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Rough approximation based strategy model between a green building developer and a contractor under a fuzzy environment

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ABSTRACT

This paper considers a bi-level multi-objective benefit trade-off problem between a green building developer and a contractor under a fuzzy environment. The objective functions and constraints are established on the characteristics and mechanism of the problem. In contrast to previous studies, a similarity relation based on the fuzzy measure *Pos* is defined, based on which, the rough approximation method is adopted for addressing the feasible region featured by the constraints that contain fuzzy coefficients. In order to deal with the fuzzy coefficients in the objective functions, an expected value operator based on *Me* is employed. Then two rough approximation-based bi-level multi-objective strategy models are developed. To solve the complex and non-linear bi-level multi-objective models, a rough simulation, an interactive fuzzy programming technique and a hybrid genetic algorithm, in which the F-TODIM is embedded, is designed as a combined solution method. Finally, an application for a developer of Yuexiu real estate and its contractor is given as an illustration that demonstrates the practicality and efficiency of the optimization method.

1. Introduction

Since sustainable development was promoted and published in the Brundtland Commission Report in 1987, various sectors of society have been implementing its principles. The construction industry, and especially building construction, has been accused of causing environmental problems by the excessive consumption of global resources and the pollution of the surrounding environments. Construction and real estate are considered two of the major sectors which contribute to a mission of sustainable development which means that major players in this sector need to promote green building development techniques. Green building, also known as green construction or sustainable building, refers to the quality and characteristics of the actual created using the principles and methodologies of sustainable construction, which was defined by the Conseil International du Batiment (CIB) in 1994 as "... creating and operating a healthy built environment based on resource efficiency and ecological design" [14]. From the increasing demand for resources and awareness of environment protection, green building will be a theme trend in world-wide development.

In recent years, many studies have focus on green building. These researches can be mainly classified into two categories. The first one is studies supporting green building design. Most of the scholars are focus on this field. In this category, some researches introduce the green building design approach from the qualitative point of view, such as Kibert [14], whose work guides construction and design professionals through the process of developing commercial and institutional high-performance green buildings in today's marketplace. Other researchers study from the quantitative point of view, like Sailor [23] and Pan et al. [18]. Both of them use the simulation tool to study the green roof and the energy consuming, respectively. For Wang et al. [33], Yang and Wang [42] and Magnier and Haghighat [16], they all use multi-objective programming to handle several conflicting criteria when finding design alternatives. The conflicting criteria they deal with are economical and environmental performance, energy and comfort, and thermal comfort and energy consumption, respectively. The second category is focus on green building assessment tools and rating systems [25,7,1,21]. Besides, there are a few scholars studied some features of green building [32,19] and the behaviors of person related to green building, such as the end-user [5] and the practitioners [13]. Currently, green building techniques have not been widely used yet, especially in developing countries. And there is only a few real-estate developers invest in green buildings for just a few years. They are still unpracticed. Green building contractors, who are responsible for the design and

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construct, also lack of experiences. Meanwhile, it requires close cooperation of the contractor (its design team, architects and engineers) and the developer to develop a green building. So, effective management of the relationship between them and cooperation mechanism become an important issue. In particular, the benefit trade-off problem between them needs to be researched. To our knowledge, however, there have been few scholars whose studies have involved the problem. To study it, in this paper, a bi-level multi-objective model is adopted.

Bi-level modelling has been researched by many scholars. It has been widely used in many decision making problems in hierarchical organizations, such as [43,34,22,28]. The problem considered in this paper can be regarded as being in a hierarchical organization as developers make the first decision and the decisions they make mutually influence their objective. Thus, the problem can be formulated as a bi-level multi-objective model. However, in a construction project, obtaining the precise cost and duration is always difficult and further, the assessment of green buildings is difficult to exactly express. The problem, therefore can be seen to be in a fuzzy environment. In the past few decades, a large number of fuzzy optimization methods have been developed for dealing with many kinds of problems, such as [27,29]. The most common way to dealing with the fuzzy parameter is the expected value. But there are many ways to define the expected value in fuzzy theory. There are definitions based on the fuzzy measures *Pos* and *Nec*, which are introduced by Dubois and Prade [8], and with an extremely optimistic and pessimistic attitudes, respectively. Yet in the real world decision making problems, the attitudes of different DMs are different and may fluctuate between these two extremes. *Me* is more appropriate to represent the attitudes of DMs, so, an expected value operator based on *Me* [40] is adopted to handle these objectives thus optimizing the expected value of the objective function. As for the fuzzy parameters in constraints, the simple expected operator may lose many information about the feasible region even a optimal solution. Rough set theory, which was introduced by Pawlak [20] gives us an other direction to handle this problem. Rough approximation method has been applied to some models successfully [31,26]. In this paper, it is adopted to handle the constraints featured by fuzzy parameter to make relatively a expanding and a shrinking feasible region.

As the models here are bi-level and multi-objective, they are difficult to solve. Some solution approaches have been proposed for bi-level programming problems. The *k*th best method [4], the Kuhn–Tucker approach [4,2,3,11], and the penalty function approach [36] can only effectively solve very simple problems. Large-scale or complex problems cannot be solved optimally in a reasonable amount of time when the structure of the bi-level problem is considered, nor do they perform consistently well [37]. Interactive fuzzy programming was first proposed by Werners [35]. Sakawa then extended the principle to many different kinds of situations [24]. This method is a useful way to balance the objectives between the DMs on different levels. There is also another class of methods based on meta-heuristics but these methods need to be designed according to the problem [39]. From the characteristics of the problem considered in this paper, an interactive fuzzy programming combined with genetic algorithm is adopted.

Above all, the aim of this paper is to develop a bi-level multi-objective model to buffer the conflicts and balance the benefits between a developer and a contractor under a fuzzy environment, which can be summarized as a benefit trade-off problem. The expected value based on *Me* is adopted to handle the objective functions to fit the different attitudes of DMs in a realistic decision making process. Also, the rough approximation method is employed to addressing the feasible region featured by the constraints that contain fuzzy coefficients. Through this, two models with optimal expected values for the objective functions and a rough approximation feasible region are proposed: the lower approximation model (LAM) and the upper approximation model (UAM). After the models, a rough simulation, an interactive fuzzy programming combined with hybrid genetic algorithm is designed, in which the F-TODIM is embedded. Also, an application for a green building developer from Yuexiu real estate and a contractor from the Urban Construction Group is given as an illustration to demonstrate the practicality and efficiency of the optimization method.

The rest of this paper is organized as follows. In Section 2, the key problem between the developer and the contractor is described and the uncertain environment is defined. In Section 3, the modelling is given and a similarity relationship based on the *Pos* measure is defined. Based on this relationship, two rough approximation models with expected value objectives are obtained. Section 4 is devoted to the solution of the models and a rough simulation, an interactive fuzzy programming combined with a hybrid genetic algorithm is designed. Section 5 presents an application of the method to a developer of Yuexiu real estate and its contractor, the Urban Construction Group. Section 6 gives the conclusion.

2. Key problem statement

The problem considered in this paper is a decision making problem between a green building developer and its contractor. In this problem, the green building developer from Yuexiu real estate company intend to develop a green building project, and cooperate with its contractor the Urban Construction Group. They need the contractor to be responsible for the design and construct of the green building. Tan's research [30] showed that developing green building can make a greater contribution to future business competitiveness over the long-term. That is one of the reasons why Yuexiu real estate wants to invest in green building. But Zhang's study [44] concluded that the higher costs has hindered the extensive application of green technologies in China, which indicate that using green techniques need higher costs. So, when the contractor design the green building, the developer wants a scenario costing less but with a relatively high green assessment score. Meanwhile, the duration of the scenario also need to be short. To encourage the contractor to design a satisfactory scenario, the developer may give the contractor some rewards. The developer set the boundary value of the cost (C_g), the duration (T_g) and the assessment score (f_g). If the cost c of the scenario is less than C_g, the reward the developer give the contractor is $\alpha_c(C_g - c)$. As to assessment score (f) and duration (t), the rewards are $\alpha_s(f - f_g)$ and $\beta(T_g - t)$. The developer need to decide the appropriate incentive intensities (i.e. α_s, α_c and β) to achieve the goal of minimal total cost. To come up with a scenario with which the developer is satisfied, the contractor put forward several scenarios, and need to select appropriate ones to implement which can make the maximal income. Meanwhile, reducing duration can make more reward and bring income from other project (using the reduced duration to other project). But reducing duration also need extra cost. So, the contractor also need to decide an crash time.

2.1. Bi-level decision making problem

To solve the problem described above, a bi-level model can be developed.

Considering the relationship between the green building developer and the contractor, there are some facts need to be take into account. On the one hand, there are several contractors from which the developer can be choose, generally. On the other hand, as the contractor will find a scenario with which the developer satisfied, the developer is the 'client' of the contractor from the point view of