \times e^{bt}})$

Depended upon the first derivative rate of three functions, the Logistic function shows a symmetric rate distribution. However, the Gompertz and Reverse-Gompertz functions present a skewed rate distribution to the right or left side, respectively. In the above equations, the "a" is a shift parameter, and the "b" parameter controls the slope of the growth curve, which represents the amount of the resource allocated. "S" is an upper asymptote of the BCWS plan. The primary effort of Inference Engine is not to make a perfect forecast but to create an approximate prediction of project completion date through the updating process of the planned progress. If the prediction is properly estimated at the early stages of project execution, project managers can effectively deal with the variation of deviations of the BCWP from the BCWS plan. Prior to re-estimating completion date and assessing current progress performance, it is necessary to linearize the S-shaped curves by performing some mathematical manipulations with the natural logarithms to seek the best-fitted curve of the BCWS plan. Such a curve is employed to generate the reliable forecast and to re-produce the possible growth curve. The linearization process has been manipulated in the earlier paper, and the values of parameters are obtained from the fitted linear line. The minimum sum of the squares of the deviations (SSD) is used as an indicator to determine the best-fitted curve. The prior distributions of parameters in the best-fitted function are determined by project managers' degree of belief in the various potential outcomes. Prior information of parameters is represented by noninformative prior, informative prior, or subjective judgment with manually entered value. Their three types are plotted in Figure 2, and the results from the application are analyzed and compared in the later.

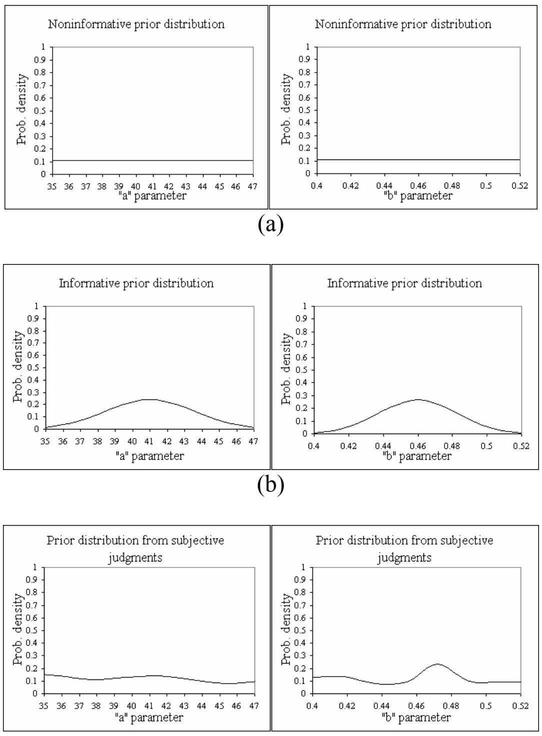

Figure 2. Types of prior information of parameters (a and b); noninformative (a), informative (b), and subjective judgment (c)

In selecting prior information of parameters, if project managers have no preference about the estimated parameter-values, prior information is defined as noninformative prior. On the other hands, as there is available information associated with parameters from experience and historical data, informative prior is appropriate. Particularly, when project managers have vague belief for those values, the belief is represented with manually scaled value under the considerations of the potential outcomes. Noninformative prior is commonly presented with uniform probability distribution, and informative prior is frequently shown with normal probability distribution in the application. This paper employs informative prior distribution for operating the proposed expert system. However, the results from noninformative prior and manually scaled subjective judgments are compared.

$$\Pr(\text{"}a_i\text{" and "}b_j\text{"} \mid BCWP(t)) = \frac{\Pr(BCWP(t) \mid \text{"}a_i\text{" and "}b_j\text{"})\Pr(\text{"}a_i\text{" and "}b_j\text{"})}{\sum_{i=-\infty}^{\infty}\sum_{j=-\infty}^{\infty}\Pr(BCWP(t) \mid \text{"}a_i\text{" and "}b_j\text{"})}$$

……………………………………………………...Eq. (1)

In the Eq.(1), the likelihood that the BCWP(t) is observed is P{$BCWP(t) \mid a=a_i$ and $b=b_j$}, given that the "a" and "b" values are a_i and b_j, respectively. From a reported progress data, a posterior distribution of parameters is derived with this likelihood and prior distribution. The theoretical demonstration of the inference introduced in this paper has been provided by Yoo and Hadipriono (2007).

(2) Prior knowledge and informed data

Project managers attempt to seek a quantitative indicator to provide them an assessment of project performance. For such a purpose, they use information generated by the project itself and monitor current progress. Before developing a project, project managers estimate an expected completion date from historical database or information from past similar projects. Hence, they obtain the BCWS plan and the reported BCWP data at a time period. This prior knowledge and informed data are employed to analyze current progress performance and to predict the expected completion date keeping a desired confidence level. In the proposed system, the Inference Engine combines prior knowledge and actual informed data, such that the expert system dynamically updates the prediction over time. The following section describes how prior knowledge and informed data are applied for operating expert system and presents how approximately project delay is evaluated.

(3) Case study

For the sake of illustration, a building project was used to explain the efficiency of the proposed expert system. The budgeted at completion (BAC) was $32,315,789. The project was scheduled to complete in 16 months; however, this was actually executed in 17 months. It indicates that the project was delayed about 1 month. Table 1 shows the BCWS plan and the BCWP data at each time period, t. The BCWS plan is denoted as a prior data and the BCWP is used as an informed data to operate the system.

Table 1. Comparison between BCWS plan and BCWP data of an applied construction project

Time period (monthly)	BCWS plan	BCWP data
0	$0	$0
1	$1,059,958	$307,000
2	$2,424,977	$1,235,368
3	$3,789,996	$2,001,684
4	$5,154,789	$2,938,368
5	$6,214,746	$3,914,305
6	$7,274,704	$5,015,842
7	$10,409,336	$7,921,032
8	$13,654,617	$11,501,189
9	$16,900,156	$14,668,137
10	$20,145,178	$18,061,295
11	$23,759,118	$20,743,505
12	$27,373,057	$23,619,611
13	$30,986,964	$26,657,295
14	$31,439,385	$29,048,663
15	$31,891,806	$30,087,768
16	$32,315,789	$31,052,632
17		$32,315,789

As seen in Figure 3, the planned progress is plotted by entering the BCWS plan, and system operation instructions are provided. In determining the best-fitted growth curve to the BCWS plan, the Inference Engine employs regression analysis. Since linearizing each S-shaped curve, the goodness-fit is examined and the best-fitted curve is selected by the S-shaped function with the minimum SSD.

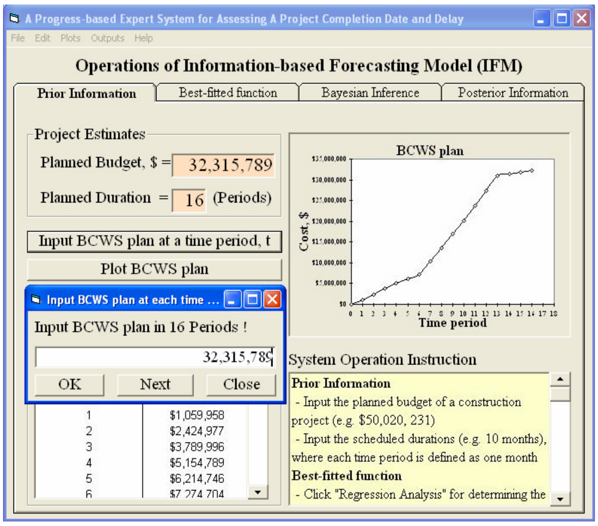

Figure 3. Planned project development and operation instruction

Figure 4 presents the comparison between the BCWS plan and the fitted curves obtained from regression technique. In case of the applied construction project, the Logistic function is determined as the best fitted growth curve, and also, parameter-values are computed by expert system (a= 40.85 and b=0.459). As presented in Figure 4, this system provides the mathematical equation of the best-fitted curve (Logistic function).

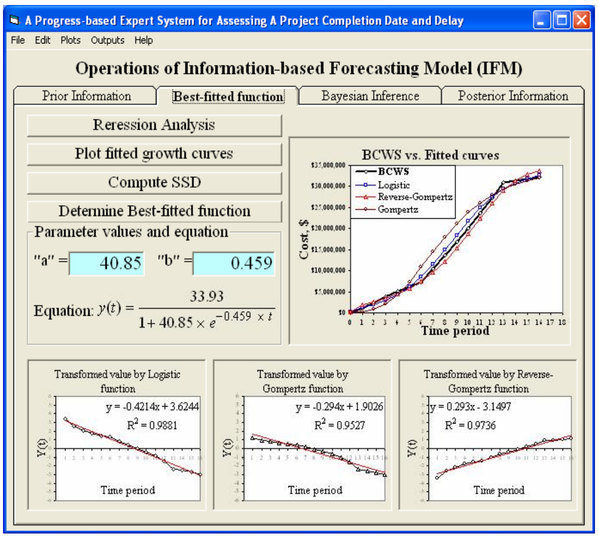

Figure 4. Determination of the best-fitted growth curve to the BCWS plan

As revealed in Figures 3 and 4, project managers obtain the maximum information generated by the project itself to satisfactorily predict completion date and assess project delay. Planned values of the BCWS are quantitative indicators to evaluate the current progress. An informed data, which is defined as a BCWP data, is employed to analyze the behavior of the uncertainty on the expected completion date at a desired confidence level. Figure 5 shows the process to enter an actual BCWP data at each time period, and this figure provides the options for project managers to select prior information of parameters (a and b) computed in the previous process. As an illustration, informative prior is applied. However, in the same manner, other two types of prior information are analyzed. Since reporting the BCWP data, the progress-based expert system combines prior information and actual informed data, such that the system updates the planned progress and probability distribution (risk function) on the expected completion date.

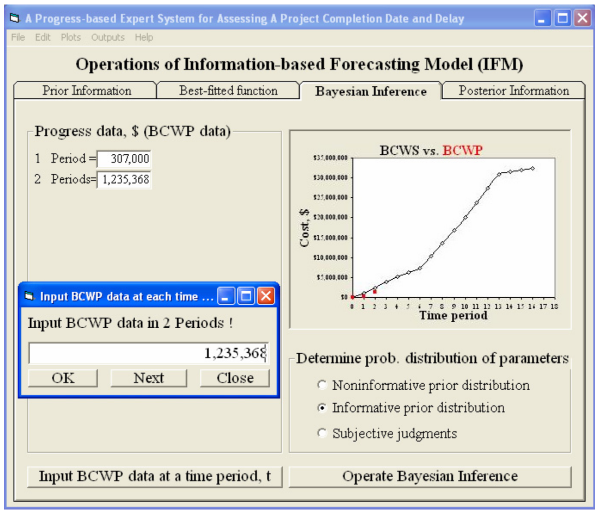

Figure 5. Reported progress data (BCWP data) during 2 Periods (months)

For instance, the system was operated with the BCWP data ($307,000 and $1,235,368, respectively, in 1st Period and 2nd Period) during 2 Periods. Figure 6 presents the modified 3-D plot of the selected prior relationship between parameters. As provided in Figure 7, informative prior distributions of parameters were updated, and consequently, the project progress and risk function (or probability distribution) on completion date were re-estimated, based on two reported data during 2 Periods. Since 2 Periods (months), the re-predicted project duration is about 16.24 months. The probability that the project is completed within the original schedule has decreased to about 37.45%, and the width of probability distribution was narrower. This is because the past progress was behind schedule and more information was available. For evaluating the forecasts at the early stages, project delay is quantitatively assessed during 6 months, which is defined as the period of 30% completion of whole execution.

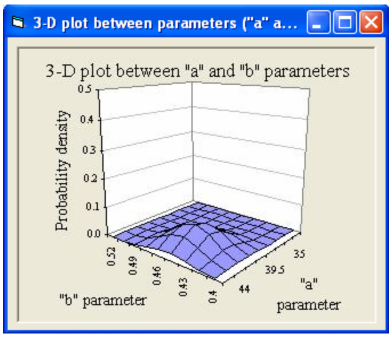

Figure 6. Updated 3-D plot between parameters ("*a*" and "b")

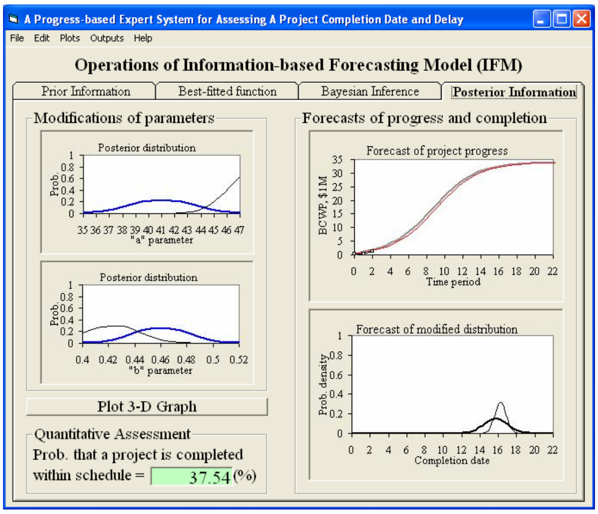

Figure 7. Forecasts of project progress and probability distribution on completion date during 2 Periods

Since the project was executed during 6 Periods, the BCWP data was entered to expert system, and the BCWS plan and reported data were plotted, indicating that the project was still behind schedule as presented in Figure 8.

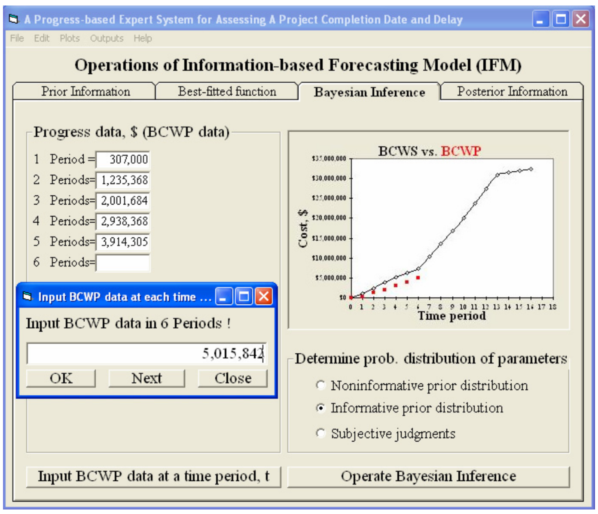

Figure 8. Reported progress data (BCWP data) during 6 Periods (30% completion)

Figure 9 shows the modifications of prior distribution of parameters and the forecasts of the project progress and risk function. The system presents that this project was continuously delayed and indicates that it is difficult for the project to be completed within the planned schedule. Figure 10 gives the posterior probability distributions of parameters. These distributions become more specific when the progress data is reported. This points out that the uncertainty related to each parameter is decreasing due to increasing information, and appropriately reflects the fundamental principle of Bayesian approach. Modifications of progress growth and changes of risk functions on completion date are tracked during 6 Periods and also shown in Figure 10.

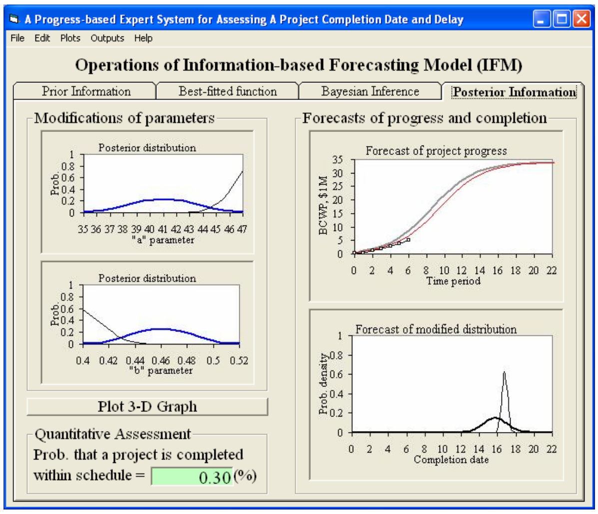

Figure 9. Forecasts of project progress and probability distribution on completion date during 6 Periods (30% completion)

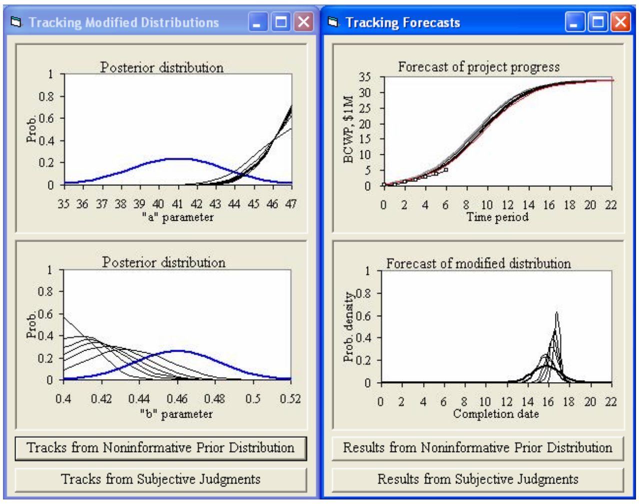

Figure 10. Behavior of the forecasts of prior distribution of parameters, project progress, and risk function

The initial risk function moved to the right direction, however, its width becomes narrow corresponding to more reported data. Project managers compute and quantify the likelihood that the project is completed within schedule and any specific date.

Table 2. Quantitative assessments of project delay during the early stages of project execution

Time period (monthly)	Probability that a project will be completed within schedule (16 months)		
	By noninformative prior	By informative prior	By subjective judgments
At start	50%	50%	50%
1	36.92%	37.93%	35.40%
2	32.86%	37.54%	34.46%
3	14.02%	16.62%	27.39%
4	9.01%	9.46%	20.49%
5	4.61%	4.25%	13.82%
6	0.37%	0.30%	4.97%

Table 2 shows the changes of its magnitude during 30% completion according to prior information of parameters (*a* and *b*). The quantitative changes are efficient information to assess project delay. As provided in Table 2, the probability resulted from informative prior at 1 Period slightly decrease from 50% to 39.93%; however, since 2 Periods, this greatly decreases as a project progresses. The results from other prior information behave similarly with a different quantity.

5. CONCLUSIONS

This paper proposes a progress-based expert system for predicting completion date and assessing project delay, based upon the planned development information and reported progress data. The Inference Engine as a core part of the system is constructed on Bayesian approach and three types of growth curves, and this generates the modifications of the initial project growth curve and risk function (probability distribution) on the forecasted duration. The efforts for collecting the BCWS plan and BCWP data is cost-effective because the former is obtained by the resource-allocation scheme associated with the initial progress plan and the latter is reported periodically during the execution. Furthermore, information resulted from operating the proposed system provides sufficiently valuable outcomes, such as the potential of project delay and its quantitative magnitude, and it assists to building effective management strategies against them. For demonstrating the effectiveness of the proposed system, the forecasts at the early stages has been produced during about 30% completion (6 Periods of the 16-months schedule), and they are compared to the actual progress and duration of the applied project. The results have showed how quantitatively the early progress causes the project to be delayed and that these forecasts are approximately similar to the actual duration. The system operation consistently creates the forecasts, and accordingly, expert system possesses the potential to be used as an early warning tool. Furthermore, this system provides project managers with quantitative indicators for helping them make an efficient management action for achieving a project on time.

This paper focused on the development and application of a progress-based expert system to assess project delay. In modeling the prototype of the system, the process of determining the best-fitted growth curve to the BCWS plan was described, and the mathematical function for updating the fitted curve was addressed with the use of the planned knowledge (BCWS plan) and available information (BCWP data). The proposed system was tested by a multi-story building project and furnished project managers a series of options on the screen in the form of the knowledged-based information. As a result, a few advantages of expert system developed in this paper are summarized as follows.

- Ability to handle subjective beliefs and to deal with unexpected inputs, considering the uncertain possibility as an expert system copes with informed data;
- Unlike the deterministic statistical approaches, the system possesses the capability to predict completion date and to quantitatively assessing project delay from reported progress information of an ongoing project;
- Capability to monitor the changes of the uncertainty of incomplete project execution and the impacts of current performance on the forecasts;
- To supplement project managers' knowledge to make strategic decisions for successful project achievement on time with an early warning indicator.

Most of information-based expert systems operate through users' supplying knowledge and actual information to the system and they return professional decision assistants. The expert system presented in this paper is a prototype model, and this needs to be elaborated further. The achievements provided by this system can be used as a quantitative indicator for assessing the potential of project delay. However, one vital area of future research is of significance to the practitioner for possible employment in construction industry. That is to substantially refine and improve this prototype model for the use as one of decision-making programs.

REFERENCES

Alkass, S., Mazerolle, M., and Harris, F. (1996) "Construction delay analysis techniques" *Construction Management and Economics*, Vol. 14, No. 5, pp. 375-394.

Al-Tabtabai, H., Kartam, N., Flood, I., and Alex, A.P. (1997) "Expert judgment in forecasting construction project completion" *Engineering Construction and Architectural Management*, Vol. 4, No. 4, pp. 271-293.

Fleming, Q.W. and Koppelman, J.M. (2002) "Using Earned Value Management" *Cost Engineering*, Vol. 44, No. 9, pp. 32-36.

Franses, P.H. (1994) "A Method to Select Between Gompertz and Logistic Trend Curves" *Technological Forecasting and Social Change*, Vol. 46, pp. 45-49.

Joglekar, N.R. and Ford, D.N. (2005) “Product development resource allocation with foresight” *European Journal of Operational Research*, Vol. 160, pp. 72-87.

Jung, Y.S. and Kang, S.H. (2007) “Knowledge-Based Standard Progress Measurement for Integrated Cost and Schedule Performance Control” Journal of Construction Engineering and Management, Vol. 133, No. 1, January, pp. 10-21.

McGartland, M. and Hendrickson, C. (1985) “Expert System for Construction Project Monitoring” *The Journal of Construction Engineering and Management*, Vol. 111, No. 3, pp. 293-307.

Meade, N. (1985) “Forecasting Using Growth Curves – An Adaptive Approach” *The Journal of the Operational Research Society*, Vol. 36, No. 12, pp. 1103-1115.

Pugh, L.A. and Soden, R.G. (1986) “Use of risk analysis techniques in assessing the confidence of project cost estimates and schedules” *Project Management*, Vol. 4, No. 3, August pp. 158-162.

Rad, P.F. (2003) “Project Success Attributes” Cost Engineering, Vol. 45, No. 4, April, pp. 23-29.

Ramgopal, M. (2003) “Project Uncertainty Management” *Cost Engineering*, Vol. 45, No. 12, pp. 21-24.

Wentworth, E.P. (1990) “Introduction to Functional Programming using Gofer” *Technical paper*, Parallel Processing Group, Rhodes University.

Yoo, W.S. and Hadipriono, F.C. (2007) “An Information-based Forecasting Model for Project Progress and Completion Date using Bayesian Inference” *Korea Institute of Construction Engineering and Management*, Vol. 8, No. 4, pp. 203-213.

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