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A fuzzy multi-objective model for solving project network problem with bonus and incremental penalty cost ☆

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ABSTRACT

Project management decisions require considering several conflicting constraints and objectives as well as uncertainties in the information over the planning period. The study aims to design a multi-objective linear programming model for solving project network problem under fuzzy environment. The developed model consists of three objectives such as minimizing total project completion time, minimizing total project completion cost and minimizing the earliest time of an event requiring special attention by taking into account several factors such as crash time, normal time, normal cost, crash cost, indirect cost as well as financial bonus and incremental penalty cost. In the study, a case study based on a real life problem is conducted to illustrate the validity and feasibility of the model. The study contributes to the project network literature by developing the fuzzy goal programming model and allows the project managers simultaneously evaluate financial bonus and incremental penalty cost with respect to total project time. In addition, the results of the sensitivity analysis highlight that the developed model can be used for helping the contractors make effective decisions.

1. Introduction

Project management and associated network decisions have been one of the major issues attracting the interest of academicians and researchers over several decades. Growing customer demand for more complex, customized products and services; exponentially increasing knowledge, requirements for worldwide markets are the main factors that make project management important and critical for organizations' competitiveness in their sector (Meredith & Mantel, 2012). Managing projects efficiently and effectively are being more difficult for the organizations because of limited resources, increasing uniqueness in projects, growing complexity and size of projects as well as uncertainties and changes in the project environments. Traditionally, the main concern of the project management is to complete project on time and on budget. However, today's highly competitive environment forces organizations to cope with various multiple criteria, objectives and goals which are usually conflicting with each other in terms of organizational resources, as well as having the priorities changing across sectors, companies and even periods of project.

The study focuses on developing a fuzzy mathematical model to multi-objective project network problem by considering several conflicting factors such as crash time, normal time, normal cost, crash cost and indirect cost as well as financial reward-bonus and penalty cost. Although in the literature there have been several valuable studies and methods on project network, the motivation for conducting this study comes from the literature review demanding the studies with bonus and penalty cost as well as fuzziness. The study differs from the literature with the fuzzy mathematical model in which financial reward and penalty cost related to total project time are simultaneously evaluated by means of piece-wise linear function.

Briefly, the study aims to introduce a fuzzy multi objective mathematical model from the contractor's perspective, in order to handle the project network problem with bonus and penalty cost issues by taking into account several conventional project factors. The developed model is considered to help project managers make effective decisions on project network problem with time–cost trade-offs. The model can be used to support managerial decisions such as whether the project completion time should be on time, later or earlier from the planned project completion time, how much the project completion cost is, and when the activities should be done in order to obtain the best compromise solutions from the conflicting objectives which the organizations desire to achieve.

The remaining paper is organized as follows: In the second section, a comprehensive literature review is presented. In the third section, the fuzzy multi-objective linear programming (MOLP) model is developed and the solution methodology is explained in

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detail for project network problem. In the fourth section, a real life case study is introduced. The developed model is applied to the problem of a company setting up turn-key cement factories. Additionally, the results obtained from the solution of the problem and the results of the sensitivity analysis are demonstrated in this section. Finally, in the last section, conclusion and future works are presented.

2. Literature review

Project management is one of the complex and inter-related issues that almost all organizations confronted with at least one time (Heizer & Render, 2008). The literature has introduced a huge amount of studies employing different techniques, methods, algorithm, and approaches to overcome the difficulties and challenges on project network decisions. Some studies in the literature have used traditional network based techniques such as projects review and evaluation technique (PERT) and critical path method (CPM) (Gupta, 1991; Kamburowski, 1992; Kuklan, Erdem, Nasri, & Paknejad, 1993) as well as mathematical programming methods for project management (Gavish & Pirkul, 1991; Vanhoucke, Demeulemeester, & Herroelen, 2001; Talbot, 1982). Some studies have introduced heuristic approaches using priority rules for solving project scheduling problem (Davis & Patterson, 1975; Fung, Huang, & Tam, 2013; Kurtulus & Davis, 1982; Li, 1995; Ozdamar, Ulusoy, & Bayyigit, 1998). By indicating computational difficulty in complex and large project management problems, the recent studies on project management literature suggested the usage of meta-heuristic approaches such as simulated annealing, particle swarm optimization, and genetic algorithm for solving the problems (Boctor, 1990; Bouleimen & Lecocq, 2003; Chan, Chua, & Kannan, 1996; Tsai & Gemmill, 1998).

Some studies have contributed the project management literature by giving an extensive literature review on project management problems. For instance, Icmeli, Erenguc, and Zappe (1993) surveyed the fundamental problems in the project management literature since 1973 by involving resource-constrained project scheduling problem, time/cost trade-off problems and payment scheduling problems as well as the integrated problems with each other. Herroelen, Reyck, and Demeulemeester (1998) overviewed the studies working on the resource-constrained scheduling problem. Kolisch and Padman (2001) analyzed the studies with regard to various aspects of project scheduling problems from the components of the problems, to data set available for the algorithms, to decision support approaches and future research directions, etc. Ozdamar and Ulusoy (1995) also surveyed the literature based on the resource-constrained scheduling problem and classified the studies according to objectives and constraints.

While the literature have highlighted the importance of completing projects within the planned period, it has also indicated that projects should not be evaluated based on only single objective such as minimizing total project completion time or total project cost for effective and efficient decision making process (He & Xu, 2008; Herroelen, Dommelen, & Demeulemeester, 1997). The project manager should consider accomplishing both of these objectives – time and cost – at the same time, even the other objectives and goals are changeable to project structure, project periods as well as company's strategy, and mission. The authors have conducted various studies related to multi-criteria and multi-objective problems on project management decisions. For instance, DePorter and Ellis (1990) developed a goal programming model for project network problem with two objectives – minimizing cost and minimizing time – and used fuzzy linear programming approach to solve the problem. Dey, Tabucanon, and Ogunlana (1996) developed a decision support system enabling managers to optimize various conflicting goals of project. Mota, Almeida, and Alencar (2009) proposed a model using multiple criteria decision aid approach for supporting project managers to focus on the main tasks. Rabbani, Fatemi Ghomi, Jolai, and Lahiji (2007) aimed to maximize the total contribution of selected activities while reducing the expected project time and its variance.

In addition to the importance of achieving multiple goals, the literature has also mentioned the difficulties in the real life applications of project management to obtain information over the project planning period. The literature indicated the necessity of evaluating objectives and constraints in terms of operating cost, activity duration, resources, and budget under fuzzy environment. The researchers introduced various multiple conflicting fuzzy goals such as minimizing total cost, total completion time, total crash cost, penalty cost, and budget in the project management decisions (Arikan & Güngör, 2001; Liang, 2009; Wang & Liang, 2004). The authors have proposed different application to fuzzy project management problem with multiple goals. Fu and Wang (1996) addressed the problem by using a fuzzy resource allocation model that can be solved by converting the fuzzy model to crisp LP model with α-cut. Hapke, Jaszkiewicz, and Slowinski (1999) presented two-stage solution application to multi objective multi-mode scheduling problem with fuzziness. Arikan and Güngör (2001) suggested a system employing fuzzy goal programming to a multi-objective project network problem considering minimizing completion time and crashing cost simultaneously. Liang (2006) used fuzzy linear programming (FLP) approach for project management decisions taking into account many conflicting goals. Liang (2009, 2010) provided a systematic approach to the problem and conducted a two-phase goal programming method in the fuzzy environment.

However, the authors on the area indicated that the literature has still been demanding the studies on the project management (PM) and project network topics because of the challenges in application of fuzziness to the problems (Pan & Yeh, 2003). On the other hand, the recent studies also mentioned that the lack of the PM models considering the indirect cost related to the projects such as interest, depreciation, contractual penalty and other overhead costs (Liang, 2009; Long & Ohsato, 2008).

In the literature, there has also been a little study working on the project management problem with bonus and penalty structure. Kramer and Hwang (1991), in an earlier study, analyzed the resource constrained project scheduling problem by developing a linear model in which bonus and penalty ratio was considered for each single activity. He and Xu (2008) studied the multi-mode project payment scheduling problem with bonus and penalty structure existing at the deadline of the project by formulating integer nonlinear programming models. The authors mentioned the necessity of more research on the problem with bonus and penalty structure by indicating the lack of studies with this type of problem. Fernandez (2012) studied project management problem by suggesting a game theoretical approach for sharing reward and penalty in a project. Apart from the studies, the paper formulates a linear programming model for project network problem requiring evaluation of a trade-off between bonus and penalty cost with respect to total project completion time.

So, this paper contributes to the literature by introducing a multi-objective linear programming model under fuzzy environment to handle the project network problem with bonus and penalty cost issue from the contractor's perspective. The model consists of multiple conflicting objectives, such as minimizing project completion time, minimizing total project cost and minimizing earliest time of an event having critical importance for the starting of the processor activities and/or completing predecessor activities, under a set of constraints related with normal time of the activities, crash time of the activities, completion time of the project, bonus and penalty cost, etc.