A new multi-actor multi-attribute decision-making method to select the distribution centers' location

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***Abstract*—The location selection of distribution centers is one of important strategies to optimize the logistics system. To solve this problem, this paper presents a new multi-actor multi-attribute decision-making method based on ELECTRE I. The proposed method helps decision-makers to select a preferred location from a given set of locations for implementing. The strength of the proposed method is to incorporate the preferences of a set of decision-makers into account, notably the role of their experience into the decision-making process, consider both quantitative and qualitative criteria, take into account both desirable directions (Min and Max) and validate the selected location by both tests of concordance and discordance simultaneously. A case study is provided to illustrate the proposed method.**

***Index Terms*—Selection of distribution center's location, Multi-attribute decision-making, Multi-actor, ELECTRE I.**

I. Introduction

The location selection problem of distribution centers consists in determining a distribution center location from a set of alternatives, taking into account the decision-makers preferences and existing constraints (e.g. the investment cost, the possibility of expansion, the availability of acquisition hardware, the human resources, the proximity to suppliers, etc.) [1]-[3]. Fig 1 presents an illustration for the problem, where a set of decision-makers want to select a location of distribution center from several alternatives in order to integrate it into the supply chain.

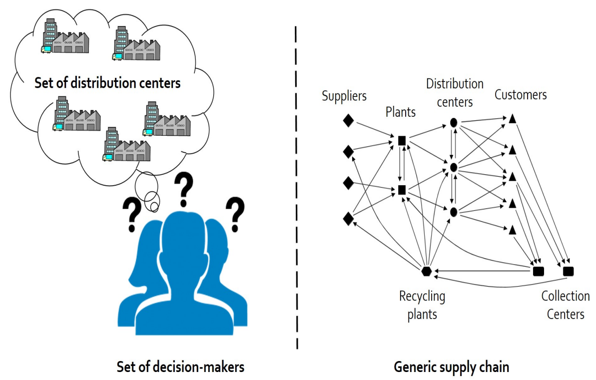

Fig. 1. The selection of distribution centers

Nowadays, selecting the location of distribution centers covers one of main strategic issues of distribution system for companies [4]. This decision is considered as one of the most important decision issues for logistic managers [5][6]. This is because it is regarded as a crucial decision in the design of efficient logistics systems (which have direct impact on the efficiency of logistics systems) [7] and as an important factor in the improvement of the logistic process in the cities.

In fact, the distribution center location plays an important role not only in minimizing traffic congestion and pollution [8] but also in decreasing transport cost [9][10]. Besides, the good location of distribution center may contribute in maximizing customers' satisfaction [10], as well as maximizing the acceptability by inhabitants, who live near the logistics platforms and are impacted by vehicles movements [8].

In this paper, we are interested in resolving the location problem of distribution centers under certainty by proposing a new multi-actor multi-attribute decision-making method. The proposed method is based on ELECTRE I [11]. The strength of our method consists in:

- incorporating the preferences of a set of decision-makers into account, notably the role of their experience into the decision-making process;
- considering both quantitative and qualitative criteria;
- taking into account both desirable directions (Min and Max);
- validating the obtained solution by both tests of concordance and discordance simultaneously.

The paper is composed of five sections. The section 2 presents a brief literature review. The proposed methodology is described in the section 3. The section 4 contains the experimental results. The conclusion and future work are provided in the last section.

II. Literature review

To arrange the survey in various aspects, we will divide it into two parts: studies on multi-criteria location problem of distribution centers and ELECTRE and its derivatives.

A. Studies on multi-criteria location problem of distribution centers

Much of the literature have studied the problem of selecting distribution centers location under a certain and a deterministic environment [3][10][12]-[21]. This kind of problem was characterized as static and deterministic, and parameters are known and fixed [22]. In practice, due to the complexity of the decision-making process and its ambiguity and vagueness related mainly to the human preferences and the anticipation of the different quantities and costs (e.g., the number of clients to serve and the fuel cost), many studies have been carried out on the problem under uncertainty [3][6][9][22]-[25]. In this category of problems, real data and information pertaining are unfixed numbers and lacked.

In this paper, we are interested to solve the problem under certain environment where the methods (see Table I and Table II) that have been proposed have some disadvantages:

- firstly, they can deal with only quantitative criteria like transport costs, proximity to customers and connectivity to multimodal transport. The consequence is that, qualitative criteria such as congestion level, customer satisfaction, safety, etc. are unconsidered in the decision-making process;
- secondly, they could not take into consideration both desirable directions (Min and Max) [26];
- thirdly, these methods do not take the preferences of a set of decision-makers into account, notably the role of their experience.

In order to overcome these disadvantages, we have proposed a new method based on ELECTRE I, which is a multi-attribute decision-making method.

B. ELECTRE and its derivatives

In the literature, ELECTRE and its different derivatives (ELECTRE I, ELECTRE II, ELECTRE III, ELECTRE IV, and ELECTRE TRI) are considered to be the most preferred methods [27] among several outranking methods like PROMETHEE and its derivatives (PROMETHEE I and II), ORESTE, QUALIFLES, MELCHIOR, MAPPACC, PRAGMA and TACTIC. ELECTRE is considered also as one of the best methods which take into account both desirable directions (Min and Max) [26].

The choice of one derivative among the ELECTRE derivatives depends on the nature of the problem [28]. In practice, ELECTRE I is suitable for selection problems, whereas ELECTRE TRI is adapted to treat the problems of assignment and ELECTRE II, III and IV to solve ranking problems.

ELECTRE I seems to be the most appropriate method to address the selection of distribution centers. However, ELECTRE I does not take into account the multiplicity of decision-makers and its preferences, which are important in the decision process. In our proposed method, we have taken into account this limit.

III. The proposed method

In this section, a new multi-actor multi-attribute decision-making method based on ELECTRE I is presented to solve the selection problem of distribution centers location. The ELECTRE I method [29] has been adapted in order to consider the preferences of a set of decision-makers. The procedure is described as follows:

Step 1. Constitution of decision-makers' committee: this step consists in forming a committee of the decision-makers involved in the decision-making process from various departments (distribution, quality, sustainable development, etc.).

Step 2. Identification of potential locations: this step consists in identifying a set of potential locations of distribution centers based on sustainable freight regulations, decision-makers' experience and knowledge conditions of freight transportation. The potential locations are those that cater to the interest of all city stakeholders, that is city residents, logistics operators, municipal administrations, etc. [23].

Step 3. Selection of location criteria: this step consists in selecting criteria like security, transportation cost and proximity to customers. Compared with the selected criteria, the alternatives will be evaluated.

Step 4. Importance weight assessment: this step consists, firstly, in assessing the importance weight by K decision-makers using the scale measurement and secondly in calculating the weight of each criterion (see Equation 1).

$$w_j = \frac{1}{K}\,[w_j^1 + w_j^2 + ... + w_j^K]. \tag{1}$$

Step 5. Alternatives rating assessment: this step consists in evaluating the rating of alternatives (see Equation 2) by K decision-makers using the scale measurement for assessing ratings, then constructing the decision matrix.

$$x_{ij} = \frac{1}{K}\,[x_{ij}^1 + x_{ij}^2 + ... + x_{ij}^K]. \tag{2}$$

The format of decision matrix can be expressed as follows:

$$D = \begin{bmatrix} x_{11} & x_{12} & ... & x_{1n} \\ x_{21} & x_{22} & ... & x_{2n} \\ . & . & & . \\ . & . & & . \\ . & . & ... & . \\ x_{m1} & x_{m2} & ... & x_{mn} \end{bmatrix}$$

$$W = \begin{bmatrix} w_1 & w_2 & ... & w_n \end{bmatrix}$$

where x_{ij}, $\forall\ i,j$ is the rating of alternative A_i (i=1,2,...,m) with respect to criterion C_j and w_j (j=1,2,...,n) is the weight of criterion C_j.

Step 6. Determination of the relationship between alternatives: this step consists in determining the relationship between the alternatives with respect to each criterion. The pairwise comparison of the alternatives (A_i and A_k where k in $[i..m]$ and $k \neq i$) can be established as follows

$$J^{+}{}_{(A_i,A_k)} = \{j \mid C_j(A_i) > C_j(A_k)\}, \quad (3)$$

where $J^{+}{}_{(A_i,A_k)}$ the set of criteria for which the alternative A_i is preferred over A_k.

$$J^{=}{}_{(A_i,A_k)} = \{j \mid C_j(A_i) = C_j(A_k)\}, \quad (4)$$

where $J^{=}{}_{(A_i,A_k)}$ the set of criteria for which the alternative A_i is equal in preference to alternative A_k.

$$J^{-}{}_{(A_i,A_k)} = \{j \mid C_j(A_i) < C_j(A_k)\}, \quad (5)$$

where $J^{-}{}_{(A_i,A_k)}$ the set of criteria for which the alternative A_k is preferred over A_i.

Step 7. Conversion the relationship between alternatives: this step consists in determining the sum of the criteria weights in each set of comparison:

$$P^{+}{}_{(A_i,A_k)} = \sum_j w_j \ \forall j \in J^{+}{}_{(A_i,A_k)}. \quad (6)$$

$$P^{=}{}_{(A_i,A_m)} = \sum_j w_j \ \forall j \in J^{=}{}_{(A_i,A_k)}. \quad (7)$$

$$P^{-}{}_{(a_i,A_m)} = \sum_j w_j \ \forall j \in J^{-}{}_{(A_i,A_k)}. \quad (8)$$

Step 8. Merging the numerical values: this step consists in merging the numerical values by calculating the Concordance Index (CI), the set of concordance and the Disconcordance Index (DI).

- Concordance Index (CI): This index expresses how much the hypothesis (A_i outclasses A_k) is consistent with the reality represented by the evaluations of alternatives. We remind that $0 \leq CI_{ik} \leq 1$.

$$CI_{ik} = \frac{P^{+}(A_i,A_k) + P^{=}(A_i,A_k)}{P(A_i,A_k)}, \quad (9)$$

where $P_{(A_i,A_k)} = P^{+}{}_{(A_i,A_k)} + P^{=}{}_{(A_i,A_k)} + P^{-}{}_{(A_i,A_k)}$.

- Set of concordance:

$$J(A_i,A_k) = J^{+}(A_i,A_k) \cup J^{=}(A_i,A_k). \quad (10)$$

- Disconcordance Index (DI):

$$DI_{ik} = \begin{cases} 0 & if \ \ J^{-}(A_i,A_k) = \emptyset \\ \frac{1}{\partial_j} \times \max\left(C_j(A_k) - C_j(A_i)\right) & where\, j \in J^{-}(A_i,A_k),\ otherwise \end{cases} \quad (11)$$

where ∂_j is the amplitude of the scale associated with criterion j. We remind that $0 \leq DI_{ik} \leq 1$.

Step 9. Filtering the alternatives: this step allows to extract, from all starting actions, the set of actions which respect Equation 12. From this set, one action will finally be retained. It is one that outclass more alternatives.

$$\left.\begin{matrix} CI_{ik} \geq ct \\ DI_{ik} \leq dt \end{matrix}\right\} \Leftrightarrow A_i \ S \ A_k \quad (12)$$

We remind that S is the outranking relation ($A_i \ S \ A_m$ means that A_i is at least as good as A_k).

IV. Experimental results

Let us assume that an accompany is interested in selecting a new distribution center location for implementing. The selection process of the best location is done by a committee of three decision-makers D_1, D_2 and D_3, the aim of which is to select a best location between three alternatives A_1, A_2 and A_3. To evaluate, the company considers six criteria:

- Security (C_1);
- Connectivity to multi-modal transport (C_2);
- Costs (C_3);
- Proximity to customers (C_4);
- Proximity to suppliers (C_5);
- Conformance to sustainable freight regulations (C_6).

The hierarchical structure of the selection process is illustrated by the Fig 2. The process selection is summarized in the following steps. First of all, the decision-makers (D_1, D_2 and

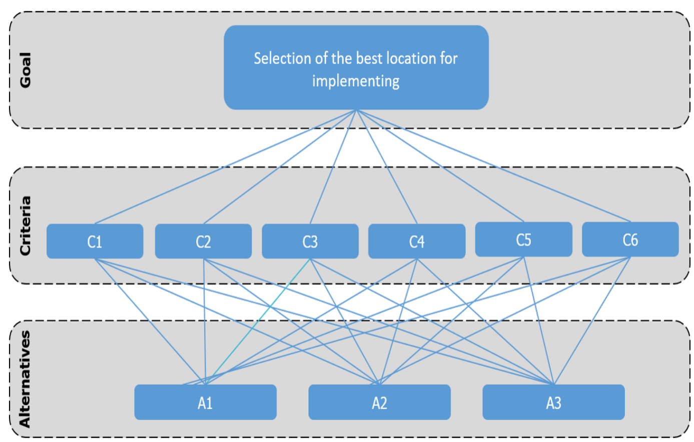

Fig. 2. The hierarchical structure of the selection of distribution centers' location

D_3) provided linguistic assessments for the criteria using the scale of weight importance (see Table III). Likewise, the rating of alternatives are attributed by the decision-makers using the appropriate scale (see Table IV).

The assessment for the criteria and alternatives are detailed respectively in Tables V and VI. We can see also in these tables (Tables V and VI) respectively the weight of each criterion (calculated using Equation (1)) and the rating of each alternative (calculated using Equation (2)).

TABLE I
THE PROPOSED METHODS FOR LOCATION SELECTION OF DISTRIBUTION CENTERS

Environment	Methods		Proposed by
Certain	Multi-criteria decision-making	Method based on k-means method	Simic et al. [16]
	Methaheuristics for the Multi-Objective Decision-Making	Conceptual framework based on Adjusted Kuehn-Hamburger model, method based on Grid model and ELECTRE	Ashayeri and Rongen [30]
		Fixed-Charge Facility Location model	Nozick and Turnquist [31]
		Genetic Algorithm	Fei et al. [12] Zhang et al. [14] Bai et al. [17]
		Bi-Level Programming model	Sun et al. [13]
		Method based on Centre of Gravity principle	Van Thai and Grewal [18]
		Binary Integer Programming	Chaiwuttisak et al. [21]
	Multi-Objective Compbinatorial Optimization	Non-Linear Integer Programming	Avittathur et al. [15]
		Branch and Bound	Crainic et al. [10]
		Method based on Exact Algorithm integrating the Adaptive Epsilon-Constraint method, method based on Branch and Bound and the Frank-Wolfe procedure	Gutjahr and Dzubur [19]
		Mixed Integer Linear method	Tang et al. [20]

TABLE II
COMPARISON OF SOME CHARACTERISTICS BETWEEN METHODS PROPOSED FOR LOCATION SELECTION OF DISTRIBUTION CENTERS

	Multi-Criteria decision-making		**Metaheuristics for the Multi-Objective Decision-Making**	**Multi-Objective Combinatorial Optimization**
	Multi-Attribute decision-making	**Multi-Objective decision-making**		
Alternatives	limited	limited	unlimited	unlimited
Solution(s)	one or more	one or more	one	one
Criteria	qualitative and/or quantitative	quantitative	quantitative	quantitative

TABLE III
LINGUISTIC VARIABLES FOR THE IMPORTANCE WEIGHT OF EACH CRITERION

Linguistic term	Weight
Very low (VL)	[0-0,2[
Low (L)	[0,2 - 0,4[
Medium (M)	[0,4 - 0,6[
High (H)	[0,6 - 0,8[
Very high (H)	[0,8 - 1]

TABLE IV
LINGUISTIC VARIABLES FOR ALTERNATIVES' RATING

Linguistic term	Rating
Very poor (VP)	1
Poor (P)	2
Fair (F)	3
Good (G)	4
Very good (VG)	5

TABLE V
THE CRITERIA WEIGHTS ATTRIBUTED BY DECISION-MAKERS

Criteria	Decision-makers			Weight
	D_1	D_2	D_3	
C_1	0,099	0,251	0,218	0,189
C_2	0,082	0,072	0,219	0,124
C_3	0,323	0,212	0,184	0,239
C_4	0,105	0,029	0,238	0,124
C_5	0,068	0,233	0,049	0,116
C_6	0,322	0,203	0,091	0,205

Next, using Equations (3), (4) and (5) we have obtained the pairwise comparison of the alternatives A_1, A_2 and A_3. The relationship between alternatives are determined (as shown in Tables VII, VIII and IX) with respect to the criteria. As an example, for C_1 the relationship between A_1 and A_2 is included in J^+ $(x_{11} > x_{12})$.

Then, considering the relationship between the different alternatives and using Equations (6), (7) and (8), we determined for each set of comparison the sum of criteria weight (see Tables X and XI).

Afterwards, the merge of the numerical values is obtained by calculating the Concordance Index CI_{ik}, and the Disconcordance Index DI_{ik}. For this step, we used Equations (9-11) as shown in Tables X-XIII and Fig 3.

Finally, to filter the alternatives we have all necessary information to realize the test of concordance and the test of disconcordance. The threshold ct of concordance test is fixed to 0,8. This test is satisfied if $CI_{ik} \geq$ 0,8. For the threshold dt of discordance test is fixed to 0,3. Then, the test is satisfied if $DI_{ik} \leq$ 0,3. The CI_{ik}, which satisfy the test of concordance is CI_{32}. The DI_{ik}, which satisfy the test of disconcordance are DI_{23} and DI_{32}. Therefore, based on both concordance and discordance tests, we found that: the action A_3 upgrade the action A_2 (as shown in Fig 4), because the relation of concordance CI_{32} and the relation of disconcordance DI_{32} are verified. Then, we can infer that the location A_3 is selected as the best location for implementing the new distribution center for the logistics company.

TABLE VI
THE DECISION MATRIX

Criteria	Alternatives	Decision-makers			Rating
		D_1	D_2	D_3	
C_1	A_1	3	3	2	2,667
	A_2	4	1	1	2
	A_3	1	3	3	2,333
C_2	A_1	4	4	2	3,333
	A_2	1	2	3	2
	A_3	3	1	2	2
C_3	A_1	4	2	3	3
	A_2	1	4	2	2,333
	A_3	2	4	2	2,667
C_4	A_1	3	1	1	1,667
	A_2	1	1	4	2
	A_3	1	4	1	2
C_5	A_1	4	1	1	2
	A_2	4	4	4	4
	A_3	4	4	3	3,667
C_6	A_1	2	3	4	3
	A_2	1	2	3	2
	A_3	3	1	2	2

TABLE VII
SUMMARIZE OF J^+

Alternatives	A_1	A_2	A_3
A_1	-	{1, 2, 3, 6}	{1, 2, 3, 6}
A_2	{4, 5}	-	{5}
A_3	{4, 5}	{1, 3}	-

TABLE VIII
SUMMARIZE OF J^-

Alternatives	A_1	A_2	A_3
A_1	-	{4, 5}	{4, 5}
A_2	{1, 2, 3, 6}	-	{1, 3}
A_3	{1, 2, 3, 6}	{5}	-

TABLE IX
SUMMARIZE OF $J^=$

Alternatives	A_1	A_2	A_3
A_1	-	∅	∅
A_2	∅	-	{2, 4, 6}
A_3	∅	{2, 4, 6}	-

TABLE X
SUMMARIZE OF P_{ik+}

Alternatives	A_1	A_2	A_3
A_1	-	0,757	0,757
A_2	0,24	-	0,116
A_3	0,24	0,428	-

TABLE XI
$P_{ik=}$

Alternatives	A_1	A_2	A_3
A_1	-	∅	∅
A_2	∅	-	0,453
A_3	∅	0,453	-

TABLE XII
THE MATRIX OF CONCORDANCE RATES

Alternatives	A_1	A_2	A_3
A_1	-	0,759	0,759
A_2	0,241	-	0,570
A_3	0,241	0,883	-

TABLE XIII
THE MATRIX OF DISCORDANCE RATES

Alternatives	A_1	A_2	A_3
A_1	-	0,5	0,417
A_2	0,333	-	0,083
A_3	0,333	0,083	-

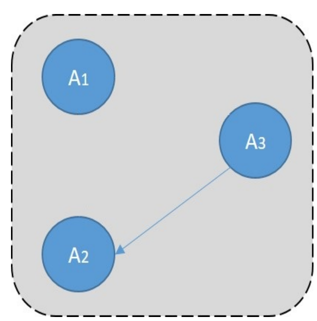

Fig. 4. The Outclass graph

V. CONCLUSION

In this paper, we present a new multi-actor multi-attribute decision-making method to select the distribution centers location under a certain environment. The decision-makers, the criteria and the set of distribution centers location are

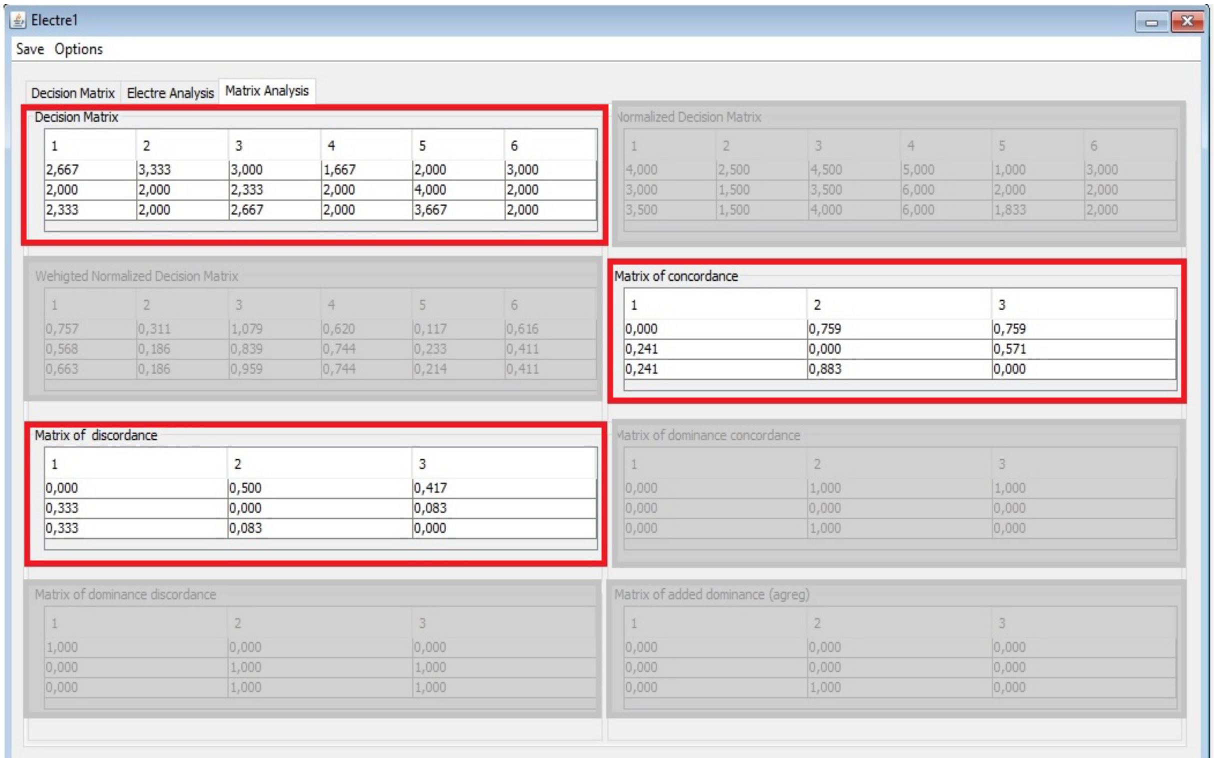

Fig. 3. The matrix analysis

determined. Then, influence factors of location selection are analyzed by means of proposed method based on ELECTRE I, and the best distribution center location is selected. The strength of our method is to:

- incorporate the preferences of a set of decision-makers into account, notably the role of their experience into the decision-making process;
- consider both quantitative and qualitative criteria;
- take into account both desirable directions (Min and Max);
- validate the selected location by both tests of concordance and discordance.

Our method was applied in a real case. The location obtained from 3 alternatives according to 6 criteria takes into account the preferences of 3 decision-makers. The proposed method can be practically applied in others selection problems such as the selection of the best location (of hospitals, hotels, and banks etc.), suppliers, projects and antibiotic, etc. Therefore, it can be used by different domains like logistic, biomedical, automatic, etc.

In our future work, we will take into account of the ambiguity and vagueness related mainly to human preferences, the real data and information pertaining, which cannot determine in advance and the data, which cannot be exact in such case.

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