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Research Article

Selecting the Best Project Using the Fuzzy ELECTRE Method

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Selecting projects is often a difficult task. It is complicated because there is usually more than one dimension for measuring the impact of each project, especially when there is more than one decision maker. This paper is aimed to present the fuzzy ELECTRE approach for prioritizing the most effective projects to improve decision making. To begin with, the ELECTRE is one of most extensively used methods to solve multicriteria decision making (MCDM) problems. The ELECTRE evaluation method is widely recognized for high-performance policy analysis involving both qualitative and quantitative criteria. In this paper, we consider a real application of project selection using the opinion of experts to be applied into a model by one of the group decision makers, called the fuzzy ELECTRE method. A numerical example for project selection is given to clarify the main developed result in this paper.

1. Introduction

Selecting the best project in any field is a problem that like many other decision problems is complicated because such projects usually tend to have more than one aspect in terms of measurement, and therefore, involve more than one decision maker. Project selection and project evaluation involve decisions that are critical to the profitability, growth, and the survival of the establishments in an increasingly competitive global scenario. Also, such decisions are often complex because they require identification, consideration, and analysis of many tangible and intangible factors [1].

There are various methods regarding project selection in different fields. The project selection problem has attracted considerable endeavor by practitioners and academicians in recent years. One of the major fields, were such selection has been applied, is mathematical programming, especially mix-integer programming (MIP), since the problem comprises selection of projects while other aspects are considered using real-value variables [2]. For instance, an MIP has been developed by Beaujon et al. [3] to deal with Research and Development (R&D) portfolio selection.

MCDM format is a modeling and methodological tool for dealing with complex engineering problems [4, 5]. The degree of uncertainty, the number of decision makers, and the nature of the criteria will still have to be carefully considered to solve this problem. In addition to MCDM methods, the ratings and the weights of the selection criteria need to be known precisely and thus are necessary for dealing with the imprecise or vague nature of linguistic assessment [6, 7].

Many mathematical programming models have been developed to address project-selection problems. However, in recent years, MCDM methods have gained considerable acceptance for judging different proposals. The objective of Mohanty's [8] study was to integrate the multidimensional issues in an MCDM framework that may help decision makers to develop insights and make decisions accordingly. They computed the weight of each criterion and, then, assessed the projects by computing TOPSIS algorithm [9]. An application of the fuzzy ANP along with the fuzzy cost analysis in selecting R&D projects has been presented by Mohanty et al. [10] in their work, they used triangular fuzzy numbers for two prefer one criterion over another using a pairwise comparison with the fuzzy set theory. In a separate study, by Alidi [11], project selection problem was presented using a methodology based on the AHP for quantitative and qualitative aspects of that problem. According to him, industrial investment companies should concentrate their efforts on the development of prefeasibility studies for a specific number of industrial projects, which have a high likelihood of realization [11].

The ELECTRE method for choosing the best action(s) from a given set of actions was introduced in 1965, and later referred to as ELECTRE I. The acronym ELECTRE stands for elimination et choix traduisant la realite' or (elimination and choice expressing the Reality), initially cited for commercial reasons [12]. In Time approach has evolved into a number of variants; today, the commonly applied versions are known as ELECTRE II [13] and ELECTRE III [14]. ELECTRE is a popular approach in MCDM, and has been widely used in the literature [15–19].

This paper is divided into five main sections. The next section provides materials and methods, mainly the fuzzy sets and the ELECTRE method. The fuzzy ELECTRE method is introduced in Section 3. How the proposed model is used in a real example is explained in Section 4. Finally, the conclusions are provided in the final section.

2. Materials and Methods

2.1. FST

Zadeh [20] introduced the fuzzy set theory (FST) to deal with the uncertainty due to imprecision and vagueness. A major contribution of this theory is its capability of representing vague data; it also allows mathematical operators and programming to be applied to the fuzzy domain. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function, which assigns to each object a grade of membership ranging between zero and one [21].

A tilde "~" will be placed above a symbol if the symbol represents a fuzzy set (FS). A triangular fuzzy number (TFN) $\widetilde{M}$ is shown in Figure 1. A TFN is denoted simply as

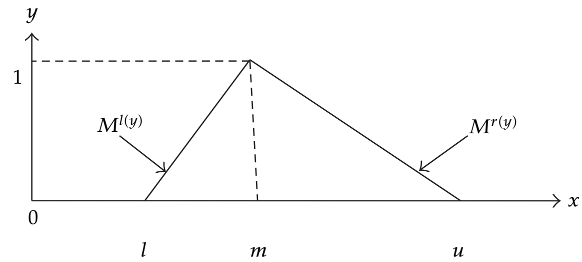

Figure 1: A TFN $\widetilde{M}$.

$(l/m, m/u)$ or (l, m, u). The parameters l, m, and u $(l \leq m \leq u)$, respectively, denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event. The membership function of TFN's is shown in Figure 1.

Each TFN has linear representations on its left and right side, such that its membership function can be defined as follows:

$$\mu\left(\frac{x}{\widetilde{M}}\right) = \begin{cases} 0, & x < l, \\ \dfrac{(x-l)}{(m-l)}, & l \leq x \leq m, \\ \dfrac{(u-x)}{(u-m)}, & m \leq x \leq u, \\ 0, & x > u. \end{cases} \tag{2.1}$$

A fuzzy number (FN) can always be given by its corresponding left and right representation of each degree of membership as in the following:

$$\widetilde{M} = M^{l(y)}, \quad M^{r(y)} = (l + (m-l)y, u + (m-u)y), \quad y \in [0, 1], \tag{2.2}$$

where $l(y)$ and $r(y)$ denote the left side representation and the right side representation of a FN, respectively. Many ranking methods for FN's have been developed in the literature. These methods may provide different ranking result, and most of them are tedious in graphic manipulation requiring complex mathematical calculation [22].

While there are various operations on TFN's, only the important operations used in this study are illustrated. If we define two positive TFN's (l_1, m_1, u_1) and (l_2, m_2, u_2), then

$$\begin{aligned} (l_1, m_1, u_1) + (l_2, m_2, u_2) &= (l_1 + l_2, m_1 + m_2, u_1 + u_2), \\ (l_1, m_1, u_1) * (l_2, m_2, u_2) &= (l_1 * l_2, m_1 * m_2, u_1 * u_2), \\ (l_1, m_1, u_1) * k &= (l_1 * k, m_1 * k, u_1 * k), \quad \text{where } k > 0. \end{aligned} \tag{2.3}$$

2.2. ELECTRE Method

To rank a set of alternatives, the ELECTRE method as outranking relation theory was used to analyze the data regarding a decision matrix. The concordance and discordance indexes can be viewed as measurements of dissatisfaction that a decision maker uses in choosing one alternative over the other.

We assume m alternatives and n decision criteria. Each alternative is evaluated with respect to n criteria. As result, all the values assigned to the alternatives with respect to each criterion form a decision matrix.

Let $W = (w_1, w_2, \ldots, w_n)$ be the relative weight vector of the criteria, satisfying $\sum_{j=1}^{n} w_j = 1$. Then, the ELECTRE method can be summarized as follows [23].

Normalization of decision matrix $X = (x_{ij})_{m\times n}$ is carried out by calculating r_{ij}, which represents the normalization of criteria value. Let $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}. \tag{2.4}$$

The weighted normalization of decision matrix is calculated with the following formula:

$$V = (v_{ij})_{m\times n} v_{ij} = r_{ij} \cdot w_{ij}, \qquad \sum_{j=1}^{n} w_j = 1. \tag{2.5}$$

After calculating weight normalization of the decision matrix, concordance and discordance sets are applied. The set of criteria is divided into two different subsets. Let $A = [a_1, a_2, a_3,]$ denote a finite set of alternatives. In the following formulation, we divide data into two different sets of concordance and discordance. If the alternative Aa_1 is preferred over alternative Aa_2 for all the criteria, then the concordance set is composed.

The concordance set is composed as follows.

$$C(a_1, a_2) = \{ j \mid v_{a_1 j} > v_{a_2 j} \}, \quad (a_1, a_2 = 1, 2, \ldots, m, \text{ and } a_1 \neq a_2) \tag{2.6}$$

$C(a_1, a_2)$ is the collection of attributes where Aa_1 is better than, or equal, to Aa_2.

On completing of $C_{a_1 a_2}$, apply the following discordance set:

$$D(a_1, a_2) = \{ j \mid v_{a_1 j} < v_{a_2 j} \}. \tag{2.7}$$

The concordance index of (a_1, a_2) is defined as follows:

$$C_{a_1 a_2} = \sum_{j^*} w_{j^*}, \tag{2.8}$$

j^* are the attributes contained in the concordance set $C(a_1, a_2)$. The discordance index $D(a_1, a_2)$ represents the degree of disagreement in $A_{a_1} \rightarrow A_{a_2}$; in the following way:

$$D_{a_1 a_2} = \frac{\sum_{j^+} \left| v_{a_1 j^+} - v_{a_2 b j^+} \right|}{\sum_{j} \left| v_{a_1 j} - v_{b_2 j} \right|}. \tag{2.9}$$

Table 1: The decision maker's opinion and the LT's.

LT's	Scale
Extremely good (EG)	9
Very good (VG)	7
Good (G)	5
Medium bad (MB)	3
Bad (B)	2
Very bad (VB)	1

j^+ are the attributes contained in the discordance set $D(a_1, a_2)$, and vij is the weighted normalized evaluation of the alternative i on criterion j.

This method implies that Aa_1 outranks Aa_2 when $C_{a_1a_2} \geq \overline{C}$ and, $D_{a_1a_2} \leq \overline{D}$.

$\overline{C}$: The averages of $C_{a_1a_2}$,

$\overline{D}$: The averages of $D_{a_1a_2}$.

3. The Proposed Fuzzy ELECTRE Method

ELECTRE I is one of the earliest multicriteria evaluation methods, developed among other outranking methods. The major purpose of this method is to select a desirable alternative that meets both the demands of concordance preference above many evaluation benchmarks, and of discordance preference under any optional benchmark. The ELECTRE I generally includes three concepts, namely, the concordance index, discordance index, and the threshold value.

In this study, our model fuzzy ELECTRE along with the opinion of decision makers will be applied by a group decision makers.

The procedure for fuzzy ELECTRE ranking model has been given as follows:

Step 1 (determination of the weights of the decision makers). Assume that the decision group contains l decision maker's criteria and gives them designated scores. The importance of the decision makers is, than, considered is linguistic terms (LT). We construct the aggregated decision matrix (ADM) based on the opinions of the decision-makers, and the LT as shown in Table 1.

Step 2 (calculation of TFN's). We set up the TFN's. Each expert makes a pairwise comparison of the decision criteria and gives them relative scores. The aggregated fuzzy importance weight (AFIW) for each criterion can be described as TFN's $\tilde{w}_j = (l_j, m_j, u_j)$ for $K = 1, 2, \ldots, k$, and $j = 1, 2, \ldots, n$. This scale has been employed in the TFN's as proposed by Mikhailov [24], and shown in Table 2.

Now, the TFN's are set up based on the FN's and assigned relative scores:

$$\widehat{G}_j = (l_j, m_j, u_j), \tag{3.1}$$

$$\begin{aligned} l_j &= (l_{j1} \otimes l_{j2} \otimes \cdots \otimes l_{jk})^{1/k}, \quad j = 1, 2, \ldots k, \\ m_j &= (m_{j1} \otimes m_{j2} \otimes \cdots \otimes m_{jk})^{1/k}, \quad j = 1, 2, \ldots k, \\ u_j &= (u_{j1} \otimes u_{j2} \otimes \cdots \otimes u_{jk})^{1/k}, \quad j = 1, 2, \ldots k. \end{aligned} \tag{3.2}$$

Table 2: The 1–9 Fuzzy conversion scale.

Importance intensity	Triangular fuzzy scale
1	(1, 1, 1)
2	(1.6, 2.0, 2.4)
3	(2.4, 3.0, 3.6)
5	(4.0, 5.0, 6.0)
7	(5.6, 7.0, 8.4)
9	(7.2, 9.0, 10.8)

Then, the AFWI for each criterion is normalized as follows:

$$\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}), \tag{3.3}$$

where

$$\tilde{G}_T = \left(\sum_{j=1}^{k} l_j, \sum_{j=1}^{k} m_j, \sum_{j=1}^{k} u_j \right). \tag{3.4}$$

The fuzzy geometric mean of the fuzzy priority value is calculated with normalization priorities for factors using the following:

$$\hat{w}_i = \frac{\tilde{G}_j}{\tilde{G}_T} = \frac{(l_j, m_j, u_j)}{\left(\sum_{j=1}^{k} l_j, \sum_{j=1}^{k} m_j, \sum_{j=1}^{k} u_j\right)} = \left(\frac{l_j}{\sum_{j=1}^{k} u_j}, \frac{m_j}{\sum_{j=1}^{k} m_j}, \frac{u_j}{\sum_{j=1}^{k} l_j} \right). \tag{3.5}$$

At a later stage, the normalized AFIW matrix is constructed as follows

$$\widetilde{W} = [\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n]. \tag{3.6}$$

Step 3 (calculation of the decision matrix). In [15], the matrix is constructed:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{21} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}. \tag{3.7}$$

Step 4. Calculation of the normalized decision matrix and the weighted normalized decision matrix.

The normalized decision matrix is calculated in the following way,

$$r_{ij} = \frac{1/x_{ij}}{\sqrt{\sum_{i=1}^{m} 1/x_{ij}^2}} \quad \text{For minimization,}$$
$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad \text{For maximization,}$$
$$i = 1, 2, \ldots, m, \qquad j = 1, 2, \ldots, n,$$
$$r_{ij} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{21} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}. \tag{3.8}$$

Thus, the weighted normalized decision matrix based on the normalized matrix is constructed as follows:

$$\widetilde{V} = \left[\tilde{v}_{ij}\right]_{m\times n}, \quad \text{where } \tilde{v}_{ij}\text{: normalized positive triangular FN's.}$$
$$i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n. \tag{3.9}$$
$$\tilde{v}_{ij} = r_{ij} \times \tilde{w}_j.$$

Step 5 (calculation of concordance and discordance indexes). These indexes are measured for different weights of each criterion (w_{j1}, w_{j2}, w_{j3}). The concordance index $C_{a_1a_2}$ represents the degree of confidence in pairwise judgments $(A_{a_1} \rightarrow A_{a_2})$ accordingly, the concordance index to satisfy the measured problem can be written with the following formula:

$$C^1_{a_1a_2} = \sum_{j^*} w_{j1}, \qquad C^2_{a_1a_2} = \sum_{j^*} w_{j2}, \qquad C^3_{a_1a_2} = \sum_{j^*} w_{j3}, \tag{3.10}$$

where J^* are the attributes contained in the concordance set $C(a_1, a_2)$.

On the other hand, the preference of the dissatisfaction can be measured by discordance index. $D(a_1, a_2)$, which represents the degree of disagreement in $(A_{a_1} \rightarrow A_{a_2})$, as follows:

$$D^1_{a_1a_2} = \frac{\sum_{j+}\left|v^1_{a_1j^+} - v^1_{a_2j^+}\right|}{\sum_j\left|v^1_{a_1j} - v^1_{a_2j}\right|}, \qquad D^2_{a_1a_2} = \frac{\sum_{j+}\left|v^2_{a_1j^+} - v^2_{a_2j^+}\right|}{\sum_j\left|v^2_{a_1j} - v^2_{a_2j}\right|}, \qquad D^3_{a_1a_2} = \frac{\sum_{j+}\left|v^3_{a_1j^+} - v^3_{a_2j^+}\right|}{\sum_j\left|v^3_{a_1j} - v^3_{a_2j}\right|} \tag{3.11}$$

J^+ are the attributes contained in the discordance set $D(a_1, a_2)$, and v_{ij} is the weighted normalized evaluation of the alternative i on the criterion j [7].

Table 3: The rating of the projects.

DMU	Criteria	DM1	DM2	DM3	DM4
P1	C1	VG	VG	G	G
	C2	G	VG	MB	MB
	C3	VG	G	B	VG
	C4	VG	VG	G	G
P2	C1	G	VG	MB	B
	C2	VG	VG	G	MB
	C3	VG	VG	B	B
	C4	VG	VG	MB	G
P3	C1	VG	VG	G	VG
	C2	VG	G	G	VG
	C3	VG	G	VG	G
	C4	VG	VG	VG	VG

Step 6 (calculating the concordance and discordance indexes). This final step deals with determining in the concordance and discordance indexes in other words, the defuzzification process using the following formula:

$$C^*_{a_1a_2} = \sqrt[z]{\prod_{z=1}^{Z} C^z_{a_1a_2}}, \qquad D^*_{a_1a_2} = \sqrt[z]{\prod_{z=1}^{Z} D^z_{a_1a_2}}, \tag{3.12}$$

where, $Z = 3$.

The dominance of the A_{a_1}over the A_{a_2} becomes stronger with a larger final concordance index $C_{a_1a_2}$ and a smaller final discordance index $D_{a_1a_2}$ [7].

Consequently, the best alternative is yielded, where

$$C(a_1, a_2) \geq \overline{C}, \qquad D(a_1, a_2) \geq \overline{D}. \tag{3.13}$$

$\overline{C}$: The averages of $C_{a_1a_2}$,

$\overline{D}$: The averages of $D_{a_1a_2}$.

4. Case Study

Each project is defined by its attributes, which are then related to the criteria. After discussion with the management team, the following four criteria were used to evaluate the projects. In our study, we employ four evaluation criteria, mainly, *net present value (C1), quality (C2), contractor's technology (C3), and contractor's economic status (C4)*. Three projects, P1, P2, and P3 under evaluation are assigned to a team of four decision maker. Mainly, DM1, DM2, DM3, and DM4 to choose the most suitable one.

First, ratings given by the decision makers to the three projects and four criteria are shown in Table 3.

Table 4: Decision matrix.

	C1	C2	C3	C4
P1	6	4.5	5.25	6
P2	4.25	5.5	4.5	5.5
P3	6.5	6	6	7

Table 5: Fuzzy decision matrix.

	C1	C2	C3	C4
P1	(4.8, 6, 7.2)	(3.6, 4.5, 5.4)	(4.2, 5.25, 6.3)	(4.8, 6, 7.2)
P2	(3.4, 4.25, 5.4)	(4.4, 5.5, 6.6)	(3.6, 4.5, 5.4)	(4.4, 5.5, 6.6)
P3	(5.2, 6.5, 7.8)	(4.8, 6, 7.2)	(4.8, 6, 7.2)	(5.6, 7, 8.4)

Next, construct the aggregated decision matrix and fuzzy decision matrix are constructed based on the opinions of the four decision makers, as shown in Tables 4 and 5.

Then, calculate the normalized aggregated fuzzy importance is calculated in the following format:

$$\begin{aligned}
\tilde{w}_1 &= (0.16 \otimes 0.25 \otimes 0.38), \\
\tilde{w}_2 &= (0.16 \otimes 0.24 \otimes 0.36), \\
\tilde{w}_3 &= (0.15 \otimes 0.23 \otimes 0.35), \\
\tilde{w}_4 &= (0.18 \otimes 0.28 \otimes 0.42).
\end{aligned} \tag{4.1}$$

Also, the normalized matrix and weighted normalized matrix are calculated:

$$\begin{aligned}
R &= \begin{bmatrix} 0.0000077 & 0.0050 & 0.108 & 0.020 \\ 0.0000048 & 0.0058 & 0.110 & 0.018 \\ 0.0000074 & 0.0047 & 0.103 & 0.012 \end{bmatrix}, \\
V_1 &= \begin{bmatrix} 0.0000013 & 0.0008 & 0.016 & 0.0036 \\ 0.0000008 & 0.0009 & 0.017 & 0.0032 \\ 0.0000012 & 0.0007 & 0.015 & 0.0022 \end{bmatrix}, \\
V_2 &= \begin{bmatrix} 0.0000019 & 0.0012 & 0.025 & 0.0056 \\ 0.0000012 & 0.0014 & 0.024 & 0.0050 \\ 0.0000019 & 0.0011 & 0.024 & 0.0034 \end{bmatrix}, \\
V_3 &= \begin{bmatrix} 0.0000029 & 0.0018 & 0.038 & 0.0084 \\ 0.0000018 & 0.0021 & 0.039 & 0.0076 \\ 0.0000028 & 0.0017 & 0.036 & 0.0050 \end{bmatrix}.
\end{aligned} \tag{4.2}$$

Finally, determine the concordance and disconcordance indexes are determined:

$$C^1{}_{12} = \{1, 4\},$$
$$C^1{}_{13} = \{1, 2, 4\},$$
$$C^1{}_{23} = \{2, 3\},$$
$$D^1{}_{12} = \{2, 3\},$$
$$D^1{}_{13} = \{3\},$$
$$D^1{}_{23} = \{1, 4\},$$
$$C^2{}_{12} = \{1, 4\},$$
$$C^2{}_{13} = \{1, 2, 4\},$$
$$C^2{}_{23} = \{2, 3\},$$
$$D^2{}_{12} = \{2, 3\},$$
$$D^2{}_{13} = \{3\},$$
$$D^2{}_{23} = \{1, 4\},$$
$$C^3{}_{12} = \{1, 4\},$$
$$C^3{}_{13} = \{1, 2, 4\},$$
$$C^3{}_{23} = \{2, 3\},$$
$$D^3{}_{12} = \{2, 3\},$$
$$D^3{}_{13} = \{3\},$$
$$D^3{}_{23} = \{1, 4\},$$
$$C_{12} = 11.67 A_1 \longrightarrow A_2,$$
$$C_{13} = 16.96 A_1 \longrightarrow A_3,$$
$$C_{23} = 10.51,$$
$$C_{21} = 10.51,$$
$$C_{32} = 11.67 A_3 \longrightarrow A_2,$$
$$C_{31} = 5.21,$$
$$\overline{C} = 11.088,$$
$$D_{12} = 0.515 \ A_1 \longrightarrow A_2,$$
$$D_{13} = 0.351 \ A_1 \longrightarrow A_3,$$
$$D_{23} = 0.599,$$
$$D_{21} = 0.547,$$
$$D_{32} = 0.453 \ A_3 \longrightarrow A_2,$$
$$D_{31} = 0.650,$$
$$\overline{D} = 0.519.$$

As a conclusion, project 1 is identified as the most suitable one.

5. Conclusion

The fuzzy ELECTRE is the focus of this paper, applied in evaluating real-life projects—in this case, in the field of construction. An MCDM is presented based on the fuzzy set theory in order to select the best project among three. In order to achieve consensus among the four decision makers, all pairwise comparisons were converted into triangular fuzzy numbers to adjust the fuzzy rating and the fuzzy attribute weight. Best project selection is a process that also contains uncertainties. This problem can be overcome by using fuzzy numbers and linguistic variables to achieve accuracy and consistency. To overcome this deficiency, fuzzy numbers can be applied to make accurate and consistent decisions by reducing subjective assessment. The main contribution of this study lies in the application of a fuzzy approach to the project selection decision-making processes, drawing on an actual case.

The project selection process is a technique for evaluating the most suitable alternatives. In this paper, this problem is addressed using the fuzzy ELECTRE, a method which is a suitable way to deal with MCDM problems. A real-life example in the construction sector is illustrated; the results point out the best project with respect to four criteria and decided by four decision makers. The fuzzy ELECTRE method is convenient because it contains a vague perception of decision makers' opinions. Finally, this method has the capability to deal with similar types of situations, including: ERP software selection, department ranking in universities, supply chain selection, and countless other area in business and management.

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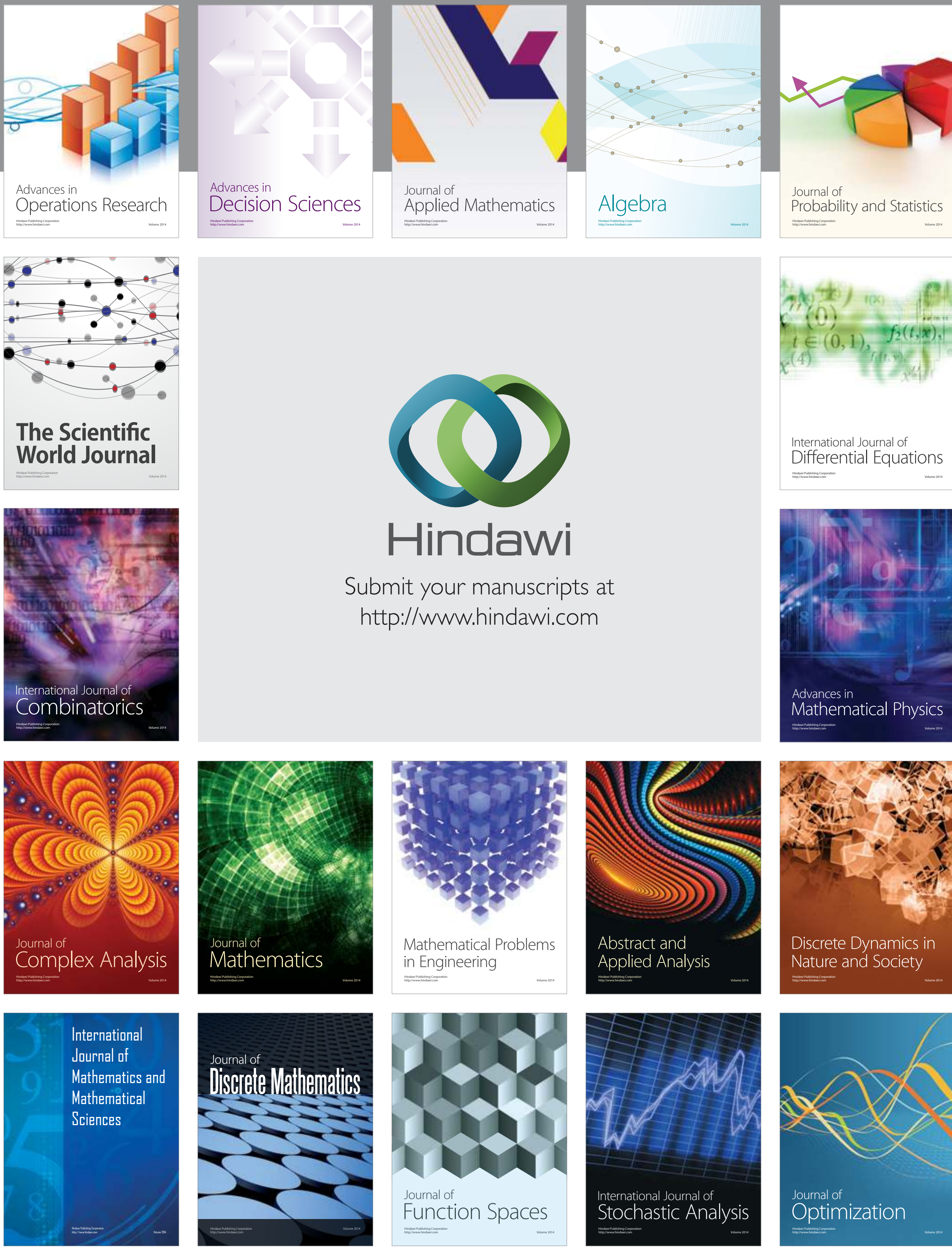
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