

A New Logarithmic Normalization Method in Games Theory

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Abstract. Multi-criteria decision making is used in many areas of human activities. Each alternative in multi-criteria decision making problem can be described by a set of criteria. Criteria can be qualitative and quantitative. They usually have different units of measurement and different optimization direction. The normalization aims at obtaining comparable scales of criteria values. The normalization of criteria values is not always needed, but it may be essential. In the new program LEVI 3.1 the following normalization methods are possible: vector, linear scale, non-linear and new logarithmic techniques. Logarithmic normalization has never been used before. The present research is focused on introducing a new logarithmic method for decision making matrix normalization.

Keywords: games theory, multiple criteria, decision matrix, logarithmic normalization, decision making in engineering, case study.

1. Introduction

A review of standard decisions made in engineering, management and economy has shown that the deficiency of information is often ignored. Experts not always make use of the appropriate initial data. The values applied are often exaggerated. Poor quality models are used which, if required, are slightly corrected based of practical experience. However, the actual situation is not properly reflected and possible effects of external actions are not known. A decision is often made by comparing costs and benefits of the available alternative under various environmental conditions.

The evaluation of all possible actions is not always sufficient. Each action may lead to several, sometimes conflicting results. As the actual result is not known, the criteria taking into consideration all possible results are needed. Therefore, multi-criteria decision making becomes extremely important. An alternative in multi-criteria evaluation is usually described by quantitative and qualitative criteria. These criteria have different units of measurement. Normalization is aimed at obtaining the comparable scales of the criteria values. Different techniques of criteria value normalization are used. Normalization of the criteria values is not always necessary.

The impact of the decision matrix normalization methods on the decision results has been investigated by many authors (Weitendorf, 1976; Hwang and Yoon, 1981; Peld-

schus *et al.*, 1983, 2002; Peldschus, 1986, 2001, 2007; Peldschus and Zavadskas, 1997; Dejus, 2002; Körth, 1969; Stopp, 1975; Jüttler, 1966; Migilinskas, 2003; Migilinskas and Ustinovichius, 2007; Kaklauskas *et al.*, 2007; Kalibatas *et al.*, 2007; Turskis *et al.*, 2006; Zagorskas and Turskis, 2006; Ginevicius and Podvezko, 2007; Noorul Haq and Kannan, 2007; Antucheviciene *et al.*, 2006; Brauers and Zavadskas, 2006; Brauers *et al.*, 2007; Brauers, 2007a, 2007b; Viteikienė, 2006; Viteikienė and Zavadskas, 2007; Hovanov, 1996; Cloquell and Santamarina, 2001; Zavadskas, 1987; Zavadskas *et al.*, 1994, 2002, 2003, 2004, 2006, 2007a, 2007b; Ustinovichius, 2001, 2004, 2007; Ustinovichius and Zavadskas, 2004; Ustinovichius *et al.*, 2007; Vaidogas and Zavadskas, 2007; Vaidogas *et al.*, 2007). The authors of many well-known programs chose one particular problem solution method or approach to decision-making matrix normalization. There are still no rules determining the application of multi-criteria evaluation methods and interpretation of the results obtained.

Vilnius Gediminas Technical University (VGTU) and Leipzig University of Applied Sciences (HTKW) have been investigating the application of games theory principles to civil engineering technology and management problems for more than 20 years (Peldschus *et al.*, 1983, 2002; Peldschus, 2001, 2007; Peldschus and Zavadskas, 1997; Zavadskas, 1987; Zavadskas and Kaklauskas, 2007). The program LEVI 3.0 was a result of the co-operation between VGTU and HTKW. All calculations were made with LEVI 3.0 (Zavadskas *et al.*, 2002, 2003, 2004; Peldschus *et al.*, 2002; Peldschus, 2007). The program LEVI 3.1 was created for evaluating various processes in economics, engineering and management.

In the new program LEVI 3.1 (Fig. 1), a new logarithmic normalization method is implemented. This new software allows us to find a solution under the conditions of risk and uncertainty and to compare the results by applying different methods.

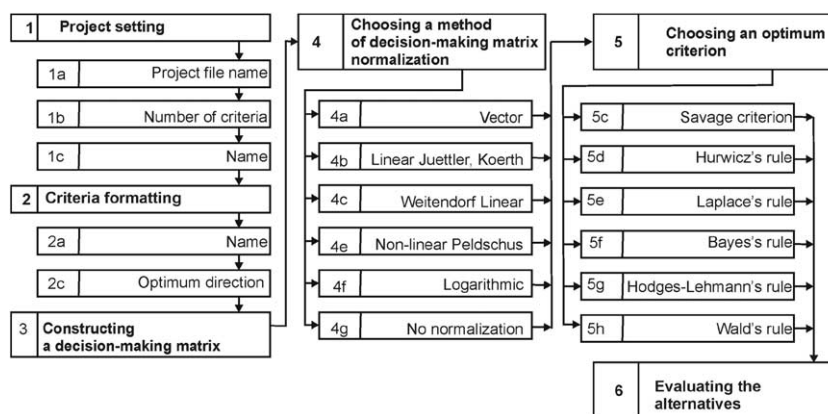


Fig. 1. Block-diagram of choosing the best alternative in LEVI 3.1 program.

2. Structure and Methodology of the Program LEVI 3.1

In the program LEVI 3.1, the games theory of the discrete optimization problem solution is used. Any problem to be solved is represented by a matrix, containing the alternatives (rows) and the criteria (columns). Usually, the criteria have different dimensions. In order to avoid the difficulties caused by different dimensions of the criteria, the ratio to the optimal value is used. There are various theories describing the ratio to the optimal value. However, the values are mapped either on the interval [0;1] or the interval [0;∞] by applying the normalization of a decision-making matrix. In the program LEVI 3.1, only the widely known and logarithmic normalization methods are used (Table 1).

When the normalization is completed, it is possible to evaluate the criteria with weighting factors $0 < q_j < 1$. The sum of the weighting factors should be equal to 1. Only well-founded weighting factors should be used because weighting factors influencing the solution are always subjective. Using the Games Theory (von Neumann and Morgenstern, 1943), the two-sided test aims at finding the equilibrium as a result of the rational behaviour of two parties having the opposite interests or searching for the equilibrium in a game against nature.

Table 1
Normalization methods in the program LEVI 3.1

Normalization method (NM)	Preferable max a_{ij}	Preferable min a_{ij}	Notes
1 Vector (VE) normalization (Van Delft and Nijkamp, 1977)	$b_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^m a_{ij}^2}}$	$b_{ij} = 1 - \frac{a_{ij}}{\sqrt{\sum_{i=1}^m a_{ij}^2}}$	The ratio of the values remains constant for this type of normalization in the interval [0;1].
2 Weitendorf's (1976) linear (WL) normalization	$b_{ij} = \frac{a_{ij} - \min_i a_{ij}}{\max_i a_{ij} - \min_i a_{ij}}$	$b_{ij} = \frac{\max_i a_{ij} - a_{ij}}{\max_i a_{ij} - \min_i a_{ij}}$	The calculated values are dependent on the size of the interval $[\max_i a_{ij}; \min_i a_{ij}]$
3 Jüttler's-Körth's (1969) normalization	$b_{ij} = 1 - \left \frac{\max_i a_{ij} - a_{ij}}{\max_i a_{ij}} \right $	$b_{ij} = 1 - \left \frac{\min_i a_{ij} - a_{ij}}{\min_i a_{ij}} \right $	The application of this type of normalization is limited to the interval [0;1].
4 Peldschus <i>et al.</i> (1983) non-linear (NL) normalization	$b_{ij} = \left(\frac{a_{ij}}{\max_i a_{ij}} \right)^2$	$b_{ij} = \left(\frac{\min_i a_{ij}}{a_{ij}} \right)^3$	The values are diminished more than when using other methods
5 New Logarithmic (LN) normalization	$b_{ij} = \frac{\ln(a_{ij})}{\ln\left(\prod_{i=1}^n a_{ij}\right)}$	$b_{ij} = \frac{1 - \frac{\ln(a_{ij})}{\ln\left(\prod_{i=1}^n a_{ij}\right)}}{n-1}$	The sum of normalized criterion values is always equal to 1.

Wald's rule (WA): This method is used to search for the best of the worst solutions (Wald, 1945). The decision-maker acts according to the worst situation occurring (a pessimistic attitude):

$$S^* = \{S_i/S_i \in S \cap \max_i \min_j b_{ij}\}. \quad (1)$$

Savage criterion (SA): The aim is to minimize the loss of appropriateness, which is the difference between the greatest and the achieved benefit (Savage, 1951):

$$S^* = \left\{ S_i/S_i \in S \cap \min_i \max_j c_{ij} \cap c_{ij} = \left(\max_r a_{rs} \right) - a_{rs} \right\}, \quad (2)$$

where $r = \overline{1, m}$ and $s = \overline{1, n}$. A disadvantage of the method is in the presence of non-optimal strategies affecting the solution.

Hurwicz's rule (HU): An optimal strategy is based on the best and the worst results (Hurwicz, 1951). These values, calculated from the row's minimum and row's maximum, are integrated into a weighted average using optimism parameters:

$$S^* = \left\{ S_i/S_i \in S \cap \max_i h_i \cap h_i = \lambda \max_j b_{ij} + (1-\lambda) \min_j b_{ij} \cap 0 \leq \lambda \leq 1 \right\}. \quad (3)$$

The value $\lambda = 1$ gives the most pessimistic solution (Wald's rule). For the value of $\lambda = 0$ only the maximum (the greatest risk) values are considered.

Laplace's rule (LA): The solution is calculated under the condition that all probabilities for the strategies of the opponent are equal (Bernoulli, 1738):

$$S^* = \left\{ S_i/S_i \in S \cap \max_i \left(1/n \sum_{j=1}^n b_{ij} \right) \right\}. \quad (4)$$

Bayes's rule (BA): Given the probabilities for the strategies of the opponent, the maximum for the expected value can be used (Arrow *et al.*, 1949):

$$S^* = \left\{ S_i/S_i \cap \max_i \left(\sum_{j=1}^n q_j b_{ij} \right) \cap \sum_{j=1}^n q_j = 1 \right\}. \quad (5)$$

Hodges-Lehmann rule (HL): According to this rule, the confidence in the knowledge of the probabilities of the opponent's strategies can be expressed by the parameter λ (Hodges and Lehmann, 1952):

$$S^* = \left\{ S_i/S_i \in S \cap \max_i \left[\lambda \sum_{j=1}^n q_j b_{ij} + (1-\lambda) \min_j b_{ij} \right] \cap 0 \leq \lambda \leq 1 \right\}, \quad (6)$$

where $\lambda = 0$ (no confidence) gives the solution according to Wald's rule, while $\lambda = 1$ (great confidence) gives the solution according to Bayes's rule.

3. Normalization Test in the Case of Various Data Intervals

In order to test the described new normalization method, we will consider the normalization of test matrices. The alternatives of the initial data for normalization are designed according to various distribution laws:

$$\begin{aligned}
 x_{1i} &= 0 + i; & x_{2i} &= 10 + i; & x_{3i} &= 100 + i; \\
 x_{4i} &= 1000 + i; & x_{5i} &= 10^{(i-1)}; & x_{6i} &= 0.001 \cdot 10^i, \text{ where } i = \overline{1, 10}.
 \end{aligned}
 \tag{7}$$

The values of the initial data are changed depending on particular intervals. The assumption is made that all criteria are maximized. A comparison of the test results is given in Table 2.

Based on the comparison of normalization results, we can make the following conclusion: the application of a new logarithmic normalization method yields the values of the normalized matrix elements approaching the average values obtained in other normalization methods. In some cases, the obtained values are approximately equivalent to the values of linear normalization.

Table 2
Comparison of the test results of matrix logarithmic normalization

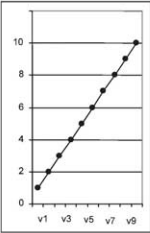
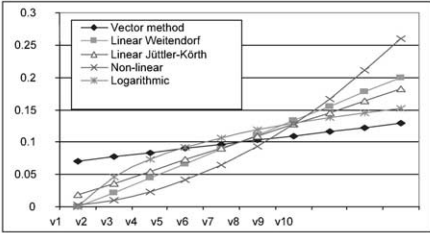
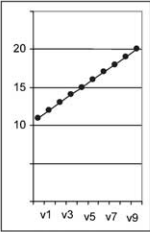
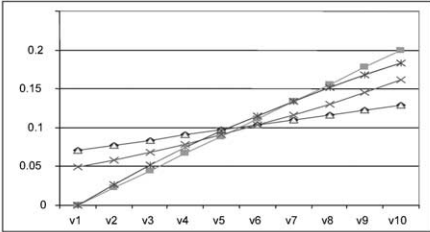
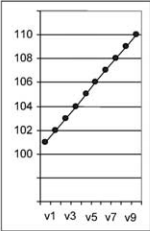
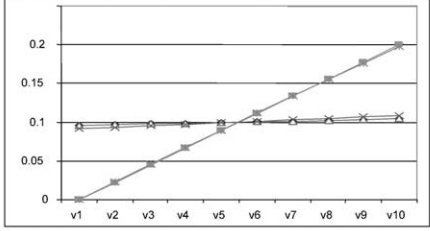
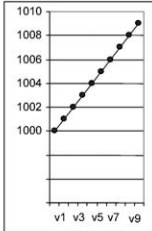
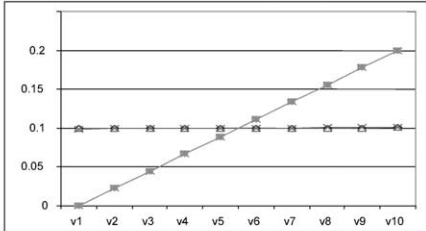
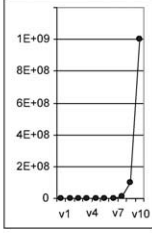
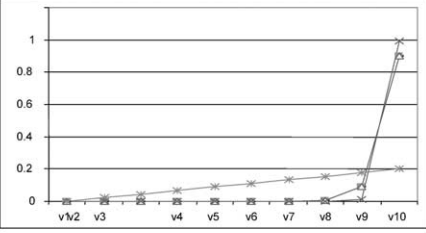
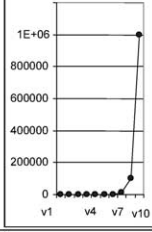
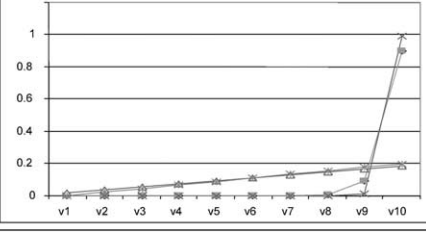
Initial data	Normalization results	Notes
		<p>The obtained values (LN) are approximately equivalent to the average values yielded by other methods of normalization.</p>
		<p>The obtained values (LN) are approximately equivalent to the average values yielded by other methods of normalization.</p>
		<p>The obtained values (LN) are approximately equivalent to the values of Weitendorf linear normalization (WL) and more segregated than values yielded by other normalization methods.</p>

Table 2 (continued)

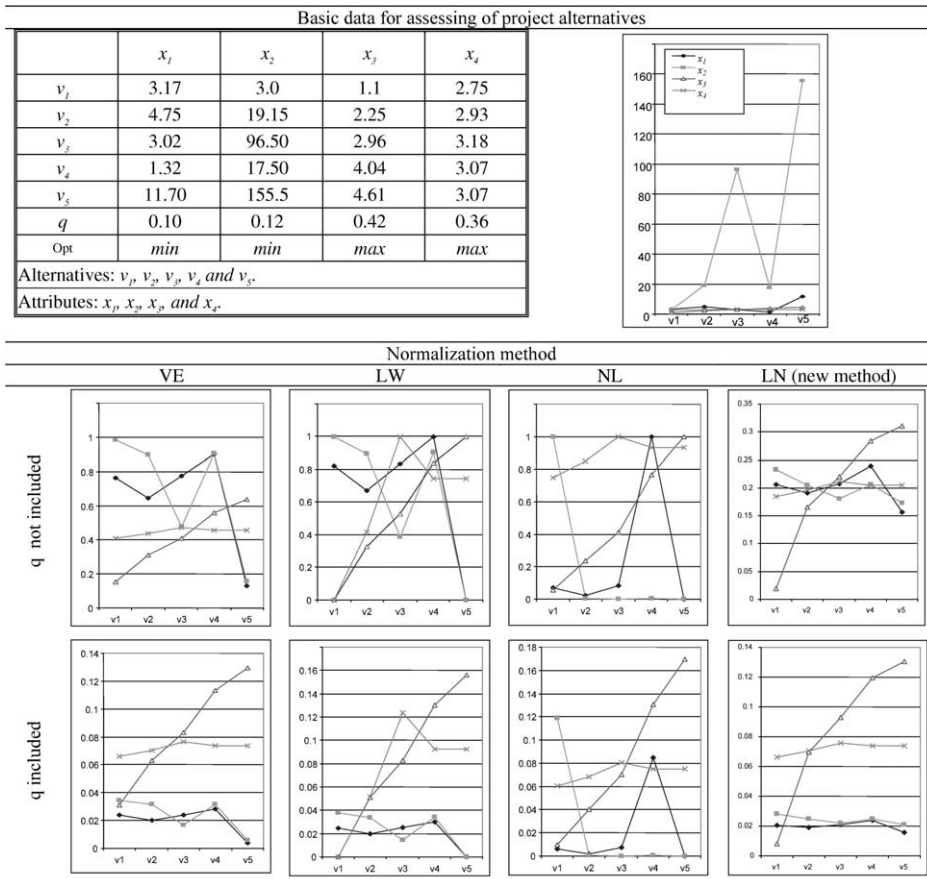
Comparison of the test results of logarithmic normalization presented in the matrix

Initial data	Normalization results	Notes
		<p>The obtained values (LN) are approximately equivalent to the values of Weitendorf linear normalization (WL). These values differ from those yielded by other methods and are more segregated.</p>
		<p>Values (LN) differ from the values of other methods and are more segregated.</p>
		<p>The obtained values (LN) are approximately equivalent to the values of Jüttler's -Körth's normalization. Values differ from values of other methods and are more segregated.</p>

4. A Case Study of Alternatives' Evaluation Using Various Solution Methods and Normalization Techniques

To illustrate the application of the described methods, the problem of the selection of a rational option of the external finishing for cast-in-place buildings will be considered (Zavadskas *et al.*, 1994). To select a rational alternative of external wall finishing in cast-in-place buildings, a survey of five technological alternatives was conducted. A 13-storey block-of flats in Justiniskes, a suburb of Vilnius, served as an example of analysis. The initial data for evaluation of the alternatives are given in Table 3. The first alternative deals with developing a relief surface of concrete by assembling the structures on formwork when concrete is placed in metal forms. The second alternative deals with the decoration of facades by open work structural elements of 1.0×0.5 m made of gypsum concrete slabs. The third alternative presents facing of ceramic tiles. The fourth alternative deals with painting of the balconies with a long-lasting paint. The fifth alternative deals with painting of the whole facade with a long-lasting paint. The evaluation of the alternatives was based on the following four attributes: 1) costs x_1 , thousand \$; 2) labour input x_2 , man-days; 3), 4) the criteria 3 and 4 (durability x_3 and aesthetics x_4) were evaluated in points by 28 experts. The criteria weights were determined by the method of pairwise

Table 3
The initial data for assessing project alternatives and results of decision matrix normalization



comparison based on the estimates of 28 experts. The obtained weight vector of attributes was $q = (0.10, 0.12, 0.42, 0.36)$.

In the present investigation, the vector, linear, non-linear and new logarithmic methods of initial decision-making matrix normalization were used. A number of different problem solution methods, such as Wald’s rule, Savage criterion, Hurwicz’s rule, also Laplace’s rule, Bayes’s rule, Hodges-Lehmann-rule, were also applied. Tables 4 and 5 provide the solution results and graphical representation of their comparative analysis. The use of logarithmic normalization improves the quality of decision matrix normalization in solving economic and organizational problems.

When the criteria weights are taken into account, the priority order of the alternatives is presented as $v_4 \succ v_3 \succ v_5 \succ v_2 \succ v_1$ (implying that the “fourth” alternative is better than the “third” one, the “third” alternative is better than the “fifth” one, the “fifth” alternative is better than the “second” one and the “second” alternative is better than the “first” one). A similar set $v_4 \succ v_5 \succ v_3 \succ v_2 \succ v_1$ is obtained when the criteria weights are not taken into account in the process of alternative assessment.

Table 4
Ranking of the alternatives

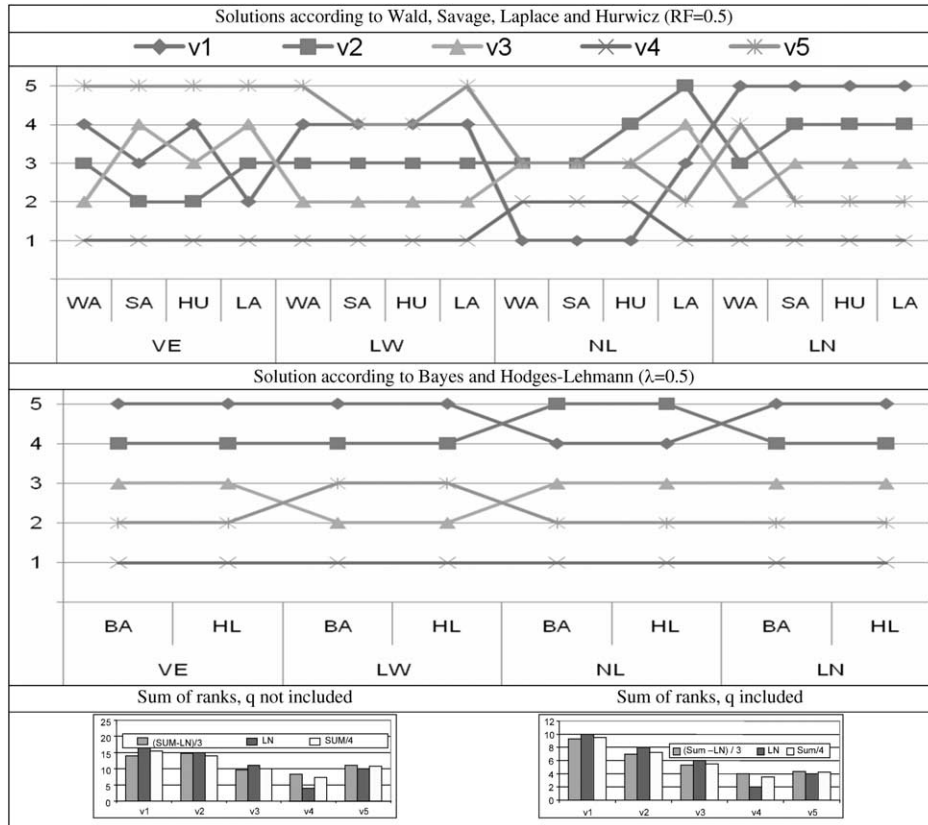


Table 5

Ranks of the project alternatives. Solutions according to Wald, Savage, Laplace and Hurwicz (RF = 0.5), Bayes and Hodges-Lehmann ($\lambda = 0.5$)

NM	Ranks of alternatives					
	q not included				q included	
	WA	SA	HU	LA	BA	HL
VE	4>3>2>1>5	4>2>1>3>5	4>2>3>1>5	4>1>2>3>5	4>5>3>2>1	4>5>3>2>1
LW	4>3>2>1>5	4>3>2>1=5	4>3>2>1=5	4>3>2>1>5	5>4>2>1>3	5>4>2>1>3
NL	1>4>2=3=5	1>4>2=3=5	1>3=4>5>2	4>5>1>3>2	4>5>3>1>2	4>5>3>1>2
LN	4>3>2>5>1	4>5>3>2>1	4>5>3>2>1	4>5>3>2>1	4>5>3>2>1	4>5>3>2>1

The results of problem solution are more stable. For example, when the weights of the criteria are included in calculation, various methods and logarithmic normalization used in solving the problem determine the alternative 4 as the most effective, while other normalization methods give different results. If weights of the criteria are not included in the evaluation process, the most effective option according to the logarithmic normalization (e.g., linear normalization) is the alternative 4, while other normalization methods describe other alternatives as optimal.

According to the results obtained in the analysis, the most effective fourth alternative was implemented.

5. Conclusions

It is hardly possible to evaluate the effect of various methods of normalization of a decision-making matrix on the numerical results obtained. These problems can be solved by applying the program LEVI 3.1.

Some modules of the program LEVI 3.1 can be used for creating decision-making systems.

Logarithmic normalization of a decision-making matrix has been used for the first time. Logarithmic normalization of a decision-making matrix yields more stable results in solving multi-criteria decision problems.

The calculations show that logarithmic normalization may be used in the cases when the values of the criteria differ considerably.

The logarithmic normalization method used in solving the problems segregates normalized values more effectively than other methods.

A comparison of results obtained by different solution methods is needed because it is not always possible to apply the games theory equilibrium to economics, engineering and management.

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Naujasis logaritminis normalizavimo metodas, naudojamas lošimų teorijoje

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Daugiakriterinis sprendimų priėmimas yra naudojamas daugelyje visuomenės veiklos sričių. Alternatyva daugiakriteriniame vertinime dažniausiai yra apibrėžiama kiekybiniais ir kokybiniais kriterijais, kurie turi skirtingus matavimo vienetus. Normalizuojant šiuos kriterijus siekiama jų suvienodinimo, kad būtų galima palyginti kriterijų reikšmes. Nors normalizavimas ne visada reikalingas, jis gali būti labai svarbus kai kuriais atvejais, pavyzdžiui, lošimų teorijoje. Naujai sukurtoje programoje LEVI 3.1 yra naudojami tokie normalizavimo metodai: vektorinis, linijinis, nelinijinis ir naujasis logaritminis. Logaritminis normalizavimas niekada nebuvo panaudotas. Šiame tyrime pagrindinis dėmesys yra skiriamas logaritminio metodo, naudojamo sprendimų priėmimo matricos normalizavimui, aprašymui.