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Evaluating fuzzy earned value indices and estimates by applying alpha cuts

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ABSTRACT

The earned value technique is an essential technique in analyzing and controlling the performance of a project by providing a more accurate measurement of both project performance and project progress. This paper presents an approach to deal with fuzzy earned value indices. This includes developing new indices under fuzzy circumstances and evaluating them using alpha cut method. The model improves the applicability of the earned value techniques under real-life and uncertain conditions. A small example illustrates how the new model can be implemented in reality.

1. Introduction

Earned Value Management (EVM/EV) is a project management technique developed to measure project progress in an objective manner. According to Project Management Institute (PMI),[1] when properly applied, EVM provides an early warning of performance problems. The EV measures project performance and progress by efficiently integrating management of three most important elements of a project, i.e. cost, schedule and scope. In fact, it calculates cost and time performance indices of a project, estimates completion cost and completion time of a project, and measures project performance and project progress.

Although being introduced in 2000 in PMBOK® guide (PMI, 2000), the first complete guide on the EV has been published in 2005 (PMI, 2005). Despite widely believed that implementing the EV techniques has many advantages and would enhance cost and schedule performances of a project; the research on the EV is very limited. Lipke (1999) developed cost and schedule ratio to manage cost and schedule reserves in projects. Later he introduced the earned schedule (ES) concept to outperform limitations of the historical EV schedule variance (SV) and schedule performance index (SPI) (Lipke, 2003). His studies were followed by Henderson (2003, 2004) and Vandevoorde and Vanhoucke (2005), where applicability and reliability of the ES were discussed. Anbari (2003) improved the effectiveness of EV implementation. Kim, Wells, and Duffey (2003) studied the implementation of the EV in different types of organizations and projects. Cioffi (2006) studied the EV mathematics to make it more applicable and flexible. Lipke et al. (2009) provided a reliable forecasting method of completion cost and duration to improve the capability of project managers for making informed decisions. Recently Moslemi Naeni et al., (2010) have worked on fuzzy earned value and applied degree of possibility method to evaluate estimates.

The motivation behind this paper is derived from the fact that despite the uncertain nature of the activities' progress involved in a project, they are considered deterministic in all available EV techniques. In reality the activities' data come from people's judgments; hence they carry some degree of uncertainty. Bringing this uncertainty into interpretations, not only helps in measuring better performance and progress of a project, but also in extending the applicability of the EV techniques under the real-life and uncertain conditions. The major contribution of this paper is to develop an approach to deal with fuzzy earned value indices and estimates when measuring project performance and project progress. Through the paper, our terminology is based on the PMBOK guideline (PMI, 2004). For the simplicity, by "activity", we mean both activities and work packages. The remaining of this paper is organized as follows: Section 2 brings an introduction into the earned value and fuzzy theory. The section forms the basis of the proposed approach of Section 3. Evaluation and interpretation of fuzzy earned value indices and estimates are covered in Section 3. For clarification purposes, a simple example is studied in details in Section 4. The paper ends with the conclusion.

2. The fuzzy earned value measurement technique

The earned value (EV) is a set of techniques to assist project managers in measuring and evaluating project progress and project performance by estimating completion cost and completion time of a project (based on its actual cost and actual time up to any given point in the project). The EV of an activity represents

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[1] In a more accurate definition by PMI (2005), the EVM combines measurements of technical performance (i.e. accomplishment of planned work), schedule performance (i.e. behind/ahead of schedule), and cost performance (i.e. under/over budget) within a single integrated methodology.

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Table 1
The EV measurement techniques.

Activity product	Activity duration	
	1 or 2 measurement periods	More than 2 measurement periods
Tangible	Fixed formula	Weighted milestone percent complete
Intangible	Level of effort apportioned effort	

the budgeted cost of work performed, and indicates how efficiently the project team utilizes the project resources.

Table 1 presents a list of available techniques in calculating the EV of either an activity or a project. More details can be found in "practice standard for earned value management" (PMI, 2005).

We explain here only the percent complete technique which forms the basis for fuzzy EV discussed here. In the percent complete, one of the simplest techniques for measuring the EV, in each measurement period the person-in-charge makes an estimate of the percentage of the activity completed, e.g. 26%. This technique can be the most subjective of the EV measurement techniques if there are no objective indicators based on which the estimates should be made. This greatly incorporates into errors and uncertainty which cause biased judgments. An idea to overcome this problem is to use the linguistic terms in estimating the completion percent of each activity, as the imprecise and uncertain data of activity performance and activity progress are common to arise.

Fuzzy theory (Zadeh, 1965) explains uncertainty in events and systems where uncertainty arises due to vagueness or fuzziness rather than randomness alone. It is reasonable to model and treat the uncertainty using the linguistic terms with the fuzzy theory. For instance, if an activity progress cannot be stated in certainty, using linguistic terms it may be stated as "very low", etc.[2] Clearly, this linguistic term cannot be applied on the EV technique before transforming it to a number. Thus, first we have to convert linguistic terms into fuzzy numbers by applying fuzzy principles. Typically, the project experts perform this transformation in accordance with their knowledge and their experience about the project and according to the activity attributes. Then we should modify the EV mathematics to consider fuzzy numbers.

The application of the proposed method arises in situations where the total amount of work required to accomplish the activities is unknown or uncertain, and is out of control. Examples are, in a dam construction project the ground should be excavated until hard layer of rock is reached. Before reaching this layer, the exact amount of the operations and the required work are unknown, and also this is out of our control, so the percent complete of excavation activity cannot exactly be measured. In medical research projects and drug development projects, a majority of resources are devoted to the clinical experiments aims at testing the new drug for its benefits and potential side effects. The exact amount of work required to derive scientific conclusions is unknown in advance. In these cases and many other similar cases, it would be better and easier to evaluate the percentage of the activity completed by linguistic terms rather to evaluate it exactly and deterministically. We strongly believe the developed technique reflects better the uncertain nature of a project. The example below clarifies the core idea of this paper.

Assume the completion percent of an activity includes uncertainty and is expressed as "half". As mentioned earlier the project expert transforms this into a fuzzy number by assigning a membership function[3] to this linguistic term (like the one showed in Fig. 1. In

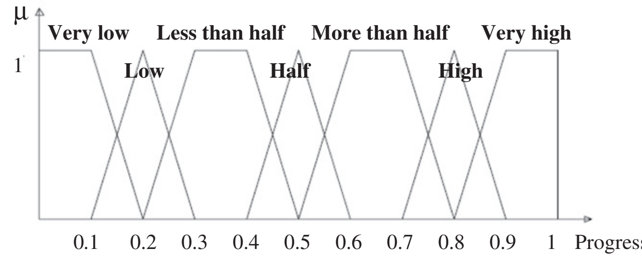

Fig. 1. A fuzzy membership including trapezoidal and triangular fuzzy numbers and the corresponding linguistic terms.

Table 2
The assigned fuzzy numbers to each linguistic term of Fig. 1.

Linguistic term	Fuzzy number
Very low	[0,0, 0.1, 0.2]
Low	[0.1, 0.2, 0.2, 0.3]
Less than half	[0.2, 0.3, 0.4, 0.5]
Half	[0.4, 0.5, 0.5, 0.6]
More than half	[0.5, 0.6, 0.7, 0.8]
High	[0.7, 0.8, 0.8, 0.9]
Very high	[0.8, 0.9, 1, 1]

figure the horizontal axis refers to the progress and is on a scale of 1). The summary of the transformation associated with Fig. 1 is shown in Table 2. Obviously, the output of this transformation is a fuzzy number. Note that Fig. 1 and Table 2 are only an example.[4]

For instance, according to Fig. 1 and Table 2, the linguistic term "half" equals to the fuzzy number [0.4, 0.5, 0.5, 0.6]. In general, the membership function of a trapezoidal fuzzy number, for example $\tilde{A} = [a, b, c, d]$ is defined as below:

$$\mu_{\tilde{A}}(x) \begin{cases} 0, & x < a \\ (x-a)/(b-a), & a < x < b \\ 1, & b < x < c \\ (x-c)/(d-c), & c < x < d \\ 0, & x > d \end{cases} \tag{1}$$

If $b = c$ a trapezoidal fuzzy number becomes triangular. Furthermore, a triangular fuzzy number can also be represented as a trapezoidal fuzzy number $[a, b, b, d]$ or $[a, c, c, d]$, for the sake of simplicity. This enables the authors to explain much easier their novel fuzzy-EV approach. We implemented the trapezoidal and triangular fuzzy numbers as these are the simplest fuzzy numbers. Thus their mathematics can be derived easily.

At first, the fuzzy EV of activity i, $\widetilde{EV}_i$, should be derived (Eq. (2)) which itself is based on fuzzy completion percent of the activity i (Eq. (3)).

$$\widetilde{EV}_i = \widetilde{F}_i \times BAC_i = [E_{1i}, E_{2i}, E_{3i}, E_{4i}] \tag{2}$$

where

$$\widetilde{F}_i = [a_{1i}, a_{2i}, a_{3i}, a_{4i}] \tag{3}$$

The BAC_i is the budget at completion of activity i and denotes the planned budget to complete the activity i. To derive the total fuzzy EV in each measurement period, someone should sum up all $\widetilde{EV}_i$ for $i = 1, \ldots, n$ (n is the total number of project activities):

[2] Other linguistic terms include but not limited to less than half, half, more than half, etc.

[3] The membership degree $\mu\widetilde{A}(x)$ quantifies the grade of membership of the element x to the fuzzy set $\widetilde{A}$.

[4] Completion percent of an activity can be expressed using terms "approximately x" or "between x and y". This way is more suitable when dealing with long duration activities.