Forecasting Project Cost and Time using Fuzzy Set Theory and Contractors' Judgment

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Abstract: This paper presents a new method for forecasting construction project cost and time at completion or at any intermediate time horizon of the project duration. The method is designed to overcome identified limitations of current applications of earned value method in forecasting project cost and time. The proposed method usesfuzzy set theory to model uncertainties associated with project performance and it integrates the earned value technique and the contractors' judgement. The fuzzy set theory is applied as an alternative approach to deterministic and probabilistic methods. Using fuzzy set theory allows contractors to: (1) perform risk analysis for different scenarios of project performance indices, and (2) perform different scenarios expressing vagueness and imprecision of forecasted project cost and time using a set of measures and indices. Unlike the current applications of Earned Value Method(EVM), The proposed method has a numberof interesting features: (1) integrating contractors' judgement in forecasting project performance; (2) enabling contractors to evaluate the risk associated with cost overrun in much simpler method comparing with that of simulation, and (3) accounting for uncertainties involved in the forecasting project cost.

Keywords: cost forecast, experience, fuzzy set, judgment, uncertainty

I. INTRODUCTION

Forecasting project cost is a critical management function in tracking and controlling of construction projects. The literature reveals that many models and methods have been developed since the introduction of Earned Value Management (EVM) in the mid- 1960s [1,2, 3, 4, 5, 6, 7, 8, 9, 10,11]). In 2000, Zwikael et al [12], conducted a study to measure the outcomes of different models that were developed in forecasting project cost. The authors selected different models from the literature and they used samples of actual projects. Those models were based on one of the following five assumptions: (1) cost variances at report date will be corrected by the time the project is completed; (2) the cost of the remaining work of the project will be executed according to the original plan, and the cost variances at reporting date will not change at project completion; (3) the cost performance index (CPI) achieved up to reporting date will remain through the remaining work [13]; (4) the CPI will affect the project final cost; and (5) the remaining work will be performed as a function of both the cost performance index and the schedule performance index. The authors concluded that the worst model in forecasting project cost is the one that is based on the assumption that the future performance will recover and the project willcomplete within the original budget, while the models that incorporate both the SPI and the CPI were inferior to the two models based on the CPI only. The models which are based on the assumption that the achieved CPI will continue for the remaining work gives the best most accurate forecasts results.

The earned value based forecasting methods have received many criticism by researchers, especially in forecasting project duration [7, 10]. Most criticism focuses on three fundamental aspects: (1) schedule performance of a project is measured, analysed, and predicted in units of value (e.g., money, labour, work quantity, and percent complete) instead of time unit [9]; (2) using SPI to forecast project duration can be misleading [7,10]; and (3)EVM is a deterministic and provides point forecasts that does not provide information on the prediction bounds based on the likely accuracy of forecasts [9]. To overcome some limitations of using EVM for forecasting project performance, several models were developed [7, 10]. Vandevoorde and Vanhoucke [7] compared three different methods to forecast project duration using earned value metrics and evaluate them on real-life project data. The authors concluded that the three methods produce a similar forecasting accuracy in the linear planned value case. Moselhi 2011[9] introduces a novel concept for the schedule performance index thatmeasures the status of critical activities only and uses this index to forecast project duration. The main limitation of the above mentioned methods and model is that they are based on a single value of CPI and SPI and they do not account for contractors' judgement. This paper presents a newly developed method for forecasting project cost and time in an effort to circumvent the above stated limitations of current methods.

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The proposed method introduces modifications to EVM which allow for providing information on the prediction bounds based on the likely accuracy of the forecasts.

The methods also integrates contractors' judgment in forecasting process in order to get more realistic predictions.

II. PROPOSED METHODOLOGY

The proposed method adopts the use of the fuzzy set theory as an alternative approach to probabilistic methods to model the uncertainties associated with project performance.

The Fuzzy set theory (FST) is pioneered by Zadeh, 1978[14], and it is useful for representing and modelling uncertainties, particularly in absence of historical data. Compared to simulation, modelling uncertainty using fuzzy set theory is computationally simpler, not very sensitive to moderate changes in the shapes of input distributions, and does not require the analyst to assume particular correlations among inputs [15]. The literature reveals that FST has been used in the development of many applications in construction engineering including; pricing construction risk [16]; project network schedule [17]; reliability assessment [18] and range cost estimating [15]. In the proposed method, the FST is used to model the uncertainties associated with the cost and time performance index. The use of FST, as presented in this paper, is particularly suited for the problem at hand due to two main reasons. Firstly, forecasting project cost and time is frequently based on deterministic methods, which is not always be accurate because the construction industry is uncertain by its nature. Secondly, FST facilitates the direct utilization of expert knowledge and judgement that applies to the unique conditions of each project at hand through the use of membership functions that best suit these unique conditions.

Integrating the contractor's judgement and experience in forecasting project time and cost would provide more reliable estimate. Using such techniques provides the contractors with an easy way to better understand the project total cost at completion and/or at any time horizon under certain conditions or assumptions. In addition, using fuzzy set theory for cost forecast can overcome the main limitations of using deterministic and simulation. The steps computations required for the application of the proposed method can be summarized as follow:

1- Measure the progress of the project under consideration at report date by calculating the percent completed based on quantities installed.

2- Calculate the cost and time performance indices at activity level using earned value technique.

3- Models the uncertainties associated with the calculated cost and time performance index using fuzzy numbers for each activity based on the contractor's inputs and judgement. This is carried out using fuzzy numbers similar to that shown in Fig. 2, in which, a and d are the lower and upper bounds, of CPI and SPI, which have membership f(x) = 0.0 , while b and c are the lower and upper modal values of the cost and time index that have full membership (i.e. f(x) = 1.0).It should be noted that here the contractorshave the flexibilities to set values of CPI and SPI that fit the project conditions. For example, the contractors can select CPI that are higher than the calculated one if the achieved performance at report date has some previousexceptional conditions that areknown to have prevailed and will not be repeated in the future.

4- Defuzzify the fuzzy estimate defined in step 3 using the centre of area (COA) method[15], which represents the expected value using Equation (1):

$$\text{EV Trapezoidal} = a + \frac{2(c-b)(b-a) + (b-c)^2 + (b-a)(d-a) + (c-b)(d-a) + (d-a)^2}{3(c-b+d-a)} \tag{1}$$

5- Having the expected value of cost performance index and schedule performance index are defined, the cost and time forecast at completion can be determined for each activity of the project network using Eq. 2, see Figure 1.

$$FTC = [a,a,a,a]_{ac} + \sum_{i=1}^{n} \left[\!\!\left[\frac{([a,a,a,a]_{cac} - [a,a,a,a]_{ev})}{[a,b,c,d]_{cpi}} \right]\!\!\right]_i \tag{2}$$

In which;

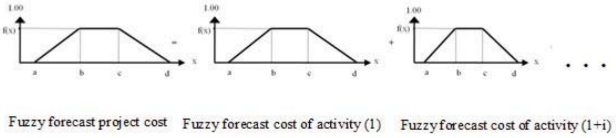
FTCis project fuzzy forecasted cost at completion;

a_{ac} is the project fuzzy actual cost at report date;

a_{ca} is activity (i) planned fuzzy cost at completion;

a_{ev} is activity (i) fuzzy earned value at report date;

a_{cpi} is fuzzy cost performance index of activity (i) at time (di) as defined by contractor.



Fuzzy forecast project cost   Fuzzy forecast cost of activity (1)   Fuzzy forecast cost of activity (1+i)

FIG 1: Calculation of fuzzy Forecasted total cost at completion

6- Analyse the generated outputs(cost forecast), and perform risk analysis for assessing the associated risks with the cost forecast of the selected scenario using the indices and measures described below to express the vagueness and imprecision associated with the forecasted costs as presented in the example project.

III. INTERPRETATION OF FUZZY OUTPUTS

A number of measures and indices were introduced to interpret the results obtained based on fuzzy set theory. The possibility measure (PM), as introduced by Zadeh in 1978[14], intends to evaluate the belonging of fuzzy number to another. The PM is the law of possibility, which is a unique concept in fuzzy set theory, and it is applied to evaluate the possibility of different outcomes. The most possible variable in the fuzzy number is the one that has a possibility measure of 1.0; i.e. has a membership value of 1.0. In the proposed method, the possibility measure is applied to evaluate the possibility of completing the project with a certain cost under certain cost performance. In applying the possibility measure, no consideration is given to the size of intersection area, which may lead to a high value of possibility measure while the intersection area is small. The possibility measure in certain circumstance does not provide an insightful assessment of the compatibility between the two fuzzy events [17].

The agreement Index (AI), which was introduced by Kaufmann and Gupta [19], on the other hand, is used as a compliment to the possibility measure. The agreement index measures the ratio of the intersection area between the two fuzzy events with respect to the area of the event being assessed. For example, assuming that A and B are two events, the agreement index of A with respect to B; AI (A, B) is defined as:

$$\mathrm{AI(B)} = (\text{area } A \cap B) / \text{area } A \qquad (3)$$

The area of intersection can be determined from partial integration given the four numerical values for quadruple of a trapezoidal fuzzy number [a,b,c,d]. Fuzziness (F) and ambiguity (AG) measures were also introduced to describe vagueness and lack of precision, respectively. The fuzziness measure (F(A)) used in this paper is based on that developed by Klir and Folger[20], and it can be calculated using the following equation:

$$\mathrm{F(A)} = \int_{\mathrm{a}}^{\mathrm{b}} (1 - |\, 2A(x) - 1 \,|\, dx = b - a - \int_{\mathrm{a}}^{\mathrm{b}} |\, 2A(x) - 1 \,|\, dx \qquad (4)$$

Ambiguity measure can be calculated as follows[15]:

$$\mathrm{AG}(\mu)\mathrm{Trapezoidal} = (c - b)/2 + [(d - c) + (b - a)]/6 \, (5)$$

For a crisp number and a fuzzy uniform number, the fuzziness measure equals zero because the lack of distinction between a fuzzy uniform number or a crisp number and their complements is zero. The variance values of fuzzy numbers is also used to provide a measure of how far the numbers lie from the expected value. The variance values of Trapezoidal fuzzy numbers (a,b,c,d) is calculated as following:

$$\mathrm{Variance(Trapezoidal)} = \left(\begin{array}{l} \frac{(\mathrm{b}-\mathrm{a})}{(\mathrm{d}+\mathrm{c}-\mathrm{b}-\mathrm{a})}\left(\frac{1}{6}(\mathrm{a}+\mathrm{b})^2 + \frac{1}{3}\mathrm{b}^2\right) + \frac{1}{(\mathrm{d}+\mathrm{c}-\mathrm{b}-\mathrm{a})} \\ \left(\frac{2}{3}\left(\mathrm{c}^3 - \mathrm{b}^3\right)\right) + \frac{(\mathrm{d}-\mathrm{c})}{(\mathrm{d}+\mathrm{c}-\mathrm{b}-\mathrm{a})}\left(\frac{1}{3}\mathrm{c}^2 + \frac{1}{6}(\mathrm{c}+\mathrm{d})^2\right) \\ -(\mathrm{EVtrapezoidal})^2 \end{array} \right)^{0.5} \qquad (6)$$

In addition, Standard deviation can also be used to measure the variation of the fuzzy output from the expected value. Fuzzy standard deviation for trapezoidal fuzzy number (a,b,c,d) can be calculated using equation(8):

$$\sigma(\mathrm{a,b,c,d}) = \frac{2(d-a)+\mathrm{c}-\mathrm{b}}{4} \qquad (7)$$

It is important to note that measures described in Equations (4) to (7) can be used in assessing the precision and quality of the method outputswhen more than one run is performed and, hence, more than one fuzzy output is generated.

IV- EXAMPLE PROJECT

This example is a hypothetical project and was analyzed to illustrate the method's essential features in forecasting project cost at completion and due to space limitation only cost forecast is provided. The project conssits of 4 activities.The project has a total cost of \$217,988.5.Table (1) depictsthe project data of progress report at reporting date. The project has a budgeted cost of work schedule (BCWS) of \$217,988.5(see column 1). As it is illustrated in column (2), at report date, the % complete of activities: A, B, C, and D were 92, 75, 87, and 100%, respectively. Based on the % completed, the Earned Value (BCWP) is calculated for each activity in progress (BCWP = % completed * BCWS). It should be noted that for activity D, the % completed is 100% (completed). Column (3) shows the calculated earned value (BCWP) for each activity. Column (4) shows the cumulative actual cost (ACWP) which is already spent up to report date for each activity. Having BCWP and ACWP are determined, the cost and schedule performance indices are then calculated using the following equations (see columns 5 and 6):

$$CPI = BCWP/ACWP \ (8)$$

$$SPI = BCWP/BCWS \ (9)$$

Based on the calculated cost and schedule performance indices, the contractors then can use their judgements to estimate a range of the performance for the remaining work. Table (2) depicts the defined CPI of the activities in progress. For activity D, the CPI for the remaining work is set to one since the activity is already completed.

TABLE 1: Project cost data

WBS ACTIVITY	BCWS ($)	% complete	BCWP ($)	ACWP ($)	CPI	SPI
A	63000	92	58,000	62,500	0.93	0.2
B	64000	75	48,000	46,800	1.025	0.75
C	22988.5	87	20,000	23,500	0.85	0.87
D	68000	100	68,000	72,500	0.94	1
	217,988.5	0.89	194,000	205,300	0.944	0.88

TABLE 2: Fuzzy numbers of project CPI

Act. no	Act. status	Calculated (CPI)	Trapezoidal representation of crash cost			
			a	b	c	d
A	In progress	0.93	0.9	0.95	0,98	1.0
B	In progress	1.025	1.0	1.0	1.05	1.1
C	In progress	0.85	0.75	0.8	0.9	0.95
D	completed	0.94	1	1	1	1

Method output

To illustrate the features of the developed method in forecasting project cost at completion, the cost at completion was estimated as fuzzy number. It should be noted that trapezoidal membership functions is used to represent uncertainties associated with activity CPI but other membership can also be used such as triangularmembership. In addition, possibility measure, agreement index, expected value, fuzziness measure, and ambiguity measure were applied to help describe the uncertainty associated with the forecasted project cost.Table .2 depicts the fuzzy forecasted cost at completion for each activity and at the project level. Fig. 2 represents the fuzzy forecasted total cost at completion. The possibility measure is applied to evaluate the possibility of estimating of cost forecast. For example, the possibility measure that the project total cost at completion is being $228,475.0 equals 0.5.The most possible and plausible variable in the fuzzy number is the one that has a possibility measure of 1.0.

TABLE 3: fuzzy forecasted cost at completion

Act	a	b	c	d
A	68,055.56	67,763.16	67,602.04	67,500.00
B	62,800.00	62,800.00	62,038.10	61,345.45
C	27,484.67	27,235.63	26,820.56	26,645.79
D	72,500.00	72,500.00	72,500.00	72,500.00
Total	230,840.22	230,298.78	228,960.69	227,991.24

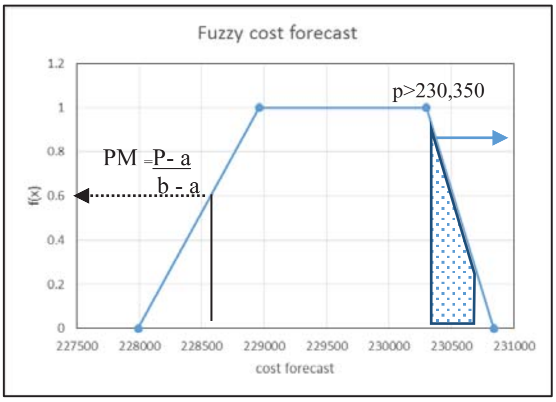


FIG 2: Calculation of fuzzy Forecasted total cost at completion

As it can be seen from Fig. 2,, the possibility measure that the project total cost at completionwill fail between $230350 and $ 230500is expressed by four numbers ($ 230350.00,$ 230350.00,$ 230500.00, $ 230500.00). As for this case, the elements which are included in the intersection range along with their associated degree of membership are: {230350|0.9, 230350|0.9, 230500|0.62, 230500|0.62}, so in this case the possibility that the cost forecast at completion falls between 230350 and 230500 is 0.9. According to the measurement of possibility it is clear that the most possible cost forecast is about $230500

The possibility measure pertinent to two events takes its value from the maximum membership function value resulted from the intersection area of the events involved, as in case described above for calculating the possibility of the cost forecast falls between 230350 and 230500. It is important to note that the possibility measure does not consider the size of that intersection area, which may lead to a high value of possibility measure while the intersection area is small. Table (3) depicts the fuzzy cost forecast at completion as calculated using Equation (2).

Tables 4 depict a comparison between the developed method and the traditional deterministic methods used in forecasting cost at completion. It can be seen from the comparison that the developed method yields more accurate results to the forecasting cost at completion, and it also offers contractors effective tools to evaluate the possibility of achieving certain forecasting cost at completion; which is not possible to determine using any probability-based analysis such as simulation.

TABLE 4: Evaluation of different measures applied to forecasted cost at completion

Method	cost forecast ($)	Probability (p>230,350)	Possibility (p=230,350)	Is it more possible that (p=230500)> (p=230350)?	Expected value:	Fuzziness measure:	Ambiguity measure:
Deterministic	229,801.98	NA	NA	NA	229,801.98	NA	NA
Developed Method	(227,991.24; 228,960.69; 230, 298.78; 230, 840.22)	0.62 ^{e}	0.9 ^{f}	No ^{f}	229,501.32	755.44	747.82

^{e} agreement index ^{f} possibility measure p = cost forecast

V- SUMMARY AND CONCLUDING REMARKS

This paper presents a new method developed for forecasting project cost and time at completion of construction projects. The method integrates in addition to earned value technique, the contractors' judgment that based on previous experience of similar projects. The method accounts for uncertainties associated with project future performance of cost and time comparing with that achieved at report date. The uncertainties are represented using fuzzy set theory. The use and the capabilities of the developed method were illustratedusing hypotheticalconstruction project. The results prove that (1) the developed method can produce more practical cost forecast at completion, and (2)FST based method can be used effectively for projects performance forecasts to model uncertainties in much easier and faster way compared to the probabilistic based models.

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REFERENCES

[1] N. Eldin, R. Hughes,"An algorithm for Tracking Labour Cost",Cost Engineering, vol.34, no.4, pp.17-23, 1992.

[2] A. Alshibani, "A computerized Cost and Schedule Control System for Construction Projects",MSc Thesis, Department of Building, Civil andEnvironmental Engineering, Concordia University, Montreal, Canada, 1999.

[3] O. Moselhi, J. Li, S. Alkass, "Web-based Integrated Project Control System",Journal of Construction Management and Economics, vol. **22**, no. 1, pp. 35-46, 2004.

[4] A. Gabriel, M. Barraza, A. Edward, M. Fernando, "Probabilistic Forecasting of Project Performance Using Stochastic S-curves", Journal *ofConstruction Engineering and Management, vol.130 , no.* 1, pp. 25-32, 2004.

[5] O. Moselhi, A. Hassanien, "Tracking and Control of linear Infrastructure Projects", 5th Construction Specify Conference of the CanadianSociety for Civil Engineering, pp. 141-149, 2003.

[6] S. Nasira, M. Abd.Majid, "Project cost performance forecasting system", Proceedings of the 6th Asia-Pacific Structural Engineering andConstruction Conference (APSEC 2006), 5 – 6 September 2006, Kuala Lumpur, Malaysia, 2006.

[7] S. Vandevoorde, M. Vanhoucke, "A comparison of Different Project Duration Forecasting Methods Using Earned Value Metrics", International journal of project management 24 (2006) 289–302, 2006.

[8] B. Kim, "Forecasting Project Progress and Early Warning of Project Overrun with Probabilistic Methods." Doctoral dissertation, Texas A&MUniversity, 2007.

[9] B. Kim, K. Reinschmidt, "Combination of Project Cost Forecasts In Earned Value Management", Journal of Construction Engineering andManagement, ASCE, posted ahead of print January 12, 2011. doi:10.1061/(ASCE)CO.1943-7862.0000352.

[10] O. Moselhi, "The use of Earned Value in Forecasting Project Duration",The 28th International Symposium on Automation and Robotics inConstruction (ISARC), June 29- July 2, 2011 Seoul, KOREA.

[11] O. Moselhi, X. Xiao, "Trending and Forecasting in Construction Operations",Proceedings of the 28th ISARC, Seoul, Korea, 905-910, 2011.

[12] O. Zwikael, S. Globerson, T. Raz, "Evaluation of Models for Forecasting The final cost of A project",Project management journal, vol. 31. No. 1, pp. 53-57, 2000.

[13] A. Shtub, F. Bard, S. Globerson, "Project Management - Engineering, Technology and Implementation", Prentice-Hall, pp. 374-497, 1994.

[14] L. Zadeh, L, "Fuzzy Sets As A basis for A theory of Possibility", Fuzzy Sets Systems, 1, pp.3-28, 1978.

[15] A. Shaheen, A. Robinson, S. AbouRizk, "Fuzzy Numbers in Cost Range Estimating", Journal of Constr. Eng. and Mgmt., ASCE, vol. 133, no. 3, pp. 325-334, 2007.

[16] J. Paek, Y. Lee, J. Ock, "Pricing Construction Risk: Fuzzy Set Theory Application", *Journal of Constr. Eng. and Mgmt.*, ASCE, vol. 119, no. 4, pp.743-756, 1993.

[17] P. Lorterapong, O. Moselhi, "Project-Network Analysis Using Fuzzy Sets Theory", *Journal of Constr. Eng. and Mgmt.*, ASCE, vol. 122, no.4, pp. 308-318, 1996.

[18] J. Booker, D. Singpurwalla, "Using Probability and Fuzzy set Theory for Reliability Assessment, 2002,http://sem proceedings.com/21i/sem.org-IMAC-XXI-Conf-s14p03-Using Probability-Fuzzy-Set-Theory-Reliability-Assessment.pdf, 08/11/2011.

[19] A. Kaufmann, M. Gupta, "Introduction to Fuzzy Arithmetic, Theory and Applications", Van Nostrand Reinhold, New York, 1985.

[20] G. Klir, T. Folger, "Fuzzy Sets, Uncertainty, and Information", Prentice-Hall, Englewood Cliffs, N.J, 1985.