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DETERMINATION OF THE RELATIVE IMPORTANCE OF CRITERIA WHEN THE NUMBER OF PEOPLE JUDGING IS A SMALL SAMPLE

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Abstract. In the multicriterial decision aid (MCDA) process, specific information is given illustrating the preferences of a decision-maker or a group of stakeholders taking part in this process. One kind of information about the preferences is the relative importance of criteria. In the article it was put forward a proposition of settling the division of variability of value of a relative importance of criteria for the case when a group of people (one stakeholder's representatives) is involved in constituting the so-called a small sample ($n < 30$). In the first place the homogeneity of the given information applying statistical-descriptive and positional measures was analysed. Then it was proposed to accept the confidence intervals (with the supposed value of the first kind of error) as a basis for determining the variability scope of the relative importance of individual criteria. The differences in the variability ol the individual criteria were determined according to the average arithmetical value calculated in the analysed test among those giving information. The application of the interval estimation constitutes the basis for carrying out of the sensitivity analysis of the final result obtained by the accepted MCDA method. In the analysed decision problem the Electre III method was used.

Keywords: multiple-criteria decision aiding, relative importance of criteria, a group of stakeholder's representatives, a small sample, the homogeneity of assessment, interval of the variability.

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1. Introduction

In the list of references, there are many publications presenting the ways for determining the relative importance of criteria that reflect the preferences of decision-makers or participants of a decision process, used in the decision-aiding process (Anokhin *et al.* 1997; Bardauskienė

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2007; Weber and Borcherding 1993; Mousseau 1992; Pöyhönen and Hämäläinen 2001; Yeh *et al.* 1999; Turskis *et al.* 2006; Ustinovichius 2007; Viteikienė 2006; Viteikienė, Zavadskas 2007; Zavadskas, Kaklauskas 2007). The article presents a situation where the decision-makers are passengers assessing different scenarios of the development of the public transport in a Polish city (Zak, Thiel 2001). Passenger representatives give the information reflecting their preferences concerning the criteria adopted to assess particular variants of the public transport development. Electre III (Skalka *et al.* 1992) was the method proposed to solve a problem. One of the information necessary to apply this method was precising the relative importance of the criteria (Noghin 2001; Roy 1996; Roy and Mousseau 1996; Thiel 1996) adopted to assess scenarios (variants) of the public transport development. This information was obtained from a numerous and diverse group of passenger representatives, based on the survey conducted. The survey concerned, among others, students between 20 and 24. The number of responses obtained was 56. The persons subject to the survey were informed about the aim of giving information. Research was conducted in two sessions, in which 21 and 35 correct responsed were obtained respectively for 60 respondents. The division into 2 groups was the base for the data analysis for a small sample, $n < 30$ (Freund 1967; Sobczyk 2007). Data analysis for a large sample $n > 30$, both for a group of 35 persons and 56 persons will be presented in a separate publication. It should be noted that the research results presented are of a universal character, that is they may be used, for example, in situations concerning the revitalising of urban areas, realisation of investments producing an impact on the environment, in case where the group of users is large and diversified, in investment planning where different opinions and preferences of participants count, in decision-making process.

2. Information concerning the relative importance of criteria provided by a group of people from a small sample

For the sake of the analysis of proceedings in a situation, where the group of people giving particular information reflecting the preferences is small, the research was concentrated in the first group (21 persons) that gave correct answers. Moreover, only one type of information reflecting the preferences was taken into consideration: the relative importance of criteria. It was assumed that the value of the relative importance of criteria would be precised from 1–10, with accuracy to 1. Such data are of a discreet character. The following criteria were adopted for assessing (Zak, Thiel 2001):

- waiting time [min] (criterion 1),
- riding time [min] (criterion 2),
- timeliness [a number of delays per 1000 rides] (criterion 3),
- reliability [number of rides which were cancelled per 1000 rides] (criterion 4),
- situational safety [number of hazards per 100 rides] (criterion 5),
- transferring frequency [number of rides/number of travels] (criterion 6),
- comfort of travel [% of comfortable rides – no overcrowding, and in low floor vehicles] (criterion 7),
- financial effectiveness [% of income to costs] (criterion 8).

It was assumed that the criteria adopted allow comparing different scenarios of public transport development (Zak, Thiel 2001).

Values of relative importance of criteria, defined by some persons representing passengers are in Table 1. Based on these values, statistical analysis was proposed. It allows précising whether average values (arithmetic mean calculated for particular criteria) are reliable before they are used in calculation procedure, within MCDA method adopted. A range of change for those values was also proposed, which, on one hand, takes into consideration inaccuracy while précising the value of relative importance of criteria, limits that the average values are reliable; on the other hand, it enables to use values ranges obtained for the sensitivity analysis of the final result.

Table 1. Values of relative importance of criteria defined by the group of 21 people.

Assessing persons	**Values of relative importance of criteria; scale 1–10**							
Person num.	cr. 1	cr. 2	cr. 3	cr. 4	cr. 5	cr. 6	cr. 7	cr. 8
1	9	9	7	7	8	5	8	3
2	9	5	7	8	4	6	8	3
3	8	8	8	9	5	6	9	5
4	9	8	8	10	7	5	7	5
5	9	7	8	10	10	7	8	7
6	9	8	9	10	10	7	7	7
7	7	4	7	8	9	9	8	2
8	8	6	7	9	9	8	8	3
9	8	5	10	10	10	7	7	4
10	10	9	8	8	10	4	8	2
11	8	6	9	10	7	5	7	4
12	7	7	4	5	9	8	9	2
13	5	5	5	6	7	6	5	2
14	8	9	8	8	10	7	7	8
15	9	8	7	10	9	6	6	4
16	10	8	8	9	8	7	9	1
17	10	7	8	8	6	4	9	1
18	7	10	4	6	8	8	9	5
19	8	10	7	7	9	9	9	6
20	8	8	5	10	10	2	10	1
21	10	10	8	10	10	1	10	1
$\overline{x}$	8.38	7.48	7.24	8.48	8.33	6.05	8.0	3.62

3. Descriptive measures applied for the data analysis

Based on the values presented in Table 1, diagrams (for each criterion separately) were created, presenting numbers of responses for values of relative importance for the criterion analysed. Examples of diagrams analysed for criterion 1 and 2 are presented in Fig. 1.

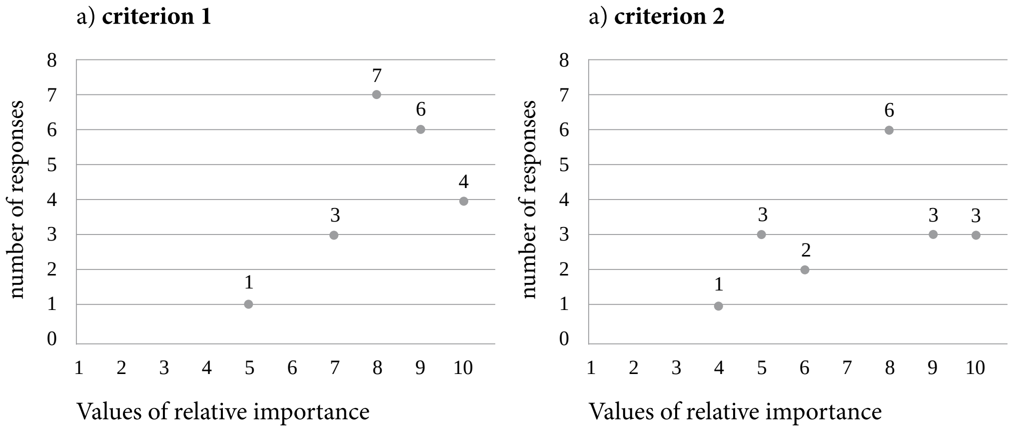

Fig. 1. Diagrams presenting the number of responses attributing particular values of relative importance to the criteria analysed – responses distribution in a given sample; a) for criterion 1; b) for criterion 2 (only 2 basic criteria were showed)

For describing the data (that constitute values of the relative importance attributed to each criterion separately, being the values of a variable in the analysed sample), it is advised to use traditional descriptive measures, that is variance $s^2(x)$, standard deviation $s(x)$, rate of change $V_{s(x)}$, asymmetry rate A_s and concentration rate (kurtosis) γ_4, if it is possible. Formulas for calculating values of these measures, in the given order are presented by the Eqs 1–5, assuming that data form an individual series (Sobczyk 2007):

$$s^2(x) = \frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^2 , \tag{1}$$

where: $\overline{x}$ – arithmetic mean from the values indicated by all respondents (N),
x_i – value of the variable for i unit analysed from the sample (i of the person).

$$s(x) = \sqrt{s^2(x)} , \tag{2}$$

$$V_{s(x)} = \frac{s(x)}{\overline{x}} , \tag{3}$$

$$A_s = \frac{\mu_3}{s^3(x)} , \quad \mu_3 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^3 , \tag{4}$$

where: μ_3 means the 3rd central moment,

$$\gamma_4 = \frac{\mu_4}{\mu_2^2} , \quad \mu_4 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^4 , \tag{5}$$

where μ_4 means the 4th central moment.

Values of these measures are calculated for particular criteria presented in Table 2.

Based on the descriptive measures values in Table 2, the diversification of each criterion, asymmetry and concentration around the average value can be precised.

It can be easily noticed that criteria 2 and 7 have smallest standard deviation (approximately 1, 2) with the smallest value dispersion (15%). Three criteria have relatively large values of standard deviation (criteria 4, 6, 8), approximately 2.0; and, at the same time, criterion 6 has relatively moderate value dispersion (32%). Criterion 8 has a high value dispersion (57.5%). This fact indicates a small homogeneity of data for criterion 8. In such a situation, the application of measures of position of community measures description. These measures were calculated and presented in point 4 of the article.

Analysis of the asymmetry rate A_s and the concentration rate γ_4 indicates the following:

- for criterion 1: left-sided asymmetrical distribution (of negative skewness) of medium, close to average asymmetry. In such a case, the concentration of values for such a criterion is not taken into consideration;
- or criterion 2: left-sided asymmetrical distribution (of negative skewness) of medium asymmetry. Therefore the concentration of value is not taken into consideration for this criterion;
- for criteria 3, 4, 5 and 6: left-sided asymmetrical distribution, of strong asymmetry. Therefore the value concentration for these values (variables) is not taken into consideration;

Table 2. Values of classical descriptive statistical measure calculated for particular criteria

Criteria	$s^2(x)$	$s(x)$	$V_{s(x)}$	A_s	γ_4
criterion 1	1.48	1.22	14.5%	-0.63	3.60
criterion 2	3.01	1.74	23.2%	-0.32	2.14
criterion 3	2.37	1.54	21.3%	-0.72	2.97
criterion 4	3.88	1.97	23.2%	-1.14	2.61
criterion 5	2.99	1.73	20.8%	-0.96	3.02
criterion 6	3.74	1.93	32.0%	-0.91	3.97
criterion 7	1.52	1.23	15.4%	-0.46	2.87
criterion 8	4.34	2.08	57.5%	0.14	2.24

- for criterion 7: left-sided asymmetrical distribution of medium asymmetry. Therefore the concentration of value is not taken into consideration for this criterion;
- for criterion 8: right-sided asymmetrical distribution (of positive value) and of weak asymmetry. In this case, the rate of concentration was taken into consideration around the average value. Based on the value of this rate, the value distribution should be flat.

Taking into consideration the values of asymmetry rate A_s calculated for particular criteria, it can be assumed that the group of assessing people was homogenous. Criterion 4 is an exception, for which $A_s < -1.0$. However, $A_s = -1.14$ is minimally smaller than the one considered as the limit. Because of the asymmetry, it was difficult to assess the concentration of values for particular criteria, except criterion 8.

According to the descriptive measures analysis, it can be assumed that the values indicated by the assessing persons constitute a homogenous set (for each criterion), except criterion 8.

4. Calculation of measures of position for data collection description

As it was presented in point 3, for the description of data (values of relative importance determined separately for each criterion constitute variable values of the sample analysed), it is proposed to use the following measures of position for statistical description: first quartile (Q_1), second quartile (Q_2) – i.e. median *Me*, third quartile (Q_3): average measures, quarter deviation (Q) and change rate for this deviation (V_Q), positional asymmetry rate ($A_{s,Q}$) and positional concentration rate (kurtosis W_s), when it is possible. Formulas for calculating these measures, in the order indicated above, are presented by Eqs 6–11, assuming that the data constitute an individual series, as in the problem analysed (Sobczyk 2007):

$$Q_1 = x_{N_{Q_1}}, \quad N_{Q_1} = \frac{N+1}{4}, \tag{6}$$

where $x_{N_{Q_1}}$ – the value of relative importance of criterion after the arrangement in a series of the data collected, for response of N_{Q_1} number,

N – total number of responses.

$$Q_2 = Me = x_{N_{Q_2}}, \quad N_{Q_2} = \frac{N+1}{2}, \tag{7}$$

where $x_{N_{Q_2}}$ – the value of relative importance of criterion after the arrangement in a series of the data collected, for response of N_{Q_2} number.

$$Q_3 = x_{N_{Q_3}}, \quad N_{Q_3} = \frac{3(N+1)}{4}, \tag{8}$$

where $x_{N_{Q_3}}$ – the value of relative importance of criterion after the arrangement in a series of the data collected, for response of N_{Q_3} number.

$$V_Q = \frac{Q}{Me} \cdot 100, \quad Q = \frac{Q_3 - Q_1}{2}, \tag{9}$$

where Q – the quarter deviation.

$$A_{s,Q} = \frac{Q_3 - 2Q_2 + Q_1}{2Q} \quad (10)$$

and

$$W_s = \frac{D_9 - D_1}{Q_3 - Q_1}\,, \quad (11)$$

where: D_1 and D_9 means the first and ninth decile,

$x_{N_{D_1}}$ and $x_{N_{D9}}$ are the values of relative importance of criterion after the arrangement in a series of the data collected, for responses N_{D_1} and N_{D_9} respectively.

Table 3 presents values of these measures calculated for 3 criteria: 4, 6 and 8. This is due to the doubts concerning the homogenous structure of the relative importance values set indicated by the assessing group.

For criterion 4, the asymmetry rate (that encompasses 50% of the values) had the value showing a medium, left-sided asymmetry ($\overline{x} < Me$). The value of the change rate and the asymmetry rate indicate the homogeneity of values within 50% of data values (i.e. values after rejecting 25% of the lowest values and 25% of the highest values). Criterion 6 shows a similar behaviour; however, in this case the asymmetry will be moderately right-sided. Calculation of measures of position for criteria 4 and 6 would confirm the fact that the collections of values ascribed to these criteria are homogenous. The case of criterion 8 proves the moderate homogeneity of data collection, because in this area the rate of change mounts to 50%. Only the value of asymmetry rate is smaller than 1.0. The value of this rate indicates strongly the right-sided asymmetrical distribution. The concentration rate for a group of 50% of values, for the criteria analysed, should not be taken into consideration because of the asymmetrical distribution.

Descriptive and measures of position for criterion 8 show that only moderate homogeneity of the set of values can be adopted in this particular case. In case of other criteria, it was assumed that the sets of values are homogenous. Therefore, the group of people that was analysed (the number of assessing people) can be considered as a whole, so as to determine the value of relative importance of criteria.

Table 3. Values of measures of position of data set calculated based on the criteria chosen

Criteria	**Measures of position**					
	Quartile Q_1	**Quartile** $Q_2 = Me$	**Quartile** Q_3	**Rate of change** V_Q	**Asymmetry rate** $A_{s,Q}$ **and** $\overline{x}$ **and** Me	**Concentration rate Ws**
criterion 4	7.5	9.0	10.0	13.9 %	–0.4; $\overline{x} < Me$	2.0
criterion 6	5.0	6.0	7.5	21.0 %	0.4; $\overline{x} \geq Me > D$	2.5
criterion 8	2.0	3.0	5.0	50.0 %	0.7; $\overline{x} < Me$	2.0

5. Interval estimation of relative value of particular criteria

If we want to precise the confidence interval for average value of importance, separately for each criterion analysed, but in reference to the entire population encompassing all the passengers, it was assumed that the probability of occurrence is 95%. Besides, it was assumed that the population has a normal distribution of unknown standard deviation. Values of relative importance indicated by the assessing group for particular criteria form the samples. Each sample is of the same number. Samples smaller than 30 are small samples (Freund 1967; Sobczyk 2007). The confidence interval for average value of relative importance for each criterion analysed might be precised in such a case based on the statistics of t-Student of n-level of freedom, expressed by the following formula (Sobczyk 2007):

$$t = \frac{\bar{x} - \mu}{s}\sqrt{n-1}, \quad s = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}, \tag{12}$$

where: $\bar{x}$ – arithmetic mean of the values indicated by all (n) assessing people, $n = 21$ – it is the mean of the sample,

$n - 1$ – number of degrees of freedom,

s – standard deviation from the sample,

μ – average value of relative importance of criteria in population.

The confidence interval for μ in population in the case of a small sample when the probability $1 - \alpha$ expressed by the formula, assuming that the population has a normal distribution and the deviation is standard σ and the average μ (Sobczyk 2007):

$$P\left(\bar{x} - t_{\frac{\alpha}{2}} \frac{s}{\sqrt{n-1}} < \mu < \bar{x} + t_{\frac{\alpha}{2}} \frac{s}{\sqrt{n-1}}\right) = 1 - \alpha, \tag{13}$$

where: n – sample size,

s – as in the formula (12),

α – estimation error (5% and 10% for the calculations).

Limits of confidence interval of average value of relative importance, calculated for particular criteria, with probability of 95%, are presented in Table 4. The confidence with which we approach the sample analysed is important, as it is connected with occurrence of the first kind of error. If we assume error probability ≤ 5%, the estimation precision will be greater, and when it is ≤ 10% and ≥ 5% – the results are more general and should be treated with caution.

It should be remembered that along with the increase of confidence rate ($1-\alpha$), the confidence interval enlarges, and at the same time – the interval estimation. In other words, a greater accuracy is obtained when the confidence rate is greater. On the other hand, a greater precision is obtained when the value of this rate is smaller. Table 4 presents the results of calculations for confidence intervals for estimation error 10%.

Table 4. Limits of confidence intervals of the value of average importance for particular criteria

Criteria	**Confidence intervals for average $\bar{x}$ of the sample and for average μ in population**	
	estimation error α = 5%	estimation error α = 10%
criterion 1	8.38 ± 0.57; $7.81 < \mu_1 < 8.95$	8.38 ± 0.47; $7.91 < \mu_1 < 8.85$
criterion 2	7.48 ± 0.81; $6.67 < \mu_2 < 8.29$	7.48 ± 0.67; $6.81 < \mu_2 < 8.15$
criterion 3	7.24 ± 0.72; $6.52 < \mu_3 < 7.96$	7.24 ± 0.59; $6.65 < \mu_3 < 7.83$
criterion 4	8.48 ± 0.92; $7.56 < \mu_4 < 9.40$	8.48 ± 0.76; $7.72 < \mu_4 < 9.24$
criterion 5	8.33 ± 0.81; $7.52 < \mu_5 < 9.14$	8.33 ± 0.67; $7.66 < \mu_5 < 9.0$
criterion 6	6.05 ± 0.90; $5.15 < \mu_6 < 6.95$	6.05 ± 0.74; $5.31 < \mu_6 < 6.79$
criterion 7	8.0 ± 0.58; $7.42 < \mu_7 < 8.58$	8.0 ± 0.48; $7.52 < \mu_7 < 8.48$
criterion 8	3.62 ± 0.97; $2.65 < \mu_8 < 4.59$	3.62 ± 0.80; $2.82 < \mu_8 < 4.42$

It can be observed that the confidence intervals for α = 10% decreased from 0.1 to 0.7 as for the average. These changes are not significant, taking into consideration the range of these intervals in both cases (i.e. if α = 5% and α = 10%). Criterion 8 is the one for which, the range of confidence interval is very high, compared to the average of the sample. In this case, the average of the sample $\left(\bar{x}_8 = 3.62\right)$ should be treated with caution and the extreme values of relative importance (2.65 and 4.59) should be checked.

Based on the values presented in Table 4, it can be seen that the values intervals might be only treated as the change limits for particular criteria. This should be used to carry out the sensitivity analysis of the final result to increase the reliability of this result for the decision-maker; at the same time, it should contribute to the effectiveness of decision-aiding process (Jimenez *et al.* 2003; Mróz, Thiel 2005; Thiel 1996, 2000, 2001, 2006).

Similarly to the average value of relative importance calculated for particular criteria, confidentiality intervals for an unknown standard deviation σ in normal population, for a small sample were calculated. It was done based on the deviation value of the sample (*s(x)* –see Table 2) and the statistics of the distribution χ^2 of n–1 of degrees of freedom, expressed by the formula (Sobczyk 2007):

$$\chi^2 = \frac{(n-1)s^2}{\sigma^2}, \tag{14}$$

where: $\bar{x}$ – is arithmetic mean of all values indicated by all (n) assessing people, in example it is the average of the sample for n = 21,

n – 1 – number of degrees of freedom,

s – standard deviation of the sample (see formula 12).

Confidentiality interval for standard deviation σ of the population for small sample, with probability of 1–α expressed by the formula, assuming that the population has a normal distribution and standard deviation σ and average μ are unknown (Sobczyk 2007):

$$P\left(\sqrt{\frac{(n-1)s^2}{\chi^2_{\frac{\alpha}{2}}}} < \sigma < \sqrt{\frac{(n-1)s^2}{\chi^2_{1-\frac{\alpha}{2}}}}\right) = 1-\alpha, \quad (15)$$

where: n – sample size,

s – as in the formula (12),

α – estimation error (5% for the calculations).

Limits of confidentiality interval for standard deviation s, calculated for particular criteria with probability of 95% are presented in Table 5. Confidentiality intervals achieved for standard deviation s for particular criteria indicate the occurrence of actual diversity of values as for the average value in population (all assessing groups). That is why the calculations should be applied, within the MCDA method adopted, for value intervals of relative importance of each criterion (compare Table 4).

Table 5. Limits of confidentiality intervals of standard relative deviation for particular criteria

Criteria	**Confidence intervals for standard deviation σ in population estimation error α = 5%**
criterion 1	$0.93 < \sigma_1 < 1.76$ ($s = 1.22$)
criterion 2	$1.33 < \sigma_2 < 2.51$ ($s = 1.74$)
criterion 3	$1.18 < \sigma_3 < 2.22$ ($s = 1.54$)
criterion 4	$1.51 < \sigma_4 < 2.85$ ($s = 1.97$)
criterion 5	$1.32 < \sigma_5 < 2.50$ ($s = 1.73$)
criterion 6	$1.48 < \sigma_6 < 2.79$ ($s = 1.93$)
criterion 7	$0.95 < \sigma_7 < 1.78$ ($s = 1.23$)
criterion 8	$1.59 < \sigma_8 < 3.01$ ($s = 2.08$)

6. Conclusions

The aim of the article was to propose the procedure, when the values of relative criteria importance are calculated based on the arithmetic mean. Particular attention was paid to homogeneity of the data and the evaluation of reliability of arithmetic mean that can be the base for the relative importance of criteria. The case of a small sample $n < 30$ was analysed. Descriptive and positional (supplementary ones) measures allowed determining the homogeneity of data collection. Confidentiality interval allowed determination of relative importance values for particular criteria, instead of using only arithmetic mean. That should influence the increase of reliability of calculations using MCDA method, where the relative importance of criteria is the information of preferences that should be provided. Electre III is such a method. Values of relative importance of criteria in intervals are the base to carry out the sensitivity analysis of the final result, obtained through the MCDA calculation method.

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SANTYKINIO RODIKLIO REIKŠMINGUMO NUSTATYMAS, KAI VERTINANČIŲ ASMENŲ SKAIČIUS NEDIDELIS

T. Thiel

Santrauka

Daugiatiksliame sprendimų priėmimo procese charakteringa informacija išreiškia vieno sprendimų priėmėjo arba grupės dalyvių prioritetus. Tai gali būti santykinis rodiklio reikšmingumas. Straipsnyje nagrinėjamas atvejis, kai santykiniam reikšmingumui nustatyti pasitelkta maža grupė asmenų (n < 30). Iš pradžių, taikant statistinius metodus, buvo analizuojamas informacijos homogeniškumas. Toliau buvo pasiūlyta taikyti pasikliautinąjį intervalą (su numatoma paklaidos reikšme) kaip bazę konkretaus santykinio rodiklio reikšmingumo kintamumui nustatyti. Naudojant vidutines aritmetines reikšmes nustatyti atskirų rodiklių kintamumo skirtumai. Nustatyti intervalai naudoti atliekant galutinio rezultato, gauto pasirinktu daugiatiksliu sprendimų priėmimo metodu, jautrumo analizę. Sprendimui priimti taikytas Elektre III metodas.

Reikšminiai žodžiai: daugiatikslis sprendimų priėmimas, prioritetai, santykinis reikšmingumas, rodiklis, Elektre III.

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