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# APPLICATION OF THE MODIPROM METHOD TO THE FINAL SOLUTION OF LOGISTICS CENTRE LOCATION

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**Abstract.** Awareness of the role of logistics centres is the precondition for successful planning, optimization, design, management, control and analysis of logistics processes and subsystems. Transportation requirements in supply chains, ecological requirements and the need for quality life in cities particularly emphasize the importance of selection of logistics centre locations, manner and time of supply. Taking into account the significance of selection and ranking of different locations, it is necessary to compare, as objectively as possible, the influences of various criteria and reduce them to a common function, i.e. present the methodology of solving complex problems associated with ranking of alternatives. The proposed method is expected to be a comprehensive tool of decision makers during the selection of the optimal logistics centre locations.

**Keywords:** multicriteria analysis, optimization, location problem, logistics centre, PROMETHEE method, criterion function.

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## Introduction

Logistics centres as an idea and real form have existed for a long time. However, their founders, function, structure and goals of development have obtained various forms, names and functions, both in terms of terminology and technology. A logistics centre represents a system which, by its marketing, information, organizational, technological and other solutions covers different aspects of transportation, different providers and users of services for the purpose of providing a complete logistic service. The development of logistic centres with a single network connecting satisfies a broader set of objectives of different interest groups from national, regional, municipal and city governments to the carrier's and users of transport services.

A large number of location factors and their heterogeneity clearly indicate that location problems have an interdisciplinary character and frequently require the application of complex procedures in selection of solutions (Taniguchi *et al.* 1999; Chen 2001; Syam 2002, Chu, Lai 2005; Avittathur *et al.* 2005; Farahani, Asgari 2007; Tabari *et al.* 2008).

The existence of several alternatives and criteria, where some of them should be maximized and some should be minimized, means that decisions are made under conditions of conflict and that the instruments which are more flexible than strict mathematical techniques of pure optimization should be applied to solving multicriteria problems. The number of heuristic techniques can be used directly in solving of the location problem or adjusted to the aim. In the meantime, the ability and experience of the decision-maker in the selection of location can significantly affect the final solution. Farahani, Asgari (2007) give a detailed overview of the efforts and development so far in the field of multicriteria location problems as well as an overview of utilized criteria and methods for solving the mentioned problems. Behzadian *et al.* (2010) give a classification scheme and a detailed overview and presentation of the PROMETHEE methodologies and the field of their application.

The outranking methods noticeably tend to assume the dominant role, both because of their adaptability to real problems and because of the fact that compared to

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similar methods they are very comprehensible to the decision maker. Numerous methodologies and models devoted to the problems of ranking alternatives in accordance with the criteria of decision making have been developed in recent years.

The PROMETHEE methods (Preference Ranking Organization Method for Enrichment Evaluation) (Brans *et al.* 1984; Brans, Vincke 1985) are based on the generalization of the concept of criterion by generalized criterion functions and by the mathematical relations for ranking which are based on them.

In the existing literature, there are numerous examples where the PROMETHEE methods and their modifications (Dias *et al.* 1998; Goumas, Lygerou 2000; Parreiras *et al.* 2006; Li, W.-X., Li, B.-Y. 2010) are used in the selection of final decisions in solving various multicriteria tasks. For example, Parreiras *et al.* (2006) present a modified version of the PROMETHEE method capable of solving convex and non-convex problems in analytical examples which have previously been optimized by means of the GA evolution algorithm. The method modified in this way starts, together with the original one, with the definition of the preference function for each criterion. The difference lies in the manner in which each of them calculates the outranking flow and defines the ranking of alternatives. In the modified version, the outranking flow of each alternative does not require calculation of the global preference index. A lot of papers (Massebeuf *et al.* 1999; Rekiek *et al.* 2001; Muniglia *et al.* 2004) also present hybrid methods based on the application of PROMETHEE and other methods for decision making (ELECTRE, AHP – Analytic Hierarchy Process) which allow selection of the optimal location that satisfies the decision maker. In recent years, the problems referring to group decision making, subjectivity of the decision maker and utilization of qualitative expressions for the values of alternatives per individual criterion have been shown by numerous extended methods based on generalized fuzzy numbers (Goumas, Lygerou 2000; Petrović, S., Petrović, R. 2002; Tabari *et al.* 2008; Li, W.-X., Li, B.-Y. 2010).

The criterion is a component which is present in almost all procedures of selection of a logistics centre location regardless of the applied methodology and model.

This paper presents a procedure of creation of an efficient method and technique for support to decision making in such a way that the selection of generalized criteria is not yielded to the experience and subjective evaluation of the decision maker. The modified PROMETHEE methods are proposed for changing of the existing generalized criteria and introduction of the new types of generalized criteria for expressing preferences of the decision maker regarding concrete criteria for the problem.

With the developed model we could analyze the effects of changing the weight coefficients; for each criterion function it is possible to see the forms of adopted generalized criteria and the positions of their respective experimental points. That could be significant contribution and basis for solving complex problems of multicriteria analysis by complex criteria. Practicality, efficiency and applicability of the proposed method in the selection of logistics centre location is presented through the analysis of a numerical example.

## 1. PROMETHEE Methods and the MODIPROM Method as a Complement

### 1.1. PROMETHEE Methods

The task of optimization is to enable selection of the best variant (best solution) from a series of variants, i.e. in its mathematical form optimization is reduced to maximization of the criterion function $\max\{f_1(x),\dots,f_n(x)\}$ in the given set $x \in A\{a_1,\dots,a_m\}$. The values $f_{ij}$ are known for each criterion $f_j$ for each possible alternative $A_i$:

$$f_{ij} = f_j\left(a_{ij}\right)\ \forall(i,j)\ ;\ i = 1,2,\dots,m\ ;\ j = 1,2,\dots,n\ . \quad (1)$$

The criteria for ranking alternatives are a specific problem which appears in multicriteria analysis.

The procedure of ranking the $m$ number of alternatives $A=\{a_1,\dots,a_i,\dots a_m\}$ covers generalization of the concept of the $n$ number of criteria $f = \{f_1,\dots,f_j,\dots f_n\}$, establishing ranking relations and a comparative analysis of results. Let $f_j(a)$ be the value of the criterion $f_j$ for the alternative $a$.

After the creation of the initial matrix, one preference value $P_j(a,b)$ is assigned to each criterion which makes the basis for comparison of two alternatives, and it expresses the intensity of preference of the alternative $a$ in relation to the alternative $b$. On the basis of preference functions, which are infinite, the type of generalized criterion function whose value is between 0 and 1 is chosen and, in a general case, that value is:

$$P_j(a,b) = \begin{cases} 0, \text{ if } f(a) \le f(b); \\ P_j\left[f(a) - f(b)\right] = P_j\left[d(a,b)\right], \text{ if } f(a) > f(b). \end{cases} \quad (2)$$

The family of PROMETHEE methods has been developed in six variants by several authors of the Brussels school (Brans *et al.* 1984; Brans, Vincke 1985). Six types of generalized criterion functions for expressing preferences of the decision maker regarding concrete criteria for the problem is the main characteristic of this family of methods, and the parameters which describe the functions are $q$ – the threshold which defines the domain of indifference; $p$ – the threshold which defines the domain of strict preference; $s$ – the parameter which is between $p$ and $q$.

For the needs of this paper, the interesting variants are variant I (which gives the partial ranking of alternatives), variant II (which gives the complete ranking of alternatives) and variant III (which gives the interval ranking of alternatives). However, the user can introduce some new types of generalized criteria for expressing preferences of the decision maker regarding concrete criteria for the problem.

Each criterion is assigned a certain weight $\omega_j$, $j = 1,\dots,n$ as a measure of relative importance of the criterion, so that $\sum_{j=1}^{k} \omega_j = 1,\ 0 < \omega_j < 1$.

The multicriteria preference index is determined in accordance with the expression:

$$\Pi(a,b) = \frac{\sum_{j=1}^{n} \omega_j \cdot P_i(a,b)}{\sum_{j=1}^{n} \omega_j}. \quad (3)$$

The index represents the measure of preference of the alternative $a$ in relation to the alternative $b$ and the closer it is to one, the preference is bigger. It takes into account all criteria at the same time. The oriented graph of ranking is thus obtained, and its arc($a$,$b$) has the value $\Pi(a,b)$ and makes the basis for ranking according to the PROMETHEE methods. So, between each pair of alternatives ($a$,$b$), there are always two arcs, one assigned to $\Pi(a,b)$, and the other assigned to $\Pi(b,a)$ (Fig. 1).

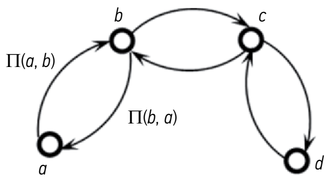



**Fig. 1.** Valued outranking graph

The positive, negative and net outranking flows of action are now defined for each alternative. The net outranking flow of the alternative $a$ represents the difference:

$$\Phi(a) = \Phi^+(a) - \Phi^-(a), \quad (4)$$

where: $\Phi^-(a)$ – the negative outranking flow; $\Phi^+(a)$ – the positive outranking flow:

$$\Phi^-(a) = \sum_{\forall b \in A} \Pi(b,a); \quad (5)$$

$$\Phi^+(a) = \sum_{\forall b \in A} \Pi(a,b). \quad (6)$$

In accordance with PROMETHEE I, it is established that the higher the output flow, the more other alternatives are dominated by the alternative $a$, and the lower the input flow, the smaller number of other alternatives dominate over $a$. In other words:

if $\Phi^-(a) \geq \Phi^+(b)$ and $\Phi^+(a) \leq \Phi^+(b)$, it is said that $a$ prefers $b$.

The equality $\Phi^-$ and $\Phi^+$ point to indifference during comparison of two alternatives. The alternatives $a$ and $b$ are incomparable if:

$$\Phi^-(a) > \Phi^-(b) \text{ and } \Phi^+(a) > \Phi^+(b)$$

or

$$\Phi^-(a) < \Phi^-(b) \text{ and } \Phi^+(a) < \Phi^+(b).$$

In PROMETHEE II, the net outranking flow indicates the priority of each alternative in relation to the others and gives the complete ranking of alternatives. Thus, the value of difference between flows is used for ranking all alternatives in such a way that a better alternative corresponds to a higher value:

- if $\Phi(a) > \Phi(b)$, it is said that $a$ prefers $b$;
- if $\Phi(a) = \Phi(b)$, it is said that $a$ is indifferent in relation to $b$.

The PROMETHEE III method performs ranking by assigning each alternative $a$ the interval $[x_a, y_a]$ on the basis of which the complete ranking for each pair of alternatives ($a$,$b$) is determined using the following definitions:

- if $x_a > x_b$, it is said that $a$ prefers $b$ (has a higher rank);
- if $x_a \leq y_b$ and $x_b \leq y_a$, it is said that $a$ is indifferent in relation to $b$,

where:

$$x_a = \underline{\Phi}(a) - \alpha \cdot \sigma_a;$$

$$y_a = \underline{\Phi}(a) + \alpha \cdot \sigma_a;$$

$$\underline{\Phi}(a) = \frac{1}{m} \cdot \sum_{b \in A} \left(\Pi(a,b) - \Pi(b,a)\right) = \frac{1}{m} \cdot \Phi(a);$$

$$\sigma_a = \sqrt{\frac{1}{m} \cdot \sum_{b \in A} \left(\Pi(a,b) - \Pi(b,a) - \underline{\Phi}(a)\right)^2};$$

$\alpha > 0$.

For practical application of the PROMETHEE III method, it is necessary to have in mind some characteristics of utilized parameters and concepts, that the centre of the interval $[x_a, y_a]$ is within the range of the outranking flow and the length proportional to the standard error of distribution of the value $\Phi(a)$, then that the selection of $\alpha$ depends on the concrete problem and, if it is required that the length of the interval should be smaller than the distance between two successive flows to which it refers, it follows that the approximate value of this parameter is $\alpha \approx 0.15$. The lower the value of the parameter $\alpha$, the higher the interval of the strict outranking, while for $\alpha = 0$ it follows that ($P^{III}$, $I^{III}$) coincides with ($P^{II}$, $I^{II}$). The denotations $P$ and $I$ point to the preference and indifference of the alternatives.

### 1.2. The Algorithm of the Modified PROMETHEE Method

The proposed procedure is based on the improvement of the family of methods for multicriteria ranking. Thus, the problem is interesting both from the theoretical and practical aspects.

From the aspect of theory, the problem refers to as realistic setting of the problem as possible and development of efficient and exact methods of multicriteria analysis, and in practical sense it is necessary to compare the effects of various criteria as objectively as possible and reduce them to the common criterion function.

The proposed MODIPROM method (MODIfied PROmethee Method) is based on the improvement of a group of methods for multicriteria ranking, as follows:

- change of the existing generalized criteria and introduction of the new ones;
- procedure of selection of generalized criteria within one criterion function;
- analysis of effects of change of weight coefficients;
- transformation of the mean values of the outranking flow for the purpose of solving complex criterion functions.

Changes of generalized criteria (Fig. 2) refer to retaining generalized criteria I (Usual criterion), II (U-shape criterion), IV(Level criterion) and VI (Gaussian criterion). Criterion III (V-shape criterion) and V (V-shape with indifference criterion) are replaced with the linear criterion whose parameters are calculated through linear regression. The square and cube criteria whose parameters are calculated by regression analysis are introduced.

The influence of experience and subjective evaluation of the decision maker in the selection of generalized criteria is reduced to minimum, in other words, the selection performed on the basis of the methods of the least squares so that the generalized criterion is chosen in which the sum of squares of deviations of experimental points from the theoretical curve of the generalized criterion is least.

Fig. 2 shows the adopted generalized criteria with the following parameters: $q$ – the threshold of indifference; $p$ – the threshold of strict preference; $\sigma$ – the standard deviation of Normal distribution; $b_0$, $b_1$, $b_2$, $b_3$ – the coefficients of the regression line.

It should be mentioned that the selection of type of generalized criterion also solves the problem of normalization of criteria values because preferences per individual criterion are distributed in the interval [0,1]. The influence of difference among measurement units of individual criteria is thus avoided.

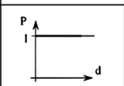
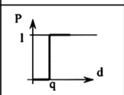
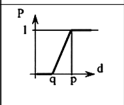
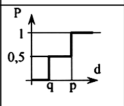
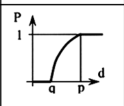
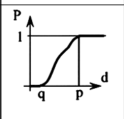
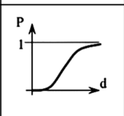
| TYPE OF GENERALIZED CRITERION | | | Parameters | $P_j(x)$ |
|---|---|---|---|---|
| Type | Name | Shape | | |
| I | Usual criterion |  | | $P_j(x)=1$ |
| II | U-shape criterion |  | q | $P_j(x)=\begin{cases} 0, & d<q \\ 1, & d \ge q \end{cases}$ |
| III | V-shape criterion |  | q, p, $b_0$, $b_1$ | $P_j(x)=\begin{cases} 0, & d<q \\ b_0+b_1x, & q \le d < p \\ 1, & d \ge p \end{cases}$ |
| IV | Level criterion |  | q, p, | $P_j(x)=\begin{cases} 0, & d<q \\ 0.5, & q \le d < p \\ 1, & d \ge p \end{cases}$ |
| V | V-shape with indifference criterion |  | q, p, $b_0$, $b_1$, $b_2$ | $P_j(x)=\begin{cases} 0, & d<q \\ b_0+b_1x+b_2x^2, & q \le d < p \\ 1, & d \ge p \end{cases}$ |
| VI | Cube criterion |  | q, p, $b_0$, $b_1$, $b_2$, $b_3$ | $P_j(x)=\begin{cases} 0, & d<q \\ b_0+b_1x+b_2x^2+b_3x^3, & q \le d < p \\ 1, & d \ge p \end{cases}$ |
| VII | Gaussian criterion |  | $\sigma$ | $P_j(x)=\begin{cases} 0, & d \le 0 \\ 1-e^{\frac{x^2}{2\sigma^2}}, & d>0 \end{cases}$ |

**Fig. 2.** Types of generalized criteria

Transformation of the mean values of the outranking flow of subfunctions into the values of criterion functions of higher rank up to the creation of a unique criterion of the first rank can be used for solving complex problems of multicriteria analysis (such as multicriteria analysis with complex criteria which are represented by subfunctions and parameters).

The complete procedure of implementation of the MODIPROM method is described by the following steps:

**a)** ***Definition of the matrix of criterion values for certain alternatives.***

Let the values $f_{ij}$ of each considered criterion $f_j$ for each of the possible alternatives $a_i$ be

$$f_{ij}=f_j\left(a_i\right)=C_{ij},\ i=1,2,\ldots,m,\ j=1,2,\ldots,n.$$

The alternatives and the criteria can be presented together by the following matrix of values:

$$\begin{bmatrix} C_{11} & C_{12} & \ldots & C_{1j} & \ldots & C_{1n} \\ C_{21} & C_{22} & \ldots & C_{2j} & \ldots & C_{2n} \\ . & . & \ldots & . & \ldots & . \\ C_{i1} & C_{i2} & \ldots & C_{ij} & \ldots & C_{in} \\ . & . & \ldots & . & \ldots & . \\ C_{m1} & C_{m2} & \ldots & C_{m2} & \ldots & C_{mn} \end{bmatrix}. \quad (7)$$

The appropriate transformation is necessary so that the criteria of minimum type could be transformed into maximum type.

$$C'_{ij}=\begin{cases} C_{ij},\ \text{for } K_j \to \text{ max;} \\ \max C_{ij}-C_{ij},\ \text{for } K_j \to \text{ min.} \end{cases} \quad (8)$$

At the end of this phase, it is necessary to calculate the standard deviation for each criterion $K_j$:

$$\sigma_j=\sqrt{\frac{1}{n}\cdot\sum_{i=1}^{m}\left(C_{ij}-\overline{C_j}\right)^2}. \quad (9)$$

**b)** ***Selection of the preference function.***

After the matrix creation phase, one preference function $P_j\left(a_i,a_k\right)$ is assigned to each criterion for which two alternatives are compared. Based on the preference functions, a type of generalized criterion function which has the value between 0 and 1 is selected. It is necessary to create tables of difference $\left(d_{ik}\right)_j=f_j\left(a_i\right)-f_j\left(a_k\right)$ and a series of positive differences $\left(d_{ik}\right)_j>0$, and then rank the data $d_{ik}$ according to their size, where $l$=1,...,$s$:

$$\begin{bmatrix} \min\left(d_{ik}\right)_j \\ . \\ . \\ . \\ \max\left(d_{ik}\right)_j \end{bmatrix}=\begin{bmatrix} x_{j1} \\ . \\ x_{jl} \\ . \\ x_{js} \end{bmatrix}.$$

Calculate threshold of indifference $q$ and the threshold of strict preference $p$:

$$q_j = \frac{1}{3} \cdot d_j \cdot \max;$$
$$p_j = \frac{2}{3} \cdot d_j \cdot \max$$

and form a series of empiricial values of the preference function $y_{jl}$, where $0 < y_{jl} > 1$. The series can be presented in the form:

$$\begin{bmatrix} y_{j1} \\ \cdot \\ y_{jl} \\ \cdot \\ y_{js} \end{bmatrix}.$$

The procedure of calculating the regression coefficients for the generalized criteria III, V and VI is given by the CRC algorithm (Calculation of Regression Coefficients) (Fig. 3).

For all values $\left(d_{ik}\right)_j$ and there can be at most $m \cdot \left(m-1\right)/2$ of them, the value of approximation error is calculated $e_l = \left[ p_j\left(x_{jl}\right) - y_{jl} \right]$. Out of all generalized criterion functions for the given set of points $\left\{ \left(d_{ik}\right)_j, P_{jik}\left(d_{ik}\right)_j \right\}$, a function which is best in terms of the least squares, i.e. the function whose sum of squares is least is chosen:

$$S = \sum_{l=1}^{s} \varepsilon_i^2 = \sum_{l=1}^{s} \left[ p_j\left(x_{jl}\right) - y_{jl} \right]^2, \tag{10}$$

where: $\varepsilon_l$ – the error of approximation of empirical values of the preferential function $y_{jl}$ by the value of the theoretical function $p_j\left(x_{jl}\right)$ for the $l$-th empirical datum and the $l$-combination of alternatives $a_i$ and $a_k$ for which $\left(d_{ik}\right)_j = f_j\left(a_i\right) - f_j\left(a_k\right) > 0$, i.e.:

$$P_{jik}\left[\left(d_{ik}\right)_j\right] = \begin{cases} 0, \text{ for } \left(d_{ik}\right)_j < 0; \\ P_j\left[\left(d_{ik}\right)_j\right], \text{ for } \left(d_{ik}\right)_j > 0. \end{cases} \tag{11}$$

where: $P_j\left(d_{ik}\right)_j$ – the selected function of the generalized criterion.

a) ***Calculation of the preference index for each pair of alternatives (P).***

For each pair of alternatives ($a_i$, $a_k$), the preference index is determined by the expression:

$$\Pi\left(a_i, a_k\right) = \frac{\sum_{j=1}^{n} \omega_j \cdot P_j\left(a_i, a_k\right)}{\sum_{j=1}^{n} \omega_j}, \quad j = 1,\ldots,n, \tag{12}$$

where each criterion is assigned a certain weight $\omega_j$, $j = 1,\ldots,n$.

b) ***Calculation of the values of flows (P).***

In accordance with the preference index and the expressions (4), (5) and (6), the input, output and outranking flows of action are defined for each alternative.

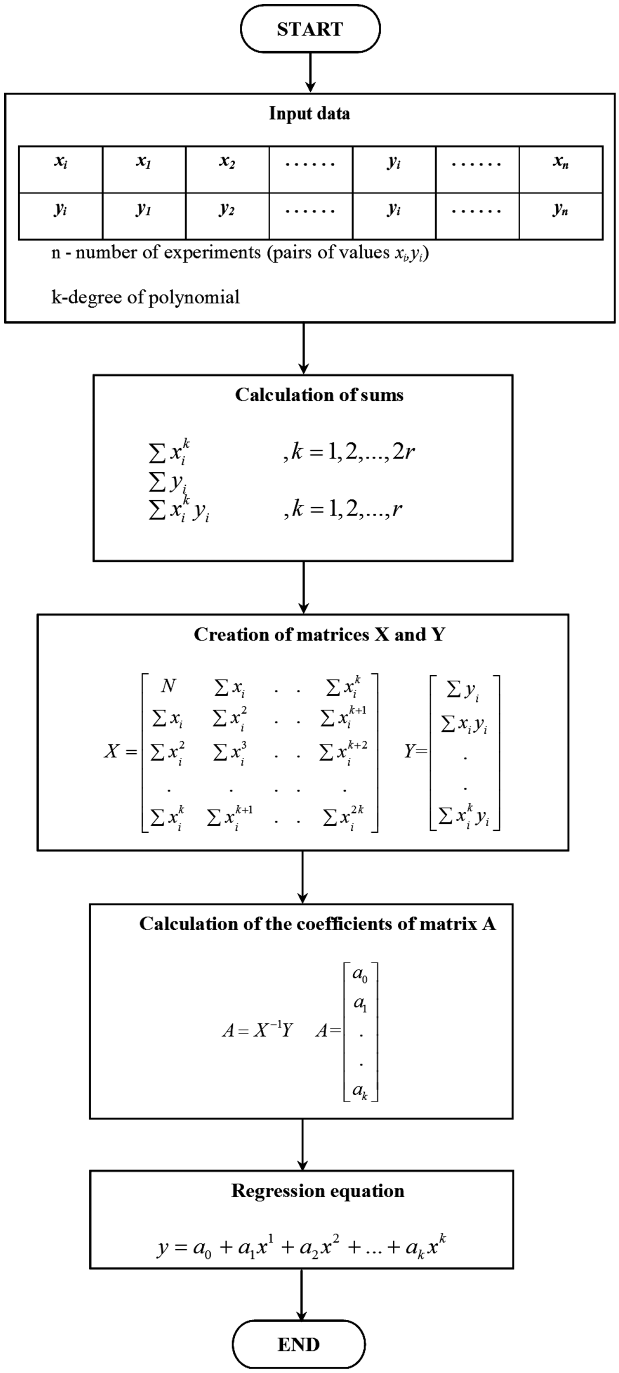



**Fig. 3.** Algorithm of the CRC method

c) ***Generation of final ranking.***

On the basis of the characteristics of the family of the PROMETHEE methods given at the beginning of this paper, the ranking procedure is performed in this step through the following phases:

- forming the table of partial ranking according to the PROMETHEE I method;
- forming the table of complete ranking according to the PROMETHEE II method;
- forming the table of interval ranking according to the PROMETHEE III method;
- comparative analysis of ranking results.

**d)** ***Analysis of effects of change of the weight coefficients.***

In real problems, the criteria of significance are most frequently different and the decision maker subjectively defines the level of significance of individual criteria through weight coefficients.

As weight coefficients can sometimes have a decisive influence on the solution, there is a possibility of analyzing the effects of change of weight coefficients on the behavior of the final solution of multicriteria analysis. The solution is stable if changes of weight coefficients do not have an important influence on the final result.

## 2. Solution of Logistics Centre Location with the Application of the MODIPROM Method

The logistics centre is a micrologistics system within which transportation, forwarding, trading, industrial and other service enterprises cooperate, also the network of centres is a macrologistics system of importance for the economic development of a region. Needs for determining potential locations of logistic centres i.e. decision of an individual or a group of people we can find in all phases of management at the local level. The local government serve as link between private (operator of LC) and public sector. The final decision of the location of logistics centre is made by operator or decision makers (DM).

Five potential locations in the selected region were analysed to define the future structure of the logistics centre. For each of various criteria of selection (Table 1) is necessary to determine the input values (preference function and weight coefficients).

It is obvious that the goals and criteria of different interest groups are complex and numerous. The degree of decomposition of criteria depends on the concrete setting of the location problem. Not all the criteria have been mentioned and not all the mentioned ones have to be applied to the concrete location problems. In the selection of criteria, their influences on alternative solutions of the location for the goods terminal are important. Generation and classification of criteria according to their technological, economic, ecological, legal-regulatory, organizational and technical characters allows the possibility of selection and noticing of weaknesses in location alternatives from the aspect of significant regions for development of terminals (Table 1).

The selection of criteria from all groups is the guarantee of their successful construction, development and sustainability. In the first stage, let us assume that the decision maker has to choose a favourable location out of 5 potential locations taking into account the influences of 20 various criteria and sub-criteria given in Table 2.

For example, a group of technological criteria is divided into sub-criteria: the intensity of goods and transportation flows ($k_1$), availability of the terminals of the centre ($k_2$) and the distance from the user ($k_3$).

The input values for evaluation of each criteria, or the relative significance of each individual attribute (ponder attribute) is determined by a set of ponders which are normalized in such a way that their total sum is equal to one.

**Table 1.** Criteria of selection of logistics centre locations

| Technological |
|---|
| 1. intensity of goods and transportation flows ($k_1$);<br>2. availability of the terminals of the centre ($k_2$);<br>3. distance from the users ($k_3$);<br>4. delivery time;<br>5. availability of technologies and types of goods;<br>6. connection with several means of transportation;<br>7. availability of the terminals of intermodal transportation |
| **Economic** |
| 1. logistics costs (transportation, storing, stocks, etc.) ($k_4$);<br>2. costs of location activation($k_5$);<br>3. investment in construction of access routes and infrastructure ($k_6$);<br>4. net present value;<br>5. internal rentability rate;<br>6. period of return on funds;<br>7. gravitation of developed economy |
| **Organizational** |
| 1. presence of logistics providers (3PL, 4PL, 5PL) ($k_7$);<br>2. presence of intermodal transportation operators ($k_8$);<br>3. possibility of organization of line connections in railway, water transportation ($k_9$);<br>4. representations, associations, societies in the field of transportation and logistics |
| **Technical** |
| 1. geological characteristics of the location ($k_{10}$);<br>2. infrastructural network (electricity, water, sewage system, etc.) ($k_{11}$);<br>3. technical possibilities for connection with the infrastructure of railway and water transportation ($k_{12}$) |
| **Ecological** |
| 1. air pollution ($k_{13}$);<br>2. noise and vibrations ($k_{14}$);<br>3. hazardous materials ($k_{15}$);<br>4. hazardous goods ($k_{16}$);<br>5. influences of the environment on the goods in the terminal ($k_{17}$);<br>6. influences of goods and processes in the terminal on the environment |
| **Legal-regulatory** |
| 1. coordination with the spatial and urban plans ($k_{18}$);<br>2. possibility of regulating ownership over land and facility ($k_{19}$);<br>3. coordination with the laws regulating presence, distance and environmental protection and protection of the terminal, control and status of goods in the terminal ($k_{20}$);<br>4. hazardous goods |

For the case of $n$ attributes, the set of ponders is given as:

$$t_j = \left(t_1, t_2, \ldots, t_j, \ldots, t_n\right), \tag{13}$$

where:

$$\sum_{j=1}^{n} t_j = 1 \text{ and } 0 < t_j < 1. \tag{14}$$

In the given case, since those are the attributes which are divided into groups, pondering was also performed on a group of characteristics and on the subgroups of considered characteristics (level of significance 1 and level of significance 2 in Table 2). The total weight

**Table 2.** Characteristics of the attributes and relative significance

| | | Level of significance | | | *Gi* | |
|---|---|---|---|---|---|---|
| Group of characteristics | Subgroup of characteristics | 1 | | 2 | *Gi* | *Gi* (%) |
| Technological | $k_1$ | 0.15 | 0.15 | 0.40 | 0.06 | 6.00 |
| | $k_2$ | | 0.15 | 0.40 | 0.06 | 6.00 |
| | $k_3$ | | 0.15 | 0.20 | 0.03 | 3.00 |
| | *K* I | | | 1.00 | 0.15 | 15.00 |
| Economic | $k_4$ | 0.3 | 0.3 | 0.40 | 0.12 | 12.00 |
| | $k_5$ | | 0.3 | 0.30 | 0.09 | 9.00 |
| | $k_6$ | | 0.3 | 0.30 | 0.09 | 9.00 |
| | *K* II | | | 1.00 | 0.3 | 30.00 |
| Organizational | $k_7$ | 0.12 | 0.12 | 0.30 | 0.036 | 3.60 |
| | $k_8$ | | 0.12 | 0.50 | 0.06 | 6.00 |
| | $k_9$ | | 0.12 | 0.20 | 0.024 | 2.40 |
| | *K* III | | | 1.00 | 0.12 | 12.00 |
| Techical | $k_{10}$ | 0.12 | 0.12 | 0.20 | 0.024 | 2.40 |
| | $k_{11}$ | | 0.12 | 0.40 | 0.048 | 4.80 |
| | $k_{12}$ | | 0.12 | 0.40 | 0.048 | 4.80 |
| | *K* IV | | | 1.00 | 0.12 | 12.00 |
| Ecological | $k_{13}$ | 0.2 | 0.2 | 0.30 | 0.06 | 6.00 |
| | $k_{14}$ | | 0.2 | 0.30 | 0.06 | 6.00 |
| | $k_{15}$ | | 0.2 | 0.18 | 0.036 | 3.60 |
| | $k_{16}$ | | 0.2 | 0.10 | 0.02 | 2.00 |
| | $k_{17}$ | | 0.2 | 0.12 | 0.024 | 2.40 |
| | *K* V | | | 1.00 | 0.2 | 20.00 |
| Legal-regulatory | $k_{18}$ | 0.11 | 0.11 | 0.30 | 0.033 | 3.30 |
| | $k_{19}$ | | 0.11 | 0.40 | 0.044 | 4.40 |
| | $k_{20}$ | | 0.11 | 0.30 | 0.033 | 3.30 |
| | *K* VI | | | 1.00 | 0.11 | 11.00 |
| | *SKi* | 1.00 | | | 1.00 | 100 |

of attributes is obtained as the product of group ponders and the subgroup ponders of the characteristic:

$$G_i = \prod K_i \ . \quad (15)$$

After defining a matrix of criterion values for certain alternatives and appropriate transformation so that the criteria of minimum type could be transformed into maximum type, the values of standard deviation for each criterion according to expression (9) are given in Table 3.

In the second stage, according to expressions (10), (11) for comparing two alternative to each criterion, should be preferred to join the function $P_j\left(a_i, a_k\right)$, determine the regression coefficients according to the algorithm in Fig. 3 and choose a generalized criterion for which the sum of squared deviations ($S_{\min}$) experimental points from theoretical curves of generalized criteria is least.

Generating the final ranking of alternative potential locations the logistic centre requires the calculation of preference index values (Table 4) and flows for each pair of alternatives, according to expressions (4), (5), (6) and (12). As the presented method requires comprehensive calculations, the procedure of multicriteria analysis is automated by development of the MODIPROM software tool. The limitation of the given tool is seen in the possibility of solving the problem of ranking 10 alternatives by means of 25 criterion function.

Fig. 4 shows the data on the value of criterion functions for individual alternatives and the value of relative weights of criterion functions entered in the interface, the type of optimization chosen for each function (*min* or *max*) and the other entries. The MODIPROM program allows us to see the forms of adopted generalized criteria (Fig. 5) and the position of their respective experimental points for each criterion function because the generalized criterion in which the sum of squares of deviations of experimental points from the theoretical curve is the least is chosen on the basis of the method of the least squares.

The results of multicriteria analysis are presented in the form of a report which gives the ranking of alternatives by variants PROMETHEE I, PROMETHEE II and PROMETHEE III and the graph of interval ranking of alternatives (Fig. 6). The graphical representation of the values of weight coefficients as well as the analysis and effects of their influence on making the final decision (solution) can be seen in the Moving Weight Chart (MWC) (Fig. 7).

**Table 3.** Standard deviation and chosen generalized criterion

| Criterion | Standard deviation σ | S – sum of squared deviations for generalized criterion | | | | | | | Chosen generalized criterion |
|---|---|---|---|---|---|---|---|---|---|
| | | Type I | Type II | Type III | Type IV | Type V | Type VI | Type VII | |
| $k_1$ | 132.66 | 2.8500 | 2.0500 | 0.03499 | 0.4500 | 0.01609 | 0.01574 | 0.0533 | Type VI |
| $k_2$ | 1.0198 | 2.5185 | 0.8519 | 0.15995 | 0.5185 | 0.14815 | 2.51852 | 0.17737 | Type V |
| $k_3$ | 1.0198 | 2.5185 | 0.8519 | 0.15995 | 0.5185 | 0.14815 | 2.51852 | 0.17737 | Type V |
| $k_4$ | 36.878 | 2.8500 | 1.4500 | 0.03458 | 0.4000 | 0.02467 | 0.02366 | 0.04272 | Type VI |
| $k_5$ | 18.547 | 2.8500 | 1.4500 | 0.03813 | 0.2500 | 0.03528 | 0.03528 | 0.06659 | Type V |
| $k_6$ | 0.7483 | 2.1875 | 1.4375 | 0.28125 | 0.3125 | 2.18750 | 2.18750 | 0.42410 | Type III |
| $k_7$ | 1.1662 | 2.5185 | 0.7407 | 0.09852 | 0.3796 | 0.09259 | 3.51852 | 0.12904 | Type V |
| $k_8$ | 0.6325 | 1.8571 | 1.8571 | 0.35714 | 0.3571 | 1.85714 | 1.64425 | 0.63067 | Type IV |
| $k_9$ | 0.6325 | 1.8571 | 1.8571 | 0.35714 | 0.3571 | 1.85714 | 1.64425 | 0.63067 | Type IV |
| $k_{10}$ | 0.6325 | 1.8571 | 1.8571 | 0.35714 | 0.3571 | 1.85714 | 1.64425 | 0.63067 | Type IV |
| $k_{11}$ | 0.4899 | 1.5278 | 1.5278 | 2.52778 | 1.5278 | 2.52778 | 2.52778 | 0.99823 | Type VII |
| $k_{12}$ | 0.4899 | 1.5278 | 1.5278 | 2.52778 | 1.5278 | 2.52778 | 2.52778 | 0.99823 | Type VII |
| $k_{13}$ | 1.0198 | 2.5185 | 0.8519 | 0.15995 | 0.5185 | 0.14815 | 2.51852 | 0.17737 | Type V |
| $k_{14}$ | 1.0198 | 2.5185 | 0.8519 | 0.15995 | 0.5185 | 0.14815 | 2.51852 | 0.17737 | Type V |
| $k_{15}$ | 0.4899 | 1.5278 | 1.5278 | 2.52778 | 1.5278 | 2.52778 | 2.52778 | 0.99823 | Type VII |
| $k_{16}$ | 0.4899 | 1.5278 | 1.5278 | 2.52778 | 1.5278 | 2.52778 | 2.52778 | 0.99823 | Type VII |
| $k_{17}$ | 0.7483 | 2.1875 | 1.4375 | 0.28125 | 0.3125 | 2.18750 | 2.18750 | 0.42410 | Type III |
| $k_{18}$ | 1.0198 | 2.5185 | 0.8519 | 0.15995 | 0.5185 | 0.14815 | 2.51852 | 0.17737 | Type V |
| $k_{19}$ | 1.0198 | 2.5185 | 0.8519 | 0.15995 | 0.5185 | 0.14815 | 2.51852 | 0.17737 | Type V |
| $k_{20}$ | 0.4899 | 1.5278 | 1.5278 | 2.52778 | 1.5278 | 2.52778 | 2.52778 | 0.99823 | Type VII |

**Table 4**. Preference index values with input and output flows

| | | Preference index values $P(a, b)$ | | | | | |
|---|---|---|---|---|---|---|---|
| | | Compared to alternative | | | | | |
| | | *A*1 | *A*2 | *A*3 | *A*4 | *A*5 | Output flow |
| Observed alternatives | *A*1 | 0 | 0.132508 | 0.1541082 | 0.2970963 | 0.351865 | 0.93558 |
| | *A*2 | 0.27188214 | 0 | 0.198424 | 0.3502665 | 0.359502 | 1.18007 |
| | *A*3 | 0.33456059 | 0.2540848 | 0 | 0.4210594 | 0.338689 | 1.34839 |
| | *A*4 | 0.21866307 | 0.1786074 | 0.2001428 | 0 | 0.323715 | 0.92113 |
| | *A*5 | 0.21890451 | 0.1002946 | 0.0415097 | 0.270042 | 0 | 0.63075 |
| | Input flow | 1.04401031 | 0.6654949 | 0.5941848 | 1.3384643 | 1.373771 | |

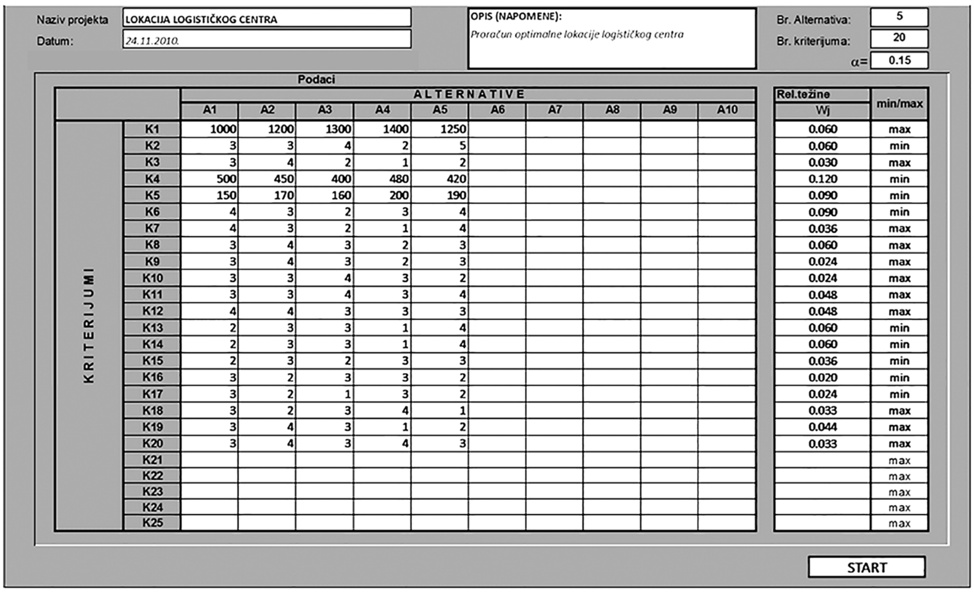



**Fig. 4.** Interface of the MODIPROM program

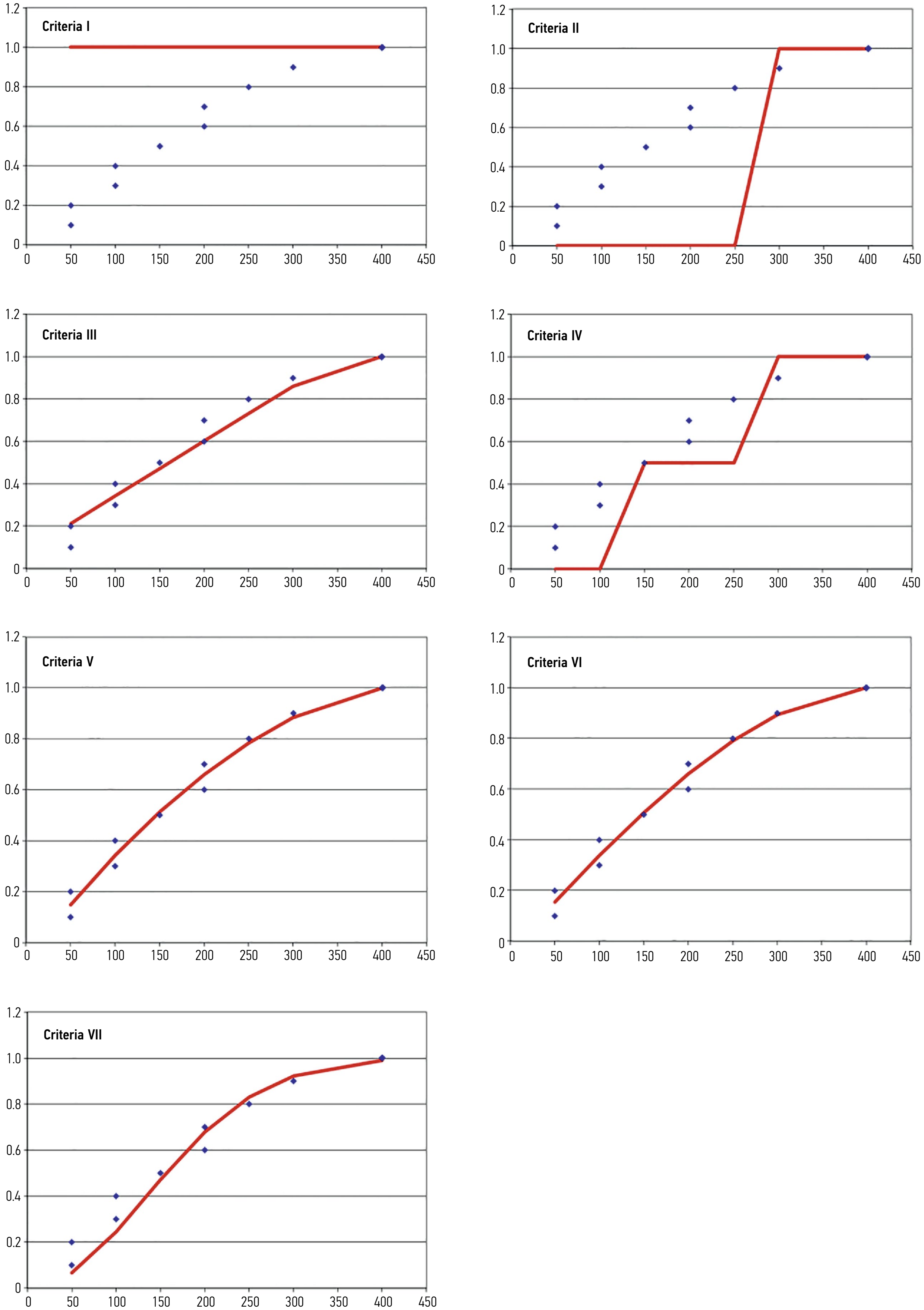
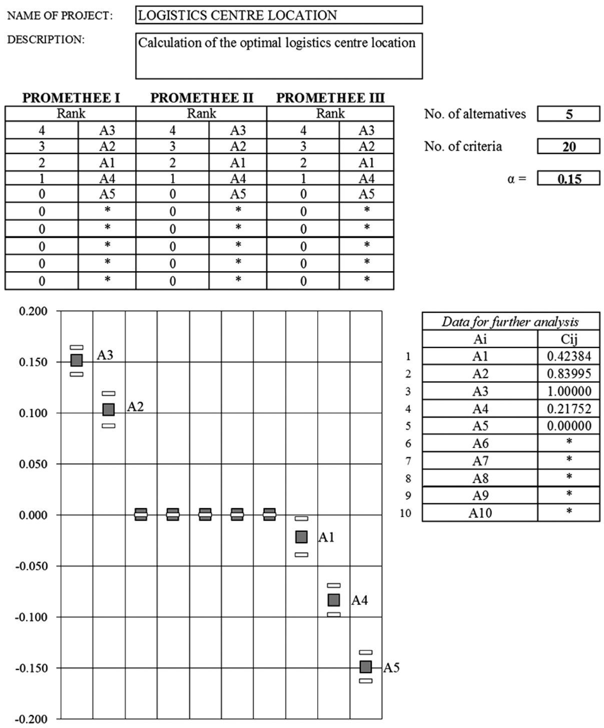



**Fig. 5.** Shapes of generalized functions which describe experimental points for criterion $k_1$



NAME OF PROJECT: LOGISTICS CENTRE LOCATION

DESCRIPTION: Calculation of the optimal logistics centre location

| PROMETHEE I | | PROMETHEE II | | PROMETHEE III | |
|---|---|---|---|---|---|
| Rank | | Rank | | Rank | |
| 4 | A3 | 4 | A3 | 4 | A3 |
| 3 | A2 | 3 | A2 | 3 | A2 |
| 2 | A1 | 2 | A1 | 2 | A1 |
| 1 | A4 | 1 | A4 | 1 | A4 |
| 0 | A5 | 0 | A5 | 0 | A5 |
| 0 | * | 0 | * | 0 | * |
| 0 | * | 0 | * | 0 | * |
| 0 | * | 0 | * | 0 | * |
| 0 | * | 0 | * | 0 | * |
| 0 | * | 0 | * | 0 | * |

No. of alternatives 5

No. of criteria 20

α = 0.15

| | *Data for further analysis* | |
|---|---|---|
| | Ai | Cij |
| 1 | A1 | 0.42384 |
| 2 | A2 | 0.83995 |
| 3 | A3 | 1.00000 |
| 4 | A4 | 0.21752 |
| 5 | A5 | 0.00000 |
| 6 | A6 | * |
| 7 | A7 | * |
| 8 | A8 | * |
| 9 | A9 | * |
| 10 | A10 | * |



**Fig. 6.** Report with the results of multicriteria analysis

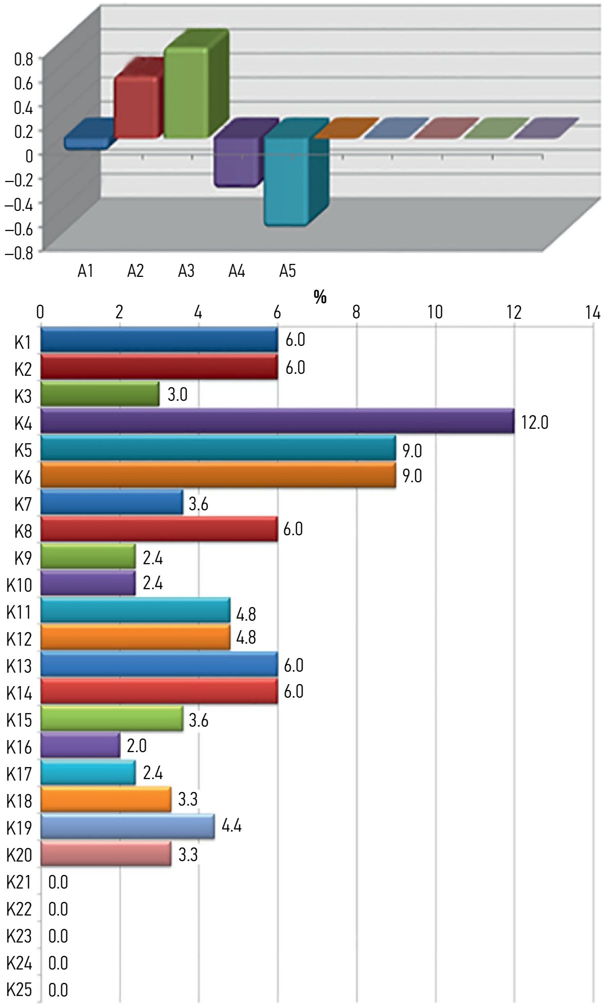



**Fig. 7.** Analysis of influence of moving weights on the results

The Decision Maker (DM) in the given example of a macro analysis of the location problem makes the final decision on the location of the logistic centre – conceptual design (alternative 3) exceeds all present potential constraints and represents the best solution. In other words, by examining the MWC it is possible to draw a conclusion on the solution stability, i.e. whether the weight coefficients have or do not have an important influence on the final result. In the next stage of solving the considered location problem, micro analysis could be carried out using proposed method, where it would be necessary to pay attention to defining a set of criteria that can be partially or completely matched and differentiated.

## Conclusions and Further Development Trends

The introductory part clearly points to the interdisciplinarity of character of location problems. The overview of literature indicates the necessity and application of complex procedures in solving location problems as well as the increased interest in problems in the decision making procedure under conditions conflict.

The analysis carried out is focused on development and application modified method in the procedure of multicriteria optimization and shows some possibilities of the decision maker to control and participate in the selection of the potential location of logistics centre. The problem of decision making in this paper is formulated by the ranking of alternative of potential locations the logistics centre in the selected region. We noticed the effectiveness and practicality of the proposed method through the ability to analyse the impact changes in weights of coefficient to the final solution.

It is obvious that the influence of experience and subjective evaluation of the decision maker in the selection of generalized criteria is reduced to minimum, by changing the existing and introducing new generalized criteria and the selection performed on the basis of the methods of the least squares so that the generalized criterion is chosen in which the sum of squares of deviations of experimental points from the theoretical curve of the generalized criterion is least.

The specific problem that occurs in multicriteria optimization is ranking of alternatives using more complex criteria which consist of sub-criteria functions and parameters. Further research and increase in the efficiency of the proposed method could be directed to solving those problems. The transformation of the mean values of the outranking flows of sub-criteria functions in the value of criterion function of the higher level until a single first-level criteria as well as the throughout formation of the difference maximum and minimum values of the outranking flows would create a basis for further improvements of the proposed method.

The proposed method could be extended with the application of the fuzzy set theory. That developed model could use both quantitative and qualitative terms for alternative values for individual criteria. Such analyses would result in the formation of a comprehensive tool for solving a wide range of real and practical problems.

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