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Project cash flow analysis in the presence of uncertainty in activity duration and cost

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Abstract

The inherent uncertainty and imprecision in project scheduling have motivated the proposal of several fuzzy set theory based extensions of activity network scheduling techniques. Building upon these, a cash flow calculation methodology for projects including activities with fuzzy durations and/or costs is proposed in this paper. According to the proposed approach, the project cash flow is represented by an S-surface (as opposed to the traditional S-curve) ensuing by connecting S-curves at different risk possibility levels. The methodology is exemplified by estimating the working capital requirements in a real world road construction project. Furthermore, the benefits of the methodology and its subsequent computerization are discussed. It is believed that the proposed approach may also be useful for both evaluating project proposals during feasibility studies and for performing earned value analysis for project monitoring and control.

Keywords: Cash flow; Fuzzy project scheduling; S-curve; S-surface

1. Introduction

While it is acknowledged that the management of uncertainty is a necessary condition for effective project management, it can be argued that it should get more sophisticated before practical results may be harvested (Atkinson et al., 2006). More specifically, with regard to project scheduling, several fuzzy set theory based extensions of CPM (Critical Path Method) and PERT (Program Evaluation and Review Technique) (Chanas and Kamburowski, 1981; Prade, 1979) usually termed collectively “fuzzy project scheduling” or FPS, have been added to the project managers armory in the past thirty years. Variations and additions have been proposed by Lorterapong and Moselhi (1996) (the FNET methodology), Bonnal et al. (2004) (resource-constrained fuzzy project-scheduling problem), Fortin et al. (2010) (criticality analysis of activity networks with uncertainty in task durations), and Maravas and Pantouvakis (2011) (Fuzzy Repetitive Scheduling Method). Although Maravas and Pantouvakis (2008) have concluded that there is considerable potential for FPS application in practice, professional project managers still, by and large, prefer to use qualitative criteria and intuition to deal with complex problems. At the same time, methods with a wider scope, such as those involving multi-criteria decision support systems (Manoliadis and Pantouvakis, 2003) or compromises in decision making with multiple objectives (Pantouvakis and Manoliadis, 2008), have not, as yet, created a recorded impact on problems related to project scheduling.

The hypothesis made in CPM that activity durations are deterministic and known is rarely satisfied in real life where tasks are often uncertain and variable (Zammori et al., 2009). Also, the sometimes changeable and unpredictable nature of project activities cannot be modelled in classical CPM (and PERT) methods (Barraza et al., 2000), especially when schedule disruptions due to uncertainty are introduced (Herroelen and

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Leus, 2005). Equally, standard cost flow S-curves, usually derived from CPM (Boussabaine and Kaka, 1998), suffer from the shortcomings of their underlying scheduling technique; a fact resulting in unrealistic and sometimes inadequate estimations. This weakness has formed the stimulus for developing and presenting in this paper a new approach to project cash flow analysis in the existence of activity duration or cost uncertainty.

2. Literature review of fuzzy project cash flows

A project cash flow curve is the cumulative plot of project cost versus time and since it usually has the shape of the letter S it is termed the “S-curve”. Overall, the S-curve method is a straightforward technique for analyzing project payments and representing the typical cost accrual in projects (Cooke and Jepson, 1979). The generation of project cash flows is crucial for both project managers and project owners. During project implementation, the cash flow is crucial for the assessment of working capital requirements since the difference between project expenditures and payments determines the necessary capital reserves. Furthermore, an accurate cash flow is required in conducting project cost–benefit analysis, the determination of project financing requirements and in performing earned value analysis.

Several researchers have recognized the importance and necessity of applying fuzzy set theory or probability theory in project cash flow generation and analysis. Boussabaine and Elhag (1999) demonstrated the application of fuzzy averaging techniques in cash flow analysis. Their method was based on developing membership functions of cash flows and defining their linguistic variables at several valuation periods. Kumar et al. (2000) presented a methodology for assessing working capital requirements using fuzzy set theory for the analysis of various quantitative and qualitative factors in which information is subjective and based on uncertainty. Lam et al. (2001) integrated the fuzzy reasoning and fuzzy optimization technique to find an optimal path of corporate cash flow with the minimum use of resources. Barraza et al. (2004) studied the use of stochastic S-curves in the probabilistic monitoring and project performance forecasting as an alternative to deterministic S-curves. The stochastic S-curves were generated by a simulation approach based on the defined variability in duration and cost of the individual activities within the process. Mavrotas et al. (2005), proposed a model for cash flow forecasting and early warning for multi-project programmes. Yao et al. (2006) presented a fuzzy, stochastic, single-period model for cash management to provide financial decision makers with more insight into real cash management problems. Cheng et al. (2009) employed artificial intelligence approaches including fuzzy logic, K-means clustering, a genetic algorithm, and neural networks to gain strategic control over project cash flows. Cheng and Roy (2011) presented the Evolutionary Fuzzy Support Vector Machine Inference Model for Time Series Data as an alternative approach to predicting cash flow.

From the above, it is concluded that several fuzzy techniques such as fuzzy averaging, fuzzy composition matrices, fuzzy reasoning, fuzzy optimization, fuzzy multi objective decision models, and neuro-fuzzy inference have been utilized to generate project cash flows. Additionally, stochastic approaches requiring simulation have been proposed. On the other hand, when evaluating existing research in FPS, evidently the main focus is principally on the calculation of early/late start and finish dates and the determination of activity and path criticality, whereas issues related to cash flows and uncertainty in cost have not yet been comprehensively addressed. Consequently, the core of the research elaborated in modelling uncertainty in cash flows and that of FPS is not closely correlated to each other. As such, the goal of this research is to integrate and enhance research from FPS with fundamental issues in cash flow generation in activity networks whose durations and costs are uncertain. Thus, fuzzy cash flows are generated based on the fuzzy dates calculated from the FPS algorithm and the respective distribution of fuzzy costs in these dates. Moreover, the presented methodology is relatively similar to what practitioners are using today to generate project cash flows but is considerably more effective and realistic in modelling uncertainty. Ultimately, FPS is considered to be a more intuitive starting point for generating cash flows in project management than alternative methodologies that employ other fuzzy techniques.

3. Fuzzy set theory fundamentals and the fuzzy CPM algorithm

Fuzzy set theory is used to characterize and quantify uncertainty and imprecision in data and functional relationships (Zadeh, 1965). In fuzzy set theory, a triangular fuzzy number $\tilde{x} = \langle a, b, c \rangle$ has the following membership function:

$$\mu_A(x) = \begin{cases} 0, & x < a \\ (x-a)/(b-a), & a \le x \le \mathrm{b} \\ (c-\mathrm{x})/(c-\mathrm{b}), & b \le x \le \mathrm{c} \\ 0, & x > c. \end{cases} \quad (1)$$

With any fuzzy set A, we can associate a collection of crisp sets known as α-cuts (alpha-cuts) or α-level sets. An α-cut is a crisp set consisting of elements of A which belong to the fuzzy set at least to a degree of α. Therefore, if A is a subset of a universe U, then an α-level set of A is a non-fuzzy set denoted by A_α which comprises all elements of U whose grade membership in A is greater than or equal to α (Zadeh, 1975).

In symbols,

$$A_\alpha = \{u | \mu_A(u) \ge \alpha\} \quad (2)$$

where: α is a parameter in the range $0 < \alpha \le 1$.

Essentially, an α-cut is a method of defuzzifying a fuzzy set to a crisp set at desired α-levels that correspond to the perceived risk (α=1 meaning no risk, α=0+ meaning the highest risk). Additionally, the low and high values of every α-cut represent the optimistic and pessimistic outcomes of that risk level.

The main objective of FPS is to apply fuzzy set theory concepts to the scheduling of real world projects. Thus, project activities can have durations that are fuzzy numbers instead of crisp numbers. The forward pass is performed by calculating the early start and