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Grey Theory, VIKOR and TOPSIS Approaches for Strategic System Selection with Linguistic Preferences: a Stepwise Strategy Approach

Y. Zare Mehrjerdi[1]

The concept of Stepwise Strategy Approach (SSA) is introduced to deal with a number of problems arising in the current state of technology. This new idea is combined with the knowledge of Grey Theory for adding flexibility to decision making process. Grey theory is useful for grasping the ambiguity existing in the utilized information and the fuzziness appears with the human judgments and preferences. A useful source of information for Fuzzy Grey and decision making using more than one decision makers is provided. A case study on system selection comprised of 12 attributes and 4 alternatives is constructed and solved by the proposed method and the results are analyzed. For the validation of the results obtained by the Grey theory, the fuzzy VIKOR and Fuzzy TOPSIS are employed for computational purposes. The results of these three approaches on the proposed case study are closely related. The proposed "Stepwise Strategy" approach for implementing a new technology in industry, although the management of an older compatible type of technology along with the grey theory concept and data whitenization are available, is expected to be a competitive alternative for decision making.

Keywords: *Stepwise strategy, Grey theory, VIKOR, TOPSIS, Fuzzy sets, System selection, Group decision making*.

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1. Introduction

For various reasons, firms are reluctant to adopt Radio Frequency Identification (RFID) as a part of their internal systems. This is because of uncertainty regarding the payoff that will (or might) result from its adoption (Reyes et al. [33]; Dutta et al. [12]). Central to this uncertainty are risks accompanying adoption that can be grouped into two broad areas – uncertainty with regard to the requirements and capabilities of the technology itself and uncertainty with regard to the effects of the technology on inter-organizational relationships (Cannon et al. [11]). Due to the fact that at the present time RFID is still in its early stages of development and acceptance by the management of large and small companies, there lots of unanswered questions regarding its actual or potential use.

Since tracking and tracing items in an organization is not an easy task tagging those items with RFID makes sense. RFID is a term used for technologies utilizing radio waves for identifying individual items automatically. The most common way is storing a serial number identifying a product and related information on a microchip attached to an antenna. RFID is used very similar to barcodes. It is designed to track items without requiring a line of sight. To read a barcode, its lines had to stay in sight of the scanner to identify product correctly. RFID has received lots of commercial attentions in recent years, specially in the areas of asset tracking, supply chain and library management. RFID is used in manufacturing to monitor the factory level (Labs et al. [41]), in service sector (Lee et al. [35]), in product design (Repo [28]), in managing restaurant (Ngai [13, 14, 15]), in monitoring patients with diet problem (Hall [31]), in supply chain management (Angles [2], Bottani and Rizzi [3], Zare Mehrjerdi [47, 48, 54]), for hospital social impacts assessment (Fisher et al. [19]),

[1] Department of Industrial Engineering, Yazd University, Yazd, Iran, Email: yzare@yazd.ac.ir.

in logistic (Chow et al. [18], and Estifania [16]), in pharmaceutical industry, and for monitoring and tracking live animals (Wismans [42]). Interested readers can see a review of RFID and its benefits in Zare Mehrjerdi [47, 48]. With regard to the library use of RFID, Seattle's RFID library project is the largest in the world, with Shenzhen's being second. All RFID vendors in the library market offer a product with anti-collision (the ability to read several tags simultaneously). The actual speed at which this can be performed, and total number of tags that can be read, does vary considerably (Curran et al. [22]).

The main purpose of this work here is to provide practitioners with the Grey point of view to traditional decision making to deal with imprecision and to obtain the prioritization of some alternatives taking finite number of attributes into consideration. Although Grey theory has been used for decision making in some industrial areas, it has not tried in the context of stepwise strategic planning of mixed RFID systems using TOPSIS and VIKOR decision making tools along with the whitenized grey numbers. Grey theory approach is employed here for evaluating RFID-based systems and determining the most appropriate system among them. The practicality of the proposed model is demonstrated using a sample case study. To check the results obtained by the proposed approach, data are collected and grey theory is used. For model validation purposes, fuzzy VIKOR and fuzzy TOPSIS are employed here.

The rest of the present work is structured as follows: Section 2 gives a background on multi criteria decision making, Grey theory, and RFID-based systems. Section 3 describes the research methodology while preliminaries which include grey theory and grey number comparison are described in Section 4. Sections 5 and 6 describe the VIKOR and TOPSIS approaches, respectively, while Section 7 discusses the whitenization concept for Grey theory. Section 8 works through a case study to show the model implication in real world. Study validation is provided in Section 9. Concluding remarks are given in Sections 10.

2. Background

This section is devoted to the descriptions of key subject matters, namely, Multi Criterion Decision Making (MCDM), Grey Theory (GT), and RFID-based systems. Because of space limitation each topic is described briefly.

2.1. MCDM

Perhaps the single most important decision faced by management when dealing with multiple objectives is the selection of an appropriate solution, which optimizes the proposed criteria simultaneously. Therefore, it is hardly surprising that much of the literature on operations research focuses on Multiple Objective Decision Making (MODM) problems. The decision space used in MODM is a continuous one and the proposed model can be solved with mathematical programming techniques. These exits various applications that concentrate on continuous space modeling in industrial areas such as production control (Zare Mehrjerdi [49]), cellular manufacturing system (Mahdavi et al. [26]), quality management (Rahimi et al. [32]), and shop floor problem (Tavakkoli-Moghaddam et al. [38]). A Multi Attribute Decision making (MADM) model deals with the problem of choosing an option from a set of alternatives which are characterized in terms of their attributes. This is a qualitative approach due to subjectivity. The aim of MADM is to obtain the optimum alternative with the highest degree of satisfaction for all of the relevant attributes.

Modeling real world problems with crisp values under many conditions is inadequate because human judgments and preferences are often ambiguous and cannot be estimated with exact numerical values (Chen [6]; Chen et al. [5]; Kuo et al. [23]).

2.2. Grey Theory

There are various ways to study uncertainties that arise in data and hence different mathematical model using various sorts of data are proposed in the literature (fuzzy data of Zadeh [46], Stochastic data of Sengupta [20, 21], and Grey data of Deng [9, 10]). One such method that can handle interval type data is known as Grey theory. Grey theory is a method used to study uncertainty, being introduced for the mathematical analysis of systems with uncertain information. Grey systems theory was first proposed by Deng [9, 10]. A grey system is a system other than white (system with completely known information) and black (system with completely unknown information) systems, and thus has partially known and partially unknown characteristics. In reality, most processes of interest in environmental management are in grey stage due to inadequate and fuzzy information. A ‘‘grey number’’ is defined to be a number whose exact value is unknown but a range within which the value lies is known [1, 24, 25].

The advantage of grey theory over fuzzy theory [24] is that grey theory considers the condition of the fuzziness; that is, grey theory can deal with the fuzziness situation. “Fuzzy” methods similarly require estimates of degrees of memberships in fuzzy sets, which in turn are distinct from probabilities and are manipulated differently from them. The value of the fuzzy approach has been demonstrated in a vast number of successful applications (Andrew [1]).

2.3. RFID-based Systems

RFID is not a new phenomenon. It has been around for decades. It was used initially for proximity access control. Thereafter, it was evolved to be used in supply chain tracking, toll barrier control, and even protecting automobiles (Potter [30]). In April 2004, Washington Hospital Center in Washington D.C. began a trial use of RFID tags focusing on RFID usage in hallways and in emergency rooms. Washington Hospital is using active UWB or ultra-wide band tags, developed by Parco Wireless, to track medical devices in the hospital. Washington Hospital Center has the staff and patients wear credit card sized RFID tags to obtain and maintain patient and healthcare provider information (Crayton [8]).

The potential benefits to RFID technology in food industry are enormous. Because each chip is unique to the specific box it is in, tracking the whereabouts of products becomes much simpler. The future seems to point in the direction of full incorporation of RFID tagging with nearly all products, equipments, supplies, and people simply because of the wide range of usage of these tags (Angeles [2]; Chopra and Sodhi [7]; Riggins [34]; Sarma [37]; Fish and Forrest [17]). Although the future for RFID technology seems very promising, its implementation varies and its utilizations in near future are uncertain.

3. Problem Description and “Stepwise Strategy” Proposition

Picture a general hospital struggling to pay monthly payments on time and there are not too many ways for competing with the big hospitals around. This general hospital has to make decision to get into the RFID-based systems for better management of the patients and drugs that are tagged already. Since more and more hospitals and healthcare centers are getting involved with the RFID based systems and more producers are using tags instead of barcodes, it is the course of industry that makes general hospital turn into using RFID-based systems, sooner rather than later.

Here, a strategy named "stepwise strategy for accepting a new technology", is proposed to help such organization to survive and fight for their existence. The reality is that most hospital owners cannot spend a large amount of money on RFID based systems but can handle a partially RFID-based system. This is also true when a general hospital owns more than one branch in its surrounding community. In this case, one or two of the branches can get involved on the RFID systemization. The “stepwise strategy” can be stated as: "accept the new technology preferably not in full at first, rather in steps, until it is fully implemented in the whole organization". To implement this stepwise strategy, the question that might be asked is with what sort of a system a small family owned hospital or a similar health center should start? Generally speaking, a new technology based system can be broken into a mix of RFID and barcode type systems, named as 10%RFID, 20%RFID, ..., 100%RFID, where 10%RFID system means a system that has 10 % RFID capability with 90% barcode capability. It is obvious enough that an organization cannot fully accept RFID in all branches of its business at once, but it can manage to partially equip some of its branches or locations. Does a mix of RFID-barcode-based system help to manage a general hospital better? This is the question to be addressed here.

Due to the fact that a policy of (1) “Stepwise Strategy” for the implementation of a new technology in industry is proposed here, where already managing an older type of comparable technology, (2) using Grey theory and (3) applying data whitenization approach, contribution to the literature on operations research is to be expected.

4. Research Methodology

The study process is as listed as follows:

(1) A group of consultants are advised to list the most significant strategies for the organization by relating RFID technology with the need and growth of the organization and industry
(2) Give and get appropriate consultations to the team of experts as needed to make the study process smooth and manageable
(3) Strategies are ranked using proposed grey based theory approach.
(4) Ranking of strategies are identified by the VIKOR approach.
(5) Ranking of strategies are identified by the Fuzzy TOPSIS approach.
(6) Results are validated and the most appropriate strategies are presented to the organization to be considered for implementation.

5. Research Assumptions

The research assumptions are:

1. Management is willing to implement stepwise strategic planning in the system under his/her control.
2. The system’s breakdown into sub-systems as described in the case study is possible.
3. The number of sub-systems under study is finite.
4. The number of attributes to be taken into consideration for each alternative is finite.
5. Experts are available in the field to provide the needed information.
6. Management supports the ideas behind the proposed approach.

6. Decision Making Tools

Three decision making tools of Grey theory, VIKOR and TOPSIS are used as being briefly described in this section.

6.1. Grey Theory Preliminaries

Before we get into the Grey theory concepts we need to concentrate on the preliminaries. We cite Wang [43], Wu [44], Chen et al. [45], Zhang [50]), Tseng [51] and Wang [52] to define the basic arithmetic's on grey numbers $G1 = [G1, G1]$ and $G2 = [G2, G2]$, on the intervals, where the four basic grey number operations on the interval are the exact range of the corresponding real operation.

Definition 1.
A grey number can be defined as a number with uncertain information. For example, ratings of attributes are described by linguistic variables; there will be a numerical interval expressing it. This numerical interval contains uncertain information.

Definition 2.
Only the lower limit of *G* can be possibly estimated and *G* is defined as a lower-limit grey number: $\otimes G = [\underline{G}, \infty]$.

Definition 3.
Only the upper limit of *G* can be possibly estimated and *G* is defined as an upper-limit grey number: $G = [\infty, \overline{G}]$.

Definition 4.
The lower and upper limits of *G* can be estimated and *G* is defined as an interval grey number: $\otimes G = [\underline{G}, \overline{G}]$.

Definition 5.
A grey number operation is an operation defined on sets of intervals, rather than real numbers. The modern development of interval operation began with R.E. Moore's dissertation [53].

Assume $G_1 = [\underline{G}_1, \overline{G}_1]$ and $G_2 = [\underline{G}_2, \overline{G}_2]$ on intervals, where the four basic grey number operations on the interval are the exact range of the corresponding real operation:

$$\otimes G_1 + \otimes G_2 = [\underline{G}_1 + \underline{G}_2, \overline{G}_1 + \overline{G}_2] \tag{1}$$

$$\otimes G_1 - \otimes G_2 = [\underline{G}_1 - \underline{G}_2, \overline{G}_1 - \overline{G}_2] \tag{2}$$

$$\otimes G_1 \times \otimes G_2 = [\min(\underline{G}_1\underline{G}_2, \underline{G}_1\overline{G}_2, \overline{G}_1\underline{G}_2, \overline{G}_1\overline{G}_2), \max(\underline{G}_1\underline{G}_2, \underline{G}_1\overline{G}_2, \overline{G}_1\underline{G}_2, \overline{G}_1\overline{G}_2)] \tag{3}$$

$$\otimes G_1 \div \otimes G_2 = [\underline{G}_1, \overline{G}_1] \times \left[\frac{1}{\underline{G}_2}, \frac{1}{\overline{G}_2}\right] \tag{4}$$

Table 1. The scales of attribute weight

Scale	Designation	$\otimes W$
Very Low	VL	[0.0, 0.10]
Low	L	[0.1, 0.30]
Medium Low	ML	[0.3, 0.40]
Medium	M	[0.4, 0.50]
Medium High	MH	[0.5, 0.60]
High	H	[0.6, 0.90]
Very High	VH	[0.90, 1.0]

Table 2. The scales of attribute rating

Scale	Designation	$\otimes G$
Very Poor	VP	[0, 1]
Poor	P	[1, 3]
Medium Poor	MP	[3, 4]
Fair	F	[4, 5]
Medium Good	MG	[5, 6]
Good	G	[6, 9]
Very Good	VG	[9, 10]

6.2. Grey Approach

The proposed approach is to find out which of the RFID based systems are the most appropriate one having S_1, S_2, ..., S_m in mind. We assume that each of these systems is associated with n independent attributes as being taken into consideration for systems' evaluation. We will use the following notations in our model building to facilitate the model referral from the beginning:

Vector of systems: $S = \{S_1, S_2, \dots, S_m\}$,
Vector of attributes: $Q = \{Q_1, Q_2, \dots, Q_n\}$,
Vector of attribute weights: $\otimes W = \{\otimes W_1, \otimes W_2, \dots, \otimes W_n\}$.

The procedure used in this model building is composed of the following steps:

Step 1
Assume that the weight of system j identified by kth decision maker is shown by $\otimes W_{jk}$. Taking these rating technique into consideration we can then obtain the vector of rates for the entire committee of K decision makers for the jth attribute as shown below:

$$\otimes W_j = \{\otimes W_{1k}, \otimes W_{2k}, \dots, \otimes W_{nk}\}, \text{ for } j = 1, \dots, n \text{ and } k = 1,2 \dots, K, \quad (5)$$

where this grey number can be shown as: $\otimes W_{jk} = [\underline{W}_{jk}, \overline{W}_{jk}]$.

Taking the same knowledge one step further, we can develop the rating for the jth attribute of the ith system by the kth decision maker as follows:

$$\otimes W_{ij} = \{\otimes W_{i1k}, \otimes W_{i2k}, \dots, \otimes W_{ink}\}, \text{ for } i = 1, \dots, m, j = 1, \dots, n \text{ and } k = 1,2 \dots, K, \quad (6)$$

where this grey number can be shown as: $\otimes W_{ijk} = [\underline{W}_{ijk}, \overline{W}_{ijk}]$.

Step 2
Using the values of $\otimes W_{ijk} = \left[\underline{W}_{ijk}, \overline{W}_{ijk}\right]$, we can establish the grey decision matrix as follows:

$$D = \begin{bmatrix} \otimes G_{11} & \otimes G_{12} & \cdots & \otimes G_{1n} \\ \otimes G_{m1} & \otimes G_{22} & & \otimes G_{2n} \\ \vdots & & \ddots & \vdots \\ \otimes G_{m1} & \otimes G_{m2} & \cdots & \otimes G_{mn} \end{bmatrix}, \tag{7}$$

where $\otimes W_{ij}$ is the linguistic variables based on the grey numbers as defined before in tables 1 and 2.

Step 3
Normalize the grey decision matrix:

$$D^* = \begin{bmatrix} \otimes G_{11}^* & \otimes G_{12}^* & \cdots & \otimes G_{1n}^* \\ \otimes G_{21}^* & \otimes G_{22}^* & & \otimes G_{2n}^* \\ \vdots & & \ddots & \vdots \\ \otimes G_{m1}^* & \otimes G_{m2}^* & \cdots & \otimes G_{mn}^* \end{bmatrix}, \tag{8}$$

where $\otimes W_{ij}$ is the linguistic variables based on the grey numbers as defined before in tables 1 and 2 and for a benefit attribute, $\otimes W_{ij}^*$ is expressed:

$$\otimes G_{ij}^* = \left[\frac{\underline{G}_{ij}}{G_j^{\max}}, \frac{\overline{G}_{ij}}{G_j^{\max}}\right], \tag{9}$$

with

$$G_j^{\max} = \max_{1 \le i \le m} \{\overline{G}_{ij}\}, \tag{10}$$

and for a cost attribute, $\otimes W_{ij}^*$ is expressed as

$$\otimes G_{ij}^* = \left[\frac{G_j^{\min}}{\overline{G}_{ij}}, \frac{G_j^{\min}}{\underline{G}_{ij}}\right], \tag{11}$$

where

$$G_j^{\min} = \min_{1 \le i \le m} \{\underline{G}_{ij}\}. \tag{12}$$

Step 4
Establish the weighted normalized grey decision matrix as

$$D = \begin{bmatrix} \otimes V_{11} & \otimes V_{12} & \cdots & \otimes V_{1n} \\ \otimes V_{m1} & \otimes V_{22} & & \otimes V_{2n} \\ \vdots & & \ddots & \vdots \\ \otimes V_{m1} & \otimes V_{m2} & \cdots & \otimes V_{mn} \end{bmatrix}, \tag{13}$$

where

$$\otimes V_{ij} = \otimes G_{ii}^* \times \otimes w_j. \tag{14}$$

Step 5
Make the ideal alternative as a referential alternative. For the purpose of our study, form systems of $S = \{S_1, S_2, \dots, S_m\}$, the ideal referential supplier alternative, and $S^{\max} = \{\otimes G_1^{\max}, \otimes G_2^{\max}, \dots, \otimes G_n^{\max}\}$ can be identified as

$$S^{\max} = \left\{\left[\max_{1\le i\le m} \underline{V}_{i1}, \max_{1\le i\le m} \overline{V}_{i1}\right], \left[\max_{1\le i\le m} \underline{V}_{i2}, \max_{1\le i\le m} \overline{V}_{i2}\right], \dots, \left[\max_{1\le i\le m} \underline{V}_{in}, \max_{1\le i\le m} \overline{V}_{in}\right]\right\} \tag{15}$$

Step 6
Calculate the grey possibility degree between the compared systems alternatives $S = \{S_1, S_2, \dots, S_m\}$and ideal referential supplier alternative $S^{\max}$,

$$P\{S_i \le S^{\max}\} = \frac{1}{n}\sum_{j=1}^{n} P\left\{\otimes V_{ij} \le \otimes G_j^{\max}\right\}. \tag{16}$$

Step 7
Rank the order of the system alternatives. The smaller $P\{S_i \le S^{\max}\}$ is the better the ranking order of S_i is.

6.3. Comparison of Grey Numbers

The comparison of grey numbers is based upon the following definition.
For two grey numbers of $G_1 = \left[\underline{G}_1, \overline{G}_1\right]$ and $G_2 = \left[\underline{G}_2, \overline{G}_2\right]$, the possibility degree of $\otimes G_1 \le \otimes G_2$ is expressed as

$$P\{\otimes G_1 \le \otimes G_2\} = \frac{\max\left(0, L^* - \max\left(0, \overline{G}_1 - \underline{G}_2\right)\right)}{L^*}, \tag{17}$$

where $L^* = L(\otimes G_1) + L(\otimes G_2)$.

6.4. The Decision Making Process

The following definitions are used in the decision making process.

- If $P\{\otimes G_1 \le \otimes G_2\} = 0.5$ then we say that $\otimes G_1$ is equal to $\otimes G_2$ and denote this by $\otimes G_1 = \otimes G_2$.
- If $P\{\otimes G_1 \le \otimes G_2\} < 0.5$ then we say that $\otimes G_2$ is smaller than $\otimes G_1$ and denote this by $\otimes G_1 < \otimes G_2$.
- If $P\{\otimes G_1 \le \otimes G_2\} > 0.5$ then we say that $\otimes G_2$ is larger than $\otimes G_1$ and denote this by $\otimes G_1 > \otimes G_2$.
- If $P\{\otimes G_1 \le \otimes G_2\} = 1$ then we say that $\otimes G_2$ is larger than $\otimes G_1$.
- If $P\{\otimes G_1 \le \otimes G_2\} = 0$ then we say that $\otimes G_2$ is smaller than$\otimes G_1$.

6.5. VIKOR Method

The technique known as VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) tries to find out the positive ideal solution and negative ideal solution while tries to determines the compromise ranking-list, the compromise solution, and the weight stability intervals for preference stability of the compromise solution obtained with the initial (given) weights (Opricovic and Tzeng [27]). This technique is adopted by many researchers (Tzeng et al. [36], Büyüközkan and Ruan [29]) since its introduction to the literature of multi attribute decision making (MADM). This procedure is comprised of some steps to find a solution of the problem. These standard steps follow the work of Opricovic and Tzeng [27] and Tzeng, Lin et al. [36]) as given next.

Step 1: Calculate the normalized value

The formula for the normalization process, with the x_{ij} as the original value of the ith option and the jth dimension, is:

$$f_{ij} = \frac{X_{ij}}{\sqrt{X_{ij}^2}}, \qquad i = 1, \dots, m; j = 1, \dots, n. \tag{18}$$

Step 2: Define rating

Determine the best rating f_i^+ and the worst rating f_i^- for all the criteria. If the ith criterion is of benefit type, then use the following formulas:

$$f_i^+ = \max_j f_{ij}, \quad f_i^- = \min_j f_{ij}.$$

Step 3: Compute S_j and R_j

Compute S_j and R_j for $j = 1,2, \dots, m$, representing the average and the worst group scores for the alternative A_i, as follows:

$$S_j = \sum_{i=1}^{n} w_i \left(\frac{f_i^+ - f_{ij}}{f_i^+ - f_i^-}\right), \quad S_j \in [0,1],$$
$$R_j = \max_i \left[w_i \frac{\left(f_i^+ - f_{ij}\right)}{\left(f_i^+ - f_i^-\right)}\right], \quad R_j \in [0,1], \tag{19}$$

Where the w_i are the weights of the criteria, give the relative importance.

Step 4: Compute values of Q_j

Compute values of $Q_j, j = 1,2, \dots, J$ as follows

$$Q_j = \frac{v\left(S_j - S^+\right)}{\left(S^- - S^+\right)} + \frac{(1-v)\left(R_j - R^+\right)}{\left(R^- - R^+\right)},$$
$$\text{where } S^+ = \min_j S_j, \quad S^- = \max_j S_j \tag{20}$$
$$R^+ = \min_j R_j, \quad S^- = \max_j R_j,$$

with v being the weight of the decision-making of the major criterion here, $v = 0.5$.

Step 5: Rank the alternatives

Rank the alternatives by sorting the S, R and Q values in increasing orders. The result is a set of three ranking lists denoted as $S_{[\cdot]}, R_{[\cdot]}$ and $Q_{[\cdot]}$.

Step 6: compromise solution

Propose as a compromise solution the alternative (a') which is ranked the best by the measure Q, if the following two conditions are satisfied:

C1: "Acceptable advantage":

$$Q(a') - Q(a'') \geq DQ, \tag{21}$$

where a'' is the alternative with second best position in the ranking list Q, $DQ = \frac{1}{J-1}$,with J being the number of alternatives.

C2: "Acceptable stability in decision making": Alternative a' must be the best ranked in S or R. This compromise solution is stable within a decision making process, which could be: "voting by major rule" (when $v > 0.5$), or "by consensus" (when $v \approx 0.5$), or "with veto" (when $v < 0.5$). Here, v is the weight of the decision making strategy "the majority of criteria".

If one of the condition is not satisfied, then a set of compromise solution is proposed, which consists of:

(1) Alternatives a' and a'' if only condition C2 is not satisfied, or
(2) Alternatives $a', a'', \ldots, a^{(M)}$ if condition C1 is not satisfied; and $a^{(M)}$ is determined by the relation $\left(a^{(M)}\right) - Q(a') < DQ$, for maximum M.

6.6. TOPSIS Method

As an MADM tool, TOPSIS has reached to a high level of popularity among researchers and practitioners for the reasons specified below:

1. It is intuitive, easy to understand, and can be modeled and computed by the consultants and managers using simple computer codes or Lotus/ Excel worksheets. These features are fundamentally very important for the implementation of the methodology by the practitioners who do not have deep knowledge of MADM.
2. It allows the straight linguistic definition of weights and ratings under each criterion, without the need of have cumbersome pairwise comparisons and the risk of inconsistencies.
3. It is unique among the most cited multi criterion group decision making techniques in the way it approaches the selection issue. The final decision is based on the closeness indexes computed using the distances from the positive ideal solution and negative ideal solution points.
4. The performance is slightly affected by the number of alternatives and rank discrepancies are amplified to a lesser extent for increasing values of the number of alternatives and the number of criteria (Triantaphyllou et al. [39, 40]).

5. It is one of the best methods for addressing rank reversal issue which is the change in the ranking of alternatives when a non-optimal alternative is introduced. This feature is largely appreciated in practical applications (Bottani and Rizzi [3]).
6. The TOPSIS top rank reversal has been proved to be insensitive to the number of alternatives and has its worst performance only in case of very limited number of criteria (Triantaphyllou et al. [39, 40]).

6.7. TOPSIS Algorithm

This algorithm is comprised of seven steps as discussed below.

Step 1 (Decision matrix and weight development)

The very first step of TOPSIS is determination of the decision matrix. This matrix has *m* rows and *n* columns, where *m* is the number of alternatives, $A_i, i = 1, \dots, m$, to be ranked, and *n* is the number of criteria based on which the ranking on C_j is done, $j = 1, \dots, n$. In the model, it is assumed that there are *K* decision makers subjectively assessing the weighting vector $W = (w_1, \dots, w_n)$ and the decision matrix $X = \{x_{ij}: i = 1, \dots, m;$ and $j = 1, \dots, n\}$, using the linguistic terms described in tables 1 and 2, above.

Taking alternatives the A_i and criteria C_j into consideration, the decision matrix is specified as follows:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix} \end{array}, \tag{22}$$

$$W = (w_1, w_2, \dots, w_n). \tag{23}$$

Given the weighting vector W and decision matrix X, the objective is to rank all the alternatives by giving each one of them an overall utility with respect to all selection criteria.

Step 2 (Normalization of decision matrix)

Before making any use of data provided in Step 1, we need to develop a normalized decision matrix. Doing so, we convert all non-commensurable criteria into unique and common sense numbers. The decision matrix must first be normalized so that the elements are unit-free:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}. \tag{24}$$

Step 3 (Weighted normalized decision matrix)

In this step, the weighted normalized decision matrix for the *k*th decision maker needs to be constructed. By considering the importance of each criterion, the weighted normalized fuzzy decision matrix is constructed as: $V = [v_{ij}]$, where $v_{ij} = r_{ij} w_j$.

Step 4 (Distances from PIS and NIS)

Two ideal solutions known as positive ideal and negative ideal solutions are very important in the decision making process. The decision maker to stay away as far as possible from the negative ideal solution and as close as possible to the positive ideal point. Although these solutions are unreachable in reality, they are very important to the decision maker. The positive ideal solution shown by A^+ and the negative ideal solution shown by A^- are determined as follows:

$$A^+ = (v_1^+, v_2^+, \dots, v_m^+), \tag{25}$$

$$A^- = (v_1^-, v_2^-, \dots, v_m^-), \tag{26}$$

where v_j^+ is the best amount of the jth criterion among all the alternatives and v_j^- is the worst amount of the jth criterion among all alternatives:

$$v_j^+ = \max_i\{v_{ij}\}, \tag{27}$$

$$v_j^- = \min_i\{v_{ij}\} \;. \tag{28}$$

Step 5 (Separation measures)

The distances from the positive ideal solution and the negative ideal solution are respectively calculated according to the following formula:

$$d_i^+ = \left\{\sum_{j=1}^n \left(v_{ij} - v_j^+\right)^2\right\}^{\frac{1}{2}}, \tag{29}$$

$$d_i^- = \left\{\sum_{j=1}^n \left(v_{ij} - v_j^-\right)^2\right\}^{\frac{1}{2}}, \tag{30}$$

Step 6 (Relative closeness to the ideal)

The relative closeness to the ideal solution for each alternative is computed in accordance with the following formula:

$$C_i^* = \frac{d_i^-}{d_i^+ + d_i^-}. \tag{31}$$

Step 7 (Ranking of alternatives)

A set of alternatives can now be ranked according to the descending order of the C_i^*, and the one with the maximum value of C_i^* is the best.

7. Whitenization Technique

The results of our calculation using TOPSIS is based upon the decision matrix used for the grey method and presented in Table 8. However, to further utilize the grey numbers from Table 8, we used the whitenization concept described below: Whitenize the distance grey number using

$$\otimes G = \delta \underline{G} + (1-\delta)\overline{G}, \qquad \text{for } \delta \in [0,1]. \tag{32}$$

If $\delta = \frac{1}{2}$, then the amount of whitenization (Liu and Lin [24]) is said to be equal to the mean value with equal weights.

8. Case Study

Often the nature of a business forces the company to accept the technology earlier faster than other industries. For units whose traceability is vitally important, e.g., medical products, and safety-related components, the resource dependence theory would predict even quicker RFID adoption, since its ability to reduce “qualified” suppliers’ bargaining power expected to be particularly strong (Caves and Porter [4]). From the combination of the two factors, we have: (1) the nature of scarcity and (2) the relative ease with which RFID enables traceability. However, this type of a business may also accept the technology stage by stage.

From the literature we understand that the most appropriate types of alternatives that should be taken into consideration are those that relates RFID systems and barcode systems together. This is because of the power of the barcode and its popularity at the present time. Barcode is going to stay for a long time and is not expected to disappear soon. This is because the barcode system is less expensive to set up, manage, work with, and it is being used all around the world. Hence, this research is up to putting to vote the RFID-based-mixed-systems as an alternative to the team of decision makers (Table 3).

This means a stage by stage conversion from barcode system into the RFID-based system to give sufficient time to both producers and consumers to prepare their own RFID-based system for service. The criterias having highest preference to most managers in the entire industries are:

1. Hardware and software costs,
2. contribution of the system on the organization,
3. change of the current situation for a better one,
4. expert reliability on the RFID-based system support.

We are to review, a system selection problem where the most appropriate alternative needs to be identified using a group of five decision makers DM1, DM2, …, DM5. For this purpose, a list containing four RFID-based systems (see Table 3) are determined, related criteria are identified and passed to a team of five decision makers. Each decision maker provides the importance level of each criterion using the fuzzy linguistic terms given in Table 1. To determine the decision matrix, the fuzzy linguistic terms in Table 2 are used by the decision makers. More details on the criteria and the alternative systems under study are given below. Linguistic terms and fuzzy numbers used in the following sections are those provided in tables 1 and 2.

Four RFID-based systems starting with a system of 20 percent RFID and 80 percent barcode capabilities and ending up with a system of 60 percent RFID and 40 percent barcode capabilities, as discussed are considered here. Strategies presented in the following table are developed by a group of experts. Since each of these strategies is related with the development of one system, we simultaneously name them system type in the following tables.

Table 3. Strategies development for organization

Strategies	**RFID-based system**	**Barcode based system**	**Motives**
Use barcode system only and stay away from the RFID based-systems. Emergency decision may be made in future on the use of RFID **(System Type 1).**	20%	80%	This is a do-nothing strategy and can be very helpful when company wants to compare this strategy against other strategies as well.
Low-RFID mixed strategy concentration. Develop an RFID based system for the use of purchased products with RFID-tags used (**System Type 2).**	30%	70%	A chance to start exists here. But consuming products inside the organization are limited.
Mixed strategy RFID-Barcode concentration **(System Type 3).**	40%	60%	Relatively high concentration on the use of RFID in the organization.
High-RFID mixed strategy concentration. Develop an RFID-based system for the mixed use of purchased products and in-house developed products. **(System Type 4)**.	60%	40%	High concentration on the use of RFID-based system in the organization.

8.1 Grey-Based Theory Decision Making

After giving appropriate information to the same group of decision makers on the meaning of linguistic variables as grey theory intends, we then ask them to determine the grey scores and the criteria weights according to company's attributes as specified for the strategies. The seven level scales shown by tables 1 and 2 are used to assess the alternatives. The result of our data summary collected from these groups of experts is available and can be obtained by request from the author. Fig. 1 shows the hierarchical structure we are faced with in our decision making.

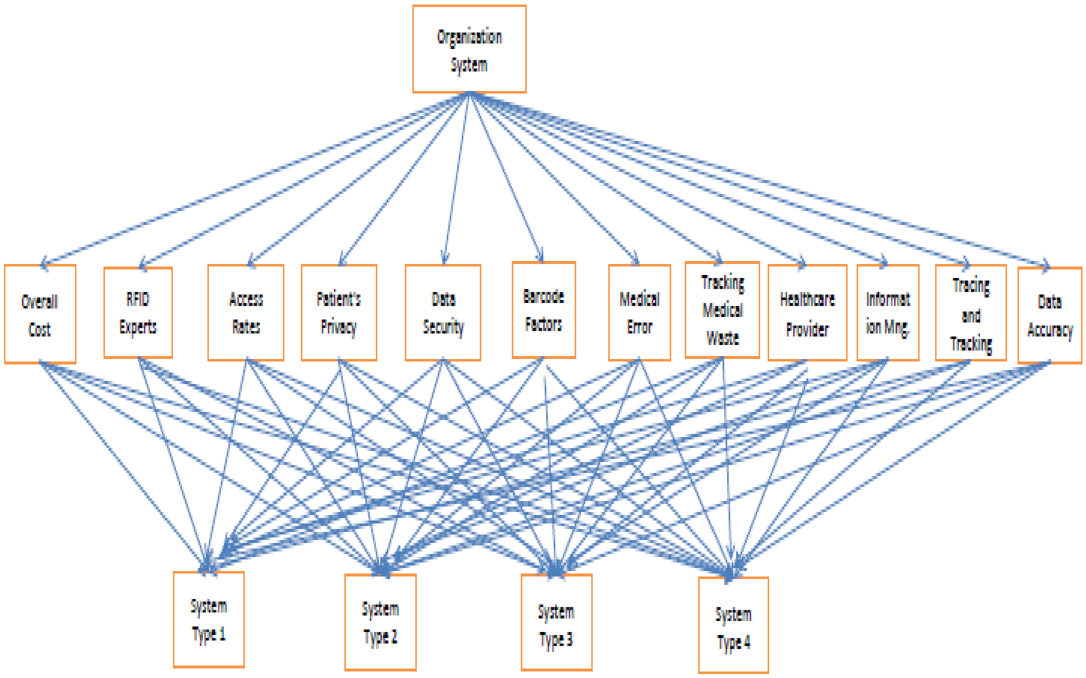

Figure 1. Hierarchical structures

8.2. Empirical Results

In our study, the eight proposed steps were followed to analyze the data provided by experts. The analysis was based on four alternatives $A_i, i = 1,2,3,4$, and 12 criteria $C_j, j = 1,2,3,\ldots,12$, as shown in Fig. 1. According to (8), the weights of the criteria were obtained from the group of experts and are shown in Table 4.

Table 4. Attributes weighted by decision makers

	Attrib 1	Attrib 2	Attrib 3	Attrib 4	Attrib 5	Attrib 6	Attrib 7	Attrib 8
DM1	VH	H	H	L	H	MH	H	VH
DM2	H	H	VH	M	VH	H	VH	H
DM3	VH	MH	VH	ML	H	MH	VH	VH
DM4	MH	VH	MH	H	H	MH	H	H
DM5	VH	H	H	ML	VH	VH	H	H
Weight	[0.76,0.9]	[0.64,0.86]	[0.7,0.88]	[0.34,0.5]	[0.72,0.94]	[0.6,0.74]	[0.72,0.94]	[0.72,0.94]

Table 4. (Attributes weighted by decision makers, Continued)

	Attrib 9	Attrib 10	Attrib 11	Attrib 12
DM1	M	VH	M	H
DM2	ML	H	MH	VH
DM3	M	H	M	H
DM4	L	VH	ML	H
DM5	MH	H	H	VH
Weight	[0.34, 0.46]	[0.72, 0.94]	[0.44, 0.58]	[0.72, 0.94]

Table 5. Decision matrix

	Attrib 1	Attrib 2	Attrib 3	Attrib 4	Attrib 5	Attrib 6	Attrib 7	Attrib 8
System1	[4.6,5.6]	[5.0,6.8]	[5.0,6.8]	[3.6,4.6]	[3.6,4.6]	[4.8,6.2]	[5.8,8.4]	[5.6,7.8]
System2	[4.6,5.4]	[5.4,7.2]	[5.6,7.8]	[3.8,4.8]	[3.8,4.8]	[5.2,7.0]	[6.6,9.0]	[5.6,7.8]
System3	[3.0,4.2]	[7.0,8.8]	[7.2,9.4]	[4.2,5.2]	[4.2,5.2]	[5.4,7.2]	[7.2,9.2]	[7.2,9.4]
System4	[2.2,3.4]	[7.2,9.4]	[7.8,9.6]	[4.8,5.8]	[4.8,5.8]	[5.8,8.4]	8.4,9.8]	[8.4,9.8]

Table 5. (Decision matrix, Continued)

	Attrib 9	Attrib 10	Attrib 11	Attrib 12	Overall
System1	[5.2 ,7.0]	[5.4, 7.6]	[5.2,6.6]	[4.6,5.6]	[4.57,6.05]
System2	[5.2 ,7.0]	[5.6,7.8]	[5.6,7.8]	[5.4,7.2]	[4.93,6.58]
System3	[6.4 ,8.6]	[7.0,8.8]	[6.6,9.2]	[6.4,8.6]	[5.60,7.42]
System4	[7.0 ,8.8]	[7.8,9.6]	[7.8,9.6]	[7.2,9.4]	[6.20,7.80]

Table 6. Normalized matrix

	Attrib 1	Attrib 2	Attrib 3	Attrib 4	Attrib 5	Attrib 6	Attrib 7	Attrib 8
System1	[0.39,0.48]	[0.74,1.00]	[0.74,1.00]	[0.78,1.00]	[0.78,1.00]	[0.77,1.0]	[0.59,0.86]	[0.57,0.8]
System2	[0.41,0.48]	[0.69,0.93]	[0.64,0.89]	[0.75,0.95]	[0.75,0.95]	[0.69,0.92]	[0.67,0.92]	[0.57,0.8]
System3	[0.52,0.73]	[0.57,0.71]	[0.53,0.69]	[0.69,0.86]	[0.69,0.86]	[0.67,0.89]	0.73,0.94]	[0.73,0.96]
System4	[0.65,1.0]	0.53,0.69]	[0.52,0.64]	[0.62,0.75]	[0.62,0.75]	[0.57,0.83]	0.86,1.0]	[0.86,1.0]

Table 6. (Normalized matrix, Continued)

	Attrib 9	Attrib 10	Attrib 11	Attrib 12	Overall
System1	[0.59,0.80]	[0.56,0.79]	[0.54,0.69]	[0.49,0.60]	[0.59,0.78]
System2	[0.59,0.80]	[0.58,0.81]	[0.58,0.81]	[0.57,0.77]	[0.63,0.84]
System3	[0.73,0.98]	[0.73,0.92]	[0.69,0.96]	[0.68,0.91]	[0.72,0.95]
System4	[0.80,1.00]	[0.81,1.00]	[0.81,1.00]	[0.77,1.00]	[0.79,1.00]

Table 7. Systems weighted by decision makers

	DM1	DM2	DM3	DM4	DM5	Overall
System1	[5.25,7.25]	[5.38,7.38]	[4.75,6.25]	[4.50,5.75]	[5.00,6.75]	[4.98, 6.68]
System2	[5.38,7.38]	[5.5,7.75]	[5.00,7.00]	[5.38,6.13]	[5.63,7.38]	[5.38,7.13]
System3	[5.88,7.88]	[6.5,8.25]	[5.38,7.50]	[5.75,7.88]	[6.38,7.63]	[5.98,7.83]
System4	[6.5,8.0]	[6.75,8.38]	[6.50,8.00]	[6.25,8.25]	[6.75,8.50]	[6.55,8.23]

Using the grey possibility degree formula, we get the following results:

$P\{S_1 \leq S^{\max}\} = 0.701,$
$P\{S_2 \leq S^{\max}\} = 0.691,$
$P\{S_3 \leq S^{\max}\} = 0.649,$
$P\{S_4 \leq S^{\max}\} = 0.621.$

Ranking the order of system alternatives is based upon the values obtained for the $P\{S_i \leq S^{\max}\}$, where a smaller value is better and a larger one is worse. Thus, we can say S4 > S3 > S2 > S1, which means that system type 1 has the lowest ranking and system type 2 is considered to be better than system type 1 but worse than type 3 and finally system type 4 has the highest ranking among all.

9. Validation of the Grey Method

To validate our model, we asked experts from the organization to compare results without telling how those results were obtained. Four experts out of five reached the results obtained by our approach. Experts recommended that the organization must start using RFID systems immediately.

9.1. VIKOR Approach

The weighted normalized matrix based upon the decision matrix of the case study is shown in Table 8. The max and min values of criteria are shown in Table 9, while the S and R values are shown in Table 10. Table 11 shows the S, R and Q values. The final ranking by the VIKOR approach is shown in Table 13. The final rankings of the four systems using the VIKOR approach are S3, S4, S2, and S1.

Table 8. Weight*normalized matrix (VIKOR)

	Attrib 1	Attrib 2	Attrib 3	Attrib 4	Attrib 5	Attrib 6	Attrib 7	Attrib 8
System1	0.602	0.411	0.394	0.443	0.443	0.438	0.439	0.431
System2	0.590	0.439	0.447	0.465	0.465	0.486	0.483	0.431
System3	0.425	0.551	0.554	0.508	0.508	0.502	0.507	0.534
System4	0.330	0.579	0.581	0.573	0.574	0.566	0.563	0.586

Table 8. VIKOR (Weighted*normalized matrix, continued)

	Attrib 9	Attrib 10	Attrib 11	Attrib 12	Overall
System1	0.439	0.433	0.400	0.369	
System2	0.439	0.446	0.454	0.456	
System3	0.540	0.526	0.535	0.543	
System4	0.569	0.580	0.590	0.601	

Table 9. Max and min values of criteria (VIKOR)

	Attrib 1	Attrib 2	Attrib 3	Attrib 4	Attrib 5	Attrib 6	Attrib 7	Attrib 8
f*j	0.330	0.411	0.581	0.573	0.573	0.438	0.563	0.586
f-j	0.602	0.579	0.394	0.443	0.443	0.566	0.439	0.431

Table 9. VIKOR (Max and min values of criteria, continued)

	Attrib 9	Attrib 10	Attrib 11	Attrib 12	Overall
f*j	0.569	0.580	0.590	0.601	
f-j	0.439	0.433	0.400	0.369	

Table 10. S and R values

	S Value	R Value
System1	7.100	0.830
System2	6.183	0.830
System3	3.381	0.625
System4	1.420	0.750
Max	7.100	0.830
Min	1.420	0.625

Table 11: S, R, and Q values

	S Value	R Value	Q Value
System1	7.100	0.830	1.000
System2	6.183	0.830	0.919
System3	3.381	0.625	0.173
System4	1.420	0.750	0.305
Max	7.100	0.830	1.000
Min	1.420	0.625	0.173

Table 12. S, R, and Q values with related system rankings

***S* Value**	**System**	***R* Value**	**System**	***Q* Value**	**System**
1.42	system 4	.625	System 3	0.17	System 3
3.38	system 3	0.75	system 4	0.31	System 4
6.18	system 2	0.83	system 2	0.91	system 2
7.1	system 1	0.83	system 1	1.0	system 1

The systems ranking in accordance with the VIKOR approach is shown in Table 13.

Table 13. Final ranking by VIKOR

ranking	Related Systems
1	System 3
2	System 4
3	System 2
4	System 1

9.2. TOPSIS Approach

The weighted normalized matrix based upon the decision matrix of the case study is shown in Table 14. Using positive and negative ideal solutions given, the systems 1, 2 ,3, and 4 are ranked as 4, 3, 2, and 1, respectively, as shown in Table 15.

Table 14. Weight*normalize matrix

	Attrib 1	Attrib 2	Attrib 3	Attrib 4	Attrib 5	Attrib 6	Attrib 7	Attrib 8
System1	0500	0.308	0.311	0.186	0.368	0.294	0.365	0.358
System2	0490	0.329	0.353	0.195	0.386	0.326	0.401	0.358
System3	0.353	0.413	0.438	0.214	0.422	0.336	0.421	0.443
System4	0.274	0.434	0.459	0.241	0.476	0.379	0.467	0.486

Table 14. (Weighted*normalized matrix, continued)

	Attrib 9	Attrib 10	Attrib 11	Attrib 12	Overall
System1	0.176	0.359	0.204	0.306	0.305
System2	0.176	0.371	0.232	0.379	0.331
System3	0.216	0.437	0.273	0.451	0.374
System4	0.227	0.481	0.301	0.499	0.402

$$A^{+} = (0.274, 0.308, 0.459, 0.241, 0.476, 0.294, 0.467, 0.486, 0.227, 0.481, 0.301, 0.499)$$

and

$$A^{-} = (0.500, 0.434, 0.311, 0.186, 0.368, 0.379, 0.365, 0.358, 0.176, 0.359, 0.204, 0.306)$$

Table 15. Positive and negative distances and ranking of systems by TOPSIS

	d+	d-	(d+) + (d-)	Ci*	Ranking
System1	0.089	0.012	0.100	0.115	4
System2	0.062	0.012	0.074	0.159	3
System3	0.016	0.044	0.060	0.731	2
System4	0.012	0.089	0.100	0.885	1

9.3. Comparison of Results

Table 16 shows the ranking results obtained by the three approaches of grey theory, VIKOR and TOPSIS. The results show that the grey theory and TOPSIS have the same ranking results while VIKOR's result is slightly different. Due to the fact that the values of S and R in the VIKOR approach are very close, one may also consider the following ranking for the VIKOR approach with some risks:

S4>S3>S2>S1

Table 16. Comparison of System's ranking by Grey, VIKOR and TOPSIS approaches

	Grey Theory	VIKOR	TOPSIS
System1	S4	S3 or S4	S4
System2	S3	S4 or S3	S3
System3	S2	S2	S2
System4	S1	S1	S1

10. Conclusion

The proposed procedure can be employed to study the impact of various attributes on system selection in an organization. Usually, the decisions may not take into account a high number of attributes. Our work here provides practitioners with the grey point of view for traditional decision making to deal with imprecision and obtain prioritization of some alternatives taking a finite number of attributes into consideration. We employed grey theory to evaluate RFID-based systems and determine the most appropriate system among them. The practicality of the proposed model was demonstrated using a case study. To check the results obtained by our proposed approach, data was collected and grey theory was used. For model validation, fuzzy VIKOR and fuzzy TOPSIS were employed. For organizations intending to evaluate new systems with the proposed criteria, our study offers several benefits:

1. One contribution of the study is the hierarchical model presented in Fig.1 which provides a structured and logical method of synthesizing judgments that can be used for the evaluation of appropriate systems.
2. The second benefit of this study is the development of attributes that are based upon a comprehensive review through the literature of RFID and healthcare management.
3. The features of an organization with similar real world problem have been examined and identified here.
4. The model developed here provides an overview of a firm's decision-making process in the presence of incomplete information.
5. Organizations can understand the evaluation criteria of System's selection better by applying the proposed model.
6. The methodology outlined here is particularly useful for making decisions based on multiple criteria in the presence of linguistic preferences and incomplete information.
7. The framework can be customized and used for the selection of similar problems such as suppliers and contractor selection activities.
8. To apply the proposed methodology, the evaluator must remove irrelevant criteria and consider applicable criteria in own organization.

9. Organizations may take more than one criteria into consideration and hence the model can be modified and refined as necessary.

Moreover, it seems that the proposed grey method provides sufficiently accurate solutions compatible with the results obtained by the TOPSIS and VIKOR decision making approaches.

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