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A MULTICRITERIA DECISION-MAKING APPROACH USED FOR THE SELECTION OF A LOGISTICS CENTER LOCATION

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Abstract**—**The logistics center represents a major part of modern logistics. The selection of an optimal location for the logistics center is crucial for a company to be competitive in today's global economy. This article presents the second stage of the multiple criteria decision-making analysis based on a two-stage procedure contributing to the selection of the most convenient location for a logistics center. In the second stage, the analysis of the counties is performed to define the most suitable locations for the logistics center within the region selected in the first stage. The appropriate criteria for the selection of logistics center location have been identified, and the considered variants are assessed, considering the decision maker's preferences and existing constraints. The variants are ranked in terms of their suitability for selecting a location by using the Electre III method. The results obtained from the simulation experiment indicate that this methodology is a feasible decision support model.

Keywords**—** logistics center, Electre III method, location problem, multiple criteria decision methods

I. INTRODUCTION

IN order to survive in today's rapidly increasing globalization of the economic environment, companies have to implement innovative strategies to improve their competitive advantages. Companies realize the importance of logistics in their organizations due to the fact that their success is not possible without efficient logistics which play a crucial role in the achievement of sustained competitive advantage.

Location problems involve establishing a suitable placement for an infrastructure in a studied area, taking into account a set of constraints and the options of the decision maker [1]. There are four components that depict location problems: facilities that will be located, customers, who are supposed to be already located on routes or at points, a space in which facilities and customers are located, and a metric that specifies geographical and chronological distances between facilities and customers [2].

Several mathematical formulations and approaches for solving the facility location problem have been reported, such as network location models, continuous location models and mixed integer programming models. In network location models, distances are considered as the shortest paths in a graph. Nodes represent demand points and possible facility sites correspond to a subset of the nodes and to points on arcs [3]. Network location models were developed by [4], [5] and so on. Continuous location models have two indispensable attributes: one is that the distance is measured with an appropriate metric and the other is that the solution space is continuous (this means that it is feasible to locate facilities on every point on a surface) [3]. Continuous location models were studied by [6], [7] and so on. Many location problems can be formulated as mixed integer programming models by using a given set of potential facility sites. In [8] a non-dominated sorting genetic algorithm approach was used to determine multi-objective facility location problems. They combined their algorithm a fast greedy fitness assignment heuristic, and a fitness assignment approach based on mixed integer programming for its fitness function. Reference [9] came up with a bi-objective mixed integer programming formulation model for integrated logistics network design.

One of the important issues in logistics is the location problem, which refers to finding the most suitable location of such logistic facilities as warehouses, distribution centers, passenger and cargo terminals, transportation hubs, material inventory and cross-docking area, parking lots, passenger's interchange terminals, and many others [1]. One of the most common logistics location problems refers to the appropriate placement of the logistics centers [10]. The logistic center is a logistical interconnection point within a logistic network whereby logistic activities (warehousing, transportation and forwarding, material handling, inventory management, cross-docking intermodal transshipment, physical distribution of goods) are performed on a commercial basis [1].

Facility location problem received a lot of attention recently. Multiple studies have been performed by using multiple criteria decision techniques, such as distribution center selection with weighted fuzzy factor rating system [11], location selection of logistics center based on Fuzzy AHP and TOPSIS [12], selection of logistics center location with fuzzy multi-criteria decision based on entropy weight [13], logistic center selection with fuzzy-AHP and Electre Method [14], selection of logistic centers location using Preference Ranking Organization

Method for Enrichment Evaluation (PROMETHEE) and Greedy heuristic algorithm [15].

The logistics center location should be considered as a two-level, hierarchical problem. In the first stage, the macro-analysis of the macro-regions should be developed to determine their overall potential and appropriateness for placing the logistics center on their territory. In the second stage, the micro-analysis is done to define the most convenient locations for the logistics center within the region selected in the first stage [1]. The main aim of this paper is to develop the analysis for the selected counties in order to define an adequate location for the logistics center and thus to perform the logistics activities within the region selected in the first stage [16]. Based on principles of multiple criteria decision analysis [1], [17], the authors formulated the issue of counties selection as multiple criteria ranking problem and solved it with software developed by them, based on the Electre III method.

The rest of the paper is organized as follows: in the second section the methodology of multiple criteria decision making is presented. The third section describes the decision problem focused on the counties evaluation, being the second component of the logistics center location problem. The variants (counties), evaluation criteria and decision making's preferences are detailed in this section. Furthermore, the results of the computational experiments are presented in the fourth section and, finally, the last section summarizes the conclusions.

II. METHODOLOGY

The goal of multiple criteria decision-making methods is to solve complex problems featuring conflicting objectives, high unpredictability, various forms of data and information, multi-interests and perspectives, and the accounting for complex and evolving socio-economic and biophysical systems [18]. There are four starting arguments that support the use of multi-criteria decision-making methods [19]:

1) Due to the fact that the input of qualitative and quantitative information from every decision maker is taken into consideration as criteria and weight factors, it enables the exploration and integration of the interests and objectives of several decision makers;

2) It provides output information that is easy to communicate to interested actors;

3) It is an acknowledged and implemented method of variants' assessment that also takes into account various versions of the method developed and researched for distinctive problems and/or contexts;

4) It is a method that allows objectivity and inclusiveness of various perceptions and interests of decision makers, and at the same time is not cost and energy intensive.

Among the existing methods, the ELECTRE III was chosen because it performs the analysis better than other multiple criteria decision-making methods; also for its ability to deal with imprecise, inaccurate, uncertain data, inevitable to complex processes in the human decision [20]. The Electre III method is based on the application of the outranking relation, this being very useful in ordering a finite set of variants from the best to the worst, on the basis of using a set of evaluation criteria [21]. Several studies have been performed using the Electre method, in various fields of expertise, such as environmental management and water consumption [22]-[24], oil and gas industry sustainability [20], energy systems selection [25]-[26], investments selection ranking actions [27], strategic sustainable management of demolition waste [28], British Universities ranking [29]. The three distinct stages of Electre III algorithm are depicted in fig. 1.

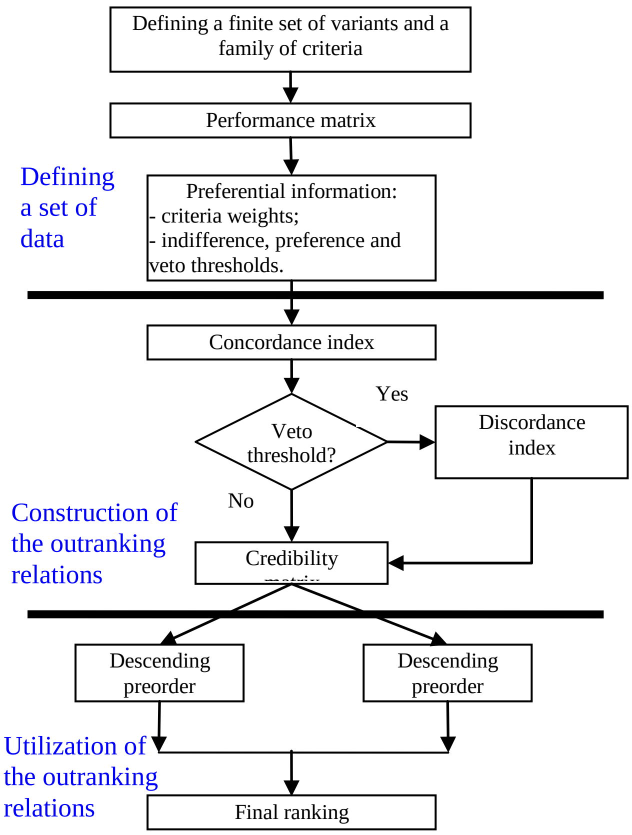

Fig. 1. The Electre III algorithm (adapted from [29])

The Electre III algorithm includes the following three stages [1], [29]:

1) *Defining a set of data* – a set of variants and a family of criteria used for comparison are defined, followed by the performance matrix development. Next, three thresholds are defined, respectively indifference (q_i), preference (p_i), and veto (v_i), as well as criteria weight indexes (w_i). The thresholds produce outranking relations with an allowance for data uncertainty.

2) *Construction of the outranking relations* – the alternatives are pairwise compared and each pairwise comparison is characterized by an outranking relation. The following types of relations between alternatives *A* and *B* can be taken into account [29]:

a) *A and B are indifferent* (*A I B*) – the decision maker cannot make any difference between alternatives.

$$A\ I\ B, \leftrightarrow q_i \geq f_i(A) - f_i(B) \quad (1)$$

where:
$f_i(A)$ – performance of alternative *A* based on criterion *i*;
$f_i(B)$ – performance of alternative *B* based on criterion *i*;
q_i – indifference threshold for the criterion *i*;
b) *A is weakly preferred to B* (*A Q B*) – the decision maker is skeptical of adopting one of them.

$$A\ Q\ B, \leftrightarrow q_i \leq f_i(A) - f_i(B) \leq p_i \quad (2)$$

where:
p_i – preference threshold for the criterion *i*;
c) *A is strictly preferred to B* (*A P B*) – the decision maker is sure that alternative *A* is favored to alternative *B*.

$$A\ P\ B, \leftrightarrow p_i \leq f_i(A) - f_i(B) \quad (3)$$

The next step is to determine the concordance index for each pair of alternatives *A* and *B* by comparing the performances of both alternatives for every criterion. The concordance index indicates the truth of the statement "*A* outranks *B*". A value of 1 establishes the full truth of the assertion and a value of 0 highlights that the statement is false. The concordance index is defined as follows [9]:

$$C(A,B) = \frac{1}{W} \cdot \sum_{i=1}^{n} w_i \cdot c_i(A,B) \quad (4)$$

where:

W – sum of all weights of criteria ($W = \sum_{i=1}^{n} w_i$);

w – weight of criterion *i*;
n – number of criteria;
$c_i(A,B)$ – concordance index over alternatives *A* and *B* with respect to the criterion *i*;

$$c_i(A,B) = \begin{cases} 1, \text{if } q_i(f_i(A)) \geq f_i(B) - f_i(A) \\ \dfrac{p_i(f_i(A)) + f_i(A) - f_i(B)}{p_i(f_i(A)) - q_i(f_i(A))}, \\ 0, \text{if } p_i(f_i(A)) \leq f_i(B) - f_i(A) \end{cases} \quad (5)$$

$$\text{if } p_i(f_i(A)) > f_i(B) - f_i(A) > q_i(f_i(A))$$

The next step is to calculate the discordance index for each pair of alternatives *A* and *B* by comparing the performances of both alternatives for every criterion. Discordance index evaluates the strength of the evidence against the statement "*A* outranks *B*", which can be overruled if the difference of performances between the alternative *A* and *B*, on any criterion *i*, is higher than the veto threshold v_i.. The discordance index for each criterion *i* ranges from 0 to 1 and is given by (6) [17].

$$D_i(A,B) = \begin{cases} 0, \text{if } p_i(f_i(A)) \geq f_i(B) - f_i(A) \\ \dfrac{f_i(B) - f_i(A) - p_i(f_i(A))}{v_i(f_i(A)) - p_i(f_i(A))}, \\ 1, \text{if } v_i(f_i(A)) \leq f_i(B) - f_i(A) \end{cases} \quad (6)$$

$$\text{if } v_i(f_i(A)) > f_i(B) - f_i(A) > p_i(f_i(A))$$

where:
v_i – veto threshold for the criterion *i*;

The degree of credibility of outranking is calculated based on the concordance and discordance indices. The credibility index *S(A,B)* is defined as follows [29]:

$$S(A,B) = \begin{cases} C(A,B), \text{if } C(A,B) \geq D_i(A,B)\ \forall i \\ C(A,B) \cdot \prod_{i \in J(A,B)} \dfrac{(1 - D_i(A,B))}{(1 - C(A,B))}, \text{otherwise} \end{cases} \quad (7)$$

where:
J(A,B) – the set of criteria for which $D_i(A,B) > C(A,B)$.

The degrees of credibility compose the credibility matrix.

3) *Utilization of the outranking relations* – in order to rank the alternatives, a procedure named distillation is used. The alternatives are ranked in two pre-orders which are constructed in different ways. By combining the two pre-orders, the final ranking is obtained. The results obtained from the partial pre-orders are aggregated into the ranking matrix. There are the following cases [29], [30]:
a) *Alternative A is higher ranked than alternative B in both distillations or A is better than B in one distillation and has the same position in the other one, then A is better than B: A P+ B;*
b) *Alternative A is higher ranked than alternative B in one distillation but B is better ranked than A the other distillation, then A is incomparable to B: A R B;*
c) *Alternative A has the same position in the ranking than alternative B in both distillations, then A is indifferent to B: A I B;*
d) *Alternative A is lower ranked than alternative B in both distillations or A is lower ranked than B in one distillation and has the same rank in the other distillation, then A is worst than B: A P – B.*

The final ranking is obtained by summing the number P+ for each alternative.

III. PROBLEM DESCRIPTION

A. Description of the options

In the first stage [16], the macro-analysis of the eight economic development regions of Romania was performed and the result determined as the most appropriate region for placing the logistic center on its location the Center Region (RC). The RC includes the following counties: Alba, Braşov, Covasna, Harghita, Mureş and Sibiu, illustrated in fig. 2.

In this paper, the six counties of the RC have been considered to represent potential areas for placing the logistics center on their territory.

Alba County (AB) is characterized by an average GDP (Gross Domestic Product) per capita ((€)7.609) and has the second most developed infrastructure in the region, after Sibiu County. The turnover of the clients and potential clients in this district is moderate ((RON)8.493 mil.) and the competitive rivalry between the existing companies is lower than average. The main disadvantage of this county is that the unemployment rate is the highest from RC (7,12(%)), which constitutes a serious social problem.

Fig. 2. The counties of the Center Region

Brașov County (BV) has many advantages: the highest turnover of the region ((RON)18.924 mil.), the highest GDP per capita ((€)9.313) and a great development potential. In this district the foreign companies invested the most, compared with the other districts from the RC, and the unemployment rate is the smallest (4,03(%)). The drawbacks are: the infrastructure of this county is not so developed, the labor cost is high ((€)497), second in Mureș County, and the most important drawback is the intense competitive rivalry among existing firms (42,57(%)).

Covasna County (CV) has a low labor cost ((€)390) and the second weakest competitive rivalry among existing companies (5,94(%)), after Harghita County. This district has several downsides: the lowest turnover of the target market ((RON)3.543 mil.), a low GDP per capita ((€)5.305), a weak development potential, the and the weakest transport infrastructure in RC.

Harghita County (HR) is characterized by the lowest GDP per capita ((€)4.907), the weakest development potential, and a low turnover of the target market, which creates an unfavorable environment for business decisions. The advantages of this district are: an average development of the infrastructure, a low competitive rivalry among existing firms (2,97(%)) and the lowest labor cost ((€)386), all which can arouse the interest to invest in this county.

Mureș County (MS) has an average GDP per capita ((€)5.962), a developed infrastructure and the second highest turnover in the region ((RON)17.666 mil.). The district is also characterized by the highest development potential and the foreign companies invested the second most ((€)966,22 mil.) compared with the other districts from the region, after Brașov County. The competitive rivalry among existing firms is average, as well as the unemployment rate (5,73(%)). The main drawback is the high labor cost ((€)465), similarly to Brașov County.

Sibiu County (SB) has many advantages: the second highest GDP per capita ((€)7.898), after Brașov County, the most developed infrastructure of the region and a high turnover of the target market ((RON)17.103 mil.), similarly to Mureș County. The district has a low unemployment rate (4,17(%)) and an average competitive rivalry among existing companies (18,81(%)). The main downside is that it has the highest labor cost in RC ((€)503).

B. Selection of the criteria

In this study, multiple criteria evaluation of the proposed counties has been accomplished with the application of a consistent family of criteria that includes economic, social and environmental aspects. In order to perform a complete evaluation of the counties, the authors have proposed the following criteria:

1) *Economic performance* (€) – is a maximized criterion, which is specified as the annual value of GDP per capita in the counties.

2) *Transport infrastructure* (points) – is a maximized criterion. It is expressed in terms of: the length of the public roads, railways network and airport infrastructure.

3) *The level of competitiveness* (%) – represents a minimized criterion and it shows the percentage share of the total competitors in each county.

4) *Target market* (units) – is a maximized criterion and it highlights the number of firms from specific industries towards which the company has decided to aim its efforts.

5) *Economic development potential* (points) – is a maximized criterion. It is expressed in terms of: net and gross investments, which directly contribute to increasing regional competitiveness, and built area.

6) *Foreign investments* (points) – is a maximized criterion and represent an important vector of economic development by creating new production capacities, implementing advanced technologies, more jobs, additional revenue from contributions, fees and taxes.

7) *Exports* (points) – is a maximized criterion and it highlights the exports of firms from specific industries towards which the company has decided to aim its efforts.

8) *State budget subsidies* (million RON) – is a maximized criterion and it shows the level of subsidies from the state budget in each county.

9) *Social dimension* (%) – is a maximized criterion. It is defined as the unemployment rate, which, from an economic perspective, may represent unused labor capacity.

10) *Labor cost* (€) – represents a minimized criterion and it shows the average gross nominal monthly wages in each county.

11) *Safety* (points) - is a maximized criterion. It is expressed in terms of: number of injured employed, the number of conflicts of interest, the number of traffic accidents, the number of offenses and crimes per 100000 inhabitants.

12) *Green areas* (ha) – is a maximized criterion and it shows green space area within the buildable perimeter of localities.

Table I shows the performance of all the alternatives to be evaluated with respect to identified criteria that meet stakeholders' expectations.

TABLE I
PERFORMANCE MATRIX [31]-[33]

Criteria / Alternatives	CI	CII	CIII	CIV	CV	CVI	CVII	CVIII	CIX	CX	CXI	CXII
AB	7,609	22.45	9.9	8,493	14.69	5.92	6.72	106.9	7.12	445.05	16.24	383
BV	9,313	14.16	42.58	18,924	22.12	6.94	7.86	117.3	4.03	497.07	18.34	389
CV	5,305	5.75	5.94	3,543	5.44	4.6	5.5	72	6.12	389.64	7.98	247
HR	4,907	11.34	2.97	3,823	5.02	4.42	5.62	103.8	5.2	385.81	8.76	496
MS	5,962	20.17	19.8	17,666	29.96	6.87	6.75	160.4	5.73	464.86	20.18	638
SB	7,898	26.14	18.81	17,103	22.77	6.12	7.65	129.8	4.17	502.7	17.67	471

Based on the preferences of company stakeholders, table II shows the values of thresholds and weights for each criterion.

TABLE II
THRESHOLDS AND CRITERIA WEIGHTS

Criteria / Preferences	CI	CII	CIII	CIV	CV	CVI	CVII	CVIII	CIX	CX	CXI	CXII
Indifference (q)	0.2	0.2	0.25	0.15	0.1	0.15	0.15	0.15	0.1	0.15	0.1	0.15
Preference (p)	0.4	0.3	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.25	0.25	0.3
Veto (v)	0.6	0.6	0.7	0.5	0.6	0.56	0.5	0.68	0.55	0.5	0.6	0.66
Weights (w)	0.06	0.2	0.05	0.22	0.12	0.08	0.07	0.04	0.03	0.08	0.03	0.02

IV. RESULTS

The computational experiments were carried out using software developed by the authors of this paper using the Electre III method algorithm. The computational experiments commence by the user' input of performance matrix and all the threshold and weight values. The software returns the concordance matrix, the discordance indices and the credibility matrix. Then, based on the credibility matrix the software develops the distillations. For displaying the final ranking, that comprises the alternative which overtakes the other ones, a matrix is constructed that contains the aggregation of the distillations results. When the final ranking is displayed, the software is able to show which is the most suitable solution based on the Electre III methodology.

In this paper, we implemented the software on a real case study. Each county from RC was examined, to determine which of these six best fits to locate a logistics center based on multiple criteria analysis. The alternatives, criteria and preferences of the company stakeholders are presented in the previous section.

Using the input data, the software generated the concordance matrix, the discordance indices and the credibility matrix, the last being presented in table III. Thereby, taking, for instance, the example of variants HR and SB, there are no arguments that HR outranks SB overall ($S_{(HR,SB)}$=0), while there are some high chances that SB outranks HR ($S_{(SB,HR)}$=0.82).

TABLE III
CREDIBILITY MATRIX

	AB	BV	CV	HR	MS	SB
AB	1	0	0.97	0.9	0	0
BV	0	1	0.28	0	0.07	0
CV	0	0	1	0	0	0
HR	0	0	0.98	1	0	0
MS	0.93	0.92	0	0.9	1	0.77
SB	0	1	0.73	0.82	0.79	1

In the next step, based on the credibility matrix, the software determined two preliminary rankings using descending and ascending distillations. The result of descending distillation showed a preference for MS, followed by AB, SB, HR, BV and CV. The ascending distillation showed that MS and SB were ranked as the best, followed by AB, HR, BV and CV. The final ranking is acquired by aggregating the pre-orders into the ranking matrix, presented in table IV.

TABLE IV
RANKING MATRIX

	AB	BV	CV	HR	MS	SB	Total P^+
AB	0	P^+	P^+	P^+	P^-	R	3
BV	P^-	0	P^+	P^-	P^-	P^-	1
CV	P^-	P^-	0	P^-	P^-	P^-	0
HR	P^-	P^+	P^+	0	P^-	P^-	2
MS	P^+	P^+	P^+	P^+	0	P^+	5
SB	R	P^+	P^+	P^+	P^-	0	3

The final ranking is obtained by summing the number of P+ from ranking matrix, for each alternative. The final ranking is shown in fig. 3.

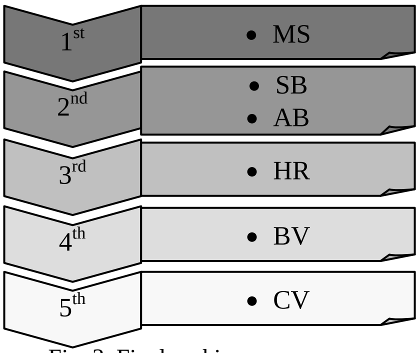

Fig. 3. Final ranking

It may be noted that MS had preference over the other counties, being the most suitable solution. Regarding variants SB and AB, there was no preference between them. At the other extreme, CV is placed at the bottom of the ranking, which denotes that it represents the least preferred county for placing a logistics center.

V. Conclusion

The logistics center location represents a complex process that should be considered as a two-level, hierarchical problem. In this paper, in order to define the most convenient locations for a logistics center within the region selected in the first stage, a micro-analysis was developed. The study presents the practical application of one of the multiple criteria decision-making methods, namely the Electre III method. Six counties have been identified and assessed according to twelve criteria that meet stakeholders' expectations. The family of criteria was adequate for evaluating the proposed counties, as it encompassed economic, social and environmental aspects of the study. By running the developed software, the final ranking of counties was acquired. As a result of the computational experiments, MS county outperformed the other counties, which means that it represents the most suitable county for placing the logistic center. The results prove that Electre III method may be very valuable in solving location problems.

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