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Project Selection Using Fuzzy Group Analytic Network Process

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***Abstract*—**This paper deals with the project selection problem. Project selection problem is one of the problems arose firstly in the field of operations research following some production concepts from primary product mix problem. Afterward, introduction of managerial considerations into the project selection problem have emerged qualitative factors and criteria to be regarded as well as quantitative ones. To overcome both kinds of criteria, an analytic network process is developed in this paper enhanced with fuzzy sets theory to tackle the vagueness of experts' comments to evaluate the alternatives. Additionally, a modified version of Least-Square method through a non-linear programming model is augmented to the developed group decision making structure in order to elicit the final weights from comparison matrices. Finally, a case study is considered by which developed structure in this paper is validated. Moreover, a sensitivity analysis is performed to validate the response of the model with respect to the condition alteration.

***Keywords*—**Analytic network process, Fuzzy sets theory, Non-linear programming, Project selection.

I. Introduction

SINCE a considerable problem is scarce resources, it is emerged to evaluate and select best projects to be executed in an organization. The project evaluation and selection problem is a multi-criteria decision-making problem, as many conflicting objectives can be regarded simultaneously [1]. This problem was firstly introduced in [2] as a new category of problem involving selection of a portfolio of projects in order to achieve specific target(s).

II. Literature Review

Project selection problem has attracted great endeavor by practitioners and academicians in recent years. One of the major fields has been applied to this problem is mathematical programming, especially Mix-Integer Programming (MIP), since the problem comprise selection of projects while other aspects are considered using real-value variables [3]. For instance, an MIP model is developed by [4] to conquer R&D portfolio selection. Other applications of MIP with single objective toward project selection can be found in [5]-[9].

Moreover, since different conflicting criteria and objective functions are involved in selection of projects, multi-criteria decision making methods have been vastly employed to cope with the problem. To do so, major contribution have been introduced using zero-one goal programming in the field of information systems [6], [10]; university resource allocation [11]-[13]; and industrial application [14]. In addition to goal programming, multi-objective programming using pareto sense optimality developed in project selection. Reference [15] developed a multi-objective model for a previously proposed goal programming model. In another case, Reference [16] introduced a bi-objective program constituting of patient satisfaction and net present value maximization. Some other instances of multi-objective programming toward project selection can be found in [17]-[20].

Another approach have been utilized is multi-attribute decision making in which criteria are mostly defined in qualitative scale and the decision is made with respect to assigned weights using some methods, such as PROMETHEE [21], [22]. To have more comprehensive study on multi-attribute decision making methods in this field, readers are referred to [23]-[28].

With regard to real-world decision making context, stochastic and fuzzy characteristics of parameters and variables are inevitable parts of project selection body. Considering the fact, several researches augmented chance-constrained as well as fuzzy mathematical programming toward project selection to make decisions more realistically, amongst fuzzy and/ or stochastic models have been proposed so far, some are notable [1], [29]-[39].

Prior project selection techniques proposed are useful, but have restricted applications, because they consider only one criterion or some independently. Another flaw of the proposed methodologies is lack of an algorithm to consider interdependent nature of the decisions to be made in the field of project selection, while project selection problems have interdependence property which can be described in different terms. Major types of dependencies existing in project selection can be categorized into three; (1) resource interdependencies, (2) benefit interdependencies, and (3) technical interdependencies.

- Resource interdependencies arise because of shared hardware and software resources among various projects such that the implementation of two or more related projects will require less resources than if they were implemented separately.

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- Benefit interdependencies occur when the total benefits to the organization derived from implementing two related projects increase due to their synergistic effect.
- Finally, when execution of a project necessitates the development of a related project, it creates a technical interdependence.

Among criteria defined to make decision about projects, are cardinal and ordinal ones that necessitate application of a methodology being able to deal with both quantitative and qualitative criteria. Furthermore, interdependent nature of the problem as described leads to adoption of a methodology such that the dependencies can be modeled. Hence, Fuzzy Analytic Network Process (FANP) is adopted to handle the above characteristics of the regarded problem [40], [41]. Moreover, the well-known FANP structure is enhanced with a modified version of Least-Square Method (LSM) which originally is proposed by [42] for crisp comparison matrices. The developed model is suited to tackle the decision making process with multiple decision makers. The remainder of the paper is structured as follows; Section 3 elaborates the proposed model, whereas a real case study is reported in Section 4 including a sensitivity analysis validating robustness of the proposed model. Finally, some concluding remarks are presented in Section 5.

III. Proposed Model

As many diverse quantitative and qualitative decision criteria are involved in project selection problem, a multi-criteria decision making process method is emerged. Moreover, dependencies and interrelations among factors guide us to select the analytic network process to cope with the nature of the problem. ANP was introduced firstly by Thomas L. Saaty [40] as a general form of the well-known Analytic Hierarchy Process (AHP) [43]. In the ANP, the hierarchical structure of AHP is replaced with a network structure whose dependency relations determine required comparisons. Weights obtained from these comparisons pass to a supermatrix process which yields overall weights of alternatives. Additionally, as the decision making process of project selection includes qualitative factors on which experts' comments are expressed; fuzzy sets theory is adopted to tackle the associated vagueness. To elicit the final weights from comparison matrices as consistently as possible, a non-linear mathematical model is augmented to the proposed ANP structure. The steps of the proposed project selection process are described through the following sub-sections.

A. Factors definition

As every decision made in any field of research and practice requires some factors to be defined upon which evaluation of alternatives can be performed and the best decision can be made, factors involved in project selection procedure should be defined clearly. Different social, economic and financial factors can be considered with respect to different aspects of projects in society, industry and services.

B. Network formation

Factors defined in the previous step are classified into clusters with respect to what effect they have on the final decision and from which source they are originated. Clustering the factors leads to a network based upon which the ANP model is implemented. In addition to the clustering, dependencies among factors are respected and therefore, clusters' interrelationships are drawn based upon the relationships of factors.

C. Pair-wise comparison of clusters and factors

As the network is formed, two kinds of comparison are performed during this step. In each kind, comparisons are performed pair-wisely for the clusters or factors which are dependent to one cluster or factor. The considered fuzzy nature is involved herein because of human judgments in alternatives' comparisons. Elements of comparison matrices reveal decision maker's judgments about his/her preferences on every pair of alternatives using comparison scale in Table I. Final weights are elicited through the next step from comparison matrices.

TABLE I
FUZZY COMPARISON SCALE

Linguistic scale	Triangular fuzzy scale
Just equal	(1,1,1)
Equally important	(1,2,4)
Weakly more important	(2,4,6)
Strongly more important	(3,5,7)
Very strongly more important	(4,6,8)
Absolutely more important	(5,7,9)

D. Eliciting weights from comparison matrices

To elicit the weights of factors or clusters compared in a non-fuzzy comparison matrix, there are different methods have been developed [44] some of which are applied in the fuzzy comparison context. In this paper, a modified model inspired by the crisp model proposed by [42] is developed which is able to cope with the fuzzy comparison matrices as well as group decision making process. Equations (1)-(7) present the developed model. In this model w_i are the relative weights of factors i following symmetric fuzzy triangular membership function, then developed model minimizes the distance of each fuzzy comparison element's core from the corresponding fuzzy relative weight. Also, l_{ij} and u_{ij} present lower and upper bound of fuzzy comparison elements aggregated from l_{ijk} and u_{ijk} which indicate associated lower and upper bounds of fuzzy elements by the k^{th} decision maker.

$$Min \sum_{i,j} \left(\frac{w_i}{w_j} - \frac{u_{ij} + l_{ij}}{2}\right)^2 \tag{1}$$

$$-w_i + l_{ij} w_j \le 0 \qquad i\ j \in \{1,2,3,\cdots,n\} \tag{2}$$

$$w_i - u_{ij} w_j \le 0 \qquad i,j \in \{1,2,3,\cdots,n\} \tag{3}$$

$$u_{ijk} \ge u_{ij} \qquad i,j \in \{1,2,\cdots n\}, k \in \{1,2,\cdots K\} \tag{4}$$

$$l_{ijk} \le l_{ij} \qquad i,j \in \{1,2,\cdots n\}, k \in \{1,2,\cdots K\} \tag{5}$$

$$w_1 + w_2 + \ldots + w_n = 1 \tag{6}$$

$$w_i \geq 0 \qquad i \in \{1,2,\cdots n\} \tag{7}$$

It must be noted that (4)-(5) declare the aggregation operator used in the proposed model. In this paper, standard fuzzy intersection operator is applied upon which the following is resulted. a_{ij} is the aggregated judgment obtained from individual a_{ijk} .

$$\tilde{a}_{ij} = \min_k \{\tilde{a}_{ijk}\} \qquad i, j \in \{1,2,\cdots n\}, k \in \{1,2,\cdots K\} \tag{8}$$

Moreover, it is shown by Chu et al. [42] that the original model (above mentioned model without (4) and (5)) yields multiple optimal solutions. Hence, they revised their model by rewriting the objective function by (9).

$$Min \sum_{i,j} (w_i - \frac{u_{ij} + l_{ij}}{2} \cdot w_j)^2 \tag{9}$$

E. Forming unweighted, weighted and limiting supermatrices

Weights of factors are elicited from comparison matrices using (1)-(7). Unweighted supermatrix is formed by blocks each of which is a matrix with elicited weights as the columns. Having the unweighted supermatrix formed, weighted supermatrix is resulted by means of multiplying the unweighted supermatrix by the elements of cluster comparison matrix. When the weighted supermatrix is calculated, this supermatrix is powered until its row values converge. The resulted supermatrix is the limiting supermatrix.

F. Project selection decision

The best alternative in the proposed ANP structure of project selection problem is the alternative with the highest value in its row of the limiting supermatrix. The alternative with the highest weight is the project with the highest utility to the decision maker(s).

IV. Experimental Results

In this section, a real case study is briefly considered to demonstrate how the proposed structure works. Thereafter, a sensitivity analysis is performed by a change in an alternative's data to validate the model.

A. Case study

An enterprise intended to construct a new head-quarter office in another building rather than their existing one. Four cases (alternatives) are introduced to the board of the company as the alternatives. The decision making group, board of the company defined 6 criteria with respect to each project (price, *C1*; quality, *C2*; finish time, *C3*; contractor's rank, *C4*; contractor's antecedents, *C5* and contractor's economic status, *C6*) to choose the best alternative among the four proposed ones. In the next step, criteria are grouped into two clusters; contractor's status (including *C1*, *C2* & *C3*), and performance (including *C4*, *C5* & *C6*). The dependencies between criteria are as follows:

- Price, quality and finish time are dependent to economic status;
- quality and finish time are directly affected by contractor's antecedents;
- contractor's rank influence on price, quality, finish time and economic status;
- economic status depends on price as contractor's rank and economic status are dependent to quality.

Moreover, it must be noted that all alternatives are influenced by the above six defined criteria. With respect to the relations, network of the problem is formed as shown in Fig. 1. The solid arrows represents the dependencies between clusters resulted from criteria dependencies within the clusters, as the criteria dependencies are not shown to simplify the network.

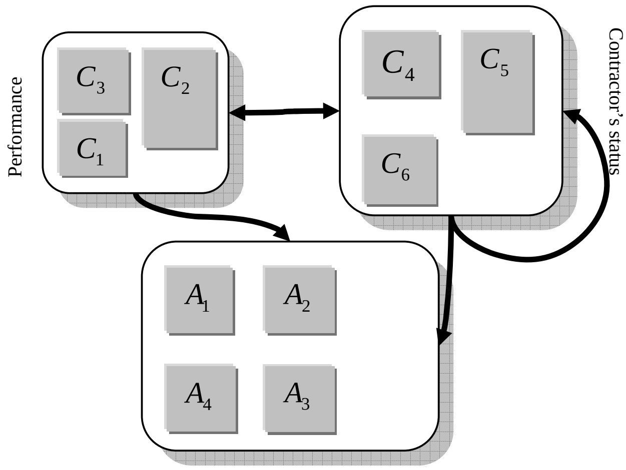

Fig. 1 Network of the office construction decision

The proposed model is applied using data in Table II, final weights are obtained from the corresponding limiting supermatrix. The resulted weights are presented in Table III.

B. Sensitivity analysis

In this sub-section, validity of model's response to parameters and conditions in which the model is run is evaluated. On the other hand, the company is to finish construction of the second building as soon as possible, while quality and price are so important to the company. Based upon, managers of the company decided to cooperate with alternative 2 by helping alternative 2 be able to take out low-interest-rate loan to finish the building sooner. The alternative 2 contractor is interested in figuring out at which level of finish time will be selected. To do so, it is firstly supposed that the finish time of alternative 2 reduces to three months. Since the reduction is drastic relative to the other alternatives' finish times, it is expected that final score of alternative 2 rises.

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Having the change applied, the resulted alternatives' weights are as ones in Table IV.

TABLE II
DATA OF ALTERNATIVES

Alternatives	Price ($\times 10^3$ units)	Quality (in a 1-9 scale)	Finish time (month)	Contractor's rank (in a 1-4 scale)	Contractor's antecedents (years)	Economic status (in 1-9 scale)
A_1	556	5	9	1	12	5
A_2	542	6	10	3	6	3
A_3	550	5	10	2	5	4
A_4	548	4	9	3	8	4

TABLE III
FINAL WEIGHTS OF ALTERNATIVES

Alternatives	Final weights
A_1	0.1314
A_2	0.1110
A_3	0.1165
A_4	0.1259

TABLE IV
NEW FINAL WEIGHTS OF ALTERNATIVES
REGARDING CHANGED FINISH TIME

Alternatives	Final weights
A_1	0.0992
A_2	0.2043
A_3	0.0875
A_4	0.0937

As it can be seen, the resulted weights were expectable due to the considerable reduction of the second alternative's finish time. Moreover, it is evaluated how finish time of the second alternative influence the final decision. To do so, a sensitivity analysis is performed as shown in Fig. 2. As it can be seen from Fig. 2, alternative 2 can win the tender with reducing their finish time to approximately less than 8 months. Another remarking conclusion of the Fig. 2 is that the relative ranking of other three alternatives is unchanged, as their scores of each criterion are consistent during the run.

V. Conclusion

In this paper, project selection problem was addressed using fuzzy group analytic network process. This methodology was chosen, because it can deal with both qualitative and quantitative criteria which are judged upon human comparisons involving vagueness and ambiguity. Moreover, a modified least-square method is developed to tackle the involved decision making process with multiple decision makers. Finally, a real case study is briefly reported and a sensitivity analysis is performed to validate the proposed decision structure.

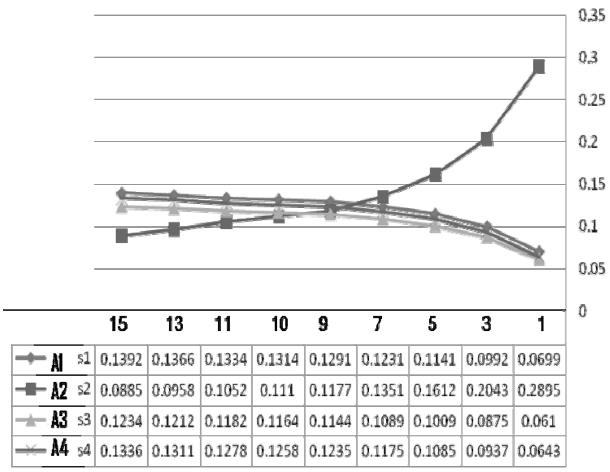

Fig. 2 Alternatives' final weights versus the second alternative's finish time

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