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LOGISTICS CENTER LOCATION: SELECTION USING MULTICRITERIA DECISION MAKING

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Abstract**—**The selection of logistics center location represents one of the most important strategic decisions made by a company, because it has a significant and a long term impact on its overall activity risk and profit. The organizations which understand and anticipate the expectations and needs of the customers will do everything possible to meet their needs. This paper presents the selection of the most appropriate location for logistics center, formulated as a multiple criteria ranking problem. This process involved a complex assessment of the considered options, taking into account the decision maker's preferences and existing constraints. The options are ranked in terms of their appropriateness for selecting a location by using the Electre III method. The results obtained from computational experiments attest that this methodology is a feasible and a practical decision support model.

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

I. INTRODUCTION

IN order to be more competitive on the market, many companies have become more focused on increasing demand from customers for higher quality and service. The attainment of competitive advantage through offered services comes from a combination of carefully thought-out strategy for service and the development of appropriate delivery system [1]. Logistics centers occupy an important position in the supply chain management. The logistics center location selection implies finding the most appropriate location for logistics its facilities.

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 performed to determine their overall potential and adequacy for placing the logistic center on their territory. In the second stage, the micro-analysis is performed to define the most suitable locations of the logistic center within the region selected in the first stage [2]. In this paper the authors took into account the first stage of the logistic center location. The main aim of this paper is to develop the macro-analysis of the selected regions and to determine the most suitable one for performing the logistics activities. Based on principles of multiple criteria decision making [2]-[3], the authors formulated the problem of regions selection as a multiple criteria ranking problem and solved it with a software developed by them, based on the Electre III method.

II. METHODOLOGY

The multi criteria decision making/analysis is a field of study originating from operations research, which aims the development of mathematical procedures and advanced computer-based-methods that support the decision maker in solving multiple criteria decision problems [2]-[3]. A multiple criteria decision problem implies the definition of an actions/variants/solutions set S and a consistent family of criteria F in which the decision maker aims to [4]:

1) *calculate the best subset of actions/variants/solutions in S depending on F* (choice problem);
2) *divide S into subsets representing specific classes of actions/variants/solutions, in accordance to clear classification rules* (sorting problem);
3) *rank actions/variants/solutions in S from the best to the worst, according to F* (ranking problem).

The ELECTRE methods [5] were designed to improve the existing multiple criteria decision making methods. Within the ELECTRE methods, ELECTRE III was chosen because it allows the use of inaccurate, indefinite, imprecise and uncertain data [6]. The Electre III method is an effective method used in solving multiple criteria ranking problems, based on the application of the outranking relation. The method used is very useful in ordering a finite set of variants from the best to the worst, on the basis of evaluation criteria [4].

ELECTRE III has been used widely in different applications, including renewable energy sources field [7]-[8], education [9], in the area of environment and management of water consumption [10]-[11], in the transport planning field [12].

ELECTRE III contains two distinct stages [3], [9]:

1) *Constructions of the outranking relation* – the alternatives are pairwise compared and each pairwise comparison is characterized by an outranking relation.
2) *Exploitation of the outranking relation* – two pre-rankings are then performed to get recommendation from the results obtained in the first stage in order to obtain the final ranking.

The starting point in ELECTRE III represents the defining of a finite set of variants and a family of criteria with which to compare them. In order to determine outranking relations with respect to the defined criteria, this method is implemented based on successive pair wise comparisons of two alternatives [13]. Three types of relations between alternatives *A* and *B* can be considered [9]:

1) *A and B are indifferent* (*A I B*) if the indifference threshold is greater than or equal to the difference between the performance of the two alternatives. If *A* and *B* are indifferent, then the decision maker can not make any difference between alternatives.

2) *A is weakly preferred to B* (*A Q B*) if the indifference threshold is less than the difference between the performance of the two alternatives and the preference threshold is greater than the difference between the performance of the two alternatives. If *A* is weakly preferred to *B*, then the decision maker is skeptical to adopt one of them.

3) *A is strictly preferred to B* (*A P B*) if the preference threshold is less than or equal to the difference between the performance of the two alternatives. If *A* is strictly preferred to *B*, then the decision maker is sure that alternative *A* is favored to alternative *B*.

The next step is to estimate the concordance index for each pair of alternatives *A* and *B* by comparing the performances of both alternatives for all criteria. The concordance index indicates the truth of the statement "*A* outranks *B*". A value of 0 shows that the statement is false and a value of 1 denotes the full truth of the assertion (alternative *A* is better than alternative *B* for all criteria). The concordance index is defined as follows [9]:

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

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;

$$\mathbf{c_i(A,B)=\begin{cases}1,\text{if } p_i(f_i(A))\ge f_i(B)-f_i(A)\\ \dfrac{p_i(f_i(A))+f_i(A)-f_i(B)}{p_i(f_i(A))-q_i(f_i(A))}\\ 0,\text{if } p_i(f_i(A))\le f_i(B)-f_i(A)\end{cases},} \tag{2}$$
$$\mathbf{\text{if } p_i(f_i(A))>f_i(B)-f_i(A)>q_i(f_i(A))}$$

$f_i(A)$ – performance of alternative A as regards to the criterion i;

$f_i(B)$ – performance of alternative B as regards to the criterion i;

q_i – indifference threshold for the criterion i;

p_i – preference threshold for the criterion i;

The next step is to estimate the discordance index for each pair of alternatives *A* and *B* by comparing the performances of both alternatives for all criteria. Discordance index quantifies the strength of the evidence against the statement "*A* outranks *B*". In order to introduce discordance into the outranking relations, the veto threshold for each criterion is assigned. The statement "*A* outranks *B*" 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 is defined as follows [3]:

$$\mathbf{D_i(A,B)=\begin{cases}0,\text{if } p_i(f_i(A))\ge f_i(B)-f_i(A)\\ \dfrac{f_i(B)-f_i(A)-p_i(f_i(A))}{v_i(f_i(A))-p_i(f_i(A))}\\ 1,\text{if } v_i(f_i(A))\le f_i(B)-f_i(A)\end{cases},} \tag{3}$$
$$\mathbf{\text{if } v_i(f_i(A))>f_i(B)-f_i(A)>p_i(f_i(A))}$$

where:

v_i – veto threshold for the criterion i;

The degree of credibility of outranking is calculated taking into account the concordance and discordance indices. The credibility index *S(A,B)* is defined as follows [9]:

$$\mathbf{S(A,B)=\begin{cases}C(A,B),\text{if } C(A,B)\ge D_i(A,B)\,\forall i\\ C(A,B)\cdot\prod_{i\in J(A,B)}\dfrac{(1-D_i(A,B))}{(1-C(A,B))},\text{otherwise}\end{cases}} \tag{4}$$

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. The next step is performing the distillation procedure. A graph can be drawn from the credibility matrix. In order to rank the alternatives, a procedure named distillation should be used. The name distillation has been adopted for the analogy with alchemists, who distil mixtures of liquid to extract a magic ingredient. The alternatives are ranked in two pre-orders which are constructed in different ways. The ranking procedure includes the following three steps [9], [14]:

Step I. By using descending distillation procedure, a complete preorder Z_1 is created.

1) *The largest credibility index is determined*, λ_{max} = max *S(A,B)*, where the maximization is taken over the current set of alternatives under consideration.

2) λ *is calculated* $\lambda^*=\lambda_{\max}-(\alpha-\beta\cdot\lambda)$, where α, β are distillation coefficients. $\alpha = 0.3$, $\beta = -0.15$

3) *λ–strength is calculated for every alternative*, namely, the number of alternatives in the current set to which it is λ–preferred using $\lambda=\lambda^*$.

4) *λ–weakness, is calculated for every alternative*, namely, the number of alternatives in the current set to which are λ–preferred to it using $\lambda=\lambda^*$.

5) *The qualification is calculated for every alternative*, by difference between its λ–strength and its λ–weakness.

6) *The set of alternative with the largest qualification is*

called the first distillate, D_1.

7) *If D_1 is composed by more than one alternative, the process on the set D_1 has to be repeated until all alternatives have been classified*; then continue with the original set of alternatives without the set D_1, repeating until all alternatives have been classified.

Step II. By using ascending distillation procedure, a complete preorder Z_2 is created. The second distillation uses the same procedure as the descending one, except that at step f above, the set of alternatives having the lowest qualification forms the first distillate.

Step III. 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:

1) *The alternative A is higher ranked than the 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;*

2) *The 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;*

3) *Alternative A has the same position in the ranking than alternative B in both distillations, then A is indifferent to B: A I B;*

4) *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 of P+ for each alternative.

III. Problem description

A. Description of the options

In this study, the eight economic development regions of Romania have been considered. Romania was divided in eight regions, based mainly on the development regions created in 1998 for a better regional coordination toward accession to the European Union. These regions, named by their geographical position in the country, are illustrated in fig. 1 and represent potential areas for placing the logistics center on their territory.

The North East Region (**RNE**) is placed in the North-Eastern part of Romania and includes the following counties: Bacău, Neamţ, Iaşi, Botoșani, Suceava and Vaslui. The total area of this region is 36.850 (km^2) and has the largest population number, close to 3,3 million (people). This region is characterized by the lowest level of GDP (Gross Domestic Product) per capita ((€)4.119) and has a high unemployment rate (6,89(%)). The advantages of this region are: the maximum aid intensity for regional investment is 50(%) of the eligible costs of the relevant investment projects and the competitive rivalry among existing firms is not intense.

Fig. 1. The regions of Romania

The South East Region (**RSE**) is placed in South-Eastern part of Romania and includes the following counties: Brăila, Călăraşi, Constanţa, Galaţi, Ialomiţa, Tulcea and Vrancea. This region has the largest area, slightly above 39.000 (km^2) and its population number amounts close to 2,7 million (people). The region is featured by lower than average level of annual GDP per capita ((€)5.142) and the transport infrastructure is underdeveloped. The maximum aid intensity for regional investment aid is the same as in the RNE and the competitive rivalry among existing firms is less intense as than in the previous region.

The South (Muntenia) Region (**RS**) is placed in the Southern part of Romania and includes the following counties: Argeş, Buzău, Dâmboviţa, Giurgiu, Prahova and Teleorman. The total area of this region is slightly above 31.000 (km^2) and its population number amounts close to 3 million (people). The region is characterized by a lower than average level of GDP per capita ((€)5.827), has a high unemployment rate (7,46(%)) and has the lowest level of education. The advantages of this region are: the less intensive competitive rivalry among existing firms and the second best transport infrastructure.

The South West (Oltenia) Region (**RSW**) is placed in South-Western part of Romania and includes the following counties: Dolj, Gorj, Mehedinţi, Olt and Vâlcea. The total area of this region is around 29.000 (km^2) and its population number amounts to 2 million (people). The region is characterized by a lower than average level of GDP per capita ((€)5.181), has the highest unemployment rate (8,31(%)) which constitutes a serious social problem and has the smallest number of clients and potential clients. The transportation level of this region is well developed and the competitive rivalry among existing firms is lower than average.

The West Region (**RW**) is placed in the Western part of Romania and includes only four counties: Arad, Caraş-Severin, Hunedoara, Timiş. The total area of this region is above 32.000 (km^2) and has the smallest population number, slightly above 1,8 million (people). This region is characterized by the second best level of GDP per capita ((€)7.612) and level of education and has a low unemployment rate (3,88(%)). The weaknesses of this region are: the maximum aid intensity for regional investment is only 35(%) of the eligible costs and the number of clients and potential clients is lower than the average level.

The North West Region (**RNW**) is placed in North-Western part of Romania and includes the following counties: Bihor, Bistriţa-Năsăud, Cluj, Maramureş, Satu-Mare and Sălaj. The total area of this region is 34.159 (km^2) and its population number amounts close to 2,6 million (people). This region is characterized by an average level of GDP per capita ((€)5.864) and a low level of unemployment rate (4,14(%)). The region is characterized by the highest number of clients and potential clients and the level of education is above average. The intense competitive rivalry among existing firms is the main drawback.

The Center Region (**RC**) is placed in the Central part of Romania and includes the following counties: Alba, Braşov, Covasna, Harghita, Mureş and Sibiu. The total area of this region exceeds 34.000 (km^2) and its population number amounts close to 2,4 million (people). It is featured by an average level of GDP per capita ((€)6.668) and unemployment rate of 6,01(%). Similarly to Region NW, it has a high number of clients, potential clients and a high level of education and the main disadvantage is the intense competitive rivalry among existing firms.

The Ilfov Region (**RI**) is placed in Southern part of Romania and includes Ilfov county and Bucureşti, the capital of Romania. This region has the smallest area, only 1.583 (km^2) and its population number amounts close to 2,3 million (people). This region is characterized by the highest: level of GDP per capita ((€)14.336), transport infrastructure and level of education. The main weaknesses are: the most intense competitive rivalry among existing firms and the maximum aid intensity for regional investment is only 25(%) of the eligible costs.

B. Selection of the criteria

Multiple criteria evaluation of the proposed regions has been carried out with the application of a consistent family of criteria that includes economic, social and environmental aspects. In order to perform a complete assessment of the regions, the authors have proposed a set of twelve criteria, which are presented below:

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

2) *Transport infrastructure* ((km)/100 (km^2)) – is a maximized criterion, being defined as the density of modernized public roads in the analyzed regions.

3) *Courier services* (units) – represents a maximized criterion and it emphasizes the number of courier companies in each region.

4) *Level of competitiveness* (%) – represents a minimized criterion and it shows the percentage share of the total competitors in each region.

5) *Investment attractiveness* (%) – is a maximized criterion. It emphasizes the maximum aid intensity for regional investment. It is defined as a percentage share of the eligible costs from the relevant investment projects.

6) *Investment level* (million €) – represents a maximized criterion. It shows the net and gross investments, which directly contribute to increasing regional competitiveness.

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

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

9) *Labour cost* (€) – represents a minimized criterion and it shows the average gross nominal monthly wages in each region.

10) *Level of education* (units) – represents a maximized criterion and it shows the number of universities per 100000 residents from specific domains in each region.

11) *Safety* (points) - is a maximized criterion. It is expressed in terms of: number of traffic accidents, number of offences and crimes per 100000 inhabitants and number of collective accidents.

12) *Environmental-friendliness* (%) – is a maximized criterion. It is defined as protected areas' percentage share of the total region's area.

The decision matrix which describes the performance of the alternatives to be evaluated with respect to identified criteria is presented in TABLE I.

TABLE I
PERFORMANCE MATRIX [15]-[16]

	C R I T E R I A											
	CI	CII	CIII	CIV	CV	CVI	CVII	CVIII	CIX	CX	CXI	CXII
Alternatives												
RNE	4,119	12.61	175	5.67	50	1,119.96	4,347	6.89	409.07	0.73	5.26	1.73
RSE	5,142	10.73	170	3.39	50	3,531.16	4,561	6.66	429.20	0.64	5.50	21.01
RS	5,827	13.62	155	2.92	50	3,480.47	4,675	7.46	455	0.14	5.45	3.99
RSW	5,181	13.50	96	3.61	50	1,804.15	2,858	8.31	446.40	0.30	6.64	13.31
RW	7,612	12.24	115	10.83	35	2,269.33	3,332	3.88	461.33	1.16	8	9.70
RNW	5,864	10.87	152	12.29	50	2,214.35	5,865	4.14	415.63	1.08	6.42	7.66
RC	6,668	11.50	171	8.68	50	3,379.57	5,694	6.01	432.83	1.02	6.39	1.44
RI	14,336	49.27	202	52.60	25	4,820.58	5,519	1.76	700.48	2.32	4.21	0.00

The preference thresholds and weights were assigned on the basis of the preferences of company stakeholders. The values of the parameters are given in TABLE II.

TABLE II
THRESHOLDS AND CRITERIA WEIGHTS

	CRITERIA											
	CI	CII	CIII	CIV	CV	CVI	CVII	CVIII	CIX	CX	CXI	CXII
Preferences												
Indifference (q)	0.1	0.05	0.05	0.1	0.1	0.1	0.05	0.05	0.05	0.1	0.1	0.1
Preference (p)	0.15	0.15	0.15	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.15	0.15
Weights (w)	0.08	0.12	0.10	0.07	0.08	0.05	0.20	0.03	0.05	0.15	0.03	0.04

IV. RESULTS

Based on the algorithm of the Electre III method described above, a software was developed in order to facilitate the decision making process, regarding the location of a logistics center. When the performance matrix and all the threshold and weight values are input by the user, the software returns the concordance matrix, the discordance indices, if it is necessary, and the credibility matrix. Then, based on the credibility matrix the software develops the two distillations: descending and ascending. In order to display the final ranking, that includes the option which overtakes the other ones, a matrix is constructed and it contains the results of the comparison between the distillations. When the final ranking it is displayed, the software is able to specify which is the most suitable solution based on the Electre III methodology.

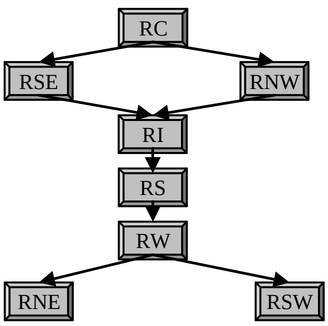
The software was implemented on a real case study. Each region of Romania was analyzed, in order to make the decision regarding which of these eight best fit to locate a logistics center based on several criteria. The options, criteria and preferences of the company stakeholders are presented in the previous paragraph.

After developing the performance matrix and preference values to be used as input, the software generated the concordance matrix, presented in TABLE III. It can be noticed that the diagonal of the matrix is the unity because the alternative is compared to itself.

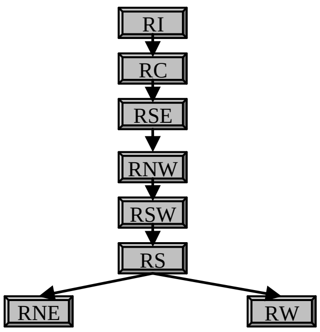
TABLE III
CONCORDANCE MATRIX

	RNE	**RSE**	**RS**	**RSW**	**RW**	**RNW**	**RC**	**RI**
RNE	1	0.76	0.62	0.68	0.65	0.45	0.49	0.3
RSE	0.82	1	0.98	0.82	0.63	0.56	0.51	0.3
RS	0.82	0.80	1	0.77	0.70	0.63	0.50	0.3
RSW	0.59	0.46	0.81	1	0.39	0.49	0.42	0.3
RW	0.57	0.47	0.39	0.72	1	0.67	0.79	0.3
RNW	0.68	0.74	0.73	0.74	0.91	1	0.71	0.5
RC	0.85	0.88	0.74	0.74	0.79	0.96	1	0.5
RI	0.70	0.70	0.70	0.70	0.70	0.65	0.70	1

In the next step, the discordance indexes are computed, but only if veto thresholds are specified; contrary, the software returns 0 values for all discordance indexes. In this case, the concordance matrix is identical with the credibility matrix. The method determined two preliminary rankings using the distillations, presented in fig. 2.



a. Descending distillation



b. Ascending distillation

Fig. 2. Results from distillations

According to descending distillation, the Central Region was ranked in the first space. In accordance with the ascending distillation, Ilfov Region was the best alternative. The final ranking is acquired by aggregating the pre-orders into the ranking matrix, presented in TABLE IV.

TABLE IV
RANKING MATRIX

	RNE	RSE	RS	RSW	RW	RNW	RC	RI	Total P^{+}
RNE	0	P^{-}	P^{-}	P^{-}	P^{-}	P^{-}	P^{-}	P^{-}	0
RSE	P^{+}	0	P^{+}	P^{+}	P^{+}	P^{+}	P^{-}	R	5
RS	P^{+}	P^{-}	0	R	P^{+}	P^{-}	P^{-}	P^{-}	2
RSW	P^{+}	P^{-}	R	0	R	P^{-}	P^{-}	P^{-}	1
RW	P^{+}	P^{-}	P^{-}	R	0	P^{-}	P^{-}	P^{-}	1
RNW	P^{+}	P^{-}	P^{+}	P^{+}	P^{+}	0	P^{-}	R	4
RC	P^{+}	P^{+}	P^{+}	P^{+}	P^{+}	P^{+}	0	R	6
RI	P^{+}	R	P^{+}	P^{+}	P^{+}	R	R	0	4

In order to obtain the final ranking, the number of P+ from ranking matrix, for each alternative, is summed. The final ranking is shown in fig. 3.

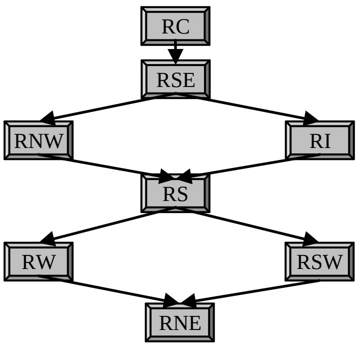


Fig. 3. Final ranking

It can be observed that RC and RSE regions outperform the remaining regions, being the most suitable solutions. At the other extreme, RNE region is placed at the bottom of the ranking, which indicates that it represents the least desired region for placing the logistic center on its location.

V. CONCLUSION

The paper presents the practical application of one of the multi criteria decision making methods. The study concerning the logistics center location selection has revealed its practical meaning and applicability. In order to select the most suitable solution the authors have applied Electre III method. Eight regions have been identified and evaluated according to twelve criteria that meet stakeholders' expectations. By carrying out the steps of Electre III methodology, while running the software developed to implement the procedure, the final ranking of regions was obtained. As a result of the computational experiments performed, the Central Region overtook the other regions, which means that it represents the most suitable region for placing the logistic center on its location. The results obtained prove that Electre III method may be very useful in solving location problems.

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