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Applying fuzzy goal programming to project management decisions with multiple goals in uncertain environments

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ABSTRACT

In real-life situations, the project manager must handle multiple conflicting goals and these conflicting goals are normally fuzzy owing to information is incomplete and unavailable. This study develops a two-phase fuzzy goal programming (FGP) method for solving the project management (PM) decision problems with multiple goals in uncertain environments. The original multi-objective linear programming (MOLP) model designed here attempts to simultaneously minimize total project costs, total completion time and total crashing costs with reference to direct costs, indirect and contractual penalty costs, duration of activities and the constraint of available budget. An industrial case is implemented to demonstrate the feasibility of applying the proposed two-phase FGP method to practical PM decisions. The contribution of this study lies in presenting a fuzzy mathematical programming methodology to fuzzy multi-objective PM decisions, and provides a systematic decision-making framework that facilitates the decision maker to interactively adjust the search direction until the preferred efficient solution is obtained.

1. Introduction

Since the program evaluation and review technique (PERT) and the critical path method (CPM) were both developed in the 1950s, relevant project management (PM) decision issues have long attracted interest from both practitioners and academics. Numerous techniques including mathematical programming, algorithms and heuristics have also been presented to PM decisions. When any of the conventional models was used to solve PM decision problems, however, the goals and related parameters were often assumed to be deterministic/crisp (Al-Fanzine & Haouari, 2005; Davis & Patterson, 1975; Deckor & Hebert, 1989; DePorter & Ellis, 1990; Elsayed, 1982; Kotiah & Wallace, 1973; Kurtulus & Davis, 1982; Lin & Gen, 2007; MacCrimmon & Ryavec, 1964; Rabbani, Ghomi, Jolai, & Lahiji, 2007; Russell, 1986; Wiley, Deckro, & Jackson, 1998). In real-life PM decisions, model inputs and environmental coefficients, such as operating costs, activities duration, available resources and total cost budget, are typically fuzzy/imprecise owing to incomplete and unobtainable information over the project planning horizon. Conventional deterministic techniques described above obviously cannot solve practical PM decision problems in an uncertain environment.

Moreover, the existing PM decision models consider only direct costs (including labor, materials, equipment and other costs directly related to projected activities), neglecting relevant indirect costs (including interest, administration, depreciation, contractual penalty and other variable overhead costs). In practical situations, a project's total costs are the sum of direct costs and indirect costs over the project planning horizon. Generally, the real PM decisions focus on the minimization of project completion time, and/or the minimization of total project costs through crashing or shortening duration of particular activities. The aim of evaluating time-cost trade-offs is to develop a suitable PM plan that will minimize the total project costs. Thus, a project decision maker (DM) may be able to shorten project completion time, realizing savings on indirect costs, by increasing direct expenses to accelerate the project.

Additionally, although various PM decision techniques have been developed to minimize project duration, most do not also minimize the total costs (Karshenas & Haber, 1990; Li, 1995; Russell, 1986). In practice, the project DM must frequently handles conflicting goals in term of the use of organizational resources, and these conflicting goals are required to be optimized simultaneously by the DM. These goals are to minimize total costs, crashing cost, completion time, contractual penalties, and/or maximizing profits and the utilization of equipment (Al-Fanzine and Haouari, 2005; Arikan and Gungor, 2001; DePorter and Ellis, 1990; Liang, 2004, 2009; Lin and Gen, 2007; Viana and Sousa, 2000; Yin and Wang, 2008). Particularly, it is critical that the satisfying goal values should normally be uncertain due to unit cost/time coefficients and related parameters are fuzzy/imprecise in nature. Solutions to fuzzy multi-objective PM optimization

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problems benefit from assessing the imprecision of the DM's judgments, such as "the objective function of project duration should be substantially less than or equal to 200 days," and "total costs should be substantially less than or equal to 2 millions". Conventional deterministic PM decision techniques cannot clearly solve the fuzzy multi-objective PM programming problems.

This study aims to develop a two-phase fuzzy goal programming (FGP) method for solving the PM decision problems with multiple fuzzy goals in uncertain environment. The original multi-objective linear programming (MOLP) model designed here attempts to simultaneously minimize total project costs, total completion time and total crashing costs with reference to direct costs, indirect and contractual penalty costs, duration of activities and the constraint of available budget. The remainder of this study is organized as follows. Section 2 dedicates to a review of the relevant literature. Section 3 describes the problem, details the assumptions and formulates the fuzzy multi-objective PM decision model. Subsequently, Section 4 develops the FGP method for solving the fuzzy multi-objective PM decision problems. Next, a real industrial case is used to implement the feasibility of applying the proposed method in Section 5. Finally, conclusions are drawn in Section 6.

2. Literature reviews

In practical situations, the goals and model inputs for the PM decisions are normally imprecise/vague owing to relevant information is incomplete and unavailable over the project planning horizon. To deal with imprecision, Lukaszewicz (1965) and Parks and Ramsing (1969) first introduced the techniques of randomness theory to solve PM decision problems for minimizing the expected project duration, in which each activity duration for a PERT type project is defined as a random variable with known probabilistic density function. Later works on stochastic PM decisions included Diaz and Hadipriono (1993), Golenko-Ginzburz and Goink (1997, 1998), Kotiah and Wallace (1973), Rabbani et al. (2007) and Touran and Edward (1992). The critical drawback of applying probability theory to PM decisions are lack of computational efficiency and inflexible probabilistic doctrines which might not be able to model the real imprecise meaning of DM because they can only take the limited form of a given non-linear distribution function, such as normal, Beta, poisson and compound poisson (Chanas & Kamburowsi, 1981; Lai & Hwang, 1992; Lootsma, 1989; Yazenin, 1987).

Fuzzy set theory, was presented by Zadeh (1965), has been found extensive applications in various fields (Klir & Yuan, 1995; Rommelfanger, 1996; Slowinski, 1986; Zimmermann, 1996). Alternatively, fuzzy set theory has also provided an appropriate methodology to deal quantitatively with decision problems that are formulated as mathematical programming models with imprecise parameters. Zimmermann (1976) first introduced fuzzy set theory into an ordinary linear programming (LP) problem with fuzzy goal and constraints. Following the fuzzy decision-making concept of Bellman and Zadeh (1970), it confirmed that an equivalent crisp LP problem exists. Subsequently, fuzzy set theory and Zimmermann's fuzzy programming technique have been developed into several fuzzy optimization methods to solve imprecise PM decision problems and avoiding unrealistic modeling in an uncertain environment.

Chanas and Kamburowsi (1981) presented a fuzzy PERT (FPERT) method that can derive the possibility distribution of the project completion time in the situation when particular activity duration times were given in the form of fuzzy variables on the time space. Mjelde (1986) originated the special structure of fuzzy resource allocation problems and defined a dedicated algorithm for their solution which is based upon a LP formulation in terms of the resource allocation variables and a single additional variable describing the aspiration level of resource consumptions and activity returns. Chang, Tsujimuta, Gen, and Tozawa (1995) adopted the fuzzy Delphi method to estimate a reliable time interval of each activity in the project network analysis and an efficient methodology for calculating the fuzzy project completion time and the degree of criticality for each path in a project was proposed based on these time estimates. Yao and Lin (2000) introduced a signed distance ranking method for fuzzy numbers in a CPM of activity-on-edge (AOE) networks, and used them to obtain fuzzy critical path. Liang (2006) designed an interactive fuzzy linear programming (FLP) approach for solving the single-goal PM decision problems with fuzzy goal and fuzzy constraints. Long and Ohsato (2008) developed a fuzzy critical approach for imprecise project scheduling problems under resource constraints which consisted of developing a desirable deterministic schedule and adding a project buffer to the end of the schedule to deal with uncertainty. Additional investigations in which fuzzy set theory was applied to PM decisions included Buckley (1989), Chanas and Zieliński (2001), Hapke and Slowinski (1996), Hussein and Abo-Sinna (1995), Okada and Soper (2000) and Wang and Fu (1998).

In practical PM decisions, however, the project DM must simultaneously handle multiple conflicting goals that govern the use of the constrained resources within organizations, and these conflicting goals are generally fuzzy in nature and are required to be solved simultaneously by the DM in the framework of imprecise aspiration levels. Conventional solution techniques clearly cannot solve fuzzy multi-objective PM optimization problems. Zimmermann (1978) extended his fuzzy programming technique (1976) to an ordinary MOLP problem. For each of the objective functions of this MOLP problem, the DM is assumed to have a fuzzy goal such as, "the objective functions should be substantially less than or equal to some value." Then, the corresponding linear membership function of each fuzzy objective functions were defined and the minimum operator is applied to aggregate all fuzzy sets to transform this MOLP problem into an equivalent ordinary LP problem. Subsequent studies on FGP included those of Chen and Tsai (2001), Hannan (1981), Kuwano (1996), Leberling (1981), Luhandjula (1982), Sakawa (1988, 1993) and Vasant et al. (2002).

Several studies about the use of FGP methods to solve PM decision problems had been presented. DePorter and Ellis (1990) developed a FGP technique for a multiple imprecise goal optimization problem in a way that compromised among the goals, and was solvable using ordinary LP computer software. Arikan and Gungor (2001) introduced a practical application of FGP technique in a project network problem with two fuzzy goals as minimize project duration and minimize total crashing costs wanted to be optimized simultaneously, and further comparisons between solutions of FGP, FLP and lexicographic maximization method (LMM) were also presented. Wang and Liang (2004) developed a multiple fuzzy goals programming (MFGP) approach to PM decisions that can yield the DM's overall degree of satisfaction with the given goal values. Chen and Huang (2006) proposed a fuzzy programming model by combining fuzzy set theory with PERT to calculate the total cycle time of a supply chain system. That model adopted triangular fuzzy numbers to describe these uncertain variables and the promise delivery possibility index is defined to indicate the order fulfillment degree of a supply chain system based on the fuzzy completion time and fuzzy due date. Wang and Liang (2006) developed an interactive FGP model with piecewise membership functions to solve multi-objective PM decision problems in a fuzzy environment. More recently, Liang (2009) proposed a possibilistic linear programming (PLP) approach attempts to simultaneously minimize total project costs and completion time with reference to direct costs, indirect costs, relevant activities times and costs, and considers constraint on the available budget.