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A COMPARATIVE STUDY OF USING MCDM METHODS INTEGRATED WITH ENTROPY WEIGHT METHOD FOR EVALUATING FACILITY LOCATION PROBLEM

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Abstract: *The location selection of facilities became a major interest for the organizations to establish their planned business for a long period of time. The choice of the best location among a set of candidate locations is a complex process. Although the multiple criteria decision making (MCDM) methods are applicable for location selection problems, different solutions can be obtained using different MCDM methods. Thus, a comparative study between four different MCDM methods was applied within numerical example to show the deviations in ranking of the alternatives that occurs when different methods are used. The weights of attributes are assigned using objective method namely Entropy weight method. The rank disagreements are expressed using spearman`s correlation coefficients.*

Keywords: *Multiple-criteria decision making (MCDM); Facility location problem (FLP); Comparative study; Rank disagreement.*

1. Introduction

Locating a facility is a common problem generally called facility location problem (FLP). The study of facilities location was mainly as a result of Weber`s book "Theory of the Locations of the Industries" as Weber and Friedrich (1929) stated how to determine the location of a single warehouse to minimize the distance function. The location theory gained the researchers` interest as Hakimi (1964) mentioned how to find the optimum location of a switching center in a communication network and the best location for police station in a highway system. Facility location models can vary according to their objective function, number and sizes of the facilities and several other decisions (Farahani, 2009).

Traditionally, the objective of FLP could be minimizing either the costs of transportation or the distance from the demand areas. The FLP was analysed by a lot of researchers (Toregas et al., 1971; Voogd, 1983; Francis et al., 1992; Marianov et al.,

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2002; Drezner & Hamacher, 2004) and throughout the analyzation, it was developed to be a MCDM problem where several criteria are taken into account. This type of problems is called multiple criteria facility location problem where it is required to assign suitable location for a facility relative to a set of criteria. These criteria could be transportation costs, the land costs, safety and security, etc. Several alternatives are evaluated, data are collected and decisions are made relative to the defined set of criteria. The decision maker (DM) is responsible for making the right decision through various MCDM methods. The main steps in MCDM may be illustrated as follows:

(1) Establishing the criteria relating to a set of goals.

(2) Generation of the alternatives.

(3) Measuring the Performance of the alternatives.

(4) Applying a MCDM technique.

(5) Ranking of the alternatives.

(6) Accepting the solution obtained from the MCDM technique(s).

Steps (1) and (6) are mainly dependent on the decision makers while the other steps are likely an engineering tasks. A lot of potential is exerted in generating and evaluating the alternatives (steps (2) and (3)), and it can be even more harder to evaluate the alternative in some cases such as in the dynamic environment where the performance can be changed as a function of time. The generation of alternatives is a complicated process where there is no exact method or mathematical model to help in such process. Nothing can replace the human creativity in generating the alternatives.

For step (4), the decision maker must show his preference in applying a certain technique for obtaining the weights of criteria and the ranking of alternatives. Many MCDM approaches are available nowadays, most of them are following the same steps of making a decision. The only doubt is that each MCDM techniques produces a diverse ranking from the other techniques (Voogd, 1983). The differences in the mathematical models of MCDM methods leads to inconsistency of ranking. Afterwards, leads to several possible solutions.

Several MCDM methods can be applied to FLPs such as technique for order of preference by similarity to ideal solution (TOPSIS) method, grey relational analysis (GRA) method, weighted sum method (WSM), analytical hierarchical process (AHP) (Alosta et al. 2021), evaluation based on distance from average solution (EDAS) method and combined compromise solution (CoCoSo) method. The pre-mentioned methods require a method for assigning the weights for criteria except for AHP as criteria weights are calculated using pairwise comparisons between the criteria.

Most of MCDM methods requires a technique for assigning the weights of criteria as each criterion must have its importance compared to other criteria. The assigned weights can be calculated through subjective or objective methods. In subjective methods, the weights are determined through the experience of judgements while the objective methods depend on mathematical computations that neglects the decision maker preference towards some criteria. One of the most common objective weighting methods is entropy weight method (EWM). The EWM is used widely by decision makers for determining criteria weights. However, it sometimes fails to express the importance of certain criterion within a set of decision criteria.

In this research, the classical methods namely TOPSIS and GRA are compared with some newly developed methods namely EDAS and CoCoSo for evaluating the facility location problem. The focus will be on the deviation of ranking for the four different methods and whether they will agree the best and worst alternative or not. The procedures of each method will be illustrated and the methods will be compared through a numerical example concerning a facility location problem.

2. Literature Review

In this section, the past studies that evaluated FLPs using MCDM is presented while there is a lot of focus on the studies that used more than one MCDM method for the evaluation of location problems as decision makers seek for optimal and consistent solutions. However, no solution will be considered to be the optimum one in the existence of conflicting criteria (Shokri et al., 2013).

Some studies used only one method to evaluate location problems as Athawale et al. (2012) applied PROMETHEE II method for FLP under linguistic expressions. The method was proved to be effective tool for location selection problems. Żak and Węgliński (2014) applied ELECTRE III/IV method for location selection of logistics center in Poland. Stević et al. (2015) applied AHP method for location selection of logistics center with three candidate locations.

Many studies headed for using more than one MCDM method to ensure the consistency of results as Chakraborty et al. (2013) applied four MCDM methods for location selection of distribution centers, the four methods are GRA, multi-objective optimization on the basis of ratio analysis (MOORA), operational competitive rating analysis (OCRA) and ELECTRE II. The four methods agreed the best location while there was a deviation in ranking for the remaining locations. They concluded that the deviation that occurred in ranking of the locations within each method is due to the difference in the mathematical model of each method. Niyazi and Tavakkoli (2014) used three MCDM methods for the same problem, the methods are TOPSIS, additive ratio assessment (ARAS) and complex proportional assessment (COPRAS). The three methods produced different ranking even for the best location.

Parhizgarsharif et al. (2019) ranked forty locations in a construction site to choose the top twenty locations for establishing twenty facilities within them. The criteria weights were determined using best-worst method (BWM), GRA and VIKOR methods were used for ranking the sites. They concluded that GRA method is reliable and its ranking can be considered as a final solution for their case study.

Mihajlović et al. (2019) applied two MCDM methods for location selection of logistics center in Serbia. They used AHP and hybrid AHP-WASPAS methods, AHP method for criteria weights, moreover, the ranking of alternatives and WASPAS for ranking of alternatives using weights from AHP method. The two methods agreed the choice of best and worst alternative, furthermore, the ranking was almost identical.

Adalı and Tuş (2021) ranked four candidate hospital site locations by TOPSIS, EDAS and combinative distance-based assessment (CODAS) methods. The three methods produced the same ranking and the authors pointed out to the simplicity of both TOPSIS and EDAS methods. Chen et al. (2018) used EDAS and modified WASPAS methods for a teahouse location selection in Lithuania. The results showed that using random weighting techniques leads to inconsistent ranking of applied MCDM methods.

The integration of fuzzy theory with MCDM methods was mostly used to overcome the problem of dealing with linguistic variables in most of MCDM methods. As a result, Chauhan and Singh (2016) applied fuzzy AHP and fuzzy TOPSIS to determine a location for throwing away the healthcare waste. Suman et al. (2021) compared between AHP and fuzzy AHP methods for location selection of furniture industry in Bangladesh. The two methods agreed the ranking of alternatives. However, there was a variation in the priority of weights developed by the two methods. Kieu et al. (2021) used hybrid spherical fuzzy AHP and CoCoSo method for location selection of distribution center in Vietnam. They proved the stability of CoCoSo method as the ranking was consistent regardless the value of parameter λ.

3. Methodology

In this study, the EWM is used to determine the criteria weights and the final ranking of alternatives will be done using TOPSIS, GRA, EDAS and CoCoSo methods. TOPSIS and GRA methods are well known to most of decision makers. However, the recently developed methods namely EDAS and CoCoSo require further analysis and preview. The beginning of the solution of any of the proposed methods must be the construction of the decision making matrix which represent the performance evaluation of alternatives with respect to criteria chosen by the decision makers.

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2j} & x_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & x_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mj} & x_{mn} \end{bmatrix}_{m\times n}$$

The rows stand for alternatives and the columns stand for criteria, $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$.

3.1 Entropy Weight Method

The entropy concept was developed by Shannon (1948) in theory of the communication to deal with uncertain information and missing data. However, the entropy concept was used to describe the irreversible motion that occurs in thermodynamics science. Later, entropy concept was found to be effective dealing with decision making problems (Zeleny, 2012). The method depends on the numerical data collected by decision makers to determine the relative importance of each criterion. In other words, the Shannon`s entropy was extended to entropy weight method which is an objective method for determining the weights of criteria. The steps of entropy weight method can be illustrated as follows:

(1) The normalization of numerical data using Weitendorf`s linear normalization (Aytekin, 2021),

$$\bar{r}_{ij} = \frac{x_{ij} - \min\limits_{i} x_{ij}}{\max\limits_{i} x_{ij} - \min\limits_{i} x_{ij}} \tag{1}$$

$$\bar{r}_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \tag{2}$$

Eq. (1) for benefit criterion and Eq. (2) for cost criterion.

(2) Calculate the intensity of the attributes using,

$$y_{ij} = \frac{\bar{r}_{ij}}{\sum_{i=1}^{m} \bar{r}_{ij}} \tag{3}$$

(3) Calculate the entropy measure using,

$$E_j = -\frac{1}{\ln(m)} \times \sum_{i=1}^{m} y_{ij} \cdot ln(y_{ij})\,;\ \{if\ (y_{ij} = 0)\ \rightarrow\ (y_{ij} \cdot ln(y_{ij})) = 0\} \tag{4}$$

(4) Determine the weight of each criterion using,

$$w_j = \frac{1 - E_j}{\sum_{j=1}^{n}(1 - E_j)} \tag{5}$$

3.2 TOPSIS Method

The classical TOPSIS procedures was developed by Hwang and Yoon (1981) in their book “Multiple-Attribute Decision Making” that was considered to be one of the most efficient MCDM methods. The basic algorithm of TOPSIS method is that the most preferred alternative having the minimum distance from the positive ideal solution (PIS) and the maximum distance from the negative ideal solution (NIS). The steps of classical TOPSIS method can be illustrated as follows:

(1) Normalize the numerical data using vector normalization represented by the formula,

$$r_{ij} = x_{ij} \Bigg/ \sqrt{\sum_{i=1}^{m} x_{ij}^2} \tag{6}$$

Where $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$ from the decision matrix [D].

(2) Calculate the weighted normalized matrix using,

$$v_{ij} = w_j r_{ij} \tag{7}$$

Where $i = 1, 2, \dots, m$, $j = 1, 2, \dots, n$ and w_i is weight of each criterion as $\sum_{j=1}^{n} w_j = 1$.

(3) Determine the PIS and the NIS for each alternative using,

$$PIS = \{v_1^+, \dots, v_n^+\} = \left\{\left(\max_i v_{ij} \mid j \in I'\right), \left(\min_i v_{ij} \mid j \in I''\right)\right\} \tag{8}$$

$$NIS = \{v_1^-, \dots, v_n^-\} = \left\{\left(\min_i v_{ij} \mid j \in I'\right), \left(\max_i v_{ij} \mid j \in I''\right)\right\} \tag{9}$$

Where I' represents benefit criteria and I'' represents cost criteria.

(4) Calculate the distances from the PIS and NIS for each alternative dependent on the Euclidean distance. The distance from the PIS is calculated as,

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \tag{10}$$

And similarly the distance from the NIS is calculated as,

$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{11}$$

(5) Calculation of the closeness coefficient for each alternative using,

$$CC_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{12}$$

(6) Ranking of the alternatives on basis of the closeness coefficient values. The higher the value of the closeness coefficient the more preferred the alternative.

3.3 GRA Method

Grey relational analysis (GRA) is derived from the grey theory that was developed by Ju-Long (1982). The grey theory proved to be efficient dealing with incomplete information. The word "grey" refers to the mixture of black and white, the colour black for unavailable information and white for the available information. Kuo et al. (2008) tested GRA method as a decision making method by comparing it with three different methods. They proved that GRA method is applicable as MCDM method for real-world problems. The steps of the GRA method can be illustrated as follows:

(1) The normalization of the decision making matrix using Weitendorf`s linear normalization represented by equations (1) and (2).

(2) Compute the deviation from reference sequences matrix using,

$$\Delta_{ij} = \left|x_{0j} - x_{ij}\right| \tag{13}$$

Where $x_{0j} = Max\{x_{ij},\ j = 1, 2, \dots, n\}$

(3) Calculation of the grey relational coefficients.

$$\gamma(x_{0j}, x_{ij}) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{ij} + \xi\Delta_{max}} \tag{14}$$

Where,

The distinguishing coefficient $\xi \in [0,1]$,

$\Delta_{min}= Min\{\Delta_{ij}, i = 1, 2, \dots, m\ ;\ j = 1, 2, \dots, n\}$,

$\Delta_{max}= Max\{\Delta_{ij}, i = 1, 2, \dots, m\ ;\ j = 1, 2, \dots, n\}$.

(4) Calculation of the grey relational grade (GRG) for each alternative.

$$\Gamma(X_0, X_i) = \sum_{j=1}^{n} w_i\ \gamma(x_{0j}, x_{ij}) \tag{15}$$

w_j is weight of each criterion as $\sum_{j=1}^{n} w_j = 1$.

(5) Ranking of the alternatives on basis of GRG values. The best alternative has the highest value of GRG.

3.4 EDAS Method

The EDAS method developed by Keshavarz et al. (2015), is claimed to be useful dealing with conflicting set of criteria in decision making problems. In EDAS method the evaluation is based only on one measure which is the distance from the average solution in positive and negative directions. The steps of EDAS method can be illustrated as below:

(1) The average solution (AV) according to a set of criteria is calculated using,

$$\overline{AV_j} = \frac{\sum_{i=1}^{n} x_{ij}}{n} \tag{16}$$

(2) The positive and negative distances from the average solution matrices are calculated using,

If $i \in I'$ then use equations,

$$PDA_{ij} = \frac{\max\left(0, \left(x_{ij} - \overline{AV_j}\right)\right)}{\overline{AV_j}} \tag{17}$$

$$NDA_{ij} = \frac{\max\left(0, \left(\overline{AV_j} - x_{ij}\right)\right)}{\overline{AV_j}} \tag{18}$$

If $i \in I''$ then use equations,

$$PDA_{ij} = \frac{\max\left(0, \left(\overline{AV}_j - x_{ij}\right)\right)}{\overline{AV}_j} \tag{19}$$

$$NDA_{ij} = \frac{\max\left(0, \left(x_{ij} - \overline{AV}_j\right)\right)}{\overline{AV}_j} \tag{20}$$

(3) Calculation of the weighted sum of PDA and NDA for each alternative using,

$$SP_i = \sum_{j=1}^{n} w_j PDA_{ij} \tag{21}$$

$$SN_i = \sum_{j=1}^{n} w_j NDA_{ij} \tag{22}$$

(4) Normalization of SP and SN values for each alternative using,

$$NSP_i = \frac{SP_i}{\max_i SP_i} \tag{23}$$

$$NSN_i = 1 - \frac{SN_i}{\max_i SN_i} \tag{24}$$

(5) Calculate the appraisal score for each alternative using,

$$AS_i = \frac{1}{2}(NSP_i + NSN_i) \tag{25}$$

Where $0 \leq AS_i \leq 1$

(6) Ranking the alternative based on the values of AS_i where the best alternative has the highest value of average score.

3.5 CoCoSo Method

This method was developed recently by Yazdani et al. (2019) which is based on two common approaches namely weighted sum model (WSM) and exponentially weighted product model. This method develops three different appraisal scores to evaluate the alternatives. Thus, a final coefficient combining these scores is calculated to obtain more robust results. The steps of the CoCoSo method is shown as follows:

(1) The normalization of the decision making matrix using equations (1) and (2).

(2) The calculation of the comparability sequences using,

$$S_i = \sum_{j=1}^{n} w_i \bar{r}_{ij} \tag{26}$$

$$P_i = \sum_{j=1}^{n} (\bar{r}_{ij})^{w_j} \tag{27}$$

S_i is the sum of the weighted comparability sequences and P_i is the sum of the power weighted comparability sequences.

(3) Three appraisal scores are calculated using,

$$k_{ia} = \frac{S_i + P_i}{\sum_{i=1}^{m}(S_i + P_i)} \tag{28}$$

$$k_{ib} = \frac{S_i}{\min\limits_i S_i} + \frac{P_i}{\min\limits_i P_i} \tag{29}$$

$$k_{ic} = \frac{\lambda S_i + (1-\lambda)P_i}{\lambda \max\limits_i S_i + (1-\lambda)\max\limits_i P_i}, \qquad \lambda \in [0,1] \tag{30}$$

(4) Final Ranking of the alternatives based on the values of coefficient k_i as the higher the value the more preferred the alternative.

$$k_i = (k_{ia}k_{ib}k_{ic})^{1/3} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \tag{31}$$

4. Numerical Example

In this section, the location problem presented by Żak and Węgliński (2014) is adopted. The aim of the problem is to select the most suitable region for placing logistics center (LC) in Poland. Ten different locations are nominated for placing the LC on their region, each location covers an area of 12 – 44 thousands km^2 and has a specific characteristic than the others. The performance of nominated locations is measured relative to nine criteria represented by C1, C2, …., C9 are considered to meet the stakeholders` interest and requirements. The set of criteria considered in this example are, Condition of transportation infrastructure (C1); Economic development (C2); Investment cost (C3); Level of transportation and logistics competitiveness (C4); Investment attraction (C5); Transportation and logistics attraction (C6); Social attraction (C7); Environmental affability (C8); Safety and security (C9). The attentive reader can refer to Żak and Węgliński (2014) for more details about the case study. The performance of alternatives within the set of criteria is shown in table (1). The outranking ELECTRE III/IV method was used to solve this problem. However, the proposed MCDM methods (Section 3) are used in this study which gives a clear ranking of the alternatives.

Table 1. The Performance of the Alternatives Respect to Criteria

Criterion	C1	C2	C3	C4	C5	C6	C7	C8	C9
Preference	MAX	MAX	MIN	MIN	MAX	MAX	MAX	MAX	MAX
A1	90.3	11350	392	9	1110	9709	4.5	7.5	7.5
A2	132.2	11558	421	12	1019	13379	7.17	6.5	4.5
A3	98	9416	395	6	1176	6991	4.33	6.5	8
A4	101.3	13275	443	9	312	11904	4.17	6.5	6
A5	138.5	11939	402	6	606	7958	7	8	7.5
A6	146.8	20049	424	18	284	15669	4	6.5	3.75
A7	133.1	9396	393	7	900	10425	7	6	7.5
A8	121.7	12989	395	10	2789	13275	8	7.5	5.25
A9	222.7	13822	406	12	1733	14382	4.17	4	3.75
A10	146.9	10131	397	13	2355	11653	7	4.5	4.75

5. Results and Analysis

In this section, the weights of each criterion are computed, the results of the four methods will be discussed and presented within tables. A comparative analysis between the four methods including spearman`s rank correlation analysis will be discussed.

5.1 EW Method

The weight of each criterion is calculated as shown in table (2). The weights of criterion C2 and C7 are the highest among the set of criteria which is realistic as the economic development (C2) and the social attractiveness (C7) are important factors for the success of the logistics center. The level of transportation and logistics competitiveness (C4) has the least value of weight which is confusing as the transportation is one of the most factors affecting the logistics centers. However, the weights obtained by the entropy method is satisfying for an objective weighting method.

Table 2. The Entropy Weights of Each Criterion

Criteria	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
E_j	0.851	0.799	0.934	0.935	0.833	0.903	0.794	0.918	0.841
w_j	**0.125**	**0.168**	**0.055**	**0.054**	**0.141**	**0.081**	**0.173**	**0.069**	**0.133**

5.2 TOPSIS Method

The ranking of each alternative on basis of the closeness coefficient values is shown in table (3). The ranked one alternative (A8) has the shortest distance from the ideal solution and the longest distance from the worst solution. Thus, it has the highest value of closeness coefficient.

Table 3. The Final Ranking of TOPSIS Method

Alternative	D_i^+	D_i^-	CC_i	Rank
A1	0.08149	0.04220	0.34117	**9**
A2	0.07506	0.04434	0.37136	**6**
A3	0.08488	0.04538	0.34837	**8**
A4	0.09632	0.03011	0.23820	**10**
A5	0.08081	0.04898	0.37739	**5**
A6	0.09445	0.05166	0.35360	**7**
A7	0.07892	0.04857	0.38097	**4**
A8	0.04640	0.08992	0.65963	**1**
A9	0.06414	0.06401	0.49948	**3**
A10	0.05745	0.07238	0.55746	**2**

5.3 GRA Method

The results of GRA method are presented in table (4). The value of the distinguishing coefficient (ξ) was set initially at 0.5 as per past researches (Tosun, 2006; Kuo et al., 2008; Abhang et al., 2021). The ranked one alternative (A8) has the highest value of GRG. In other words, A8 has the most similarity to reference sequence that makes it the best possible choice among the set of alternatives.

Table 4. The Final Ranking of GRA Method

Alternative	GRG	Rank
A1	0.51695	**8**
A2	0.49420	**9**
A3	0.52507	**7**
A4	0.43080	**10**
A5	0.58826	**2**
A6	0.53862	**4**
A7	0.55923	**3**
A8	0.68309	**1**
A9	0.53136	**5**
A10	0.52805	**6**

The value of distinguishing coefficient is analyzed to study its effect on the results of GRA method for this example. The distinguishing coefficient was set at 0.25, 0.5, 0.75 and 1 respectively. The results are shown in Fig (1). It is important to mention that the ranking of the of alternatives A8, A5, A9 and A4 are always ranked 1, 2, 7 and 10 respectively regardless the value of the distinguishing coefficient.

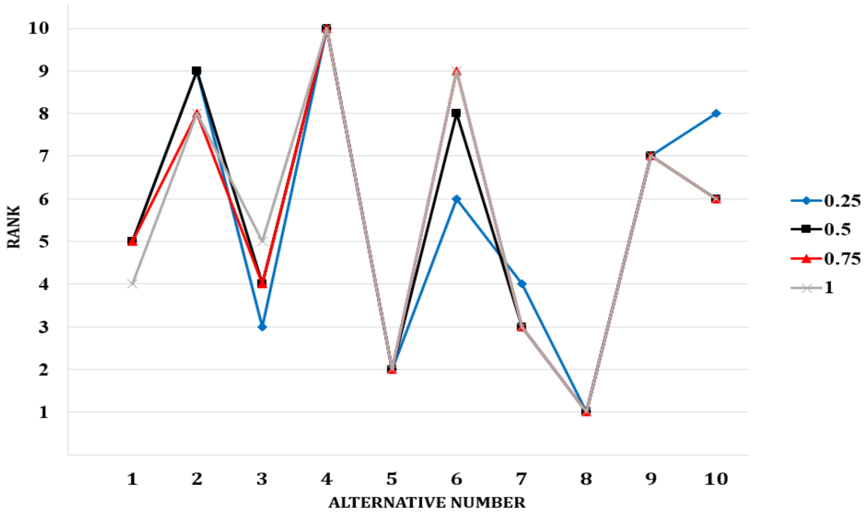

Figure 1. The Ranking of GRA Method for Different Values of Distinguishing Coefficient

5.4 EDAS Method

The results of EDAS method are presented in table (5). The best alternative (A8) has the highest positive distance from average solution and the shortest negative distance from average solution (after normalization using Eq. 24, the value of NSN_i increases as the value of SN_i decreases). As a result, the appraisal score of alternative (A8) is the highest among the set of alternatives. It is valuable to note the gap in the appraisal score between A8 (rank one) and A10 (rank two).

Table 5. The Final Ranking of EDAS Method

Alternative	NSP_i	NSN_i	AS_i	Rank
A1	0.20661	0.53047	0.36854	**7**
A2	0.20521	0.68894	0.44708	**6**
A3	0.26318	0.38895	0.32606	**8**
A4	0.09187	0.25713	0.17450	**10**
A5	0.43053	0.59305	0.51179	**4**
A6	0.52181	0	0.26090	**9**
A7	0.33481	0.64312	0.48896	**5**
A8	1	0.90288	0.95714	**1**
A9	0.64331	0.48344	0.56338	**3**
A10	0.64531	0.64019	0.64275	**2**

5.5 CoCoSo Method

The coefficient (λ) in Eq. 30 is usually given the value of 0.5 by the decision makers. Hence, the results of this method when $\lambda = 0.5$ are presented in table (6).

Table 6. The Final Ranking of CoCoSo Method

Alternative	K_{ia}	K_{ib}	K_{ic}	K_i	Rank
A1	0.09961	2.9070	0.82907	1.9001	**6**
A2	0.11205	3.2108	0.93264	2.1134	**4**
A3	0.09051	2.6170	0.75332	1.7166	**8**
A4	0.08936	2.3526	0.74374	1.6006	**9**
A5	0.11451	3.5790	0.95307	2.2798	**2**
A6	0.06815	2.3060	0.56724	1.4272	**10**
A7	0.10513	3.3134	0.87505	2.1042	**5**
A8	0.12015	4.0929	1	2.5270	**1**
A9	0.08841	2.8061	0.73584	1.7774	**7**
A10	0.11208	3.3375	0.93282	2.1648	**3**

The values for coefficient (λ) must be checked to measure the effect of (λ) on the ranking of the alternatives. The test values are 0.25, 0.5, 0.75, 1 respectively. The results of the analysis are shown in figure (2). The only change occurred due to the variation of (λ) is the ranking of alternatives A1 and A2 as they switched the ranks when the value of (λ) equal to one. The remaining alternatives had the same ranking regardless the value of (λ) coefficient.

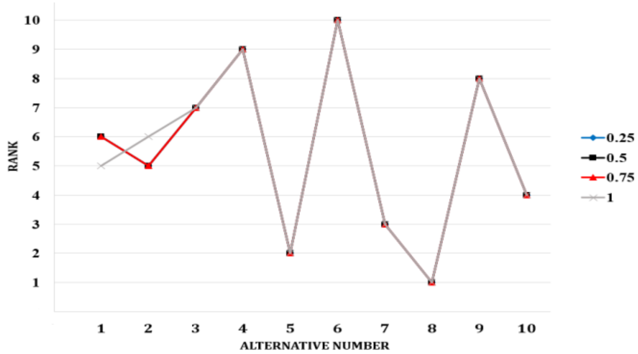

Figure 2 The Ranking of CoCoSo Method for Different Values of (λ) Coefficient.

5.6 Comparative Analysis

The final ranking of TOPSIS, GRA, EDAS, CoCoSo and reference method is shown in table (7). The results show that there is an agreement on the rank one alternative (A8). A disagreement occurred between the methods for the second choice alternative as EDAS and TOPSIS methods stand for A10 while GRA and CoCoSo methods stand for A5.

Table 7. The Comparative Ranking between the Four Methods and Reference Method.

Alternative	TOPSIS	GRA	EDAS	CoCoSo	Reference Method
A1	9	8	7	6	7
A2	6	9	6	4	6
A3	8	7	8	8	10
A4	10	10	10	9	9
A5	5	2	4	2	3
A6	7	4	9	10	4
A7	4	3	5	5	4
A8	1	1	1	1	1
A9	3	5	3	7	1
A10	2	6	2	3	7

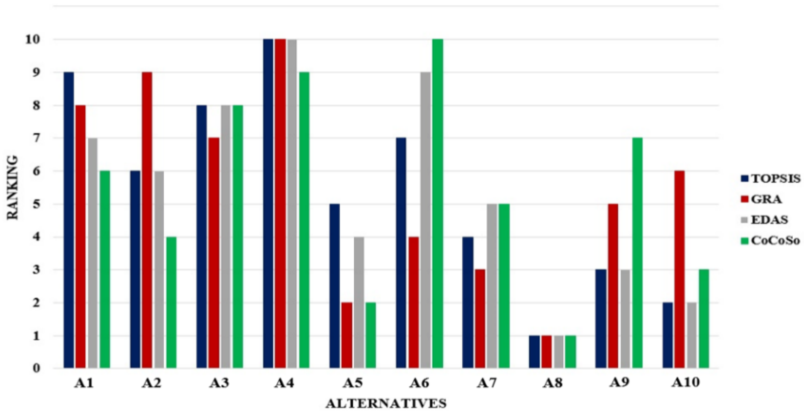

Figure 3. Graphical Representation of the Ranking Order for Each Method

A spearman`s rank correlation coefficient (r_S) is calculated to express the deviation between the rankings of different methods in numerical numbers. The value of (r_S) always lies between +1 and -1 where the value of (+1) indicates a perfect coincidence between the two methods and the value of (-1) indicated that there is no coincidence between the two methods. The closer the value of (r_S) to zero, the weaker the association of the ranking between the two methods. The value of spearman`s rank correlation coefficient can be calculated using,

$$r_S = 1 - \frac{6\sum d_i^2}{m \times (m^2 - 1)} \tag{32}$$

Where d_i is the difference in ranking of the alternative by the two methods and m is the number of alternatives.

Table 8. Rank Correlation Coefficients Between the Four MCDM Methods

MCDM Method	GRA	EDAS	CoCoSo
TOPSIS	0.69697	0.93939	0.69697
GRA	-	0.61212	0.49090
EDAS	-	-	0.8303

As shown in table (8), there is almost a perfect match between TOPSIS and EDAS methods as the two methods are similar to each other in the concept of solution while the smallest value of (r_S) was between GRA and CoCoSo methods. In general, the GRA method has a moderate correlation coefficient when compared to the other three methods

6. Conclusions

In this study, four MCDM methods namely TOPSIS, GRA, EDAS and CoCoSo were compared to show the deviation in the ranking of alternatives that occurs when using different MCDM methods. The four methods were applied to solve FLP regarding LC location selection and the weights of the criteria were assigned using EWM. The subsequent observations are:

1. The weights obtained by EWM is unreasonable regarding two criteria namely level of transportation and logistics competitiveness (C4) and transportation and logistics attraction (C6) as the transportation criterion is one the most important criterion for LC location selection problem. The decision maker`s preference must be present for such cases when the objective methods fail to express the importance of a certain criterion. However, the two criteria namely economic development (C2) and social attraction (C7) has reasonable weights.
2. Although the presence of two conflicting criteria namely investment cost (C3) and investment attraction (C5), the four different MCDM methods proved to be efficient dealing with such case. The alternative (A8) was selected as the best alternative by the four methods while the ranking of the other alternatives has some deviations from a method to others.
3. TOPSIS and EDAS methods has a very strong relation on basis of the spearman`s correlation value. The result was expected due to the similarity on concept of solution between TOPSIS and EDAS method.
4. Among the four methods, GRA method has the lowest correlation coefficient especially with CoCoSo method. The value of distinguishing coefficient is still confusing as it is based on the decision maker preference without a reasonable explanation. However, the choice of the best alternative has not changed when changing the value of distinguishing coefficient.
5. CoCoSo method is one of the newly developed methods that proved to be efficient as a MCDM tool. In this study, the value of the coefficient (λ) almost had no effect on the ranking of the alternatives. For further researches, the effect of changing the coefficient (λ) must be analyzed for different numerical examples.

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