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CONTRACTOR SELECTION FOR CONSTRUCTION WORKS BY APPLYING SAW-G AND TOPSIS GREY TECHNIQUES

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Abstract. The accuracy of performance measures in common multicriteria methods is usually assumed to be accurate. Grey theory is a new technique for performing prediction, relational analysis and decision-making in many areas. This paper presents applicability of grey theory techniques for defining the utility of an alternative. Proposed assessment model covers well known method of TOPSIS (*Technique for Order Preference by Similarity to Ideal Solution*), method with attributes values determined at intervals (*TOPSIS-grey*) and a new method of *Simple Additive Weighting with Grey relations* (*SAW-G*). A case study of the assessment of contractors' competitive ability was used to demonstrate the applicability and the effectiveness of the proposed approach. The results show that the methods of grey relations methodology can be implemented as an effective decision aid for tasks with uncertain data.

Keywords: contractors, construction, multicriteria, decision-making, grey numbers, SAW, SAW-G, TOPSIS, TOPSIS grey.

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1. Introduction

The progress of a national economy and society is impossible without the construction, because the result of construction – real estate of various purposes – is necessary for people to live, to work and to satisfy their social and other needs. Globally, the construction sector contributes one tenth to the total (annual) production of goods and services on average (Urbanavičienė *et al*. 2009). The construction products are very expensive, buildings and structures make the biggest share of assets both at the level of households, companies and the entire country. Therefore, negotiations on contract provisions (construction, services, management, maintenance, etc.) and on real estate sales must be efficient (Urbanavičienė *et al*. 2009). An increasing number of studies

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have identified the importance of management in construction projects. With a focus on different aspects of management, various sets of critical success factors have been suggested in the literature (Yang *et al*. 2009a). Decision-making or "problem solving", as a broader term, is the process of selecting one or a few alternatives that should be the most favourable. In this respect, the choice of construction contractor can be handled as a multiple-criteria decision-making problem. In order to reach an optimum decision, well-defined criteria and superb solution techniques are required (Ulubeyli and Kazaz 2009). It is important to evaluate the environmental impact and to integrate sustainability concepts into decision-making. A simple distinction should be drawn between "external" sustainability assessments that may be conducted by regulators as part of a project approval process, and "internal" sustainability assessment conducted by companies themselves as part of their business planning and decision-making processes (Stasiškienė and Šliogerienė 2009).

Many researchers emphasize the importance of rational decision-making in constantly changing environment. In an intricate and dynamic market, decision making is a complex human cognitive process with regard to uncertainties such as price and interest volatility. Therefore, institutional investors and practitioners are always immersed in managing their investment portfolios, not only to optimize returns, but more importantly to minimize potential risks (Hui *et al.* 2009).

Construction industry, though quite specific, obeys the same laws of economy as other sectors. Construction companies encounter the risks, like many others, operate in the market and can go bankrupt (Kapliński 2008). To find and accept the right decision in construction industry is a difficult problem. Decision-maker usually has too little information and it is usually incomplete. The rational mean for the decision-making is application of the multi-criteria decision-making (MCDM) techniques and their modifications.

2. The problem of the contractor selection

Selection of the right contractor is a very important task in construction. Choosing the proper contractor from numerous applicants that are available today in market is a complicated problem for clients. In dealing with the long-term assets, it is crucial to select a proper contractor, which could ensure the quality of the constructed building. The achievement of this aim largely depends on the efficiency of the performance of the contractor that is selected.

Contractor prequalification makes it possible to admit for tendering only competent contractors. The undertaken decisions demand taking into consideration many criteria, including among others, experience and financial standing of the candidates that are often difficult to be quantified (Plebankiewicz 2009). Long-term, performance-based contracting offers many advantages compared to the competitive tendering approach (Straub 2009). One of the main benefits is that long-term performance-based contracting reduces both direct and indirect costs. The modelling of multicriteria selection is getting more and more important (Jakimavičius and Burinskienė 2009) because of the increasing rate of competitiveness in business. To plan, control and organize contractor selection in the most efficient way, it is needed to consider the different aspects of business environment and all life cycle of a building. The multi-alternative design and multiple criteria analysis of the life cycle of a building is described by Banaitienė *et al.* (2008); management control systems and stakeholders' interests in multinational companies industry are presented by Jurkštienė *et al.* (2008).

On one side, contractor selection process has influence on the general situation in Lithuanian economy (Tvaronavičienė and Grybaitė 2007). On the other side, claims are influenced by the external environment (Mitkus and Šostak 2008). Contractor choice influences the project success. In the primary stage it is necessary to perform the strategic planning and management (Karnitis and Kucinskis 2009). Schieg (2008) analysed strategies for avoiding asymmetric information in construction project management and proposed the model for integrated project management (Schieg 2009). Zavadskas *et al.* (2008c) offered a new approach to determining the retrofit effectiveness of houses based both on expected energy savings and the increase in market value of renovated buildings. Reichelt *et al.* (2008) suggested the theoretical model for rational maintenance strategy selection with an emphasis on rapidly changing environmental conditions for the proper maintenance of buildings. In internal environment, main influences have the selection of the right project manager for construction project. Contractors' project managers' characteristics are considered to be less important (Zavadskas *et al*. 2008e).

Many authors analysed the problem of contractor selection in the following fields:

- Arslan *et al.* (2008) presented sub-contractor selection process in construction projects: Web-based sub-contractor evaluation system (WEBSES);
- Bayraktar and Hastak (2009) proposed a decision support system for selecting the optimal contracting strategy projects;
- Chan and Au (2009) stated that the main step is establishing the criteria influencing assessment of the contractors' for construction works assets;
- Hartmann *et al.* (2009) analysed relative importance of contractor selection criteria;
- Enshassi *et al.* (2009) analysed contractors' perception towards causes of claims in construction projects;
- Walraven and de Vries (2009) analysed contractor selection from demand-driven towards value-driven contractor selection;
- Padhi and Mohapatra (2009) proposed centralized construction contractor selection considering past performance of contractors;
- Darvish *et al.* (2009) presented application of the graph theory and matrix methods to contractor ranking;
- Lam *et al.* (2009) proposed the model for contractor prequalification;
- Mitkus and Trinkūnienė (2008) analysed connection of the contractors with sub-contractors and suppliers;
- Padhi and Mohapatra (2009) investigated contractors' selection problem in government procurement auctions;
- Smyth and Fitch (2009) presented contractor application of relationship marketing and management;

– Šiškina *et al.* (2009) investigated evaluation problem of the competitiveness of construction company overhead costs.
– Bageis and Fortune (2009) had analysed the factors affecting the bidding decision in construction.

All construction process is risky. Contractual risk management forms only one part of the companies' legal risk management and, in this way, it is part of companies' comprehensive general risk management. The goals of contractual risk management do not restrict the management of legal risks in contracting. Contractual risk management also covers other risks in business by using methods of contractual planning and management (Tieva and Junnonen 2009). Risk management in construction is a tedious task as the objective functions tend to change during the project life cycle (Dikmen *et al.* 2008). Risk management process in construction is analysed and the importance of it was emphasized by many authors (Han *et al.* 2008; Shevchenko *et al*. 2008; Suhobokov 2008; Zavadskas *et al.* 2008d; El-Adaway and Kandil 2009; Huang 2009; Zavadskas and Vaidogas, 2008).

To understand and manage risks in construction projects, the construction process can be divided into four phases, which describe the primary and implementation stages of construction project (Fig. 1):
– design phase,
– bidding phase,
– construction phase,
– completion phase.

The model of project implementation at primary stage and elaboration of contractor selection in bidding phase during primary stage of project implementation is shown in Fig. 2.

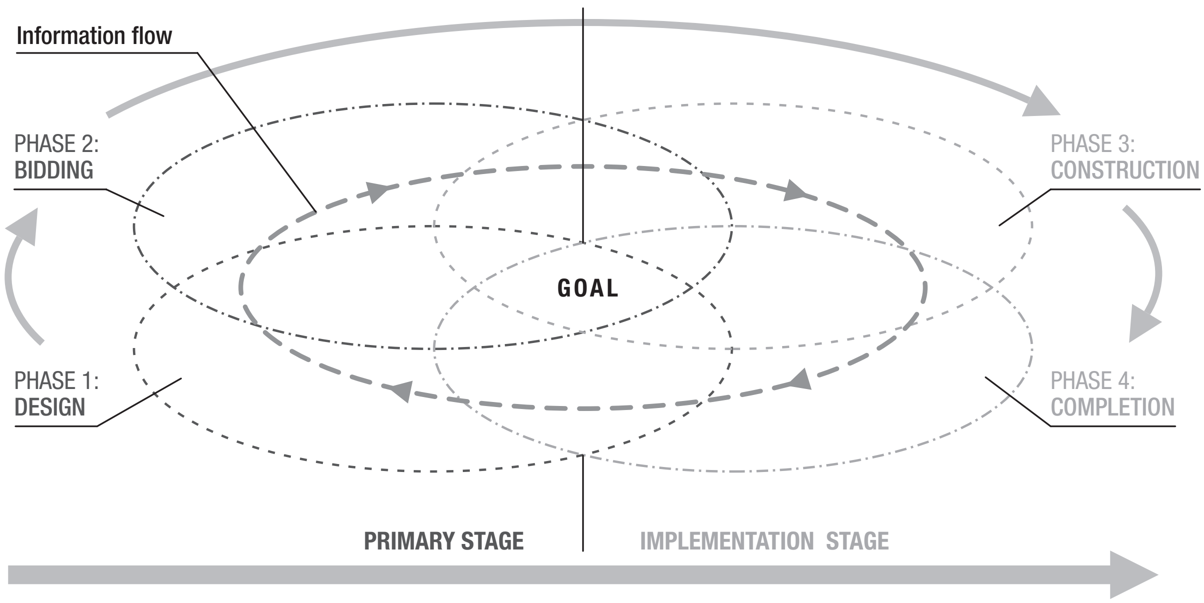

Fig. 1. The information flow between interacting stages in construction

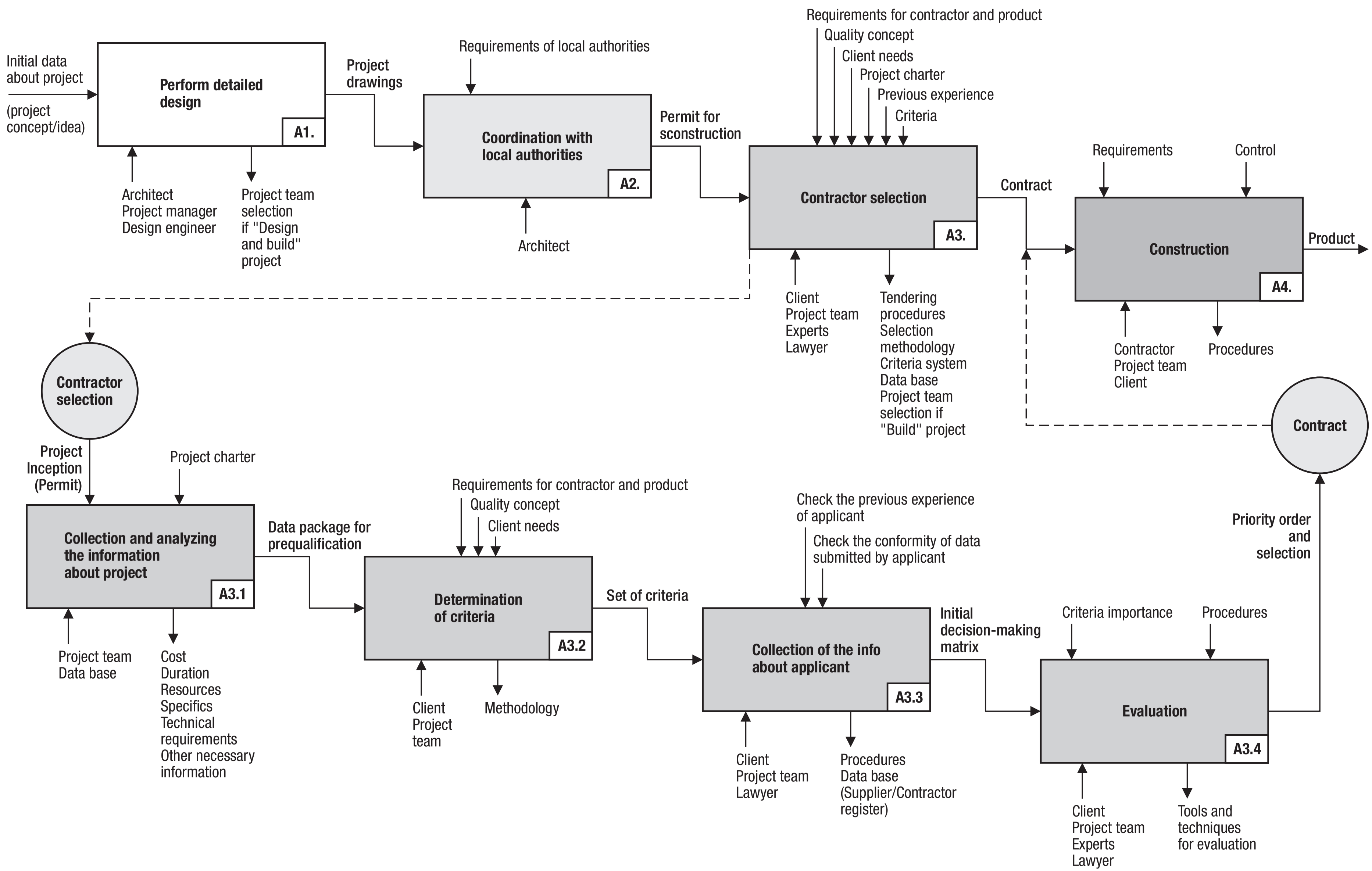

Fig. 2. Elaboration of contractor selection in bidding phase during primary stage of project implementation

3. Combining MCDM methods with Grey theory system

Multiple criteria decision aid provides several powerful solution tools for confronting sorting problems (Hwang and Yoon 1981; Figueira *et al.* 2005; Zavadskas and Kaklauskas 2007; Ginevičius *et al.* 2008a, b; Liaudanskiene *et al*. 2009; Zavadskas *et al*. 2008b). There can be used very simplified techniques for the evaluation such as SAW – *Simple Additive Weighting* (MacCrimon 1968); TOPSIS – *Technique for Order Preference by Similarity to Ideal Solution* (Hwang and Yoon 1981).

When we consider a discrete set of alternatives described by some criteria, there are three different types of analysis that can be performed in order to provide significant support to decision-makers:

- Ensure that the decision-maker follows a „rational" behaviour (normative option) – Value functions, Utility theory, distance to the Ideal;
- Give some advice based on reasonable (but not indisputable) rules;
- Find the preferred solution from the partial decision hypothesis – interactive methods.

The analysis of the purpose is to be achieved by using criteria of effectiveness, which have different dimensions, different significances as well as different directions of optimization (Kendall 1970; Ehrgott 2005). The discrete criteria values can be normalized by applying different normalization methods (Zavadskas and Turskis 2008). The purpose of analysis can also be different (Bregar *et al.* 2008). Multiple criteria decision aid analysed by Hwang and Yoon (1981) provides several powerful and effective tools for confronting sorting problems analysed by Figueira *et al*. (2005).

There is a wide range of methods based on multi-criteria utility theory: SAW (MacCrimon 1968; Ginevičius *et al.* 2008a, b); MOORA – Multi-Objective Optimization on basis of Ratio Analysis (Brauers *et al*. 2008a, 2008b; Kalibatas and Turskis 2008); TOPSIS (Hwang and Yoon 1981); VIKOR – compromise ranking method (Opricovic 1998; Opricovic and Tzeng 2004); COPRAS (Zavadskas *et al*. 2008a, 2009); and other methods (Turskis 2008; Turskis *et al.* 2009).

Decision-makers in their activities deal with uncertain future. The multicriteria decision-making could be applied to assess different alternatives of future activities. Hui et al. (2009) incorporated the fuzzy concept in linear programming to obtain the best possible outcome in portfolios, when direct real estate investment is included.

The best strategy could be selected from available scenarios, and information. In strategic decisions, dealing with uncertainty, the values of criteria could be determined at intervals – from pessimistic value to optimistic value.

The limits of criterion value could also be determined by expert. In this case determination of limits depends on the qualification and experience of expert. Therefore it is better to collect the objective data.

Deng (1982) developed the Grey system theory and described operations with grey numbers. Grey relational analysis possesses advantages (Deng 1988, 1989), i.e.:

- involves simple calculations,
- requires smaller samples,

- a typical distribution of samples is not needed,
- the quantified outcomes from the Grey relational grade do not result in contradictory conclusions to qualitative analysis,
- the Grey relational grade model is a transfer functional model that is effective in dealing with discrete data.

Lin *et al.* (2004) analysed the state-of-the-art of the theory and applications of the so-called grey systems theory founded in the 1980s. Li and Liu (2009a) had performed the input-occupancy-output analysis and proposed grey model of input-occupancy-output analysis for grey situations and for managing the economic systems with missing information. They also explained the connotation of grey number, which is the basic unit of grey mathematics and the key to establish the mathematical framework of grey system theory (Li and Liu 2009b). Li *et al.* (2009) developed Grey-Markov chain algorithm. They found that combining the grey model, Markov chains, and least square method, can be a new algorithm for forecasting the tendency of the gross amount of energy sources consumption. Cakir (2008) developed the grey extent analysis and had shown that the proposed procedure can be used as a decision-making tool where the judgments of the decision-maker are not exact (i.e. in terms of grey system terminology they are not "white"). Kuo *et al*. (2008) analysed the use of grey relational analysis in solving multiple criteria decision-making problems. Du and Sheen (2005) developed the pavement permanent deformation prediction model by grey modeling method. Lin and Lee (2007) presented a novel high-precision grey forecasting model.

Liu and Lin (2006) have specified free possibilities for occurrence of the White, Grey and Black information (Table 1).

Grey theory was applied:

- to thermal point optimization (Yan and Yang 2009),
- to automatic stock market forecasting and portfolio selection (Huang 2009),
- to emergence and development of grey system theory (Liu *et al*. 2009),

Table 1. Comparison of White, Grey and Black systems (Liu and Lin 2006)

	Systems		
	White	**Grey**	**Black**
Information	Known	Incomplete	Unknown
Appearance	Bright	Grey	Dark
Process	Old	Replace old with new	New
Property	Order	Complexity	Chaos
Methodology	Positive	Transition	Negative
Attitude	Seriousness	Tolerance	Indulgence
Conclusion	Unique solution	Multiple solution	No results

- to a hybrid model for stock market forecasting and portfolio selection based on ARX, grey system and RS theories (Huang and Jane 2009),
- to grey forecasting in vibration condition monitoring of machines (Cempel 2008),
- to supplier selection by a grey-based rough decision-making approach (Li *et al.* 2008),
- to grey prediction on indoor comfort temperature for HVAC systems (Leephakpreeda 2008),
- to building thermal process analysis (Wending *et al.* 2002).

4. Methodology and application

This paper presents the application of newly developed TOPSIS grey, SAW-G methods for the case study of contractor selection.

The TOPSIS method was developed by Hwang and Yoon (1981). TOPSIS method belongs to MCDM (Multi-criteria decision-making method) group and identifies solutions from a finite set of alternatives based upon simultaneous minimization of distance from an ideal point and maximization of distance from a negative ideal point. TOPSIS can incorporate relative weights of criteria. The only subjective input needed is weights. Lin *et al.* (2008) developed TOPSIS method with grey number operations to the problem solution with uncertain information. A new decision support system for performance measurement using combined fuzzy TOPSIS/DEA approach was presented by Zeydan and Colpan (2009).

TOPSIS method was applied in many fields:
- to selection of the strategic alliance partner (Buyukozkan *et al.* 2008),
- for supplier selection with TOPSIS method (Boran *et al.* 2009),
- to risk evaluation in workplaces (Grassi *et al.* 2009),
- to customer evaluation using fuzzy methods based on TOPSIS (Chamodrakas *et al*. 2009),
- in safety management (Yang *et al.* 2009b).

The general algorithm of problem solution, applying SAW-G and TOPSIS grey method is presented in Fig. 3.

MacCrimon (1968) developed SAW method and it was applied for multicriteria decision-making in various fields:
- for a simulation and comparison of selected methods (Zanakis *et al.* 1998),
- for solving fuzzy MADM problems (Hui *et al.* 2009),
- for facility location selection with objective/subjective criteria by applying a fuzzy simple additive weighting system under group decision-making (Chou *et al.* 2008),
- e-commerce performance assessment model in the retail sector of China (Huang *et al.* 2009),
- for contractors ranking (Darvish *et al.* 2009),
- for evaluation of transportation zones in Vilnius City, analysis and ranking (Jakimavicius and Burinskiene 2009b).

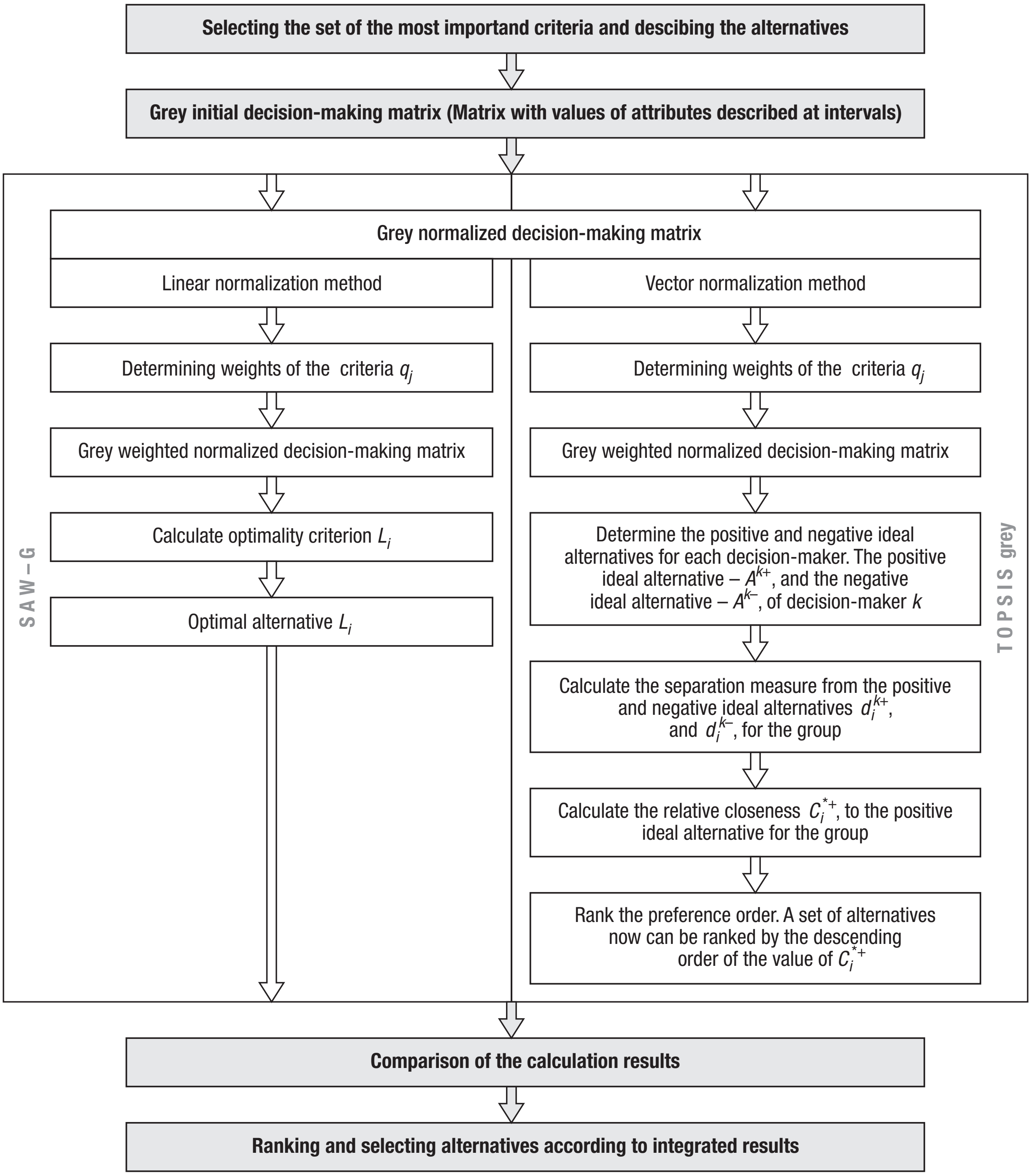

Fig. 3. The main algorithm of problem solution applying SAW-G and TOPSIS grey method

4.1. Newly developed technique – SAW-G method

The Simple Additive Weighting method with grey number can be described as stepwise procedure:

Step 1: Selecting the set of the most important criteria, describing the alternatives;

Step 2: Constructing the decision-making matrix $\otimes X$.

Step 3: Normalization procedure for obtaining comparable scales. The normalized values are calculated as follows:

$$\overline{w}_{ij} = \frac{w_{ij}}{\max\limits_{j} w_{ij}}; \ \overline{b}_{ij} = \frac{b_{ij}}{\max\limits_{j} w_{ij}}; \tag{1}$$

$$\overline{w}_{ij} = \frac{\min\limits_{j} b_{ij}}{w_{ij}}; \ \overline{b}_{ij} = \frac{\min\limits_{j} b_{ij}}{b_{ij}}. \tag{2}$$

If min x_{ij} is preferable

$$\otimes X = \begin{bmatrix} [\overline{w}_{11};\overline{b}_{11}] & [\overline{w}_{12};\overline{b}_{12}] & \dots & [\overline{w}_{1m};\overline{b}_{1m}] \\ [\overline{w}_{21};\overline{b}_{21}] & [\overline{w}_{22};\overline{b}_{22}] & \cdots & [\overline{w}_{2m};\overline{b}_{2m}] \\ \vdots & \vdots & \ddots & \vdots \\ [\overline{w}_{n1};\overline{b}_{n1}] & [\overline{w}_{n2};\overline{b}_{n2}] & \cdots & [\overline{w}_{nm};\overline{b}_{nm}] \end{bmatrix}. \tag{3}$$

Step 4: Determining weights of the criteria q_j.

Step 5: Weighted – normalized decision-making matrix is obtained according to equation (4):

$$\otimes\hat{x}_{ij} = \otimes\overline{x}_{ij} \cdot q_j; \ \hat{w}_{ij} = \overline{w}_{ij} \cdot q_j; \ \hat{b}_{ij} = \overline{b_{ij}} \cdot q_j. \tag{4}$$

In formula (19), q_j is the weight of the $j - th$ attribute.

Step 6: The next step is to calculate optimality criterion L which is determined as maximal value of L_i:

$$L_i = \frac{1}{n}\sum_{j=1}^{m} \frac{\overline{w}_j + \overline{b}_j}{2}. \tag{5}$$

Step 7: Optimal alternative is determined as maximal value of L_i.

4.2. TOPSIS method with criteria values determined at intervals (Lin *et al.* 2008)

The TOPSIS method is one of the best described mathematically and not simple for practical using. Lin *et al.* (2008) proposed the model of TOPSIS method with attributes values determined at intervals that includes the following steps:

Step 1: Selecting the set of the most important attributes, describing the alternatives;

Step 2: Constructing the decision-making matrix $\otimes X$. Grey number matrix $\otimes X$ can be defined as:

$$\otimes X = \begin{bmatrix} \otimes x_{11} & \otimes x_{12} & \dots & \otimes x_{1m} \\ \otimes x_{21} & \otimes x_{22} & \dots & \otimes x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes x_{n1} & \otimes x_{n2} & \dots & \otimes x_{nm} \end{bmatrix}; \ i = \overline{1,n}; \ \ j = \overline{1,m}. \tag{6}$$

where $\otimes x_{ij}$ denotes the grey evaluations of the *i*-th alternative with respect to the *j*-th attribute; $\left[\otimes x_{i1},\ \otimes x_{i2},\ ...,\ \otimes x_{im}\right]$ is the grey number evaluation series of the *i*-th alternative.

Step 3: Construct the normalized grey decision matrices. The normalized values of maximizing attributes are calculated as:

$$\otimes \overline{x}_{ij,b} = \frac{\otimes x_{ij}}{\max\limits_i (b_{ij})} = \left(\frac{w_{ij}}{\max\limits_i (b_{ij})},\ \frac{b_{ij}}{\max\limits_i (b_{ij})} \right). \tag{7}$$

The normalized values of minimizing attributes are calculated as (formula (4) which differs from formula used by Lin *et al.* (2008):

$$\otimes \overline{x}_{ij,w} = 1 - \frac{\otimes x_{ij}}{\max\limits_i (b_{ij})} = \left(1 - \frac{b_{ij}}{\max\limits_i (b_{ij})};\ 1 - \frac{w_{ij}}{\max\limits_i (b_{ij})} \right). \tag{8}$$

Step 4: Determining weights of the criteria q_j.

Step 5: Construct the grey weighted normalized decision-making matrix.

Step 6: Determine the positive and negative ideal alternatives for each decision-maker. The positive ideal alternative A^+, and the negative ideal alternative A^- can be defined as:

$$A^+ = \left\{ \left(\max_i b_{ij} \middle| j \in J \right),\ \left(\min_i w_{ij} \middle| j \in J' \right)\ \middle| i \in n \right\} = [x_1^+,\ x_2^+, ..., x_m^+] \tag{9}$$

and

$$A^- = \left\{ \left(\min_i w_{ij} \middle| j \in J \right),\ \left(\max_i b_{ij} \middle| j \in J' \right)\ \middle| i \in n \right\} = [x_1^-,\ x_2^-, ..., x_m^-]. \tag{10}$$

Step 7: Calculate the separation measure from the positive and negative ideal alternatives, d_i^+ and d_i^-**,** for the group. There are two sub-steps to be considered: the first one concerns the separation measure for individuals; the second one aggregates their measures for the group.

Calculate the measures from the positive and negative ideal alternatives individually. For decision-maker k, the separation measures from the positive ideal alternative d_i^+ and negative ideal alternative d_i^- are computed through weighted grey number as:

$$d_i^+ = \left\{ \frac{1}{2} \sum_{j=1}^m q_j \left[\left| x_j^+ - \overline{w}_{ij} \right|^p + \left| x_j^+ - \overline{b}_{ij} \right|^p \right] \right\}^{1/p}; \tag{11}$$

$$d_i^- = \left\{ \frac{1}{2} \sum_{j=1}^m q_j \left[\left| x_j^- - \overline{w}_{ij} \right|^p + \left| x_j^- - \overline{b}_{ij} \right|^p \right] \right\}^{1/p}. \tag{12}$$

In equations (11) and (12), for p≥1 and integer, q_j is the weight for the attribute j, which can be determined by attribute weight determination methods. If $p = 2$, then the metric is a weighted grey number Euclidean distance function. Equations (11) and (12) will be as follows:

$$d_i^+ = \sqrt{\frac{1}{2}\sum_{j=1}^{m} q_j \left[\left| x_j^{k+} - \overline{w}_{ij}^k \right|^2 + \left| x_j^{k+} - \overline{b}_{ij}^k \right|^2 \right]}, \quad (13)$$

$$d_i^- = \sqrt{\frac{1}{2}\sum_{j=1}^{m} q_j \left[\left| x_j^{k-} - \overline{w}_{ij}^k \right|^2 + \left| x_j^{k-} - \overline{b}_{ij}^k \right|^2 \right]}. \quad (14)$$

Step 8: Calculate the relative closeness C_i^+, to the positive ideal alternative for the group. The aggregation of relative closeness for the i-th alternative with respect to the positive ideal alternative for the group can be expressed as:

$$C_i^+ = \frac{d_i^-}{d_i^+ + d_i^-}. \quad (15)$$

where $0 \le C_i^+ \le 1$. The larger the index value is, the better the evaluation of alternative will be.

Step 9: Rank the preference order. A set of alternatives now can be ranked by the descending order of the value of C_i^+.

5. Case study: contractor's selection for construction of prefabricated wooden shield-shaped houses

To illustrate the effectiveness of the MADM approach method, we have ranked the contractors for the construction works of the wooden houses**.**

Rising prices of multi-flat dwellings and their expensive maintenance and additional costs force more and more people in Lithuania to consider the possibility to live in an individual house instead of a flat in multi-flat dwellings. Another reason to change the living space is the appearance of new construction technologies and cheaper materials, which make housing affordable.

Recently in Lithuania in construction of individual houses the traditions of wooden construction are revitalizing. The construction of prefabricated wooden shield-shaped houses became popular due to fast construction, healthy indoor environment, less construction duration in comparison with the same houses constructed from brick or stone.

In Lithuania there are about 80 small and medium companies, which produce, construct and sell the wooden shield-shaped houses.

Great part (about 95%) of wooden shield-shaped houses produced in Lithuania is sold abroad, mostly in Europe – Norway (30%), Sweden (16%), Denmark (14%), Finland (13%), Island (11%), Spain (8%), France (6%), and others (5%).

The survey of consumers in Lithuania shows that the most part of them will choose the wooden shield-shaped house because it is comparatively cheap (10%), healthy (36%)

and construction of it is fast (34%). 20% of respondents had showed many other reasons to choose the wooden shield-shaped house, e.g. it is well insulated (warm house), comfortable, modern, healthy. The priority was given to good insulation, comparatively low price, healthy materials and fast construction process. The model for contractor selection is presented in Fig.3. Explanation of criteria used in case study:

Experience of executives. This criterion shows the range of experience (measured in years) of executives employed directly in company production division and authorized to manage the processes.

Number of constructed houses. This criterion shows the change of annual number of constructed prefabricated wooden houses in the period of 2005–2008.

Turnover. Company turnover at the beginning and the end of the year measured in million Lt.

Number of executives. Number of executives employed in company production division in different positions.

Market share. Market share is the portion or percentage of sales of a particular product or service in a given region. In case study the distribution of shares of companies in Lithuanian market was analysed. The market share was calculated by comparing the number of prefabricated wooden houses of each company with the total of prefabricated wooden houses produced by all companies in analysed market. In initial data table the change of share for one-year period (at the beginning and the end of the year 2008) is presented.

Production method of wooden houses. Production of components for prefabricated wooden houses could be organized by different ways. Most of Lithuanian companies (58%) use semi-automated methods for production, fully automatic production lines are used by only 2% of companies, and even 40% produce wooden components for houses manually. The level of automation in production in case study was evaluated in points: one point was given to the manual production method, two points – for semi-automated methods, and three points – for fully automated production lines. The companies analysed in case study in the beginning of their activities had used manual production.

In Table 2 the data of the following criteria are presented:
$\otimes x_1$ – experience of executives (years),
$\otimes x_2$ – number of constructed houses (units in 2005–2008, year),
$\otimes x_3$ – turnover (in 10^6 €, 2005-2008, year),
$\otimes x_4$ – number of executives (persons in 2005–2008, year),
$\otimes x_5$ – market share (portion of sales),
$\otimes x_6$ – production method (in point).

Optimization directions of the selected criteria are as follows:

$$x_4 \xrightarrow{optimization\ \ direction} \min;$$

$$x_1, x_2, x_3, x_5, x_6 \xrightarrow{optimization\ \ direction} \max.$$

Ranking of alternatives by applying SAW-G and TOPSIS grey technique is performed by applying TOPSIS method.

The initial decision-making matrix with values determined at intervals is presented in Table 2. In Table 2 given notations q_j are the criteria weights and $A_1, \dots, A_5$ are alternative contractors. The full names of the contractors are not provided for the sake of confidentiality.

To determine the weights of the attributes, the expert‘s judgment method is applied (Kendall 1970). In order to establish the weights, a survey has been carried out and 10 experts have been questioned. These experts, basing their answers on their knowledge, experience and intuition, had to rate attributes of effectiveness starting with the most important ones. The rating was done on a scale from 1 to 6, where 6 meant “very important” and 1 “not important at all”. In Table 3 the normalized decision-making matrix with value of each criteria expressed at intervals is presented. The weights of the criteria are calculated by both: SAW-G and TOPSIS grey technique. The results of the calculation for each project are presented in Table 4.

Table 2. Initial decision-making matrix with values (TOPSIS grey and SAW-G methods)

Alternatives	***Criteria***											
	$\otimes x_1$		$\otimes x_2$		$\otimes x_3$		$\otimes x_4$		$\otimes x_5$		$\otimes x_6$	
Optimum	**max**		**max**		**max**		**min**		**max**		**max**	
A_1	11	15	10	15	3.30	4.5	35	48	0.152	0.203	1	2
A_2	10	14	7	13	2.54	3.68	40	58	0.111	0.162	1	2
A_3	14	18	5	9	1.95	2.46	42	53	0.079	0.121	1	3
A_4	12	16	1	4	0.42	1.73	15	63	0.01	0.054	1	2
A_5	6	10	2	9	0.62	2.67	10	46	0.012	0.122	1	2
Optimal value	**18**		**15**		**4.5**		**10**		**0.203**		**3**	

Table 3. Normalized decision-making matrix (TOPSIS grey and SAW-G methods)

Alternatives	***Normalized values of criteria***											
	$\otimes \bar{x}_1$		$\otimes \bar{x}_2$		$\otimes \bar{x}_3$		$\otimes \bar{x}_4$		$\otimes \bar{x}_5$		$\otimes \bar{x}_6$	
	$\bar{w}_1$	$\bar{b}_1$	$\bar{w}_2$	$\bar{b}_2$	$\bar{w}_3$	$\bar{b}_3$	$\bar{w}_4$	$\bar{b}_4$	$\bar{w}_5$	$\bar{b}_5$	$\bar{w}_6$	$\bar{b}_6$
Weights q_j	0.22	0.22	0.26	0.26	0.11	0.11	0.09	0.09	0.15	0.15	0.17	0.17
A_1	0.611	0.833	0.667	1.000	0.733	1.000	0.444	0.238	0.749	1.000	0.333	0.667
A_2	0.556	0.778	0.467	0.867	0.564	0.818	0.365	0.079	0.547	0.798	0.333	0.667
A_3	0.778	1.000	0.333	0.600	0.433	0.547	0.333	0.159	0.389	0.596	0.333	1.000
A_4	0.667	0.889	0.067	0.267	0.093	0.384	0.762	0.000	0.049	0.266	0.333	0.667
A_5	0.333	0.556	0.133	0.600	0.138	0.593	0.841	0.270	0.059	0.601	0.333	0.667

Table 4. Weighted-normalized decision-making matrix (TOPSIS grey and SAW-G methods)

Alternatives	***Weighted-normalized values of criteria***												***TOPSIS grey method***				***SAW-G method***	
	$\otimes\hat{x}_1$		$\otimes\hat{x}_2$		$\otimes\hat{x}_3$		$\otimes\hat{x}_4$		$\otimes\hat{x}_5$		$\otimes\hat{x}_6$		d^+	d^-	C^+	**Rank**	L	**Rank**
	$\hat{w}_1$	$\hat{b}_1$	$\hat{w}_2$	$\hat{b}_2$	$\hat{w}_3$	$\hat{b}_3$	$\hat{w}_4$	$\hat{b}_4$	$\hat{w}_5$	$\hat{b}_5$	$\hat{w}_6$	$\hat{b}_6$						
A_1	0.134	0.183	0.173	0.260	0.081	0.110	0.040	0.021	0.112	0.150	0.057	0.113	0.107	0.221	0.674	1	0.120	1
A_2	0.122	0.171	0.121	0.225	0.062	0.090	0.033	0.007	0.082	0.120	0.057	0.113	0.132	0.187	0.587	2	0.100	2
A_3	0.171	0.220	0.087	0.156	0.048	0.060	0.030	0.014	0.058	0.089	0.057	0.170	0.158	0.147	0.482	3	0.097	3
A_4	0.147	0.196	0.017	0.069	0.010	0.042	0.069	0.000	0.007	0.040	0.057	0.113	0.226	0.110	0.327	5	0.064	5
A_5	0.073	0.122	0.035	0.156	0.015	0.065	0.076	0.024	0.009	0.090	0.057	0.113	0.206	0.125	0.377	4	0.070	4
A^+	0.220	0.220	0.260	0.260	0.110	0.110	0.076	0.076	0.150	0.150	0.170	0.170						
A^-	0.073	0.073	0.017	0.017	0.010	0.010	0.030	0.000	0.007	0.007	0.057	0.057						

According to the TOPSIS grey and SAW-G methods the order of alternatives ranks is the same. The priority order is: $A_1 > A_2 > A_3 > A_5 > A_4$. The first alternative contractor must be selected as best performing contractor.

6. Conclusions

In competitive and risky environment the selection of contractors must be performed according to multiple criteria. In actual multicriteria modelling of multi-alternative problems, values of criteria referring to the future can be expressed at intervals.

The results of the study showed that the newly developed methods TOPSIS grey, SAW-G could be successfully applied for the assessment of alternatives described by multiple criteria with values expressed at intervals. This approach is intended to support decision- making process and to increase its efficiency.

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RANGOVŲ PARINKIMAS STATYBOS DARBAMS ATLIKTI TAIKANT SAW-G IR TOPSIS GREY SKAIČIŲ TECHNOLOGIJAS

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Santrauka

Taikant daugiatikslius metodus įprastai rodiklių reikšmės imamos kaip tikslios. Pilkųjų skaičių teorija yra naujas metodas, kurį galima taikyti daugelyje sričių: tinkamumui numatyti, nagrinėti santykius ir priimti sprendimus. Šiame straipsnyje pateiktas pilkųjų skaičių teorijos taikymo pavyzdys alternatyvų tikslingumui nustatyti. Pasiūlytas metodas apima gerai žinomą TOPSIS (pirmumo eilės nustatymo būdas pagal našumą ir idealų sprendinį) metodą su rodiklių reikšmėmis, apibrėžtomis intervaluose (TOPSIS-grey) ir paprastojo suminio svėrimo su pilkaisiais santykiais (SAW-G) metodą. Rangovų kompetencijos vertinimo pavyzdys pateiktas naujo metodo efektyvumui parodyti. Uždavinio sprendimas parodo, kad uždavinių modeliai, aprašyti pilkaisiais santykiais, gali būti efektyviai taikomi uždaviniams su neapibrėžtais duomenimis spręsti.

Reikšminiai žodžiai: rangovai, statyba, daugiatikslis sprendimų priėmimas, pilkieji skaičiai, SAW, SAW-G, TOPSIS, TOPSIS grey.

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