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Research Article

AN EFFICIENT MADM METHOD: ELECTROMAGNETISM-LIKE METHOD FOR SELECTION AND ORDERING

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ABSTRACT

Multiple Attribute Decision Making methods aims to improve the quality of decisions in various fields of management science. Decision makers are mostly faced with new decisions involving conflicting multiple objectives. Practically, these problems include a ranking information including individual/group judgments on a number of pre-determined alternatives with respect to different criteria. This study proposes a new method, called Electromagnetism-like Method for Selection and Ordering, to select the best alternative and/or to determine the rank order of finite number of alternatives. We investigated the performance of proposed method and achieved satisfactory results for many selection and ordering case. The comparative analysis with other multiple criteria decision making methods verifies the performance of the proposed method. The results show that the method is a useful tool to assist decision-makers in terms selection and ordering decisions.
Keywords: Multi-attribute decision analysis, electromagnetism-like heuristics, attraction-repulsion, distance based methods.

1. INTRODUCTION

Multiple criteria decision analysis (MCDA) methods have been frequently studied in the literature. Even though MCDA methods are widespread all the time, as a discipline it only has a relatively short history of about 30 years (Xu and Yang, 2001). Recent developments in computer technology accelerated the developments in MCDA field. Therefore, more extensive analysis can be performed on complex decision making problems. MCDA methods assist decision makers commonly in economic, financial, planning, health, dispute resolution, project selection, marketing, computer technologies, budget allocation, accounting, education, sociology, engineering, architecture and many different fields (Zahedi, 1986).

Recent studies in MCDA literature is generally based on adapting the existing MCDA methods to solve discrete decision making problems under varying decision making environments. Most of these studies propose a modification of existing methods to represent the uncertainty in decision making. In order to determine a particular MCDA method, the complexity of the problem in terms of scientific, social and technical factors, the system necessities, the objectives, decision space and available knowledge on the system should be well understood.

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Furthermore, decision making level, varying from operational to strategic, also reinforces the problem due to the participation of external stakeholders. Since the literature on MCDA methods has significantly expanded over the past decade, rational decision makers still need well-designed decision making tools in order to assess all feasible alternatives in detail within a reasonable amount of time.

The complexity of decision making problems increased the use of MCDA methods. In real life decision making, investigating a decision with multiple objectives is more common than investigating a decision with single objective. These objectives generally conflict each other and no single solution can be provided to optimize all objectives, simultaneously. MCDA methods provide pareto optimal solutions that does not necessarily satisfy all objective functions simultaneously and show the trade-offs between the competing objectives by pareto frontier. Without further information, such as subjective preference data, all pareto optimal solutions are considered as equally good and they are nondominated each other. For pareto optimality, we refer Korhonen et. al. (1981) for further reading.

This paper proposes a new MCDA method, so-called Electromagnetism-like Method for Selection and Ordering (EMSO), by inspiring Electromagnetism-like heuristics which is firstly introduced by Birbil and Fang (2003). Electromagnetism-like heuristics is a population based stochastic global optimization algorithm that employs an attraction-repulsion mechanism to move particles toward to optimal solution. The ease of implementation and flexibility of the heuristics enable us to adapt the analogy for selecting the best one among a pre-determined set of alternatives. The remainder of the paper is organized as follows: preliminary definitions are given Section 2; next, the proposed is explained Section 3; then, Section 4 presents an empirical example in order to understand the implementation of EMSO method; then, we employ EMSO for solving three MCDA problems in the literature in order to validate our results in Section 5; finally, some concluding remarks and further research suggestions are furnished in Section 6.

2. PRELIMINARIES

In this section, we briefly recall some fundamental notions of electromagnetism-like mechanism and distance based methods. Birbil and Fang (2003) introduced a novel method by employing an attraction-repulsion mechanism to move the sample points towards the optimality for global optimization. Similar to that in the elementary electromagnetism, each sample point is thought to be a charged particle that is released to a space. The charge of each point relates to the objective function value, which to be optimized. This charge also determines the magnitude of attraction or repulsion of the point over the sample population – the better the objective function value, the higher the magnitude of attraction. These charges are used to find a direction for each point to move in subsequent iterations (Birbil and Fang, 2003).

Birbil and Fang (2003) proposed that every feasible solution is charged positively in sign and the magnitude of the charge can be determined with respect to objective function. A particle which has a better objective value has greater value in charge and vice versa. The charge of a particle also determines the magnitude of attraction or repulsion effect in the population. A highly charged particle, in other words, a superior solution attracts every inferior particle of the population in order to converge to the optimal. The charge of particle i is calculated as follows:

$$q_i = \exp\left(-n\,\frac{f(x_i)-f(x_{best})}{\sum_{k=1}^{m}(f(x_i)-f(x_{best}))}\right) \tag{1}$$

where n denotes the dimension of the problem, m denotes the number of sample points.

The reason of multiplying the fraction by the dimension n is to restrain the fraction from getting very small for greater number of points in the population which can cause overflow problems in calculating the exponential function (Birbil and Fang, 2003).

2.1. Distance based Methods

Distance based MCDA methods are based on ranking alternatives according to how far they are from an ideal (or anti-ideal) alternatives. One of the difficulties here is to give a precise meaning to the intuitive concept of how far (Pomerol and Barba-Romero, 2000). We refer Pomerol and Barba-Romero (2000) for further reading on the concept of ideal alternative in distance based methods.

The first use of the notion of ideal in discrete MCDA was Linear Programming Technique for Multidimensional Analysis of Preference (LINMAP) method by Srinivasan and Shocker (1973). Afterwards, Hwang and Yoon (1981) introduced TOPSIS method by considering both proximity to the ideal and remoteness from the anti-ideal in order to evaluate the best one among a set of alternatives in terms of a set of pre-defined criteria. TOPSIS is a commonly preferred method in MCDA literature, such as, in facility location (Chu, 2002), supplier selection (Shahanaghi and Yazdian, 2009), EFQM Excellence Award Evaluation (Aydın et.al., 2012), information source selection (Tian et.al. 2013) and outsourcing decisions (Bottani and Rizzi, 2006).

This study investigates the adaption of a global optimization heuristics to discrete decision making environment. By defining two artificial solutions (the most attractive and the most repellent), we derive electromagnetic forces on feasible alternatives exerted by these artificial solutions in order to determine the rank order of alternatives. Since the forces and charges are calculated by using distance measure, the proposed method can be seen as a distance based method.

3. PROPOSED METHOD: EMSO

Let I be the set of alternatives $I = \{i \mid \forall i \in \{1,2,\dots,m\}\}$ where m denotes the number of alternatives and J is the set of criteria $J = \{j \mid \forall j \in \{1,2,\dots,n\}\}$ where n is the number of criteria. x_{ij} denotes for performance evaluation of alternative i with respect to criterion j and forms the decision matrix $X = [x_{ij}]_{m\times n}$.

The procedure of EMSO can be expressed in a series of steps:

Step 1: Construction of the decision matrix

Obtain judgement data for m alternatives over n criteria by utilizing a data elicitation process.

Construct the decision matrix X with the judgements of decision maker(s) on each alternative candidate with respect to each criteria.

Step 2: Standardization Procedure

To standardize raw measurements/assessments, normalize the assessments x_{ij} into standardized measures r_{ij}. The normalized decision matrix $R = [r_{ij}]_{m\times n}$ is calculated by using Euclidean normalization as in the following:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} {x_{ij}}^2}} \qquad \forall i \in I, \forall j \in J \qquad (2)$$

Step 3: Setting the Importance Weights

Determine the importance weights w_j for each of the criteria. In the literature, there several approaches to define the weight vector. Choosing an arbitrary weight vector $\boldsymbol{w} = [w_j]$ or an initial estimation given by the decision maker or weights equal to $1/n$ are appropriate approaches for determining weights (Zionts, 1978). Moreover, it is possible to employ more methods, such as analytical hierarchy process method, goal programming, etc.

Then, calculate the weighted normalized decision matrix $V = [v_{ij}]_{m\times n}$.

$$\mathrm{V} = \mathrm{W}\,.\,\mathrm{R} = [w_j][r_{ij}] \qquad \forall i \in I, \forall j \in J \qquad (3)$$

Step 4: Determination of Electromagnetically Attractive/Repulsive Artificial Solutions

Determine the Electromagnetically Attractive Artificial Solution (EAAS) A^A by:

$$\mathrm{A}^{\mathrm{A}} = \{v_1^A, v_2^A, \dots, v_n^A\} = \{(\max_j v_{ij} | i \in J^+), (\min_j v_{ij} | i \in J^-)\} \quad (4)$$

Determine the Electromagnetically Repulsive Artificial Solution (ERAS) A^R by:

$$\mathrm{A}^{\mathrm{R}} = \{v_1^R, v_2^R, \dots, v_n^R\} = \{(\min_j v_{ij} | i \in J^+), (\max_j v_{ij} | i \in J^-)\} \quad (5)$$

where J^+ is associated with benefit criteria, and J^- is associated with cost criteria.

Step 5: Calculation of Electrical Charges

Calculate the electrical charges for each alternative.

By mimicking the algorithm of electromagnetism-like mechanism, an EAAS A^A defines the highly attractive solution that to be converged. Contrarily, an ERAS A^R defines the least attractive point that to be diverged. For each alternative, we calculate the two different electrical charges, say q_{ij}^A and q_{ij}^R, which are respectively associated to EAAS and ERAS, in terms of criterion j. The calculation of charge is adapted from Birbil and Fang (2003) as in the following:

$$q_{ij}^A = \exp\left(\frac{v_j^A - v_{ij}}{\sum_{i=1}^m (v_j^A - v_{ij})}\right) \quad \forall i \in I, \forall j \in J \quad (6)$$

$$q_{ij}^R = \exp\left(\frac{v_{ij} - v_j^R}{\sum_{i=1}^m (v_{ij} - v_j^R)}\right) \quad \forall i \in I, \forall j \in J \quad (7)$$

It is possible to calculate the electrical charges as in Eq.8 - 9 which is proposed by Debel et.al (2006). We tested two formulations for several instances and they yield consistent results with each other.

$$q_{ij}^A = \frac{v_{ij} - v_j^A}{v_j^R - v_j^A} \quad \forall i \in I, \forall j \in J \quad (8)$$

$$q_{ij}^R = \frac{v_j^R - v_{ij}}{v_j^R - v_j^A} \quad \forall i \in I, \forall j \in J \quad (9)$$

In Debel et. al. (2006), better points have higher scores on q_{ij}, where $q_{ij} \in [-1; 1]$. If the objective function $f(x_i) > f(x_j)$, q_{ij} is positive and j attracts i. The opposite, i.e. repulsion, occurs when $f(x_i) < f(x_j)$, and no action is taken when $f(x_i) = f(x_j)$.

In this study, better points have smaller scores on q_{ij}^A and higher scores on q_{ij}^R. If $q_{ij}^A = 1$, then this point i will attracted most to approach the best solution and if $q_{ij}^A = 0$, then this point i will not be attracted since it has already been the best solution. Correspondingly, better points have higher scores on q_{ij}^R and smaller scores on q_{ij}^A. If $q_{ij}^R = 1$, then this point i will be repelled most in order to diverge from the worst solution and if $q_{ij}^R = 0$, then the point i will not be repelled since it has already been the worst solution. Here, we note that the points (alternatives) are stable and never moved through the best solution in EMSO method. The forces are calculated in order to evaluate the magnitude of the exerted forces by EAAS and ERAS.

Step 6: Calculation of Forces

Calculate the force vector for each alternative.

Birbil and Fang (2003)'s electromagnetism-like mechanism proposes that a point that has a better objective function value attracts the worse points and contrarily, a point that has a worse objective function value repels the others. Since the most attractive solution has the minimum objective function value, it attracts all other points in the population in electromagnetism-like mechanism. By preserving same viewpoint, Debel et. al (2006) calculates the exerted force on point i by point j as:

$$F_{ij} = (x_j - x_i)q_{ij} \qquad \forall i \in I, \forall j \in J \tag{10}$$

As the EAAS is the absolute point of attraction in EMSO; it attracts all other points in the population. On the contrary, the ERAS is the absolute repellant point that it repels all other points in the population. Since this study is devoted to discrete multi-criteria decisions (finite number of alternatives available), we do not need to move the points in order to determine a better new alternative. Therefore, we ignore attraction-repulsion abilities of all non-artificial alternatives.

In our study, we calculate two different force vectors in terms of each criteria. The first one is calculated according to attractive effect of EAAS and the second force vector is calculated according to repellant effect of ERAS. Thus, in terms of each criterion j, we compute the forces F_{ij}^A and F_{ij}^R exerted on alternative A_i by EAAS and ERAS respectively, as:

$$F_{ij}^A = (v_j^A - v_{ij})q_{ij}^A \qquad \forall i \in I, \forall j \in J \tag{11}$$

$$F_{ij}^R = (v_{ij} - v_j^R)q_{ij}^R \qquad \forall i \in I, \forall j \in J \tag{12}$$

The forces exerted on alternative i by EAAS/ERAS according to each criterion are combined by means of vector summation.

$$F_i^A = \left\| \sum_j F_{ij}^A \right\| \qquad \forall i \in I \tag{13}$$

$$F_i^R = \left\| \sum_j F_{ij}^R \right\| \qquad \forall i \in I \tag{14}$$

Step 7: Evaluation for Ordering

Determine a ratio of forces $\not{f}$ equal to the force exerted on alternative i by EAAS divided by the sum of the forces exerted on alternative i by EAAS and ERAS.

$$\not{f} = \frac{F_i^A}{F_i^A + F_i^R} \tag{15}$$

Then, all alternatives are ranked in accordance with the order of their force ratio $\not{f}$. Here, $\not{f}$ determines the ratio of attractive force over net force on alternative i. As the ratio gets higher, we can simply understand that this alternative requires relatively more force to reach the best solution EAAS, and vice versa. More specifically, an alternative i tends to be the best alternative as the force exerted by EAAS gets smaller and the force exerted by ERAS gets higher correspondingly.

4. AN ILLUSTRATIVE EXAMPLE

In this section, we represent an elementary selection/ordering problem in order to demonstrate the applicability and the implementation process of EMSO Method.

Step 1: Consider a set of three alternatives and four criteria to be maximized and let the importance weight vector for criteria is given as $w = [0{,}4 \quad 0{,}2 \quad 0{,}2 \quad 0{,}2]^T$.

Criteria

Alternatives	C1	C2	C3	C4
A	5	15	8	14
B	10	10	12	12
C	15	5	14	8

Step 2: The normalized decision matrix $R = [r_{ij}]_{m \times n}$ is calculated by using Euclidean normalization (Eq.2) as in the following:

Criteria

Alternatives	C1	C2	C3	C4
A	0,267	0,802	0,398	0,697
B	0,535	0,535	0,597	0,597
C	0,802	0,267	0,697	0,398

Step 3: The weighted normalized decision matrix $V = [v_{ij}]_{m\times n}$ **is calculated as in** Equation 3.

Criteria

Alternatives	C1	C2	C3	C4
A	0,107	0,160	0,080	0,139
B	0,214	0,107	0,119	0,119
C	0,321	0,053	0,139	0,080

Step 4: The EAAS and ERAS are determined with respect to each criterion which is given in Equations 4-5.

Criteria

	C1	C2	C3	C4
EAAS	0,321	0,160	0,139	0,139
ERAS	0,107	0,053	0,080	0,080

Step 5: The electrical charges q^A and q^R for each alternative are calculated as in Equations 8-9.

Criteria

Alternatives q^A	C1	C2	C3	C4
A	1,000	0,000	1,000	0,000
B	0,500	0,500	0,333	0,333
C	0,000	1,000	0,000	1,000

Criteria

q^R	C1	C2	C3	C4
A	0,000	1,000	0,000	1,000
B	0,500	0,500	0,667	0,667
C	1,000	0,000	1,000	0,000

Step 6: Calculate the force vector for each alternative by using Equations 11-12.

Criteria

Alternatives F_{ij}^A	C1	C2	C3	C4
A	0,2138	0,0000	0,0597	0,0000
B	0,0535	0,0267	0,0066	0,0066
C	0,0000	0,1069	0,0000	0,0597

Criteria

F_{ij}^R	C1	C2	C3	C4
A	0,0000	0,1069	0,0000	0,0597
B	0,0535	0,0267	0,0265	0,0265
C	0,2138	0,0000	0,0597	0,0000

The forces exerted on alternative i by EAAS/ERAS according to each criterion are combined as in the following:

Alternatives		$\|\|F^A\|\|$	$\|\|F^B\|\|$
	A	0,2220	0,1224
	B	0,0605	0,0706
	C	0,1224	0,2220

Step 7: Determine the ratio ∯

Alternatives		∯	Rank Order
	A	0,645	3
	B	0,462	2
	C	0,355	1

The alternative C with the minimum ratio ∯ represents the optimal choice which requires less force to converge the ideal solution.

5. COMPARATIVE PERFORMANCE ANALYSIS

This section presents the application results of proposed method for three selection/ordering problem in the literature.

The first problem, that we solved, is the cutting tool material selection problem (Maity et.al.,2012) in order to verify the performance of EMSO method. The results has been compared to the results of PROMETHEE, GRA, COPRAS-G and VIKOR methods. The problem and relevant data, is given in Maity et al.(2012), for evaluating 19 alternatives regarding 10 evaluation criteria. We employ 7-step EMSO method for cutting tool material selection problem and illustrate the final rank order of alternatives in Figure 1.

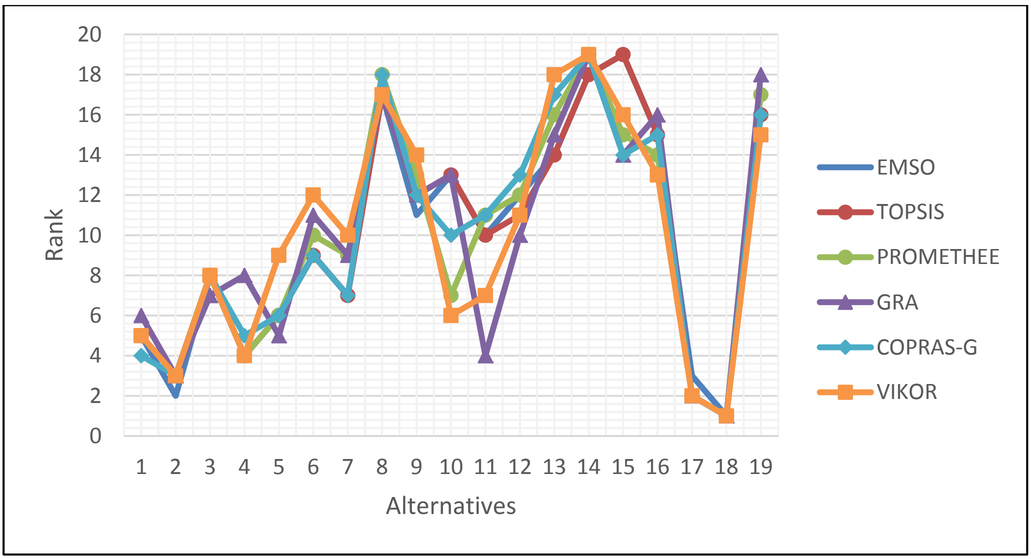

Figure 1. The comparison of EMSO results with respect to Maity et.al.(2012)

Figure 1 shows that the rank order proposed by EMSO method is consistent with the solutions which are obtained by using PROMETHEE, GRA, COPRAS-G and VIKOR (Maity et.al., 2012).

Table 1. Correlation coefficients for EMSO Method

	TOPSIS	*PROMETHEE*	*GRA*	*COPRAS-G*	*VIKOR*
EMSO	0,996	0,937	0,911	0,954	0,888

Table 1 represents the correlation coefficients between EMSO and other MCDA methods. EMSO method yields consistent results with respect to TOPSIS, PROMETHEE, GRA, COPRAS-G and VIKOR methods.

The second problem, that we solved, is a bank branch performance comparison problem (Ertuğrul et.al., 2009) has been solved by employing EMSO in order to compare the results obtained by VIKOR method. To compare the performances of 18 bank branches, they determine 10 evaluation criteria. Relevant data and criteria can be found in Ertuğrul et al. (2009). The comparative results of EMSO and VIKOR methods for bank branch performance comparison problem are illustrated in Figure 2.

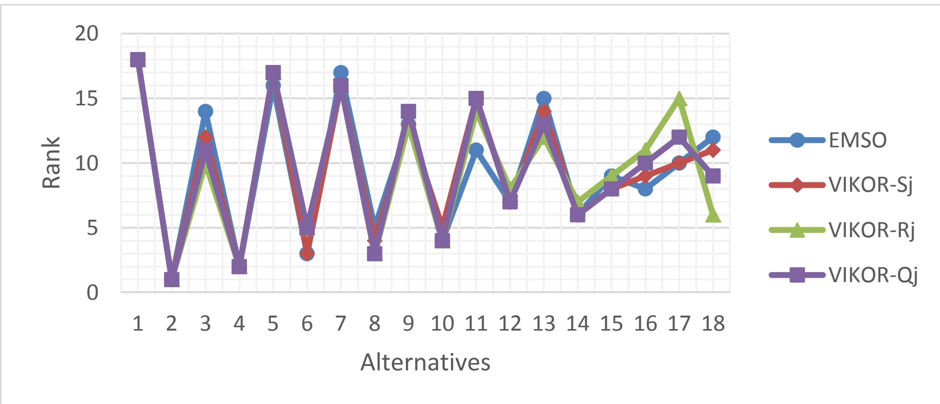

Figure 2. The comparison of EMSO results in regard to Ertuğrul et.al., (2009)

Figure 2 shows that the rank order proposed by EMSO method is perfectly compatible and again consistent with the solutions which are obtained by using VIKOR. the strong correlation between EMSO and VIKOR can be observed in Table 2.

Table 2. Correlation coefficients for EMSO Method in regard to VIKOR Methods

	VIKOR-Sj	*VIKOR-Rj*	*VIKOR-Qj*
EMSO	0,971104	0,880289	0,940144

The third problem, that we solved, is presented by Gomes and Rangel (2009). The study aimed to define a reference value for the rents of residential properties in the city of Volta Redonda, Brazil. They defined 8 criteria and employed TODIM method.

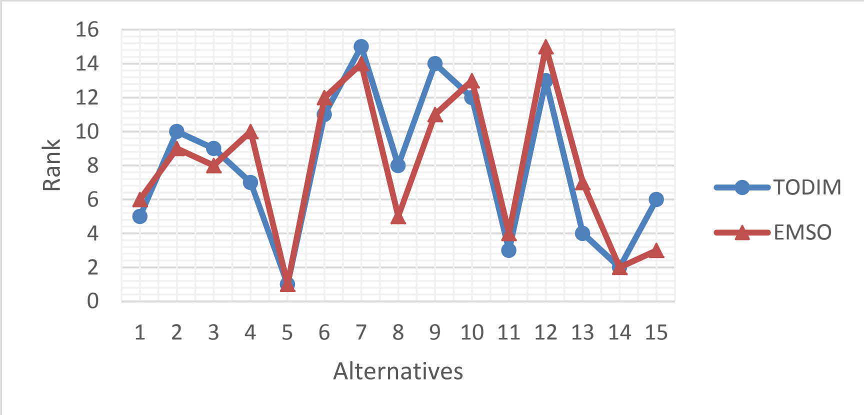

Figure 3. The comparison of EMSO results in regard to Gomes and Rangel (2009)

We utilized EMSO method and obtained similar ordering of alternatives with TODIM method. Figure 3 shows that both rank orderings, proposed by EMSO and TODIM, yields consistent results each other. The correlation coefficient, which is calculated as 0,90, enable TODIM to verify the conclusions of EMSO method.

6. CONCLUSIONS AND FUTURE RESEARCH

MCDA problems have been frequently encountered in real-life decision making. Researchers have continuously been proposing new approaches/methods to solve numerous types of MCDA problems in different decision making environments.

In this context, we propose a new approach for selection/ordering a finite number of alternatives by processing an attraction-repulsion mechanism inspiring by Electromagnetism-like heuristics (Birbil and Fang, 2003). The proposed method defines two artificial solutions; EAAS (the absolute point of attraction) and ERAS (the absolute repellant point) in order to determine the ranking of alternatives. By analyzing the comparative performance of proposed method, EMSO yields competitive results with popular MCDA methods; TOPSIS, VIKOR, PROMETHEE, GRA, COPRAS-G and TODIM methods. Although we illustrate the implementation of EMSO method with three selection/ordering problems in the literature, it can also be applied to problems such as supplier selection and many MCDA problems.

Since the EMSO method is flexible and easy to implement for many decision making problems, it enables decision makers to achieve satisfactory results for many selection and ordering case, straightforwardly.

For future study, EMSO method open for new developments; such as

- by adapting a fuzzy/interval mechanism for handling information vagueness,
- by defining an aggregation/consensus procedure for group decisions,
- by introducing specialized elicitation method for collecting data,
- by testing the performance of EMSO method with regard to MCDA methods for different decision making environments.

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