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Multicriteria decision-making based on goal programming and fuzzy analytic hierarchy process: An application to capital budgeting problem

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ABSTRACT

Our objective in this paper is to develop a decision-making model to assist decision-makers and researchers in understanding the effect of multiple criteria decision-making on a capital budgeting investment. This decision-making model helps decision-makers with reducing decision-making time and choosing a suitable decision alternative for a capital budgeting investment within the companies' goals, constraints and strategies. The methods utilized in this paper are goal programming (GP) and fuzzy analytic hierarchy process (FAHP). We demonstrate a case study of the capital budgeting investment by using these two methods in a small car rental company.

1. Introduction

Capital budgeting decision-making is one of the most demanding responsibilities of top management [21,12]. An increasing number of companies have struggled to justify strategic technology investments using traditional capital budgeting systems [2]. The existing accounting-based decision-making models (such as discounted cash flow (DCF)) are said to be no longer adequate to help evaluate investments in technological innovation, mainly because of the strategic, intangible nature of the benefits involved [13,22].

When business decisions are made, they involve not only consideration of information which is quantifiable in numerical terms (e.g. financial information), but also consideration of subjective (e.g. non-financial information) opinions [27,2,1]. Such subjective considerations are naturally expressed in linguistic rather than in numerical terms [14]. Therefore, we realized that non-financial information needs to be quantified in order to integrate it with numerical information.

This research will focus on how to integrate financial and non-financial information in the company's constraints, goals and strategies. The methodologies presented within this research are goal programming (GP) and fuzzy analytic hierarchy process (FAHP) which address the problem of capital budgeting in uncertain environments.

Capital budgeting is primarily concerned with sizable investments in long-term assets. Investment decisions deal with the funds raised in financial markets which are employed in productive activities to achieve the firm's overall goal, in other words, how much should be invested and what assets should be invested are the main objectives. Therefore within this research it is assumed that the objective of the investment or capital budgeting decision is to achieve the company's goals and to stay within its constraints.

GP normally deals with conflicting objective measures. Each of these measures is given a goal or target value to be achieved. FAHP provides a relatively more complete description of decision-making process involving the subjective and imprecise judgments of decision makers [4]; [17]; [11].

The methods are divided into two steps. Firstly, financial and other objectives along with a company's goals, constraints and strategies are formulated as important selection criteria. A set of decision alternatives (DAs) as preliminary outcomes will be sifted by using GP from financial information. Secondly, subjective opinions elicited from decision-makers (DMs) are transformed into fuzzy comparison matrices (for the details of FAHP also refer to Chang [8], Tang [23]). A simple practical preference ranking method (synthetic extent method) is investigated to rank alternatives in a multiplicative aggregation process.

The extent analysis method has been employed in quite a number of applications, such as capital measurement [5], budget allocation [23], assets selections and investment [6,7,24] and for more detail refer to Wang et al. [26]. However, disadvantages have also

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been pointed out, such as an inability to derive the true weights from a fuzzy or crisp comparison matrix [26]. This research will utilize the formulation of a degree of possibility for comparing two triangular fuzzy numbers as proposed in Zhu et al. [30].

One aspect of the FAHP method within this research is the prevalence of and allowance for incompleteness in the judgements made by DMs. For example, if a DM is not willing or is unable to specify the preference judgements, s/he is able to omit a judgement in the form of a pairwise comparison between two DAs. The rest of the paper is organized as follows. Section 2 describes the details of the used cars selection problem. Section 3 proposes GP procedures and the synthetic extent method of the FAHP. Section 4 illustrates the results of the used cars selection problem. The conclusion is provided in Section 5.

2. Identification of the used cars selection problem

The case study concerns a small car hiring company and their choice of type of fleet cars to be adopted. This choice is an important investment decision, with a large proportion of their budgets being tied up in their final choice. In order to find out which are the most important criteria used by the DMs, two interview phases are implemented, semi-structured and structured interviews.

The semi-structured interview within this research was designed to identify all the relevant issues affecting the decision-making (e.g. the company's goals, constraints and objectives, etc.). It was difficult to discover all these issues in the beginning until the DMs were reassured. In this phase, the semi-structured interview shows that there are two constraints (i.e., five cars can be chosen each time and the total size of engines are limited to under 8000cc); two goals (i.e., to minimize the cost of suitable cars and to minimize the cars' age and mileage); four pieces of objective information (i.e., size of engine, price, car age and mileage). There are six subjective criteria identified by this company's DMs, i.e., "Equipment, Comfort, Car Parts and Components, Customer Demand, Safety, and Image", denoted as $C_1, C_2, \ldots, C_6$, respectively. Apart from those constraints, goals and criteria, the semi-structured interviews also identified ten type of most commonly used cars, denoted herein $A'_1, A'_2, \ldots,$ and A'_{10}, respectively (see Appendix A). They are the initial DAs in this case study.

After we identified their constraints, goals and objectives, we utilized the GP methodology to obtain the DAs. With respect to the AHP's pairwise comparison method, we still needed to explain a lot to the DMs as it is difficult for people to understand the judgment matrices in the first time. Therefore, in the second phase of interviews, the DMs were asked to indicate their preferences between pairs of criteria, and then between pairs of DAs over the different criteria. In this phase, a DM can leave a judgement out without giving any judgement on the fuzzy comparison matrix. The results from the second phase of interview are shown in Tables 1 and 2.

Table 1
Pairwise comparisons between criteria based on the DM's opinions.

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1	3	1/9	–	–	3
C_2	1/3	1	1/3	1/9	1/9	–
C_3	9	3	1	1/9	1/9	–
C_4	–	9	9	1	1/9	1
C_5	–	9	9	1	1	7
C_6	1/3	–	–	9	1/7	1

Table 2
a to *f*: Comparisons between DAs over the different criteria.

(a) C_1	A_1	A_2	A_3	A_4	A_5	(b) C_2	A_1	A_2	A_3	A_4	A_5
A_1	1	–	–	–	5	A_1	1	1/8	1/8	1/7	–
A_2	–	1	7	1/3	5	A_2	8	1	–	–	5
A_3	–	1/7	1	1/5	5	A_3	8	–	1	1/8	5
A_4	–	3	5	1	5	A_4	7	–	8	1	5
A_5	1/5	1/5	1/5	1/5	1	A_5	–	1/5	1/5	1/5	1
(c) C_3	A_1	A_2	A_3	A_4	A_5	(d) C_4	A_1	A_2	A_3	A_4	A_5
A_1	1	7	1/3	–	1/5	A_1	1	1/3	3	1/5	–
A_2	1/7	1	5	–	–	A_2	3	1	–	1/5	5
A_3	3	1/5	1	5	5	A_3	1/3	–	1	1/5	–
A_4	–	–	1/5	1	–	A_4	5	5	5	1	5
A_5	5	–	1/5	–	1	A_5	–	1/5	–	1/5	1
(e) C_5	A_1	A_2	A_3	A_4	A_5	(f) C_6	A_1	A_2	A_3	A_4	A_5
A_1	1	1/8	–	1/7	–	A_1	1	1/7	1/5	1/9	–
A_2	8	1	–	1	3	A_2	7	1	7	–	1/6
A_3	–	–	1	1/8	3	A_3	5	1/7	1	1/8	6
A_4	7	1	8	1	3	A_4	9	–	8	1	6
A_5	–	1/3	1/3	1/3	1	A_5	–	6	1/6	1/6	1

3. Proposition of GP procedures and the synthetic extent method of the FAHP

3.1. First step: introduction of the procedure of GP

GP is an important technique for allowing DMs to consider several objectives in finding a set of acceptable solutions. It has been accomplished with various methods such as Lexicographic (Preemptive), Weight (Archimedean), and MINIMAX (Chebyshev) achievement functions [18]. It can also be said that GP has been, and still is, the most widely used technique for solving multi-criteria decision-making problems. The purpose of GP is to minimize the deviation between the achievement of goals, $f_i(Y)$, and their acceptable aspiration levels, g_i. A mathematical expression for the standard version of GP is given below.

(GP) method

$$\text{Minimize} \quad \sum_{i=1}^{n} |f_i(Y) - g_i|,$$
$$\text{subject to} \quad Y \in F, \quad (F \text{ is a feasible set});$$

where $f_i(Y)$ is the linear function of the ith goal, Y is a $1 \times N$ vector of decision variables and g_i is the aspiration level of the ith goal.

The oldest and still most widely used form of achievement function for GP is represented as follows.

(GP-achievement)

$$\text{Minimize} \quad \sum_{i=1}^{n} d_i^+ + d_i^-,$$
$$\text{subject to} \quad f_i(Y) - d_i^+ + d_i^- = g_i, \quad \text{for } i = 1, 2, \ldots, n,$$
$$Y \in F, \quad (F \text{ is a feasible set});$$

where d_i ($i = 1, 2, \ldots, n$) are additional continuous variables.

3.2. Second step: construction of the FAHP comparison matrices

The aim of any FAHP method is to elucidate an order of preference on a number of DAs, i.e., a prioritised ranking of DAs. Central to this method is a series of pairwise comparisons, indicating the relative preferences between pairs of DAs in the same hierarchy. It is difficult to map qualitative preferences to point estimates, hence a degree of uncertainty will be associated with some or all pairwise comparison values in an FAHP problem [28]. By using triangular fuzzy numbers (TFNs), via the pairwise comparisons made, the fuzzy comparison matrix $X = (x_{ij})_{n \times m}$ is constructed.

The pairwise comparisons are described by values taken from a pre-defined set of ratio scale values as described in Saaty [19]. The ratio comparison between the relative preference of elements