TECHNOLOGICAL AND ECONOMIC DEVELOPMENT OF ECONOMY
Baltic Journal on Sustainability
2008
14(4): 546–565

SYSTEM OF PROJECT MULTICRITERIA DECISION SYNTHESIS IN CONSTRUCTION

Vaidotas Šarka[1], Edmundas K. Zavadskas[2], Leonas Ustinovičius[3], Edita Šarkienė[4], Česlovas Ignatavičius[5]

Dept of Building Technology and Management,
Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania
E-mail: [2]edmundas.zavadskas@adm.vgtu.lt; [3]leonasu@st.vgtu.lt; [4]edita.sarkiene@adm.vgtu.lt

Received 24 September 2008; accepted 25 November 2008

Abstract. The construction industry, compared to other industries, is distinguished by a small productivity of work and large fragmentation. Solution of construction-related problems requires a great deal of time and financial resources.

Method of project multicriteria decision synthesis with decision success criterion is used for realisation of construction projects which require analysis of constituent parts in close relationship of components. On every level of the whole project, the decision of closeness to ideal solution method is made and, on the basis of the obtained results, several alternatives are chosen. At the last decision stage, there is performed a synthesis by the chosen alternatives and relying on their interrelations. During decision process on the intermediate stages, having eliminated irrational alternatives, effective and precise results are achieved.

The developed multicriteria decision synthesis method is one of the elements of the newly created group of multicriteria decision methods. Using this method algorithm, software is prepared that entirely manages the whole decision process from database filling to calculation and result processing.

Keywords: MCDA, synthesis method, project, construction.

Reference to this paper should be made as follows: Šarka, V.; Zavadskas, E. K.; Ustinovičius, L.; Šarkienė, E.; Ignatavičius, Č. 2008. System of project multicriteria decision synthesis in construction, *Technological and Economic Development of Economy* 14(4): 546–565.

ISSN 1392-8619 print/ISSN 1822-3613 online
doi: 10.3846/1392-8619.2008.14.546-565
http://www.tede.vgtu.lt

1. Introduction

Explorers of multicriteria decision-making methods and other specialists solving various practical and theoretical problems are faced with continuously growing amounts of criteria and methods which are becoming more and more complicated. The main problem is that, in this environment, it is hardly possible to determine which of the available solutions or procedures is most effective, when considered from various perspectives. Decision support methods are aimed at processing the collected data which could be further used for making rational solutions. Unlike the methods applied to the analysis of the interrelationships between alternatives, multicriteria evaluation methods are not aimed at obtaining the objectively best solutions because, in this case, the latter hardly exist.

Decision-making problems have always been especially significant for any state, company or individual at any level of management, either strategic or functional. Therefore, much time and energy have been expended in investigating these problems all over the world. However, the analysis of the available old and new decision-support systems (DSS) used in construction in Lithuania and other countries shows that they are restricted to solving only one problem. The development of DSS requires much time and finances. The created systems can only be used in very specific areas of construction, economics, environment protection, etc., being restricted to solving the problems at one particular level. The above DSS systems are not aimed at making comprehensive multistage analysis of the alternatives in decision -making, except for some methods of multivariant design (Churchman and Ackoff 1954; Churchman *et al.* 1957; Dawes 1964; Figueira and Yoon 2005; Hwang *et al.* 1981; Hwang and Lin 1987; Jakimavičius and Burinskienė 2007; Keeney and Raiffa 1976; MacCrimmon 1968; MacCrimmon and Wehrung 1977; Morkvėnas *et al.* 2008; Paelnick 1976; Roy and Vincke 1981; Ustinovichius *et al.* 2007; Zavadskas *et al.* 1994).

In the present research based on integrating multicriteria decisions into decision support systems, an algorithm of the method of synthesizing a number of various stages of developing construction project or operations into a unified system is considered.

In 1957, Churchman, Ackoff and Arnoff (Churchman *et al.* 1957) first used the sum of values for selecting a rational investment policy. In 1968, MacCrimmon (1968) made a survey of *multiple attribute decision making* methods (MADM). A method of synthesis (a decision tree method) was also used in quantitative financial and commercial models (Rutkauskas 2000).

Multi-attribute decision-making methods have different characteristics (Triantaphyllou 2000). There are different ways to classify them. Multi-attribute methods can be classified by the type of initial information (deterministic, stochastic, fuzzy set theory methods) or by the number of decision-makers (one or a group).

Many researchers (Zavadskas and Vilutienė 2006; Zavadskas *et al.* 2006, 2007, 2008a; Peldschus and Zavadskas 2005; Sivilevičius *et al.* 2008; Šaparauskas and Turskis 2006; Viteikienė and Zavadskas 2007; Ginevicius *et al.* 2007, 2008; Ginevicius and Podvezko 2008; Su *et al.* 2006; Brauers *et al.* 2008; Turskis *et al.* 2006; Ugwu *et al.* 2006; Zagorskas and Turskis 2006; Kaklauskas *et al.* 2006, 2007) have pointed out that in construction 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.

Selection of contractor is an important issue in the field of construction management (Turskis 2008; Mitkus and Trinkūnienė 2006, 2007, 2008; Zavadskas *et al.* 2008b) for the success or failure of a project is usually influenced by the quality of contractor.

A question arises what are the content and areas of application of synthesis methods in the context of various multicriteria evaluation methods. A synthesis is a decision combining various intermediate (stage) decisions into a single project based on the use of the relationship tables (reflecting the agreement of the alternatives). In this process, a decision tree (DT) (Fig. 1) is generated and a rational integrated decision is found. This explains the significance of the word *synthesis* used in the present investigation, while the main goal of the authors is to find the most effective solutions of particular multistage problems.

Synthesis methods are mentioned in the work of Zavadskas (1991); however, no final analysis or case study are provided. Therefore, some innovative methods of multicriteria decision synthesis will be discussed below (Šarka *et al.* 1999, 2000).

In particular, a decision algorithm and a case study illustrating the application of DSS1, a method of multicriteria decision synthesis, will be described. The problem is to choose a rational alternative of investment into the construction of a block of one-family houses.

As mentioned above, a similar concept and multicriteria decision algorithm were mentioned in 1991 in the work of E. K. Zavadskas (1991), though the final analysis and case

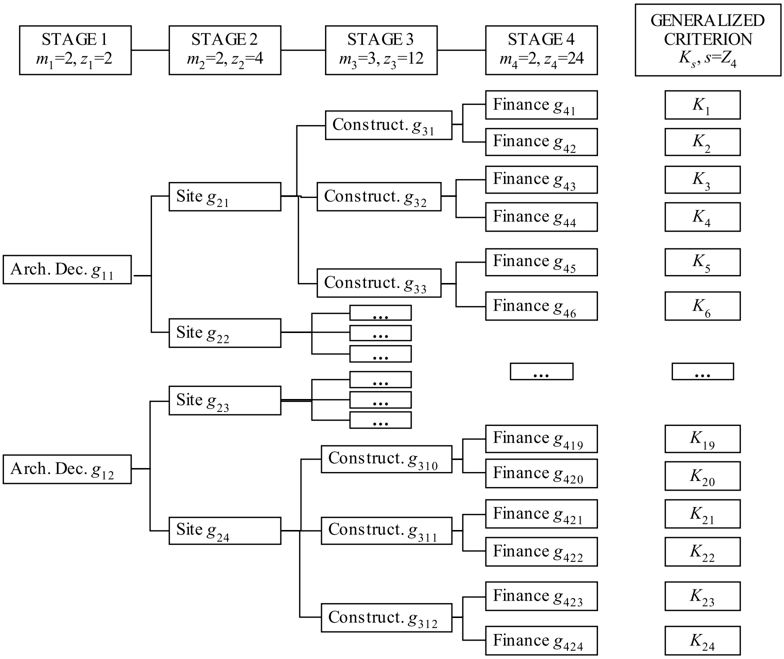

Fig. 1. A fragment of decision tree (DT) development by using multicriteria project synthesis methods (c = 4)

studies were missing. In 2000, V. Šarka, in collaboration with Prof. E. K. Zavadskas, offered a revised method of multicriteria decision synthesis (DSS1) based on the criterion of decision success (PSS2), which was used to solve several problems associated with selecting rational construction projects. In the period of 2000–2006 the authors of the present paper applied the above method to solving a number of actual construction problems (Šarka *et al.*, 2004, 2005; Ustinovičius *et al.* 2003; Šarkienė *et al.* 2005).

2. A general scheme of developing a database of construction project and processes

Decision-making by using the methods of synthesis requires step-by-step selection of the most effective option from a generated set of alternatives. To solve this problem, a matrix should be constructed (Hwang and Yoon 1981; Keeney and Raiffa 1976). The above matrix contains the data on the alternatives considered at any stage of decision making, as well as the criteria describing them and their values and initial significances (weights). Based on the available information, decision-making matrices are generated for each step, which are provided with the tables, showing the relationship between the alternatives of a particular step and with any alternative of any other step.

All data required for decision-making are collected, analysed, combined and entered the offered database system (DBS) (Fig. 2). It should be noted that not all information about particular construction projects or operations can be reduced to a digital form. The required information that cannot be digitized (initial significances of the criteria describing the projects and qualitative criteria of the available alternatives) should be obtained from experts and mathematically processed (by using expert systems) or methods of pairwise comparison, entropy, games theory and comparison of group estimates.

Based on the database (DB) structure and using the algorithm of DSS1 method, a decision-support system was created to illustrate the application of multicriteria synthesis methods (SPS_DS) in construction. A computer-aided version of SPS_DS system is successfully used in research, teaching of students and for solving various business problems.

The development of DBS is the first out of 3 steps (stages) implemented in multicriteria methods of decision synthesis. An algorithm for preparing and filling in a database system is schematically shown in Fig. 3.

The first stage includes the statement of the problem and generation of decision-making steps $k=\overline{1,c}$. Every step is intended for one table of data on construction projects or operations describing a considered problem. The following operations are performed at the stage of database system generation:

- defining the constituting parts of construction projects and operations and generating codes of the tables of data for multicriteria project evaluation (MCE) for $k=\overline{1,c}$ steps of decision – making (Fig. 2, Table A). MCE tables are described in terms of particular projects or operations (for example, A_1 is construction site, …, A_k denotes contractors, …, A_c is maintenance);
- defining the constituting parts of construction projects and operations and generating codes of the tables of data for multicriteria project evaluation (MCE) for $k=\overline{1,c}$ steps of decision-making (Fig. 2, Table B). MCE tables are described in terms of particular

Codes of MCE tables of data (Table A)

Code of table	Name of data table
A_1	Construction site
A_2	Project
...	...
A_k	Contractors
...	...
A_c	Maintenance

Codes of criteria tables describing the parts of construction projects and operations (Table B)

Code of table	Name of criteria table
B_1	Construction site
B_2	Project
...	...
B_k	Contractors
...	...
B_c	Maintenance

A set of criteria presented in the tables (Table B_k)

Code of criteria table	Code of criterion	No of criterion	Name of criterion	Monetary or other expr.	Units of measure	Mini-mized or maxi-mized	Initial sig-nificance	Quanti-tative or qualita-tive
B_1	Rod_{11}	b_{num11}	b_{pav11}	b_{pin11}	b_{mat11}	b_{mima11}	b_{prad11}	b_{kok11}
...	...	...	...	...	...	...	...	...
B_1	Rod_{n1}	$b_{num\ n1}$	$b_{pav\ n1}$	$b_{pav\ n1}$	$b_{mat\ n1}$	$b_{mima\ n1}$	$b_{prad\ n1}$	$b_{kok\ n1}$
B_2	Rod_{12}	b_{num12}	b_{pav12}	b_{pin12}	b_{mat12}	b_{mima12}	b_{prad12}	b_{kok12}
...	...	...	...	...	...	...	...	...
B_2	Rod_{n2}	$b_{num\ n2}$	$b_{pav\ n2}$	$b_{pav\ n2}$	$b_{mat\ n2}$	$b_{mima\ n2}$	$b_{prad\ n2}$	$b_{kok\ n2}$
B_c	Rod_{1c}	b_{num1c}	b_{pav1c}	b_{pin1c}	b_{mat1c}	b_{mima1c}	b_{prad1c}	b_{kok1c}
...	...	...	...	...	...	...	...	...
B_c	Rod_{nc}	$b_{num\ nc}$	$b_{pav\ nc}$	$b_{pav\ nc}$	$b_{mat\ nc}$	$b_{mima\ nc}$	$b_{prad\ nc}$	$b_{kok\ nc}$

A set of alternatives represented in the tables of data (Table V_k)

Code of data table	Code of alternative	Name of alternative	Brief description of alternative	Reference of graphi-cal view of alternative to a disk
A_1	Var_{11}	v_{pav11}	v_{apr11}	v_{gra11}
...	...	...	...	...
A_1	Var_{m1}	$v_{pav\ m1}$	$v_{apr\ m1}$	$v_{gra\ m1}$
A_2	Var_{12}	v_{pav12}	v_{apr12}	v_{gra12}
...	...	...	...	...
A_2	Var_{m2}	$v_{pav\ m2}$	$v_{apr\ m2}$	$v_{gra\ m2}$
A_c	Var_{1c}	v_{pav1c}	v_{apr1c}	v_{gra1c}
...	...	...	...	...
A_c	Var_{mc}	$v_{pav\ mc}$	$v_{apr\ mc}$	$v_{gra\ mc}$

Fig. 2. Diagram of the initial data database (DBS) of construction projects and operations for SPS_DS

Codes of the tables illustrating the relationships between the constituent parts of construction operations and projects (matrix R)

Code of table	**Code of data table**					
	A_1	A_2	...	A_k	...	A_c
A_1	–	$R_{1,2}$	...	$R_{1,k}$	...	$R_{1,c}$
A_2	–	–	...	$R_{2,k}$	...	$R_{2,c}$
...	...	...	–	...	...	...
A_k	–	–		–	...	$R_{k,c}$
...	...	...	...	...	–	...
A_c	–	–	...	–	...	–

Fig. 2 (continued). DBS, the structure of relationship tables

projects or operations (for example, B_1 is construction site, …, B_k denotes contractors, …, B_c is maintenance);

- generating codes for the tables presenting the relationships between the constituent parts of construction operations and projects (matrix R). In particular, the codes of the tables, illustrating the relationships between various stages of decision-making are generated (for example, A_1 at stage 1 presents the codes of construction site tables showing the relationships with other stages: r_{12} with A_k denote contractors, r_1 with A_c is maintenance;
- generating a set of criteria to describe the constituent parts of construction projects and operations for the K-th stage (Fig. 2, Table Bk). The criterion description includes: b_{num11} is the criterion number (1); b_{pav11} is the criterion name (project cost); b_{pin11} shows if the criterion is expressed in monetary or other units ($/-); b_{mat11} is a measuring unit of the criterion (thous. Lt);
- b_{mima11} denotes minimization/maximization. In various problems one and the same criterion may be minimized or maximized (minimized-), depending on the goals pursued by the interested parties; b_{prad11} is the initial significance of the criterion. By filling in expert forms, it is calculated by expert method or its value is taken from a similar project database (calculated as 0.58); b_{kok11} indicates if the criterion is quantitative and described in units of measurement, e. g. thousands, years, decibels, kilowatts, etc. or qualitative – described in points;
- generating alternatives to fill in MCPE knowledge tables for the k-th stage (Fig. 2, Table V_k). A system describing the alternatives (in brackets, an example of entering alternative 1 is given) consists of: v_{pav11} is the name of alternative (Project 1); v_{apr11} is a brief description of alternative (according to customer's specifications, six-floor office building is designed for 312 working places, of rectangular form, reinforced concrete frame, 'Gyproc' wall slabs); v_{gra11} is a reference to a computer file, where a considered alternative is graphically shown, a recommended JPEG, graphical JPG formats which are sufficiently accurate and of minimal size;

- generating a knowledge table $A_k=[x_{ik,jk}]$, $i=\overline{1,m}$, $j=\overline{1,n}$ for the k-th MCE stage based on a set of criteria B_k. It is made in a matrix form, with the alternatives of the stage presented in a line and the criteria describing them given in the columns (Fig. 3, Tables $A_1, A_2 \ldots A_c$);
- generating the relationship matrices of the systems of the alternatives V_1 and V_d from MCE tables $R_{1,d}=[r_{id}(1),h(d)]$, $i=\overline{1,m(l)}$, $h=\overline{1,m(d)}$. They are aimed at forming the interrelationships between the alternatives of projects and operations considered in the process of decision-making. At this stage it is possible to veto the conflicting alternatives found at different stages of decision-making, to eliminate incompatible structures or units or take into consideration the limitations imposed by bidding companies on their products (e. g. cast-in-place framework is incompatible with the time of project completion, specified by the customer; brick or 'Gyproc' partitions should not be combined with glass doors).

When these operations are completed, the stage of DBS preparation and filling is over.

3. A method of multicriteria decision synthesis (DSS1) based on decision success criterion (PSS2)

Multicriteria design often requires decision-making based on the analysis of a number of problems or their synthesis, implying the integration of several problems into a coherent whole. DSS1 consists in synthesizing some interrelated solutions by selecting only 2 alternatives (or more, if a user of the method specifies it) at every stage by default. The number of the alternatives retained at any stage of decision-making depends on the significance of the problem considered and the number of the available alternatives; however, in any case, the number of the considered alternatives is $m_k > 1$. If $m_k = 1$, it is not rational to include the operation or process in the problem to be solved by a synthesis method because it has only one possible solution. If $m_k > 2$, ineffective alternatives are discarded, when it is evident that after considering all available alternatives and obtaining the final result a user gets detailed information about the best alternatives provided by the system.

Thus, DSS1 offers more freedom to users in decision-making because at any stage of the process, they can finally obtain a preference order of synthesized alternatives. The user is provided with an effective solution of the problem associated with a number of construction projects or operations.

In making the calculations according to this method, absolute, rather than relative, significance of the alternatives describing projects or operations is determined, when intermediate decisions are made at a particular stage. This problem was identified when the decision success criterion (PSS2 K3s) was used in DSS1 method and a numerical experiment was made. To solve the above problem, a method based on the similarity to an ideal solution was applied, in which some new decision-making elements were introduced and TOPSIS algorithm was improved (Šarka *et al.* 2000).

The initial data are collected according to stage I algorithm (Fig. 3).

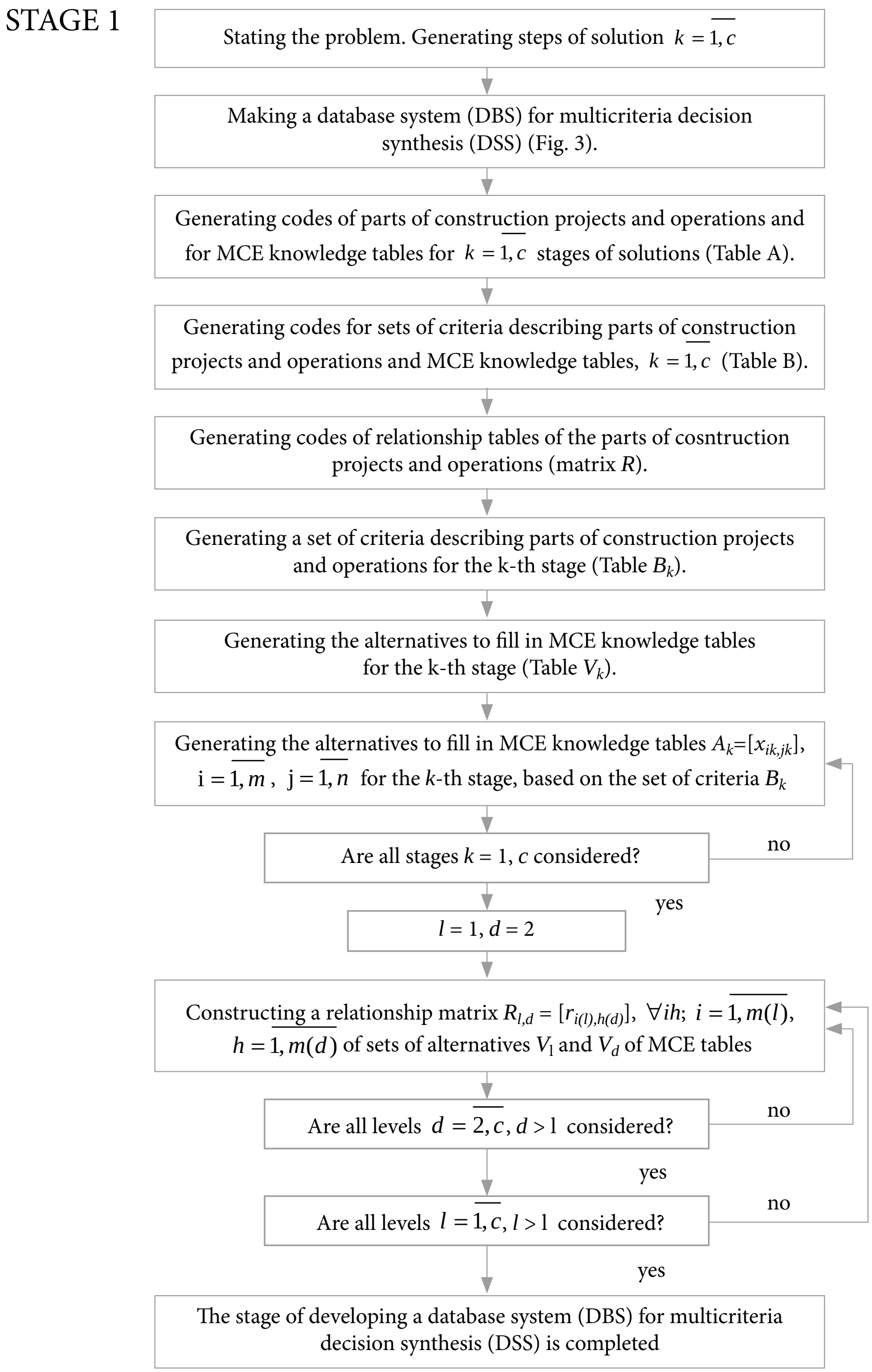

Fig. 3. Block-diagram of database system (DBS) development in DSS1 method

Stage 2 of decision (Fig. 4) – making is aimed at processing the tables ($A_1, A_2, \ldots, A_c$ MCE tables) (Fig. 2) presenting the data on particular construction projects or operations and preparing them for further treatment. The stage consists of the following steps:

- considering the initial data of the k-th MCE stage and constructing decision-making matrix P based on the table A_k of MCE data;
- determining the initial significance of the criteria for the k-th stage by using expert or pairwise comparison methods;
- determining a series of criteria K_{bit} of the relative significance of alternatives for the k-th stage by using a method of similarity to ideal solution (TOPSIS).

Then, the initial preference order of alternatives is established for the k-th stage based on relative significance of alternatives obtained by K_{bit} criteria. A relative preference order of alternatives for k-th stage (6) is as follows:

$$\left\{\bar{a}_k\right\} = \left\{a_5 \succ a_2 \succ a_m \succ \ldots \succ a_i \succ \ldots \succ a_7\right\}. \tag{1}$$

Thus, when a relative preference order of alternatives is established for all $k = \overline{1,c}$ stages, where c – the number of decision-making stages, stage 2 is completed.

Stage 3 (Fig. 4) of decision-making includes a synthesis of the available alternatives. The operations performed at this stage are described below:

the formation of the k-th stage node $g_{k,e}, \forall ke = \overline{1,c},\ e = \overline{1,z_k}$ of a decision tree (DT), where, z_k is the number of the k-th stage nodes determined by the formula (2):

$$z_k = (z_{k-1} \times m_k);\ \forall k,\ k = \overline{2,c},\ z_1 = m_1, \tag{2}$$

while the total number of nodes z formed in the process of decision-making is calculated by the formula (3):

$$z = \sum_{k=1}^{c} z_k; \tag{3}$$

- the generation of the variants of the k-th stage DM node g_k, e from the specified number of m_k best alternatives of the considered k-th stage based on the relationship matrix R_1, d. At this stage, two or more (if specified by the user) best alternatives are selected. The alternatives are chosen out of i options $i = \overline{1,m}$ (where m is the number of the k-th stage alternatives) according to j criteria, describing these alternatives ($j = \overline{1,n}$) (where n is the number of the criteria, describing the k-th stage alternatives);
- determination of absolute significance of the best alternatives left at the k-th stage DT node $g_{k,e}$ by applying the method TOPSIS (similarity to the ideal point). The experimental research has shown that special calculations should be made before synthesizing the alternatives mk selected at each k-th stage for the final decision;
- recalculation of the obtained data and determination of absolute interrelationships K_{bita} between the alternatives in the k-th stage DT node $g_{k,e}$. Then, another k-th stage is considered, simultaneously synthesizing the adjacent previously considered nodes of the stage 1-k. Synthesis is made by combining the alternatives left at the considered stages into a coherent whole based on the use of relationship tables, depending on the types of alternatives selected at a particular stage and taking into account the previ-

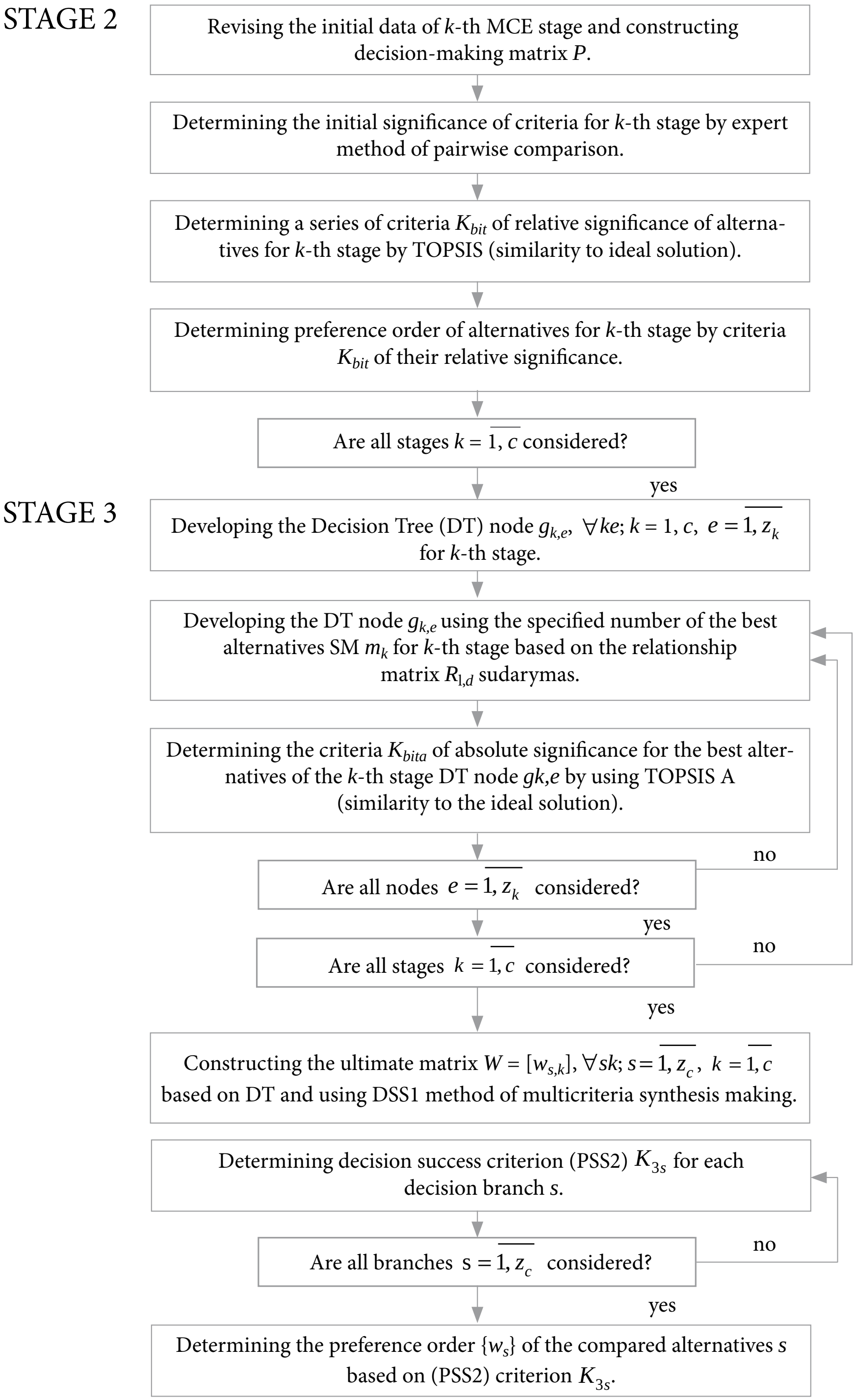

Fig. 4. Block-diagram of determining preference order of alternatives by using *DSS1* method

ous stages (if a considered stage is not the first in decision-making). In particular, a decision branch is generated for each available node, then, via the relationship tables R_1,d $l=\overline{1,k-1}$ and $d=\overline{2,k}$, the numbers of the stages for which a relationship table is made are generated by linking two best alternatives automatically (or more alternatives if specified by the user);

- the construction of the multicriteria decision synthesis matrix $W=[ws,k]$ $\forall sk, s=\overline{1,z_c}$, $k=\overline{1,c}$ based on DT. The ultimate matrix W is formed based on the DT branches $s=\overline{1,z_c}$. Any line of the matrix reflects an alternative obtained in the synthesis aimed at making a final decision, which represents a synthesized system of the most effective alternatives of construction projects or operations considered at the stages $k=\overline{1,c}$;
- Determination of the decision success (PSS2) criterion for each DT branch $s=\overline{1,z_c}$ K_{3s} by the formula (4) taken from the works of E. K. Zavadskas (1989, 1991):

$$K_{3s}=max\prod_{k=1}^{c} w_{s,k},\ \forall sk;\ \ s=\overline{1,z_c}\ ,\ k=\overline{1,c}\ , \tag{4}$$

where s is the number of DT branches synthesized in decision-making. The synthesis of the alternatives is implemented by using the criterion K_{3s}, with the expected result being $\{ws\}\in W$;

- generation of the k-th stage DT node $g_{k,e}$ variants out of the specified number of the best alternatives m_k found at the considered k-th stage based on the relationship matrix R_1,d. The best two or more alternatives (if specified by the user) are being selected. The choice is made from i alternatives $i=\overline{1,m}$ (where m is the number of the k-th stage alternatives) according to i criteria describing these alternatives ($j=\overline{1,n}$) (where n is the number of the criteria describing the k-th stage alternatives);
- generation of the preference order (w_s) of the compared alternatives s based on the decision-success criterion K_{3s} (PSS 2). Based on the assumption that the best alternative (w_s, $s=\overline{1,z_c}$) is the option with the highest K_{3s} value and relying on the calculated K_{3s} values, the ultimate preference order $\{\overline{w_s}\}=\{w_1\succ w_2\succ w_3\succ\ldots\succ w_s\succ\ldots\succ w_{z_c}\}$ is obtained (where z_c – the number of branches involved in the synthesis of the alternatives). A fragment of each decision tree branch s of a decision matrix (DM), where decision is reached by using the decision success criterion K_{3s}, is shown.

Hence, in general, the above described method of multicriteria project synthesis (DSS1) based on the decision success criterion (PSS2) is aimed at evaluating large projects and operations described by various sets of criteria and relationship tables of the alternatives.

4. Some problems of applying the method of similarity to ideal solution (TOPSIS) to DSS1 model

In TOPSIS approach, the values of K_{bit} depend on the number of alternatives. When applied to the method of synthesis, this technique would reduce the reliability of results. This gave an incentive to search for the arrangement of the alternatives according to the absolute, rather than relative, values of the relationship between the alternatives. To achieve this, the authors of DSS1 created a modified version of the method based on the similarity to the ideal solution (TOPSIS_A). The analysis performed has shown that the value of the criteria K_{bit} as well utility degree depend on the number of alternatives. It was decided that the method of decision-making based on determination of absolute significance of only 2 alternatives would be more effective. At the same time, some fictitious alternatives should be introduced in decision-making based on the suggested method, i.e. the ideal best alternative and two ideal worst alternatives as well as a coefficient showing relative accuracy of relative significance of alternatives, T_{fs}. If more than 2 alternatives should be considered for making a decision, the use of matrix T may be suggested. The method consists in determining the most accurate value of the criterion of relative significance of the alternatives K_{bita}. The solution is made by artificially controlling the values of the ideal best and the ideal worst alternatives introduced in the process. The values of the ideal best alternative are increased by, for example, $T = 5\%$, while the values of the ideal worst alternatives are reduced by $T = 5\%$. In the process of decision-making the value of the coefficient T_{fs} is calculated as follows (5):

$$T_{fs} < T_{fa} = \frac{T^2}{m_k \ 100} \, . \tag{5}$$

When the value of the above coefficient is equal or lower than the coefficient of absolute accuracy of relative significance of the considered alternatives T_{fa}, then the solution by the method TOPSIS_A is considered to be over. Then, based on this coefficient, the values of absolute significance of the considered alternatives are determined. Here, every element of matrix T indicates the absolute significance value for two alternatives. The value of absolute accuracy coefficient T_{fa} is determined as the relationship between the square of the alternative value increase $T = 5\%$ and the number of the considered alternatives m_k, multiplied by 100. This method can be used, when the number of the available alternatives is small and problem solution requires that absolute significance values of the alternatives should be determined.

5. Case study

An actual case of selecting effective architectural solutions at the initial construction stage of a block of individual dwelling houses in Vilnius is considered (including the analysis of architectural solutions and building processes). A decision-making process is implemented at 3 stages as follows:

- at stage 1 the data are collected (the criteria of the project are outlined, the data on the alternatives gathered and the relationship matrices are made) and organized into a database;
- at stage 2 the data for calculations are prepared (based on the already available data), entering the required fuzzy information into a database in cooperation with the experts;

- at stage 3 a decision is made by applying multicriteria decision-making synthesis method DSS1. Multicriteria analysis of the alternatives obtained is made and their properties and weights are stated.

All the data analysed are taken from an actual building project of an individual dwelling house, though, for the sake of confidentiality, the real names of the companies are not mentioned. Such data as the volumes of work, the materials and costs have been taken from the project. All quantitative data are closely connected with numerical expressions of the project. The information relating to qualitative characteristics was obtained by an expert method and by using the integrated solutions offered in the model. The expert system was used to obtain the criteria for which numerical expressions were non-existent.

Selection of architectural solutions. Project 1 is a single-family (4 persons) individual dwelling house with the basement and loft. The built-up area is 149.60 m^2, total area – 297.75 m^2; and a garage for one car is provided. A shelter for another car is nearby; 3 rooms (a bedroom and 2 children rooms) are at the loft. A drawing room, a dining room and a kitchen are integrated into the same space. The kitchen is usually separated from the L-shaped drawing room. The building has a single-pitch roof.

The parameters of other projects to be compared are described in a similar way and Table 1 is filled in.

A group of experts has been formed to evaluate qualitative criteria. It consists of a chairman – a customer of the project and 2 other experts. The alternatives of the first criterion (designer's rating), the initial data of an expert form for determining the values and the values calculated by an expert method are provided. For this purpose, a developed expert form has been printed (Table 2).

Selecting the sitting alternatives. Here, the plot cost will be considered. To determine the cost, differentiation technique taking into account the location and size of the plot to be purchased should be used. For example, the cost of 1 a of land in Antakalnis district in Vilnius ranges from 12,000 to 32,000 Lt, while in Vilnius region the costs vary from 400 to 6,000 Lt/a.

Therefore, in choosing the site it would be not rational to compare plots of the same size. Site 1 is a plot of 9.75 a in Vilnius, Pylimėliai street. There are electric, gas and water lines there. It costs 98,000 Lt. The plot is at the end of a blind alley, surrounded by adjacent plots on 3 sides, and by the forest on the one side. Strategic siting of the plot is good and transport services are available.

In a similar way, the parameters of other plots to be compared are described in Table 3.

The weights of engineering services, environment and infrastructure are obtained by considering actual alternatives. Here, the value of an integrated decision offered by the authors is assigned to the actual description of the criterion which is most similar to it (ideal point method). If such a decision cannot be applied, an expert system should be used to evaluate an actual alternative in the context of the alternatives offered by the authors (Table 4).

In a similar way, the alternatives referring to constructions (Table 5) and sources of financing are compiled. When major data are entered, weights of the concordance (relationship) tables are revised. These tables are aimed to check the relationship (concordance) between the alternatives relating to the data of various levels.

Table 1. Alternatives of architectural solutions of the projects prepared for multiple criteria evaluation

Criterion	Expressed in monetary units or not	Units of measure	Min or Max	Weight	Project 1	Project 2	Project 3	Project 4
Design cost	+	1000 Lt	–	0.61	7.00	8.00	5.00	4.20
Estimated cost	+	1000 Lt	–	0.72	356.40	414.48	259.00	197.00
Designer rating	–	points	+	0.54	5.70	5.97	4.77	7.17
Project presentation quality	–	points	+	0.61	4.67	4.37	4.97	6.83
Project terms	–	month.	–	0.36	4.00	4.00	5.00	4.00
Construction area	–	m^2	+	0.42	297.75	35.40	185.00	123.00
Number of bedrooms	–	amount	+	0.73	4.00	5.00	3.00	3.00
Building functionality	–	points	+	0.80	8.15	7.28	6.30	6.75
Number of floors	–	amount	+	0,43	3.00	3.00	1.00	1.00
Aesthetic view of building	–	points	+	0.75	8.10	7.45	6.98	6.98
Project type	–	points	+	0.51	8.10	8.35	7.25	7.18
Building interior	–	points	+	0.71	7.80	8.17	7.23	6.67

Table 2. Determination of quality indicator rating of designer of prepared projects using expert method Rating of project designers determined by expert method

Expert name	Experience level	Project 1	Project 2	Project 3	Project 4	Equal range
Expert 1	1.00	6	6	5	8	6
Expert 2	0.90	7	7	5	7	24
Expert 3	0.80	6	7	6	9	6
Recommended calculated values		5. 70	5.97	4.77	7.17	
concordance coefficient. weight (X)		14.1600				
concordance coefficient. weight (Xlent)		6.6300				

Here, several groups of potential discordance may be established:

1. The alternatives are in discordance from technical or technological perspectives (i.e. strip foundations cannot be built under water; it is not economical to construct strip foundations under columns, etc.).
2. A decision-maker (an expert) can identify inefficient elements of a particular solution and prevent them from being implemented by deliberately introducing a discordance

Table 3. Alternatives of multiple criteria evaluation of the plot

Criteria	Expressed in monetary units or not	Units of measure	Min or Max	Weight	Place 1	Place 2	Place 3	Place 4
Cost	+	1000 Lt	–	0.91	98.00	96.00	65.00	72.00
Engineering services	+	Points	–	0.80	6.88	8.40	7.56	6.50
Environment	–	Points	+	0.74	7.16	7.11	4.22	7.22
Plot configuration	–	Points	–	0.50	6.56	6.22	5.26	6.24
Plot area	–	m^2	+	0.50	975	1000	600	600
Plot relief	–	Amount	+	0.45	6.74	6.64	7.14	7.02
Recreational potential	–	Amount	+	0.45	7.62	7.66	6.22	6.3
Infrastructure	–	Points	+	0.60	6.32	6.32	7.22	6.50

Table 4. Determinated weight values of integrated facilities variants

Variant number	Recommended values
Fac1 (Electricity, water supply, sewerage, gas, heat supply lines)	8.40
Fac2 (Electricity, water supply, sewerage, gas, heat supply lines)	7.56
Fac3 (Electricity, water supply, gas, communication lines)	6.88
Fac4 (Electricity, water supply, sewerage)	6.50
Fac5 (Electricity, water supply)	5.78
Fac6 (Electricity)	4.64
Other	Expert evaluation

Table 5. Alternatives of multiple criteria evaluation of construction

Criteria	Expressed in monetary units or not	Units of measure	Min or Max	Weight	Var. 1	Var. 2	Var. 3	Var. 4	Var. 5
Cost	+	Lt/m^2	–	0.76	749.0	503.0	656.0	503.0	656.0
Aesthetics	–	points	+	0.58	5.27	6.83	6.20	6.83	6.20
Durability	–	points	+	0.48	4.97	6.83	6.23	6.83	6.23

mark between them (i.e. it is not rational to make expensive aluminium windows on a cheap façade; not all construction firms can perform specific operations, etc.).

In general, 239 project alternatives (options) have been distinguished based on the initial data, expert methods and multistage multicriteria decision synthesis DSS1 approach (Šarka *et al.* 1999).

Table 6. Determination of the most efficient construction variant for a dwelling house using project multiple criteria evaluation synthesis method DSS1. The data of 5 best variants

Variant priority	**Variant No**	**K_{bita} value**	**Variant composition**		**Value of K_{bit} alternatives**
1	41	1,0000	1	project 1	1,0000
			4	construction 7	1,0000
			2	plot 2	1,0000
			2	financed by customer and bank	1,0000
2	53	0,9958	1	project 1	1,0000
			4	construction 9	0,9958
			2	plot 2	1,0000
			2	financed by customer and bank	1,0000
3	47	0,9464	1	project 1	1,0000
			4	construction 7	1,0000
			2	plot 4	0,9464
			2	financed by customer and bank	1,0000
4	59	0,9424	1	project 1	1,0000
			4	construction 9	0,9958
			2	plot 4	0,9464
			2	financed by customer and bank	1,0000
5	227	0,9011	4	project 4	0,9521
			4	construction 7	1,0000
			2	plot 4	0,9464
			2	financed by customer and bank	1,0000

Then the most efficient alternative of architectural solutions including design, choice of structure and source of financing was calculated by the DSS1 method (Table 6).

This was as follows:

- project 1;
- construction 7;
- plot 2;
- financed by customer and bank.

It should be noted that the above system does not provide precise calculations. A model is based on generalized criteria giving a possibility to choose among a number of the available decisions.

The authors believe that the model suggested may help harmonize the needs of various interested parties with minimum expenses at least at the initial stage of construction, thereby allowing to make a contract and further develop and implement the project.

6. Conclusions

A new management procedure for a decision-support system in construction is offered. It assures the selection of an effective alternative in the process of multiple criteria decision-making, especially taking into consideration a selected explanation method for decision multitask problems.

A method of multicriteria decision synthesis (DSS1), based on decision success criterion (PSS1), was created.

The method of similarity to the ideal solution (TOPSIS) was extended by introducing the absolute significance for a single level of alternatives (TOPSIS_A).

A theoretical and computer models for a decision support system applying multicriteria synthesis methods (DSS_MS) with the integrated elements of the above system were created.

The reliability of DSS_MS system and new synthesis method (DSS1) were tested by numerical experiments. The results of the assessment were implemented in actual projects.

The above considerations allow us to assert that multicriteria decision synthesis is an elaborately theoretically described and mathematically grounded method.

With an additional analysis performed and the appropriate sets of criteria provided, a method DSS1 may be used in other areas, e.g. finances, medicine, transport, IT, etc.

Based on the analysis of the investment alternatives in a 4 hectare plot made in the present investigation, it is recommended to parcel out the plot in a number of smaller plots of 15–20 are, with an area of 1 hectare provided with the networks of service lines and built-up with one-, two-storey houses of 200–250 m^2 floor area and normal comfort conditions.

Algorithms for calculating the evaluation criteria have been developed for the conditions of Lithuania. However, when some additional market analysis is made, the above algorithms can be used in any other region.

References

Churchman, C. W.; Ackoff, R. L. 1954. An approximate measure of value, *Journal of Operations Research Society of America* 2(2): 172–187.

Churchman, C. W.; Ackoff, R. L.; Arnoff, J. 1957. *Introduction to operational research.* Wiley, New York.

Brauers, W. K. M.; Zavadskas, E. K.; Peldschus, F.; Turskis, Z. 2008. Multi-objective decision-making for road design, *Transport* 23(3): 183–193.

Dawes, R. M. 1964. Social selection based on multidimensional criteria, *Journal of Abnormal and Social Psychology* 68(1): 104–109.

Figueira, J.; Greco, S.; Ehrgott, M. (Eds.). 2005. *Multiple criteria decision analysis: State of the art surveys.* Springer.

Ginevičius, R.; Podvezko, V.; Raslanas, S. 2008. Evaluating the alternative solutions of wall insulation by multicriteria methods, *Journal of Civil Engineering and Management* 14(4): 217–226.

Ginevičius, R.; Podvezko, V. 2008. Multicriteria graphical-analytical evaluation of the financial state of construction enterprises, *Technological and Economic Development of Economy* 14(4): 452–461.

Ginevičius, R.; Podvezko, V.; Andruškevičius, A. 2007. Quantitative evaluation of building technology, *International Journal of Technology Management* 40(1/2/3): 192–214.

Hwang, C. L.; Yoon, K. 1981. *Multiple attribute decision making – methods and applications.* A State-of-the-Art Survey, Springer Verlag, Berlin.

Hwang, C. L.; Lin, M. J. 1987. *Group decision-making under multiple criteria.* Berlin: Springer-Verlag.

Jakimavičius, M.; Burinskienė, M. 2007. Automobile transport system analysis and ranking in Lithuanian administrative regions, *Transport* 22(3): 214–220.

Kaklauskas, A.; Zavadskas, E. K.; Banaitis, A.; Šatkauskas, G. 2007. Defining the utility and market value of real estate a multiple criteria approach, *International Journal of Strategic Property Management* 11(2): 107–120.

Kaklauskas, A.; Zavadskas, E. K.; Raslanas, S.; Ginevičius, R.; Komka, A.; Malinauskas, P. 2006. Selection of low-e windows in retrofit of public buildings by applying multiple criteria method COPRAS: A Lithuanian case, *Energy and Buildings* 38(5): 454–462.

Keeney, R. L.; Raiffa, H. 1976. *Decision with multiple objectives: Preferences and value tradeoffs.* Wiley, New York.

MacCrimmon, K. R. 1968. *Decision marking among multiple-attribute alternatives: A survey and consolidated approach*, RAND Memorandum, RM-4823-ARPA.

MacCrimmon, K. R.; Wehrung, D. A. 1977. Trade-off analysis: the indifference and preferred proportions approaches, in Bell, D. E.; Keeney, R. L. and Raiffa, H. (eds.). *Conflicting Objectives in Decisions.* Wiley, New York, 123–147.

Mitkus, S.; Trinkūnienė, E. 2008. Reasoned decisions in construction contracts evaluation, *Technological and Economic Development of Economy* 14(3): 402–416.

Mitkus, S.; Trinkūnienė, E. 2007. Analysis of criteria system model for construction contract evaluation, *Technological and Economic Development of Economy* 13(3): 244–252.

Mitkus, S.; Trinkūnienė, E. 2006. Models of indicator systems of construction contraction agreements, *Journal of Civil Engineering and Management* 12(4): 327–335.

Morkvėnas, R.; Bivainis, J.; Jaržemskis, A. 2008. Assessment of employee's knowledge potential in transport sector, *Transport* 23(3): 258–265.

Paelnick, J. H. P. 1976. Qualitative multiple criteria analysis, Environmental Protection and Multiregional Development, *Papers of the regional Science Association* 36, 59–74.

Peldschus, F. and Zavadskas, E. K. 2005. Fuzzy matrix games multi-criteria model for decision-making in engineering, *Informatica* 16(1): 107–120.

Roy, B.; Vincke, Ph. 1981. Multicriteria analysis: survey and new directions, *European Journal of Operational Research* 8(3): 207–218.

Rutkauskas, A. V. 2000. *Quantitative models in the finance and commerce.* Vilnius: Technika (in Lithuanian).

Sivilevičius, H.; Zavadskas, E. K.; Turskis, Z. 2008. Quality attributes and complex assessment methodology of the asphalt mixing plant, *Baltic Journal of Road and Bridge Engineering* 3(3): 161–166.

Su, Ch.-W.; Cheng, M.-Y., Lin, F.-B. 2006. Simulation-enhanced approach for ranking major transport projects, *Journal of Civil Engineering and Management* 12(4): 285–291.

Šaparauskas, J.; Turskis, Z. 2006. Evaluation of construction sustainability by multiple criteria methods, *Technological and Economic Development of Economy* 12(4): 321–326.

Šarka, V.; Budinas, S.; Šarkienė, E. 2004. Model of economic evaluation of hotel construction based on multiple criteria decision synthesis methods, in *8th International Conference "Modern Building Materials, Structures and Techniques"*, held on May 19–21, 2004, Vilnius, 260–267.

Šarka, V.; Šarkienė, E.; Budinas, S. 2005. Model of investment evaluation of public building based on multiple criteria decision synthesis methods, *Transport and Telecommunication* 6(1): 172–182.

Šarka, V.; Ustinovičius, L.; Zavadskas, E. K. 1999. Project synthesis using compromise-compensating model in decision support system in construction industry, *Statyba* [Civil Engineering] 5(6): 374–385.

Šarka, V.; Zavadskas, E. K.; Ustinovichius, L. 2000. Method of project multicriteria decision synthesis on the basis of decision success criterion, *Statyba* [Civil Engineering] 6(3): 193–201 (in Lithuanian).

Šarkienė, E.; Ustinovichius, L.; Šarka, V. 2005. Model of selection architectural solutions in housing construction based on multiple criteria decision synthesis methods, *Foundations of Civil and Environmental Engineering* 6, 191–202.

Triantaphyllou, E. 2000. *Multi-criteria decision-making methodologies: A comparative study.* Vol 44 of Applied Optimization. Kluwer Academic Publishers, Dordrecht.

Turskis, Z. 2008. Multi-attribute contractors ranking method by applying ordering of feasible alternatives of solutions in terms of preferability technique, *Technological and Economic Development of Economy* 14(2): 224–239.

Turskis, Z.; Zavadskas, E. K; Zagorskas, J. 2006. Sustainable city compactness evaluation on the basis of GIS and Bayes rule, *International Journal of Strategic Property Management* 10: 185–207.

Ugwu, O. O.; Kumaraswamy, M. M.; Wong, A.; Ng, S. T. 2006. Sustainability appraisal in infrastructure projects (SUSAIP): Part 2: A case study in bridge design, *Automation in Construction* 15(2): 239–251.

Ustinovichius, L.; Zavadskas, E. K.; Podvezko, V. 2007. Application of a quantitative multiple criteria decision making (MCDM-1) approach to the analysis of investments in construction, *Control and Cybernetics* 36(4): 251–268.

Ustinovichius, L.; Šarkienė, E.; Šarka, V. 2003. A model of selecting effective architectural solutions of one-family houses based on multicriteria decision synthesis methods, *Technological and Economical Development of Economy* 9(1): 18–26 (in Lithuanian).

Viteikienė, M.; Zavadskas, E. K. 2007. Evaluating the sustainability of Vilnius city residential areas, *Journal of Civil Engineering and Management* 13(2): 149–155.

Zagorskas, J.; Turskis, Z. 2006. Multi-attribute model for estimation of retail centres influence on the city structure. Kaunas city case study, *Technological and Economic Development of Economy* 12(4): 347–352.

Zavadskas, E. K.; Kaklauskas, A.; Turskis, Z.; Tamošaitienė, J. 2008a. Selection of the effective dwelling house walls by applying attributes values determined at intervals, *Journal of Civil Engineering and Management* 14(2): 85–93.

Zavadskas, E. K.; Turskis, Z.; Tamošaitienė, J. 2008b. Contractor selection of construction in a competitive environment, *Journal of Business Economics and Management* 9(3): 181–187.

Zavadskas, E. K.; Kaklauskas, A.; Peldschus, F.; Turskis, Z. 2007. Multi-attribute assessment of road design solutions by using the COPRAS Method, *The Baltic Journal of Road and Bridge Engineering* 2(4): 195–203.

Zavadskas, E. K.; Vilutienė, T. 2006. A multiple criteria evaluation of multi-family apartment block's maintenance contractors: I-Model for maintenance contractor evaluation and the determination of its selection criteria, *Building and Environment* 41(5): 621–632.

Zavadskas, E. K.; Zakarevičius, A.; Antuchevičienė, J. 2006. Evaluation of ranking accuracy in multicriteria decisions, *Informatica* 17(4): 601–618.

Zavadskas, E. K.; Peldschus, F.; Kaklauskas, A. 1994. *Multiple criteria evaluation of projects in construction.* Vilnius: Technika. ISBN 9986-05-046-4.

Завадскас, Э.-К. 1991. *Системотехническая оценка технологических решений строительного производства* [Zavadskas, E. K. 1991. Systems approach to the evaluation of technological solutions in construction industry]. Ленинград: Стройиздат. ISBN 5-274-01169-1.

PROJEKTO DAUGIATIKSLIŲ SPRENDIMŲ SINTEZĖS SISTEMA STATYBOJE

V. Šarka, E. K. Zavadskas, L. Ustinovičius, E. Šarkienė, Č. Ignatavičius

Santrauka

Straipsnyje nagrinėjamas daugiatikslių sprendimų sintezės metodas ir jo taikymo galimybės. Svarbus investicijų efektyvumo garantas yra projektų analizė ir vertinimas. Tai leidžia pagal tam tikrą rodiklių sistemą nustatyti projekto varianto efektyvumą. Vertinimo rodikliai turi būti grindžiami tiek projektą įgyvendinančio subjekto, tiek investuotojo interesais. Analizuojant projektavimo procesus susiduriama su įvairaus pobūdžio informacija – kokybine ir kiekybine. Čia siūlomas ir aprašomas DSS1 metodas, sprendimų priėmimo etapai, duomenų bazės sudarymo principai. Pateikti metodo taikymo rezultatai.

Reikšminiai žodžiai: sprendimų paramos sistemos, sintezės metodai, projektai, statyba, integruoti sprendiniai.

Vaidotas ŠARKA. Doctor, Assoc Prof. of department of Construction Technology and Management. Vilnius Gediminas Technical University. Doctor (2000) Publication: more than 10 scientific papers. Research interests: building technology and project management, decision-making theory, automation in design, expert systems.

Edmundas Kazimieras ZAVADSKAS. Doctor Habil, Professor, Doctor Honoris causa of Poznan, Sankt-Petersburg University and Kiev Universities, Principal Vice-Rector of Vilnius Gediminas Technical University, Member of Lithuanian Academy of Sciences, President of Lithuanian Operational Research Society, President of Alliance of Experts of Projects and Buildings of Lithuania. Editor-in-Chief of the following journals: “Journal of Civil Engineering and Management”, “Technological and Economic Development of Economy”, Editor of the International Journal of Strategic, Property Management. His research interests include building technology and management, decision-making theory, automation in design, decision support systems.

Leonas USTINOVIČIUS. Doctor Habil, Professor, Chairman of laboratory of Construction Technology and Management. Vilnius Gediminas Technical University. Doctor (1989), Doctor Habil (2002). Publication: more than 150 scientific papers. Research interests: building technology and management, decision-making theory, automation in design, expert systems.

Edita ŠARKIENĖ. PhD student in department of Construction Technology and Management. Vilnius Gediminas Technical University. MSc degree (Building management and economics) Vilnius Gediminas Technical University (2002). Publication: more than 10 scientific papers. Research interests: building technology and project management, decision-making theory, architectural design, expert systems.

Česlovas IGNATAVIČIUS. Doctor, Assoc Prof. of department of Construction Technology and Management. Vilnius Gediminas Technical University. Research interests: testing and determination of buildings’ deterioration; proposal of renewal solutions; building energy audits; metering of quality of building indoor climate; metering of building energy consumption and parameters of heating insulation of external partitions; preparation of technological projects for renovation processes.