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Estimation of Project Performance Using Earned Value Management and Fuzzy Regression

Mohammad Mahdi Asgari Dehabadi*
Department of Industrial engineering,
University of Economic Science
Tehran, Iran

Mostafa Salari
Department of Industrial engineering,
Sharif University of Technology
Tehran, Iran

Ali Reza Mirzaei
Department of Technology Management,
Allameh Tabataba'ee University
Tehran, Iran

Abstract. Earned Value Management is a critical project management methodology that evaluates project performance from cost and schedule viewpoints. The novel theoretical framework presented in this paper estimates future performance of project regarding the past relative information. It benefits from fuzzy regression (FR) models in estimation process in order to deal with the vagueness and impreciseness of real data. Furthermore, fuzzy-based estimation is evaluated using linguistic terms to interpret different possible condition of projects. The proposed model can greatly assists project managers to assess prospective performance of project and alerts them in taking of necessary actions. Finally, one illustrative case associated with a construction project has been provided to illustrate the applicability of theoretical model in real situations.

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*Corresponding author

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1. Introduction

Earned value management (EVM) is a project management technique which reveals great capability in measurement of project performance from different viewpoints. When EVM is properly applied, it provides an early warning of performance problems. The PMBOK Guide initially defines EVM as "a management methodology for integrating scope, schedule, and resources for objectively measuring project performance and progress" [1]. The introduced indices of EVM make such measurement possible. Due to the simplicity and application of EVM systems in different situations, many researchers applied the EVM in various organizations and projects [2-6]. On the other hand, there other researchers discussed and improved the efficiency of EVM in real case projects [7-13].

Actually, there are two distinctive viewpoints for cost management in an EVM system: Initially, it looks backward, measuring the past cost and schedule performances of project via using cost performance index (CPI) and schedule performance index (SPI), respectively. Secondly, it looks forward proposing a process called estimate at completion process (EAC and EACt) for estimation of project total cost and duration. Regarding the second viewpoint, EVM is a method for assisting project managers to reach reasonable decisions concerning the future of ongoing projects. However, there are some situations in real case projects that project managers require obtaining the cost future performance of project in the upcoming milestones or to observe the future trend of cost performance for taking necessary actions.

Hence, being aware of project total cost or duration is not enough for taking managerial decisions. It seems that it would be an appropriate idea to bridge the gap between these backward and forward viewpoints of EVM which means to employ CPI and SPI for prediction of project future performances. However, there are many studies that just addressed the estimation at completion process and attempted to improve their obtained estimation. In this regard, [7, 10, 14]introduced planned value

(PV), earned schedule (ES) and earned duration (ED) in order to develop distinctive models for prediction of project total cost. Moreover, [15] utilized stochastic S-curves for forecasting of project performance. In another study, [16] discussed cost estimation method in terms of effort spent on a software project [17]introduced a final time and cost forecasting method applying statistical approach. [18] Developed a model for estimation of project final cost concerning how to exceed the convergence to the appropriate result with less variation than typical model for estimate at completion calculations. [19] Discussed a fuzzy neural network to estimate at completion costs of construction project. [20] Studied the accuracy of preliminary cost estimation in public work departments. Recently, [21] proposed a Bayesian approach to improve estimate at completion in earned value management.

To the best of authors' knowledge, none of the researches in EVM area of research attempted to take the advantage of CPI and SPI for periodic estimation of project performance from cost and schedule view point. Hence, the main contribution of this study is to concentrate on this available lack in EVM technique and to develop a model which is capable of project future performances. The rest of this study is organized as follows:

Fuzzy theory is comprehensively described in section 2. It is followed by introduction of EVM indices in section 3. Section 4 is dedicated to explain how the fuzzy regression can be applied as a powerful tool to predict EVM indices in future. The question related to the interpretation of fuzzy-obtained values is responded in section 5. Eventually, in section 6, a case study is employed to show how the proposed can be utilized for a real case project.

2. Utilization of Fuzzy Theory in the Proposed Model

In 1965, Lotfi Zadeh [22] introduced fuzzy set and theory to cope with vagueness in systems where uncertainty increases due to fuzziness rather than randomness. In doing so, the fuzzy theory utilizes different types of numbers with specified membership functions. Let us assume $\tilde{A} = (a_1, a_2, a_3, a_4)$ is a trapezoidal fuzzy number. Figure 1 portrays a trapezoidal fuzzy number which the assigned membership function is defined as below:

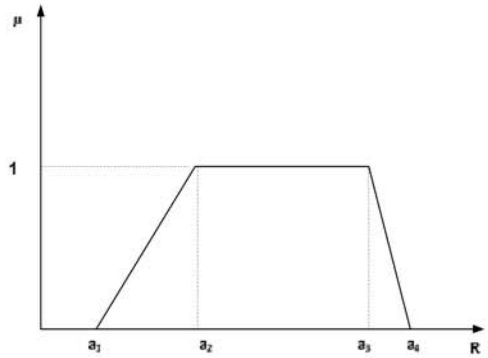

Figure 1. A trapezoidal fuzzy number

$$\mu_{\tilde{A}}(x) = \begin{cases} 0 & x < a_1 \\ \dfrac{x - a}{a_2 - a_1} & a_1 < x < a_2 \\ 1 & a_2 < x < a_3 \\ \dfrac{x - a_3}{a_4 - a_3} & a_3 < x < a_4 \\ 0 & x > a_4 \end{cases} \tag{1}$$

The trapezoidal fuzzy number can be changed into triangular fuzzy number if $a_2 = a_3$. In order to deal with basic operation of fuzzy numbers, let us supposes $\tilde{A}$ and $\tilde{B}$ are two trapezoidal fuzzy numbers, and then the following arithmetic can be applied for these numbers [22]:

$$\tilde{A} = (a_1, a_2, a_3, a_4) \;\; \& \;\; \tilde{B} = (b_1, b_2, b_3, b_4)$$

$$\tilde{A} + \tilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4) \tag{I}$$

$$\tilde{A} - \tilde{B} = (a_1 - b_1, a_2 - b_2, a_3 - b_3, a_4 - b_4) \tag{II}$$

$$\tilde{A} \times \tilde{B} = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3, a_4 \times b_4) \tag{III}$$

$$\tilde{A} \div \tilde{B} = (a_1/b_4, a_2/b_3, a_3/b_2, a_4/b_1) \tag{IV}$$

3. Earned Value Management

The indexes in the EVM evaluate the project performance from different point of views. These indices work comparing actual progress (AP) and planned progress (AP) of project activities. In this paper, the actual progress of each individual activity (AP) is described as fuzzy-based linguistic terms, in accordance with the proposed approach by [23] due to available imprecision in statement of progress in real case projects. Table 1 and Figure 2 illustrate the assigned fuzzy numbers and the fuzzy membership of corresponding linguistic terms, respectively.

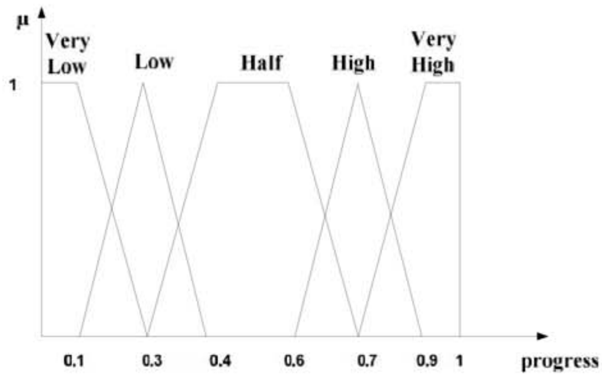

Figure 2. Illustration of membership functions related to the actual progress

Table 1. Linguistic terms of actual progress and assigned fuzzy numbers

Linguistic term	Fuzzy number
Very low	(0,0,0.1,0.3)
Low	(0.1,0.3,0.4)
Half	(0.3,0.4,0.6,0.7)
High	(0.6,0.7,0.9)
Very High	(0.7,0.9,1,1)

In addition to the AP, budget at completion of each activity (BACi) and planned value (PV) are also considered as fuzzy numbers in order to deal with the inaccuracies in the determination of activities cost in the planning phase of project. Then the actual progress of activity i is multiplied by activities' budget and resulted in earned value (EV):

$$EV_i = AP_i \times BAC_i \tag{2}$$

Since the AP and BAC are both fuzzy numbers, the EV can be obtained as fuzzy number either:

$$\begin{aligned} &EV_i = BAC_i \times AP_i = (BAC_{i1}, BAC_{i2}, BAC_{i3}, BAC_{i4}) \\ &\times (AP_{i1}, AP_{i2}, AP_{i3}, AP_{i4}) = (EV_{i1}, EV_{i2}, EV_{i3}, EV_{i4}) \end{aligned} \tag{3}$$

Finally, earned value of project results from summation of activities' earned values:

$$EV = \sum_{i=1}^{n} EV_i = (\sum_{i=1}^{n} EV_{1i}, \sum_{i=1}^{n} EV_{2i}, \sum_{i=1}^{n} EV_{3i}, \sum_{i=1}^{n} EV_{4i}) \tag{4}$$

One of the most employed indexes in the EVM is the cost performance index (CPI). CPI mainly assesses the project performance from the aspect of cost by comparing the actual value earned and the actual amount spent. The fuzzy-based CPI can be calculated as follows.

$$CPI = \frac{EV}{AC} = (\frac{EV_1}{AC_1}, \frac{EV_2}{AC_2}, \frac{EV_3}{AC_3}, \frac{EV_4}{AC_4}) \tag{5}$$

Where, the AC stands for the actual cost of the performed works. The SPI evaluates the behavior of the project by comparing the AP against the planned value. In other words, the SPI is calculated as a proportion of the EV to the planned value (PV) as shown below:

$$SPI = \frac{EV}{PV} \tag{6}$$

Furthermore, the fuzzy illustration of SPI can be obtained according to the following equation:

$$SPI = \frac{EV}{PV} = (\frac{EV_1}{PV_4}, \frac{EV_2}{PV_3}, \frac{EV_3}{PV_2}, \frac{EV_4}{PV_1}) \tag{7}$$

There are inefficiencies in using the SPI for measuring project schedule performance. Normally, the SPI does calculations based on cost units. Therefore, it is not meaningful enough to employ it individually for the evaluation of the schedule performance. Moreover, the SPI leads to the value 1 at the end of project in deterministic calculation. [10] Discussed the ineffectiveness of a typical SPI in his study and proposed the ES for the assessment of project performance from the schedule aspect. Generally, the ES can be considered as a time equivalent of the EV. Figure 3 and Eq. (8) demonstrate the basic concept and calculation of the ES, respectively [10].

$$ES = N + \left(\frac{(EV - PV_N)}{(PV_{N+1} - PV_N)}\right) \tag{8}$$

Where the longest time interval that the PV is less than the EV has been determined as N. PV_N and PV_{N+1} are PV at time N and $N+1$, respectively [24]

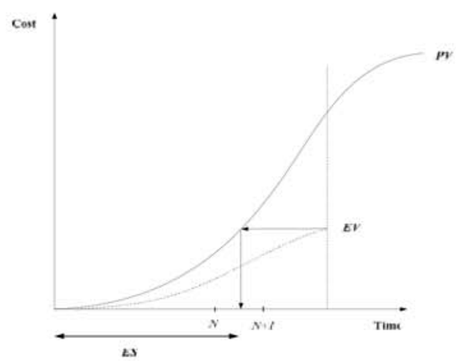

Figure 3. The ES position in comparison with the EV

Eq. (9) illustrates the new formulation for the ES using the novel calculation for the EV presented in prior sections.

$$ES = N + \left(\frac{(EV - PV_N)}{(PV_{N+1} - PV_N)}\right) = (ES_1, ES_2, ES_3, ES_4) \tag{9}$$

The concept of the ES also incorporates the calculation of the SPI and provides a novel schedule index based on time units (i.e., SPIt). The SPIt addresses the available restrictions of the SPI. It is calculated as the proportion of the ES to the actual duration (AD),

$i.e. SPI_t = \frac{ES}{AD}$.

Eq. (10) demonstrates the other possible calculation of the SPIt using the fuzzy-based ES:

$$\tilde{SPI_t} = \frac{ES}{AD} = \left(\frac{ES_1}{AD}, \frac{ES_2}{AD}, \frac{ES_3}{AD}, \frac{ES_4}{AD}\right) = (SPI_{t_1}, SPI_{t_2}, SPI_{t_3}, SPI_{t_4}) \quad (10)$$

4. Application of Fuzzy Regression in EVM Indices Prediction

One great expansion of fuzzy theory can be mentioned as integration of classical regression with fuzzy theory that results in fuzzy regression models. Primarily, [25] introduced linear regression analysis with fuzzy model and subsequently other studies focused not only on the development of the fuzzy regression models [26-28] but also on the application of the fuzzy regression in different systems [29, 30]. One great advantage of the fuzzy regression, likewise the basic regression, is to predict the future value of variables [30]. The proposed model utilizes the fuzzy regression to predict the SPI and CPI at different period of ongoing project based on their past records. The predicted SPI and CPI also provide this opportunity for project managers to be aware of the final status of the cost and schedule performances. Additionally, these indices assist project managers in making appropriate decisions for rescheduling of the project. In the proposed model, the fuzzy regression model presented by Yang and Lin [28] has been employed in prediction process. The main arithmetic of their fuzzy regression model is demonstrated as below:

$$\tilde{y} = \beta_0 + \beta_1 \tilde{x}_i + \tilde{\varepsilon}_i \qquad i = 1, 2, ..., n \quad (11)$$

Eq. (11) presents the basic functional form of the employed fuzzy regression where is the fuzzy response variable, β_0 and β_1 are crisp parameters and $\tilde{x}_i$ is the i^{th} fuzzy predictor variables. The following procedure is presented to find the values of β_0, β_1 : Let $\tilde{x}_i, \tilde{y}_i$ be the following trapezoidal fuzzy numbers:

$$x_i = (x_{i1}, x_{i2}, x_{i3}, x_{i4})$$

$$y_i = (y_{i1}, y_{i2}, y_{i3}, y_{i4})$$

Then

$$\hat{\beta}_1 = \frac{\sum_{i=1}^{n}(x_{i1}\ y_{i1}+0.5\ x_{i2}\ y_{i2}+0.5\ x_{i3}\ y_{i3}+x_{i4}\ y_{i4})-3n\bar{x}\bar{y}}{\sum_{i=1}^{n}(x_{i1}^2+0.5\ x_{i2}^2+0.5\ x_{i3}^2+x_{i4}^2)-3n\bar{x}^2} \tag{12}$$

$$\hat{\beta}_0 = \bar{y} - \beta\bar{x} \tag{13}$$

Where

$$\bar{y} = \frac{\sum_{i=1}^{n}(y_{i1}+0.5\ y_{i2}+0.5\ y_{i3}+y_{i4})}{3n}$$

and

$$\bar{x} = \frac{\sum_{i=1}^{n}(x_{i1}+0.5\ x_{i2}+0.5\ x_{i3}+x_{i4})}{3n}$$

EVM mainly concerns with the past performance of project and the presented model applies pervious trend for assessment of future behavior of project. Consequently, statistical modeling is employed to predict EVM's indices at the end of project. Regarding Eq. (12) and Eq. (13), the employed approach for the predictions of SPI and CPI are presented as follow:

$$(S\tilde{P}I_t)_T = \beta_0 + \beta_1 \times (S\tilde{P}I_t)_{T-1} \tag{14}$$

$$C\tilde{P}I_T = \beta_0 + \beta_1 \times C\tilde{P}I_{T-1} \tag{15}$$

Where $(SPI_t)_T$ and $(CPI)_T$ are the response variables and indicate the cost and schedule performance at time T, respectively. $(SPI_t)_{T-1}$ And $(CPI)_{T-1}$ are the predictor variables and illustrate the values of these indices at time T-1. The value of the response variables are predicted based on their past values in Eq. (14) and Eq. (15). It means the values of the SPI_t and CPI at time T is predicted based on their value of at time T-1. For instance, let us assume that the project is at time T-1 and the value of aforementioned indices at time T+1 should be obtained. Firstly, Eq. (14) and Eq. (15) are employed to predict these values at time T. Afterward, The predicted values at time T replaced with the predictor variables to achieve the value of the SPI_t and CPI at time T+1. To obtain the final value of the SPI_t and CPI, this process is repeated until T will be equal to the completion time of the project.

5. Interpretation of Project Status

It seems as a necessary step to evaluate and interpret the fuzzy-based SPI and CPI. In this regard, the value 1 should be compared against of these performance indices. As it can be observed from the calculation the SPI and CPI are obtained as trapezoidal numbers during the prediction process. Hence, we divided a trapezoidal fuzzy number into 5 separated zones to facilitate the interpretation process. If the value 1 locates in each of these zones, it results in a distinctive interpretation of project cost or schedule performances. Let us initiate with CPI, Figure 4 illustrates how the fuzzy-based CPI is divided to different zones. Each zone is labeled as a different state and the interpretation of these states are provided in Table 2.

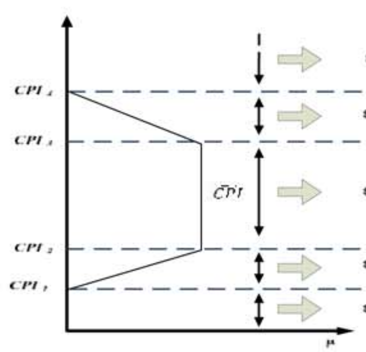

Figure 4. Different states related to CPI

Table 2 Interpretation of fuzzy-based CPI

State	Condition of CPI against 1	Interpretation of fuzzy-based CPI
State 1	If 1 is greater than CPI_4	Project suffers from cost weak performance
State 2	If 1 is between CPI_4 and CPI_3	Project suffers almost from cost weak performance
State 3	If 1 is between CPI_2 and CPI_3	Project reveals suitable performance from cost viewpoint
State 4	If 1 is between CPI_2 and CPI_1	Project executes in almost great performance from cost viewpoint
State 5	If 1 is smaller than CPI_1	Project executes in great performance from cost viewpoint

The applied interpretation for CPI can be similarly employed for SPI. In doing so, the Figure 5 and Table 3 make the evaluation of project performance from schedule standpoint possible.

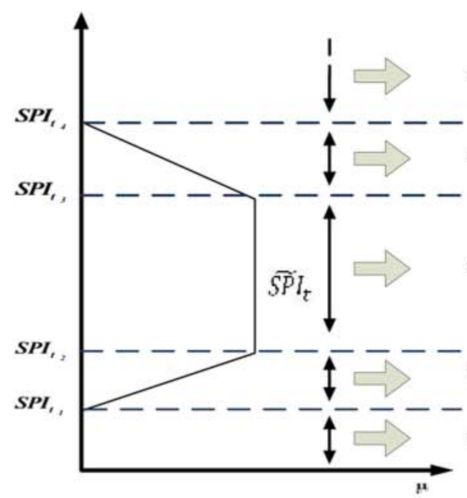

Fig 5. Different states related to SPI_t

Table 3 Interpretation of fuzzy-based SPI_t

state	Condition of $\tilde{SPI}_t$ against 1	Interpretation of fuzzy-based SPI_t
State 1	Condition of $\tilde{SPI}_t$ against 1	Project suffers from schedule weak performance
State 2	If 1 is greater than	Project suffers almost from schedule weak performance
State 3	If 1 is between and	Project reveals suitable performance from schedule viewpoint
State 4	If 1 is between and	Project executes in almost great performance from schedule viewpoint
State 5	If 1 is between and	Project executes in great performance from schedule viewpoint

By way of illustration for this, consider a condition in a project in which the fuzzy-based CPI and SPI_t are calculated as follows:

$$CPI = (0.6, 0.7, 0.81, 0.93) \text{ and } SPI_t = (0.9, 0.98, 1.02, 1.09)$$

According to the Figure4 the project is in state 1 from cost viewpoint which means that "Project suffers from cost weak performance". Regarding the value of fuzzy-based SPIt, the project is in state 3 which is interpreted as "Project reveals suitable performance from schedule viewpoint". Note that the linguistic interpretations provided in Tables 2 and 3 can vary based on condition of different projects or assessments of decision makers.

6. Case Study

In this section, a case study from construction industry is applied to exhibit that how the proposed model can be employed for real case projects. The planned duration of this project is scheduled for 17 months. This project consists of 7 main work packages which their duration, cost and actual progress are provided in Table 4.

Table 4. Raw data of the project

Work packages	Planned Cost	Actual Progress	Earned Value
Excavation	(2450,2600,3360,3400)	Very High	(1715, 3340, 3360, 3400)
Well diggering	(1430,1500,1805,2100)	Low	(143, 450, 541.5, 840)
Sewer system	(1940, 1602, 1803, 1940)	Not started	N/A
Ert well	(1710, 1860, 1920, 2000)	High	(1026, 1302, 1344, 1800)
Embankment	(2200, 2301, 2403, 2410)	Not started	N/A
Incinerating sludge	(1100, 1111.5, 1112, 1114)	Not started	N/A
Constructing garden	(1340, 1390, 1460, 1495)	Not started	N/A
Explosion	(1510, 1630, 1680, 1710)	Half	(453, 652, 1008, 1197)

Table 5. Planned duration and actual cost for each month of the project execution

month	Planned value (PV)	Actual cost(AC)
1	(90, 120, 210, 290)	200
2	(350, 400, 450, 470)	500
3	(650, 750, 850, 866)	950
4	(1000, 1200,1400,1515)	1500
5	(1550, 1700, 1850, 2050)	2100
6	(2100, 2350, 2450, 2700)	
7	(2830, 2950, 3100, 3330)	
8	(3400, 3600, 3700, 3940)	
9	(4200, 4350, 4500, 4800)	
10	(5100, 5400, 5800, 6220)	
11	(6200, 6350, 6600, 6850)	
12	(7100, 7250, 7400, 7600)	
13	(7580,8100,8300,8500)	
14	(8600, 8900, 9150, 9460)	
15	(9600, 10500, 10800, 11200)	
16	(11500, 12100, 12800, 13600)	
17	(13342, 14195.5,15678, 16172)	

The process of cost and schedule performance prediction can be performed using Eq. (13) and Eq. (14). Table 6 shows the obtained coefficients and the fuzzy regressions models applied for CPI and SPI_t.

Table 6. Fuzzy regression models of SPI_t and CPI

Performance Index	β_0	β_1	Fuzzy regression equation
$\tilde{C}PI$	0.356	0.522	$\tilde{C}PI_T = 0.356 + 0.522 \times \tilde{C}PI_{T-1}$
$\tilde{S}PI$	0.214	0.541	$(\tilde{S}PI_t)_T = 0.214 + 0.514 \times (\tilde{S}PI_t)_{T-1}$

Taking the advantages of using these fuzzy regressions, project performances can be predicted periodically. Eventually, the project cost and schedule performance are predicted for the end of project planned duration:

$$(C\tilde{P}I)_T = (0.74, 0.83, 0.92, 1.04) \ \& \ (S\tilde{P}I_t)_T = (0.4, 0.51, 0.64, 0.75)$$

According to the proposed model, the next mandatory step is to interpret the SPI_t and CPI. Figure 6 and Figure 7 exhibit the final status of project performance from cost and schedule viewpoints, respectively. These values can be simply evaluated using Tables 2 and 3. The project final cost performance is interpreted as "Project suffers almost from cost weak performance" using Table 2 (See state 2 in Table 3). Similarly the project final schedule performance can be obtained employing Table 3, as according to this table, it is interpreted as "Project suffers from schedule weak performance" (See state 1 in Table 3).

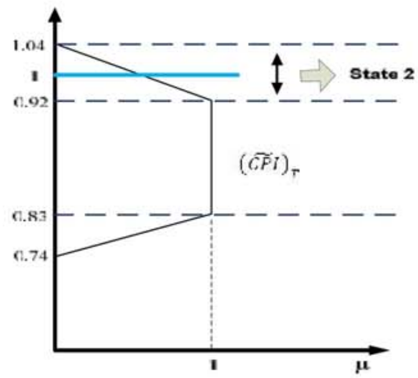

Figure. 6 Final status of CPI

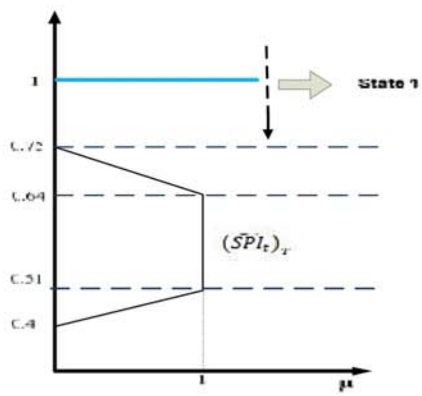

Figure 7. Final status of SPI_t

7. Conclusion

A new method for prediction of project performance from two distinctive viewpoints, i.e. cost and schedule, is presented in this paper. Fuzzy regressions as a powerful prediction tool and linguistic terms for interpretation of fuzzy values are then employed in the proposed model. Research finding of applying the presented method for the case study indicates that how efficiently the model is capable of providing initial warning in the cases that the current condition of project performances are according to the plan but their general trend tend toward the weak sides. Using integrated time series and simulation is recommended for further development of the proposed model.

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