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Multi-criteria Optimization System for Decision Making in Construction Design and Management

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All new ideas and possible variants of decisions must be compared according to many criteria. The complex nature of decision-making requires practitioners to select investment options based on a wider variety of policy considerations in addition to cost benefit analysis and pure technical considerations. In economics and decision making it is essential to be able to take into account the impacts of cultural, social, moral, legislative, demographic, economic, environmental, governmental and technological change, as well as changes in the business world on international, national, regional and local markets. Cost benefit analysis approach is a useful tool for investment decision-making from an economic perspective. Cautions should also be given to the methods of determining the value of social and local interests. Some social externalities, such as employment and regional economic impacts, are generally omitted in current practices. Current practices tend to use cardinal or ordinal scales in measure in non-monetized criteria. The use of unreasonable monetization methods in some cases has discredited cost benefit analysis in the eyes of decision makers and the public. It may be appropriate to consider these externalities in qualitative forms in a multi-criteria analysis. Multi-criteria decision making is used in various areas of human activities. The Criteria can be qualitative and quantitative. They usually have different units of measurement and differ in optimization direction. The normalization aims at obtaining comparable scales of criteria values. In the new version of the program LEVI 4 the normalization methods are including vector, linear scale, non-linear and new logarithmic techniques may be used. This software considers the main aspects of two-sided game problems. The following strategic principles are used: Wald's rule, Savage criterion, Hurwicz's rule, Laplace's rule, Bayes's rule and Hodges-Lehmann rule. This program is demonstrated by considering a real case study involving 4 evaluation criteria of the currently used external walls of individual residential buildings.

Keywords: *construction, optimization, multi-criteria, game theory, two-sided problem, normalization, logarithmic, software.*

Introduction

The research problem. Economics and management develop very rapidly with other scientific directions (Martinkus, 2006). All developments and changes require methods to evaluate them. All new ideas and possible variants of decisions must be compared according to many criteria. Each decision-maker has own interests and is always interested in states of environment factor (Christauskas and Stungurienė, 2007). Many researchers (Zavadskas and Vilutiene 2006; Turskis, 2008; Kalibatas and Turskis, 2008) have pointed out that in economics and decision making it is essential to be able to take into account the impacts of cultural, social, moral, legislative, demographic, economic, environmental, governmental and technological change, as well as changes in the business world on international, national, regional and local real estate markets. Therefore, after the popularity of cost benefit analysis (Susnienė and Vanagas, 2007) and related engineering economic evaluation techniques, there was an increasing popularity of *multi-criteria analysis*, which is capable of dealing with the multiple dimensions of evaluation problems. These techniques aim to solve conflicting social, environmental, political and economic issues in modern decision-making. Multi-criteria decision-making methods intuition is closely related to the way humans have always been making decisions. Consequently, despite the diversity of multi-criteria decision-making methods approaches, methods and techniques, the basic ideas of multi-criteria decision-making methods are very simple: a finite or infinite set of actions (alternatives, solutions, courses of action ...), at least two criteria, and, obviously, at least one decision-maker. Given these basic elements, multi-criteria decision-making methods are an activity which helps making decisions mainly in terms of choosing, ranking or sorting the actions.

The purpose of the article. The idea of multi-criteria decision-making methods is so natural and attractive that thousands of articles and books have been devoted to the subject, with many scientific journals regularly publishing articles about multi-criteria decision-making methods. The main ideas are well established there.

The last decade saw a great increase in application of multi-criteria decision making methods application in construction and management. Analytic Hierarchy Process (AHP) has been a tool in the hands of decision makers and researchers since its invention; it is still one of the most widely used multi-criteria decision-making methods. Many outstanding works including applications of AHP in different fields have been published based on AHP. AHP and its numerical extensions are flexible enough to be integrated with different techniques like Linear Programming, Quality Function Deployment, Fuzzy Logic, etc. This enables the user to extract benefits from all the combined methods, and, hence, achieve the desired goal in a better way. Skibniewski (1992) applied this method to the selection of rational construction technology. Hsueh et al. (2007) used AHP method. The authors argue that using the utility function to set up an assessment model shows the advantages of the method and it can not only overcome the difficulties of building a multi-criteria model but also help decision-makers to adjust it properly according to their preference and attitude risk in order to reduce inconsistent decisions influenced by various factors, such as emotion, environment, information, etc. This study presents a novel procedure for determining construction project budgets. Lai et al. (2008) proposed a procedure for integrating the AHP - based multi-criteria evaluation model with a simulation-based cost model. First, a set of budget evaluation criteria and their associated weights for public building construction projects were established via a questionnaire survey and application of AHP, respectively. Using the same criteria and weights, they performed consistent evaluation of budgets for different projects. Su et al. (2006) proposed a revised method by applying Monte Carlo simulation analysis to rank the major transport projects. They determined implementation priorities and budget allocations which were derived from the AHP and direct subjective rankings to set funding priorities.

Ugwu et al. (2006a, 2006b) discussed the development of key performance sustainability indicators, computational methods, and analytical models for achieving sustainability in infrastructure projects. They used the ‘weighted sum model’ technique in multi-criteria decision analysis and the ‘additive utility model’ in AHP for multi-criteria decision making to develop the model based on the outlined one.

Wong et al. (2008) research was conducted towards aiding in decisions and appraisal of building systems and components in the intelligent building. The authors aimed to identify the key intelligent indicators and map analytical decision models for intelligence appraisal of the intelligent building systems. A total of 69 key intelligence criteria were identified for eight major intelligent building systems. Two multi-criteria decision making approaches, the AHP and analytic network process (ANP), were employed in this study to evaluate the intelligence level of the intelligent building systems.

Kauko (2007) developed a pairwise comparison procedure of the house buyers’ or renters’ criteria based on expert judgements and the AHP. The author‘s study is based on expert elicited residential location quality profiles in the city, and builds on prior work on housing market analysis reported elsewhere. Several authors (Zavadskas, 1990; Ugwu 2006a, 2006b; Hsueh et al. 2007) applied the utility theory methods to select rational alternatives in construction. Zavadskas (1986, 1987), Zavadskas and Antucheviciene (2006), Zavadskas et al. (2006), Ginevicius and Podvezko (2008), Ginevicius et al. (2008), Ustinovichius et al. (2007), Lin et al. (2008), and other authors applied TOPSIS method in construction.

The multi-criteria decision making method COPRAS was first announced in 1994 by Zavadskas and Kaklauskas (1999). This method assumes direct and proportional dependence of the significance and utility degree of the investigated versions on a system of criteria adequately describing the alternatives and values and weights of the criteria. Many problems of alternatives’ ranking and decision assessment in construction have been solved by applying this method (Viteikiene and Zavadskas, 2007; Kaklauskas et al, 2007; Zavadskas et al, 2008; Kaklauskas et al, 2006; Kaklauskas et al, 2005; Zavadskas et al, 2007; Banaitiene et al, 2008).

Fuzzy AHP (Lin et al., 2008), fuzzy TOPSIS (Wang and Elhag, 2006), fuzzy COPRAS (Zavadskas and Antucheviciene, 2007) and game theory (Perng et al, 2005) methods can be applied in the cases of uncertainty. The number of cases based on the game theory application for solving construction problems and of the papers dealing with this method is very small. This paper presents a decision support system based on game theory application intended for problem solution in construction design and management.

A review of standard decisions made in engineering, management and economy has shown that the evaluation of all possible actions is not always sufficient (Zavadskas and Vaidogas, 2008). Each action may lead to several, sometimes conflicting results. As the actual outcome is not known, the criteria taking into consideration all possible results are needed. Therefore, multi-criteria decision making becomes extremely important.

The main objective of this research is – apply Game Theory, well known normalization and newly proposed logarithmic normalization method in software.

Research tasks. The main steps of multiple criteria decision making are as follows:

a) generating a set of evaluation criteria that relate system capabilities to goals;

b) developing alternative systems for attaining the goals (generating alternatives);

c) evaluating alternatives in terms of criteria (the values of the criterion functions);

d) applying a normative multiple criteria method of analysis;

e) accepting one alternative as "optimal" (preferable);

f) if the final solution is not accepted, gather new information and go into the next iteration of multiple criteria optimization.

Any problem to be solved is represented by a matrix containing the alternatives (rows) and the criteria (columns). An alternative in multi-criteria evaluation is usually described by quantitative and qualitative criteria. Usually, the criteria have different dimensions. In order to avoid the difficulties caused by different dimensions of the criteria, the ratio for a particular value is used. There are various theories describing the ratio for a particular value. However, the values are mapped either on the interval [0; 1] or the interval $[0; \infty]$ by applying the normalization of a decision-making matrix. When the normalization is completed, it is possible to evaluate the criteria with weighting factors $0 \prec q_j \prec 1$. The sum of the weighting factors should be equal to 1.

The impact of the decision matrix normalization methods on the decision results has been investigated by many authors (Weitendorf, 1976; Hwang and Yoon, 1981; Peldschus et al., 1983; Peldschus, 1986; Stopp, 1975; Jüttler and Körth, 1969; Brauers and Zavadskas, 2006; Brauers et al, 2007; Zavadskas et al, 2003; Van Delft and Nijkamp, 1977; Zavadskas and Turskis, 2008; Peldschus, 2007; Peldschus et al, 2002). The authors of many well-known programs chose a particular problem solution method and a particular 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.

The novelty of the article. Vilnius Gediminas Technical University (VGTU) and Leipzig University of Applied Sciences (HTKW) have been investigating the application of game theory principles to civil engineering technology and management problems for more than 25 years (Peldschus et al, 1983; Peldschus et al, 2002; Peldschus, 2007, 2008; Peldschus and Zavadskas, 1997; Peldschus and Zavadskas, 2005; Zavadskas et al, 1994; Zavadskas et al, 2003; Zavadskas et al, 2004; Zavadskas and Turskis, 2008). The program LEVI 3.0 was a result of the co-operation between VGTU and HTKW. The program LEVI 4 was modified for evaluating various processes in economics, engineering and management.

All calculations were made with LEVI 4 (Peldschus et al, 2002; Peldschus and Zavadskas, 2005; Zavadskas et al, 2002; Zavadskas et al, 2003). In the new program version LEVI 4 (Figure 1 and Table 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. Scientific novelty of this research – newly proposed logarithmic normalization method is applied in a new version of the program. Game Theory is applied for multi-criteria assessment of external walls.

The object of the research is developing and applying of the multi-criteria optimization system for decision making in construction design and management.

***The methods of the research are**:* solution of real problem by applying new developed software and systemic, logic and comparative analysis of obtained results.

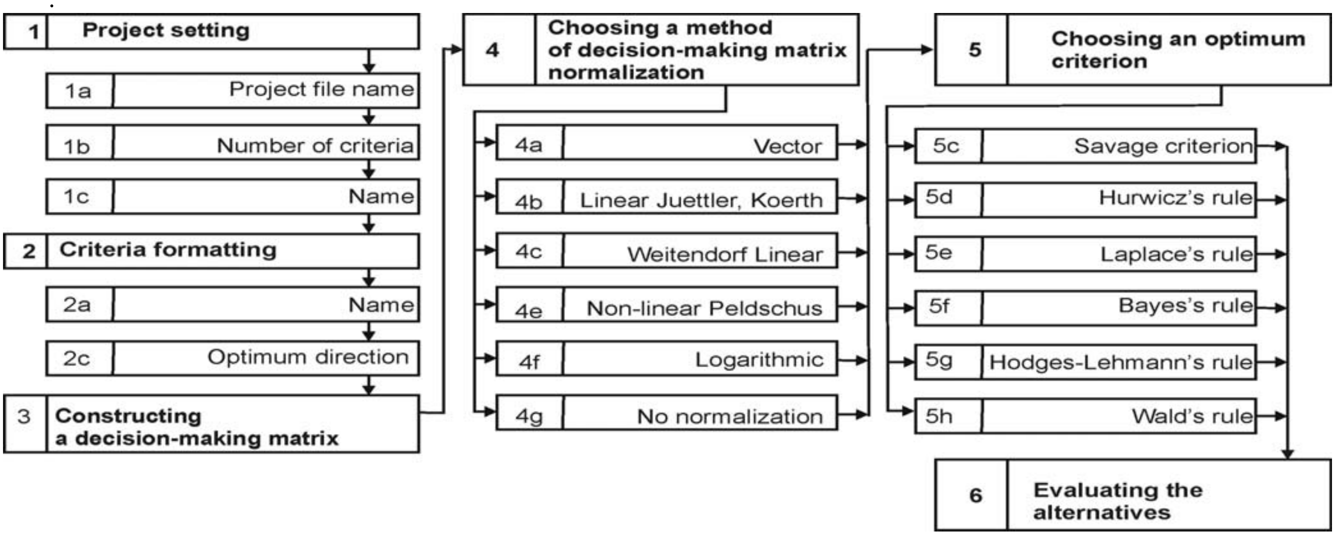


Figure 1. Block-diagram of choosing the best alternative in LEVI 4 program

Table 1

Normalization methods in program LEVI 4

Normalization method (NM)	Preferable $\max_i a_{ij}$	Preferable $\min_i a_{ij}$	Notes
Vector Van Delft and Nijkamp (VE) (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].
Weitendorf's linear (WL) (1976)	$b_{ij}=\frac{a_{ij}-\min_i a_{ij}}{\max_i a_{ij}-\min_i a_{ij}}$	$b_{ij}=\frac{\max_i a_{ij}-a_{ij}}{\max_i a_{ij}-\min_i a_{ij}}$	The calculated values are dependent on the size of the interval $\left[\max_i a_{ij};\min_i a_{ij}\right]$
Jüttler's -Körth's (1969)	$b_{ij}=1-\left\lvert\frac{\max_i a_{ij}-a_{ij}}{\max_i a_{ij}}\right\rvert$	$b_{ij}=1-\left\lvert\frac{\min_i a_{ij}-a_{ij}}{\min_i a_{ij}}\right\rvert$	The application of this type of normalization is limited to the interval [0; 1].
Non-linear Peldschus et al. (NL) (1983)	$b_{ij}=\left(\frac{a_{ij}}{\max_i a_{ij}}\right)^2$	$b_{ij}=\left(\frac{\min_i a_{ij}}{a_{ij}}\right)^3$	The values decreased more than when using other methods
Logarithmic Zavadskas and Turskis (LN) (2008)	$b_{ij}=\frac{\ln(a_{ij})}{\ln\left(\prod_{i=1}^{n} a_{ij}\right)}$	$b_{ij}=\frac{1-\frac{\ln(a_{ij})}{\ln\left(\prod_{i=1}^{n} a_{ij}\right)}}{n-1}$	The sum of normalized criterion values is always equal to 1.

Structure and methodology of the program LEVI 4

In the program LEVI 4, the game theory of the discrete optimization problem solution is used.

Only well-founded weighting factors should be used because weighting factors are always subjective and influence the solution. In using the Game Theory (von Neumann and Morgenstern, 1943), the two-sided question aims at finding the equilibrium as the result of the rational behavior of two parties having the opposite interests or searching for the equilibrium in a game against nature.

Wald's rule (WA) is the method used to search for the best of the worst solutions (Wald, 1945). The decision-maker acts according to the occurrence of the worst situation – 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 the minimization of the loss of appropriateness, which is the difference between the greatest and the achieved benefit (Savage, 1951):

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

where $r = \overline{1,m}$ and $s = \overline{1,n}$. A disadvantage of the method lies 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 maximum values, are integrated into a weighted average using optimism parameters:

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

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

Laplace's rule (LA): the solution is calculated under the condition that all probabilities for the strategies of the opponent are equal (Bernoulli, 1954):

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

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 strategies of the opponent can be expressed by the parameter λ (Hodges and Lehmann, 1952):

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

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.

A case study of external wall alternatives evaluation using various solution methods and normalization techniques

In recent years the number of residential houses in Lithuania has been increasing. The introduction of various thermo-insulation systems in the current civil engineering practice was caused by a considerable rise in prices of energy resources in the world market. As a result, there is a growing need for significant heatloss reduction during the life time of civil engineering structures, which, as a rule, could be achieved using sufficiently effective building systems to prevent heat loss through outer walls. For a non-insulated building, which could be situated in different climatic conditions, these particular heatlosses can vary between 10-20% (through floors), 25-30% (through outer walls), 25-30% (through attic slabs and roof plates) and 30-40% (through windows) of the total heatlosses. According to the Ministry of Environment of the Republic of Lithuania, nearly half of the total heat losses are through low quality walls. Therefore, careful and professional selection of an optimal building thermo-insulation system represents one of the most important technical and economic goals for both the designer and the investor. Wall rationality is highly dependent on how rational the construction of external walls is. Building and maintenance expenses depend on how effective the external wall solution is. Good result may be achieved by establishing the requirements and aims till the expiry of a building. The benefit obtained from effectively heating up the external walls could be defined by indices presented in Figure 2.

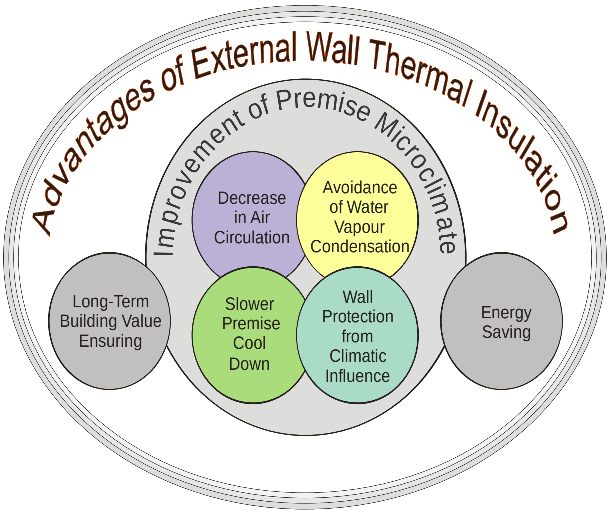


Figure 2. Advantages of thermal insulation of external walls

Multi-layered external walls

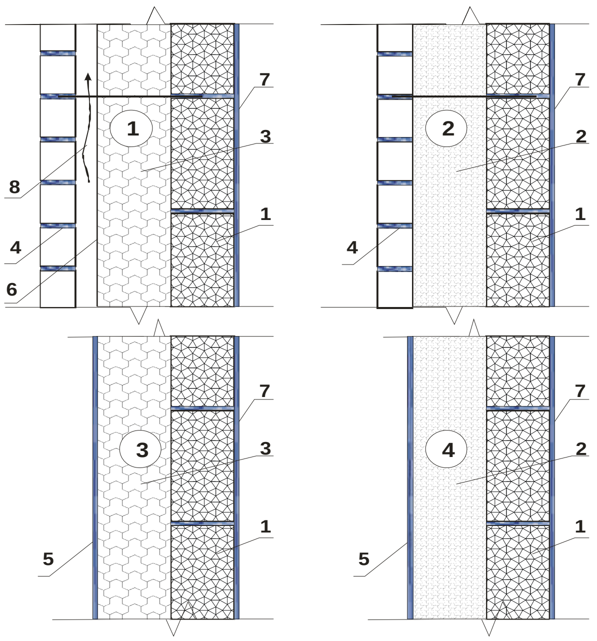
Facade structures of residential and office buildings should satisfy the following requirements:

1. Ability to function as bearing or self-bearing walls.
2. High thermo-insulation properties.
3. Good soundproofing.
4. Moisture resistance.
5. Frost resistance.
6. Air permeability.
7. Steam permeability.
8. Sufficient light-weightiness.
9. Ecological cleanliness.
10. Satisfactory fireproofing.
11. Durability.

Attention paid is usually to the fact that multi-layered facade structures are made as composite sections of heterogeneous materials with different physical-mechanical properties, such as:

- expansion and shrinkage coefficients,
- compressive and tensile strength,
- adhesion properties,
- behaviour under different types of wind load,
- behaviour under exposure to ultraviolet ray,
- difference between strain values in adjacent walls with relatively high temperature,
- variation due to different sun rays exposure and colour of the final facade coating,
- difference in aging properties of each composite in usage,
- air and steam permeability values.

Multi-layered exterior wall systems (Figure 3) have several advantages:



1 – Bearing block
2 – Expanded polystyrene
3 – Rock wool
4 – Finishing brick
5 – Outer plaster
6 – Wind insulation
7 – Inner plaster
8 – Air space (2-3 cm)

Figure 3. Main alternatives of multi-layered external walls

- The system covers the entire building wall (except windows and doors). Thus, multi-layered exterior wall system provides an insulation layer over potential thermal bridges such as wall studs and columns and floor-wall junctions.
- Since the entire exterior wall is covered, building airtightness is improved.
- Since insulation is placed on the building exterior surface, the building structure is kept warm; this minimizes thermal expansion and contraction.
- Finally, if properly installed, the system avoids a build-up of moisture in the building cladding.

Cost-effectiveness in application of multi-layered external walls in civil engineering is the most significant issue for the investor, without getting into all the inferior physical, thermo-technical and ecological properties (not to mention poor durability) of the usually applied facade structures (blocks insulated with mineral wool or Styrofoam and coated with mineral polymer-cement plaster over glass-fibber net or simply protected with facade bricks).

For multilayered walls, three basic material configurations were considered: insulation inside or outside the massive layer, and insulation located between two massive layers.

The results of a comprehensive parametric analysis have shown explicitly that walls with the insulation outside always performed better than those with the insulation inside:

- The system covers the entire building wall (except windows and doors). Thus, multi-layered exterior wall systems provide an insulation layer over the potential thermal bridges such as wall studs and columns and floor-wall junctions.
- Since the entire exterior wall is covered, building airtightness is improved.
- Since the insulation is placed on the building exterior surface, the building structure is kept warm; this minimizes thermal expansion and contraction.
- Finally, if properly installed, the system avoids a build-up of moisture in the building cladding.

Model of the problem

The aim of the present investigation is to create a technique for choosing and selecting effective alternatives of the construction of external walls. Different variants of external wall construction are being formed by using various materials with thermal insulation as well as different kinds of decoration masonry and thin daub layer. A set of criteria for evaluating wall construction effectiveness has been chosen (Fig. 3). These criteria define positive and negative characteristics of an object under investigation.

Criteria values were calculated according to valid standards. Work expenditures of a three-layer masonry wall and of the decoration of walls with thin daub layer were calculated according to "Standards of Construction Works, Materials, Mechanisms, and Expenditures in Building". The durability of a partition is associated with frost resistance of a decoration layer. Bricks, having frost resistance exceeding 35 cycles, are used for decorating masonry. A thin layer daub decoration can resist cold air up to 25 cycles.

Table 2

Evaluation criteria of external wall activeness and results of decision matrix normalization

Initial decision-making matrix

Alternative No.	Part of wall bearing loading	Wall description		Criteria under consideration			
		Finishing material	Thermal insulation	The estimated cost of m² walls (€)	Weight of m² walls (kg)	Thermal insulation of walls (m²K/W)	Durability of walls (cycles)
				x_1	x_2	x_3	x_4
	Optimal values			***min***	***min***	***max***	***max***
	Criteria weights – ***q***			***0.37***	***0.10***	***0.40***	***0.13***
v_1	Silicate blocks	Brick	Mineral-wool	43	368	5.13	50
v_2			Polystyrene	40	367	5.22	50
v_3		Thin plaster	Mineral-wool	44	283	5.13	25
v_4			Polystyrene	34	282	5.22	25

Normalization method and results

Linear (Weitendorf) normalization

	a_1	a_2	a_3	a_4
v_1	0.1000	0.0000	0.0000	1.0000
v_2	0.4000	0.0116	1.0000	1.0000
v_3	0.0000	0.9884	0.0000	0.0000
v_4	1.0000	1.0000	1.0000	0.0000

Non linear (Peldschus) normalization

	a_1	a_2	a_3	a_4
v_1	0.4943	0.4500	0.9658	1.0000
v_2	0.6141	0.4537	1.0000	1.0000
v_3	0.4614	0.9894	0.9628	0.2500
v_4	1.0000	1.0000	1.0000	0.2500

Logarithm (Zavadskas &Turskis) normalization

	a_1	a_2	a_3	a_4
v_1	0.2484	0.2481	0.2487	0.2743
v_2	0.2500	0.2481	0.2513	0.2743
v_3	0.2479	0.2519	0.2487	0.2257
v_4	0.2537	0.2519	0.2513	0.2257

The calculation process includes a theory that there are 5-7 cold cycles every year. The selection of a wall construction is determined by technical, usage and other indicators of a building.

One of the most important parameters of wall partition is its aesthetic view, which is not, however, an objective indicator. A score scale is used to assess the criteria.

The price of partitions is calculated by including all the expenses associated with the materials a partition is composed of. The price of a three-layered masonry wall embraces the following: silicate bearing walls, thermal and wind insulation, decoration masonry, and grout. The price of walls with thin daub layer includes the pure of silicate bearing walls, thermal insulation and thin daub layer system. In order to establish the importance of criteria, a survey was conducted, when 39 experts were questioned.

These experts, basing their answers on their knowledge, experience and intuition, had to rate criteria of effectiveness starting with the most important ones. The rating was done against the scale from 1 to 4, where 4 meant "very important" and 1 "not important at all". The importance of criteria (e.g. 3) was established according to the rating methods of these experts, also demonstrating the priorities of the user (owner).

The data on the external wall alternatives under investigation are given in Table 2.

There is a wide variety of external wall constructions which are defined by many different criteria of effectiveness (a closer look at the most commonly used outer-wall building systems is given in Figure 3).

According to the opinion of building experts, these alternatives of walls can be characterized by the following parameters, as shown in Table 2. The activeness of the variant was evaluated by the following effectiveness criteria: estimated cost of m² (€), weight of m² (kg), thermal insulation (m²K/W) and durability of walls (cycles).

The task of the selection of different versions of the effective external wall construction is solved by applying LEVI 4 software.

A special feature of the model is the determination of criteria weights. Many multi-criteria decision making methods requires information about the relative importance of each criterion (Hwang and Yoon, 1981).

To determine the weights of the criteria, the expert judgment method proposed by Kendall (Kendall, 1970) was used (Fisher and Yates, 1963). Zavadskas, 1987; Zavadskas et al., 2004; Turskis et al., 2006; Zavadskas and Vilutiene, 2006 discussed the application of this method in the construction field.

In the present investigation, the vector, linear, non-linear and new logarithmic methods of normalization of the initial decision-making matrix were used. A number of different problem solution methods, such as Wald's rule, Savage criterion, as well Laplace's rule and Bayes's rule were applied.

Table 3

Solution results

Logarithm normalization

Favourable variant according to Savage: 2

(Non equivocal solution)

VAR.	x1	x2	x3	x4		Result
2	0.2500	0.2481	0.2513	0.2743		0.0000
1	0.2484	0.2481	0.2487	0.2743		0.0100
3	0.2479	0.2519	0.2487	0.2257		0.0500
4	0.2537	0.2519	0.2513	0.2257		0.0500

Favourable variant according to Wald: 1

(Polysemantic solution)

VAR.	x1	x2	x3	x4		Result
1	0.2484	0.2481	0.2487	0.2743		0.2500
2	0.2500	0.2481	0.2513	0.2743		0.2500
3	0.2479	0.2519	0.2487	0.2257		0.2300
4	0.2537	0.2519	0.2513	0.2257		0.2300

Favourable variant according to Laplace: 2

(Unequivocal solution)

VAR.	x1	x2	x3	x4		Result
2	0.2500	0.2481	0.2513	0.2743		0.2559
1	0.2484	0.2481	0.2487	0.2743		0.2549
4	0.2537	0.2519	0.2513	0.2257		0.2457
3	0.2479	0.2519	0.2487	0.2257		0.2436

Favourable variant according to Bayes: 2

(Trivial solution)

VAR.	x1	x2	x3	x4		Result
q	0.370	0.100	0.400	0.130		
2	0.2500	0.2481	0.2513	0.2743		0.2535
1	0.2484	0.2481	0.2487	0.2743		0.2519
4	0.2537	0.2519	0.2513	0.2257		0.2489
3	0.2479	0.2519	0.2487	0.2257		0.2457

Linear Normalization

Solution according to Savage

Favourable variant according to Savage: 2

(Non equivocal solution)

VAR.	x1	x2	x3	x4		Result
2	40.0000	367.0000	5.2200	50.0000		0.9900
1	43.0000	368.0000	5.1300	50.0000		1.0000
3	44.0000	283.0000	5.1300	25.0000		1.0000
4	34.0000	282.0000	5.2200	25.0000		1.0000

Favourable variant according to Wald: 2

(Clear solution)

VAR.	x1	x2	x3	x4		Result
2	40.0000	367.0000	5.2200	50.0000		0.0100
1	43.0000	368.0000	5.1300	50.0000		0.0000
3	44.0000	283.0000	5.1300	25.0000		0.0000
4	34.0000	282.0000	5.2200	25.0000		0.0000

Favourable variant according to Laplace: 4

(Unequivocal solution)

VAR.	x1	x2	x3	x4		Result
4	34.0000	282.0000	5.2200	25.0000		0.7500
2	40.0000	367.0000	5.2200	50.0000		0.6029
1	43.0000	368.0000	5.1300	50.0000		0.2750
3	44.0000	283.0000	5.1300	25.0000		0.2471

Favourable variant according to Bayes: 4

(Trivial solution)

VAR.	x1	x2	x3	x4		Result
q	0.370	0.100	0.400	0.130		
4	34.0000	282.0000	5.2200	25.0000		0.8700
2	40.0000	367.0000	5.2200	50.0000		0.6792
1	43.0000	368.0000	5.1300	50.0000		0.1670
3	44.0000	283.0000	5.1300	25.0000		0.0988

Non linear Normalization

Favourable variant according to Savage: 2

(Non equivocal solution)

VAR.	x1	x2	x3	x4		Result
2	40.0000	367.0000	5.2200	50.0000		0.5500
1	43.0000	368.0000	5.1300	50.0000		0.5500
3	44.0000	283.0000	5.1300	25.0000		0.7500
4	34.0000	282.0000	5.2200	25.0000		0.7500

Favourable variant according to Wald: 2

(Clear solution)

VAR.	x1	x2	x3	x4		Result
2	40.0000	367.0000	5.2200	50.0000		0.4500
1	43.0000	368.0000	5.1300	50.0000		0.4500
3	44.0000	283.0000	5.1300	25.0000		0.2500
4	34.0000	282.0000	5.2200	25.0000		0.2500

Favourable variant according to Laplace: 4

(Unequivocal solution)

VAR.	x1	x2	x3	x4		Result
4	34.0000	282.0000	5.2200	25.0000		0.8125
2	40.0000	367.0000	5.2200	50.0000		0.7670
1	43.0000	368.0000	5.1300	50.0000		0.7275
3	44.0000	283.0000	5.1300	25.0000		0.6667

Favourable variant according to Bayes: 4

(Trivial solution)

VAR.	x1	x2	x3	x4		Result
q	0.370	0.100	0.400	0.130		
4	34.0000	282.0000	5.2200	25.0000		0.9025
2	40.0000	367.0000	5.2200	50.0000		0.8026
1	43.0000	368.0000	5.1300	50.0000		0.7442
3	44.0000	283.0000	5.1300	25.0000		0.6885

Table 4

Ranking of the alternatives

Normalization	Raking			
	Savage	Wald	Laplace	Bayes
LW	$v_2 \succ v_1 = v_3 = v_4$	$v_2 \succ v_1 = v_3 = v_4$	$v_4 \succ v_2 \succ v_1 \succ v_3$	$v_4 \succ v_2 \succ v_1 \succ v_3$
NL	$v_1 = v_2 \succ v_3 = v_4$	$v_1 = v_2 \succ v_3 = v_4$	$v_4 \succ v_2 \succ v_1 \succ v_3$	$v_4 \succ v_2 \succ v_1 \succ v_3$
LN	$v_2 \succ v_1 \succ v_3 = v_4$	$v_1 \succ v_2 \succ v_3 = v_4$	$v_2 \succ v_1 \succ v_4 \succ v_3$	$v_2 \succ v_1 \succ v_4 \succ v_3$
Mediocre	$v_2 \succ v_1 \succ v_3 = v_4$	$v_2 \succ v_1 \succ v_3 = v_4$	$v_2 \succ v_1 \succ v_4 \succ v_3$	$v_2 \succ v_1 = v_4 \succ v_3$
Result	$v_2 \succ v_1 \succ v_3 \succ v_4$			$v_2 \succ v_1 = v_4 \succ v_3$
Final result	$v_2 \succ v_4 \succ v_1 \succ v_3$			

Table 5

Alternatives' rank

Var.	Description of wall		Rank
	Finishing material	Thermal insulation	
v_1	Brick	Rockwoll	3
v_2	Brick	Polystyrene	1
v_3	Thin external plaster	Rockwoll	4
v_4	Thin external plaster	Polystyrene	2

Tables 3 and 4 provide the solution results and a comparative analysis.

When the criteria weights are taken into account, the priority order of the alternatives is presented as "$v_2 \succ v_1 \succ v_3 \succ v_4$" (implying that the "second" alternative is better than the "first" one, the "first" alternative is better than the "third" one, the "third" alternative is better than the "second" one and the "fourth" one).

A similar set "$v_2 \succ v_1 = v_4 \succ v_3$" is obtained when the criteria weights are not taken into account. Finally, the alternatives were arranged in the following order: $v_2 \succ v_4 \succ v_1 \succ v_3$. The final ranking of alternatives is provided in Table 5.

The analysis of the problem decision results has shown that walls with the external brick layer are most effective. Furthermore, it is possible to state, that the application of a 175 mm layer of rockwoll is more effective than the application of a 200 mm layer of polystyrene.

Conclusions

Some social and environmental externalities cannot be readily and credibly quantified or monetised. Such as service quality and reliability, landscape, etc. These externalities should be incorporated in a multi-criteria analysis.

The basic ideas of multi-criteria decision-making methods are very simple.

In early stages of project development, multi-criteria analysis may be particularly helpful.

The conventional cost benefit analysis approach and multi-criteria analysis approach should be regarded as complementary rather than competitive analytical tools.

It is hardly possible to evaluate the effect of various normalization methods of a decision-making matrix and the effect the applied solution method on numerical results obtained. This problem can be solved by applying the program LEVI 4.

Some particular modules of the program LEVI 4 can be used for creating decision-making systems.

Logarithmic normalization of a decision making matrix yields more stable results in solving multi-criteria decision problems.

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

A comparison of the results obtained by different solution methods is required because it is not always possible to apply the game theory equilibrium to economics, engineering and management. It can be stated that:

1. The multi-criteria assessment model of multi-layered external walls was developed.
2. This model and solution results are of practical and scientific interest. It allows the investor to make decisions evaluating multiple criteria.
3. Walls with an external brick layer describing the alternatives considered are most effective.
4. The created model for the analysis of external wall efficiency can be also applied to the solution of other economic and engineering problems associated with evaluating the available alternatives (investment or strategy selection).

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Zenonas Turskis, Edmundas Kazimieras Zavadskas, Friedel Peldschus

Statybos projektavimo ir vadybos daugiatikslio sprendimų priėmimo optimizavimo sistema

Santrauka

Naujos idėjos ir galimos sprendimų alternatyvos yra labai svarbios sparčiai ir efektyviai plėtojami ekonomikai ir mokslui. Idėjos ir alternatyvos turi būti vertinamos, ranguojamos, išrenkamos geriausios ir efektyviausios. Sudėtingoje ir kintančioje aplinkoje vien kainos ir naudos analizės nebeužtenka. Sprendimų priėmėjams reikia įvertinti sprendinius pagal daugelį aspektų. Reikia įvertinti tokius rodiklius: kultūrinius, socialinius ir moralinius veiksnius, įstatyminius, demografinius, valstybinius, technologinius pokyčius ir t. t. Taip pat turi būti vertinami pokyčiai ir tendencijos verslo pasaulyje: tarptautinės, šalies ir vietinės. Kainos ir naudos analizė yra naudinga priemonė investuotojams. Investuojant ir plėtojant ekonomiką, remiantis tik tokios analizės duomenimis, socialiniai ir vietiniai interesai nevertinami. Netikslingas vertinimo pinigais ir naudos analizės taikymas kartais diskredituoja pritaikytus metodus visuomenės ir sprendimų priėmėjų akyse. Daugiatiksliais vertinimo metodais galima vertinti kokybinius ir kiekybinius rodiklius. Kasmet pasirodo tūkstančiai straipsnių šia tema, išleidžiama daug knygų. Pagrindinės daugiatikslio vertinimo idėjos yra paprastos ir artimos įprastiniam žmonių elgesiui: baigtinė veiksmų (alternatyvų, sprendinių, veiksmų seka ir t. t.) aibė, mažiausiai du kriterijai ir mažiausiai vienas sprendimų priėmėjas. Tokiais metodais aprašant uždavinius galima įvertinti įvairių visuomenės grupių tikslus. Daugia-tiksliuose vertinimo uždaviniuose alternatyvos gali būti aprašomos kiekybiniais (išmatuojamais) rodikliais, kokybiniais (nustatomais ekspertų apklausa pagal vienokią ar kitokią skalę) ir kai kuriuose metoduose žodžiais aprašomais rodikliais (verbaliniai, arba leksikografiniai, rodikliai).

Peržvelgus daugelį mokslinių straipsnių, paskelbtų mokslo duomenų bazėse, matome, kad statybos ir vadybos srityje tokių straipsnių nėra labai daug. Vienas iš labiausiai paplitusių daugiatikslio vertinimo metodų yra AHP (analitinis hierarchinis procesas). Šį metodai dažniausiai taiko JAV mokslininkai (Saaty, Skibniewski ir kiti), tačiau jis gerai žinomas ir kitose šalyse (Hsueh ir kt., Lai ir kt., Su ir kt., Ugwu ir kt., Wong ir kt.; Kauko ir t. t.). Šis metodas yra pritaikytas, vadybos, ekonomikos, statybos, karinėje, medicinos ir kitose mokslo bei praktinėse srityse. Gana plačiai yra taikomas artumo idealiajam taškui metodas – TOPSIS. Šis metodas pasiūlytas 1981 metais (Hwang ir Yoon). Šio metodo taikymo sritys panašios kaip ir AHP metodo. Vadybos, technologijos ir statybos srityse šį metodą taikė daugelis mokslininkų ir praktikų (Zavadskas; Ugwu; Hsueh ir kt.; Zavadskas ir Antuchevičienė; Ginevičius ir Podviezko; Ustinovicius; Liu ir kt.).

1994 metais Zavadskas kartu su Kaklausku sukūrė ir pradėjo taikyti metodą COPRAS (kompleksinis proporcingas vertinimas). Šį metodą statybos, vadybos, ekonomikos, ekologijos ir daugelyje kitų sričių taikė autoriai ir daugelis kitų mokslininkų (Banaitis; Ginevičius; Podviezko; Turskis; Antuchevičienė; Viteikienė ir kt.).

Galima būtų paminėti dar nemažai daugiatikslių vertinimo metodų.

Pagrindiniai daugiatikslio verinimo veiksmai gali būti išdėstyti tokia seka: a) alternatyvų, susijusių su siekiamu tikslu, kūrimas, projektavimas, generavimas, atranka→b) kriterijų, apibūdinančių nagrinėjamas alternatyvas, atranka, analizė, susietų rodiklių atmetimas→c) svarbiausiųjų kriterijų atranka ir neesminių kriterijų išmetimas→d) kiekvieno kriterijaus svorio (reikšmingumo ar prioriteto) nustatymas→e) kriterijų, aprašančiųjų alternatyvas, reikšmių surinkimas→f) surinktų kriterijų reikšmių patikrinimas→g) nagrinėjamųjų alternatyvų pagal surinktas kriterijų reikšmes vertinimas taikant daugiatikslę funkciją→h) norminio daugiatikslio analizės metodo taikymas→i) vienos iš alternatyvų kaip priimtiniausios (optimalios) atrinkimas→j) jei nė viena iš nagrinėtų alternatyvų nepriimtina, tai ieškomos kitos alternatyvos, surenkami duomenys apie jas ir vėl kartojamas vertinimo ciklas.

Dažniausiai tokie uždaviniai sprendžiami matricine forma. Pirmiausia sudaroma uždavinio sprendimo priėmimo matrica, turinti tiek eilučių kiek yra alternatyvų ir tiek stulpelių kiek yra kriterijų. Sprendimų priėmimo matrica yra normalizuojama- paverčiama tokia, kurioje kriterijų skaitinės reikšmės neturi jokių matavimo vienetų. Įvairūs normalizavimo būdai turi tokią savybę- juos pritaikius, kriterijų reikšmės neturi mato vienetų ir patenka į intervalą [0; 1] arba į intervalą [0;∞). Toliau normalizuota sprendimų priėmimo matrica yra pasveriama: kiekvieno kriterijaus reikšmės yra dauginamos iš atitinkamo kriterijaus reikšmingumo. Kriterijų reikšmingumų suma turi būti lygi vienetui. Vieni iš kriterijų reikšmingumo nustatymo metodų yra pagrįsti ekspertų apklausos metodais, kiti - objektyviais metodais. Kai kurie autoriai išskiria subjektyvius, objektyvius ir integruotus kriterijų reikšmingumus. Reikšmingumų nustatymo teoriją tyrinėjo šio darbo autoriai ir kiti mokslininkai: Van Delft ir Nijkamp; Weitendorf; Hwang ir Yoon.

Normalizavimo būdo parinkimas ir sprendimo metodo pritaikymas yra kiekvieno sprendimą priimančio asmens reikalas. Daugelis iki šiol sukurtų ir mums žinomų metodų autorių pasirinkdavo ir taikydavo vieną išskirtinį sprendimo metodą ir vieną sprendimų priėmimo matricos normalizavimo metodą.

Vilniaus Gedimino technikos universiteto ir Leipcigo Taikomųjų mokslų universiteto mokslininkai jau daugiau kaip 25 metus nagrinėja ir taiko lošimų teorijos metodus vadybos, ekonomikos ir statybos klausimams spręsti. Šių darbų pradininkai Peldschus ir Zavadskas kartu su savo mokiniais yra išleidę keliolika knygų ir monografijų, kuriose apibendrinami jų tyrimai ir taikymai. Šiame straipsnyje pristatoma ketvirtoji LEVI programos versija, kuri skiriasi nuo ankstesnės trečiosios versijos naujomis galimybėmis. Naujoje programos LEVI 4 versijoje vartotojas (sprendimų priėmėjas) gali pasirinkti vieną iš galimų dviejų asmenų lošimo metodų. Galimi tokie sprendimo metodai: a) taikant Valdo (Wald) taisyklę; b) taikant Sevidžo (Savage) kriterijų; c) taikant Hurvičo (Hurwicz) taisyklę; d) taikant Laplaso (Laplace) taisyklę; e) taikant Bajeso (Bayes) taisyklę ir f) Hodžes ir Lėmano (Hodges-Lehmann) taisyklę. Rodikliai normalizuojami- paverčiami bemačiais skaičiais. Sprendimų priėmėjas (agentas) gali pasirinkti vieną iš galimų normalizavimo metodų. Į šią programos versiją yra įtraukti keli iš įmanomų normalizavimo metodų: vektorinis, tiesinis, netiesinis ir naujai sukurtas logaritminis normalizavimo metodas.

Šis metodas buvo sukurtas tam, kad būtų galima realiau atspindėti išsibarsčiusių įvairiuose intervaluose kriterijų reikšmių poveikį uždavinio sprendiniui. Šioje programoje yra aprašyti dviejų asmenų lošimo su nuline mokėjimo suma metodai. Sprendžiant uždavinius kai kuriais programos metodais galima vertinti skirtingą rizikos laipsnį.

Programa demonstruojama sprendžiant realų uždavinį: racionalios individualaus namo išorinės sienos konstrukcijos parinkimas.

Prieš sprendžiant uždavinį išnagrinėtos galimos išorinės sienos konstrukcijos, išsiaiškintos tokių sienų silpnybės ir stiprybės, atrinkti efektyvumo rodikliai: $1m^2$ sąmatinė kaina (€); $1m^2$ svoris (kg); šiluminė izoliacija (m^2k/w) ir sienų ilgaamžiškumas (ciklai).

Ekspertų apklausos būdu nustatyti efektyvumo rodiklių reikšmingumai (atitinkantys kiekvieną kriterijų): 0,37; 0,10; 0,40 ir 0,13. Matome, kad ekspertų nuomone šiuo metu svarbiausia yra sienų šiluminė varža ir kaina. Toliau buvo surinktos ir apskaičiuotos efektyvumo rodiklių reikšmės.

Pagal šiuo metu galiojančius standartus, technologijos ir gamybos pasiekimus ir ekonominius skaičiavimus yra tikslinga taikyti sluoksniuotas išorinių sienų konstrukcijas. Išnagrinėjus visus pateikiamus teigiamus ir neigiamus argumentus, kur taikyti šiluminę izoliaciją, aiškiai matyti, kad geriau ją taikyti iš išorės. Be to, sluoksniuotų išorės sienų kiekvienas sluoksnis turi savo skirtingą paskirtį: vienas sluoksnis laiko apkrovas (turi ir tam tikrą šiluminę varžą bei akumuliuoja šilumą), kitas sulaiko šilumą, o išorinis sluoksnis apsaugo šiluminę izoliaciją nuo išorinių poveikių. Visų sienų vidinis sluoksnis, laikantis apkrovas, buvo parinktas iš blokų. Šiluminei izoliacijai buvo parinkta akmens vata arba putų polistirenas, o išoriniam sluoksniui - plonasluoksnis tinkas arba plytų apdaila.

Nagrinėjami keturi sienų variantai a) su akmens vatos šilumine izoliacija ir plytų apdaila; b) su putų polistireno izoliacija ir plytų apdaila; c) su akmens vatos šilumine izoliacija ir plonasluoksniu tinku ir d) su putų polistireno izoliacija ir plonasluoksniu tinku. Parinkti 4 sienų variantai.

Variantai atitinka visus šiuo metu galiojančius standartus ir normas ir yra taikomi statybose. Uždavinys išspręstas taikant įvairius normalizavimo būdus ir sprendimo metodus. Rezultatai parodė, kad iš nagrinėtų alternatyvų geresnės sienos yra tos, kurių išorės apdaila yra iš plytų. Pagal rezultatus galima spręsti, kad geriau yra apšiltinti 175 mm akmens vatos sluoksniu nei 200 mm putų polistireno. Alternatyvos pagal gerumą yra tokios: $c \succ a \succ d \succ b$. Todėl, sprendimų priėmėjas galėtų rinktis c variantą. Uždavinys išspręstas per vieną valandą. Ekspertų apklausa ir duomenų surinkimas bei apdorojimas užtruko dvi dienas.

Viską apibendrinus galima padaryti tokias išvadas: a) kai kurie socialiniai ir aplinkos veiksniai negali būti matuojami pinigų suma; b) daugeliu kriteriju aprašomų uždavinių sprendimui daugiatikslių metodų taikymas yra nepakeičiama priemonėi; c) lošimų teorijos metodai yra tinkami spręsti daugiatikslius vertinimo uždavinius ir jų taikymas daugelyje sričių jau yra pasiteisinęs; d) daugelis sukurtų ir aprašytų daugiatikslių vertinimo būdų taiko tik vieną sprendimo metodą ir vieną normalizavimo būdą; e) programa LEVI 4 leidžia praktikams gana lengvai parinkti geriausias alternatyvas iš aprašytųjų ir surikiuoti aprašytąsias alternatyvas pagal gerumą, taikant įvairius lošimų teorijos metodus ir normalizavimo būdus; f) ši programa gali būti kaip viena iš daugiakriterinių sprendimo paramos sistemos dalių ir jos taikymas nėra apribotas kuria nors viena mokslo ar veiklos sritimi; g) moksliniu požiūriu ši programa yra naudinga tuo, kad kiekvienas asmuo, tyrinėjantis procesus, gali greitai gauti rezultatus, juos, gautus skirtingais sprendimo metodais, palyginti ir taip tobulinti savo nagrinėjamo uždavinio modelį.

Raktažodžiai: *statyba, optimizavimas, daugiatikslis, lošimų teorija, dvipusis uždavinys, normalizavimas, logaritminis, programinė įranga.*

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