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MULTICRITERIA EVALUATION OF APARTMENT BLOCKS MAINTENANCE CONTRACTORS: LITHUANIAN CASE STUDY

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ABSTRACT. The paper presents the comparative analysis of dwelling maintenance contractors aimed at determining the degree of their utility for users and bidding price of services by applying the method of multicriteria complex proportional assessment. To compare the performance of various maintenance contractors, the data from 15 dwelling maintenance organizations was used. A questionnaire survey of dwelling owners was conducted. Contractors were evaluated by a set of 44 criteria characterizing them from various perspectives. The analysis was made taking into account the standpoints of building owners (clients). The initial weights of qualitative criteria were calculated by expert methods. Then they were coordinated with the calculated values of quantitative criteria using the method of multicriteria complex proportional assessment. Multicriteria analysis of the performance of maintenance contractors allows us to determine the importance of particular contractor characteristics for achieving the aim to meet the needs of different participants of the maintenance process.

KEYWORDS: Multicriteria analysis; COPRAS; Maintenance contractors; Selection; Utility

1. INTRODUCTION

The efficiency of maintenance depends on various micro- and macro-environmental factors. Therefore, planning and successful implementation of building maintenance requires the evaluation of the capabilities of the participants of this process and the influence of the environment on its efficiency. The participants of the maintenance process can perform their functions efficiently only taking into consideration the changing environment, pursuing the best coordination of actions, raising the quality of services and meeting the needs of apartment owners.

Efficiency is hereby perceived as the process of providing building maintenance services, which results in ultimate implementation of the goals of the interested groups participating in the process. The efficiency of any process is assessed in terms of criteria, which vary depending on the problem concerned and the

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particular goals of the interested groups. The utmost efficiency is often associated with the maximum gain from a specific activity. The more various and significant aims are achieved, the higher is the gain and the efficiency of the activity. The efficiency of building maintenance in case study is estimated from the standpoint of building user. The efficiency of a decision made will depend on the impact of the micro- and macro-environmental factors. Maintenance contractors cannot correct or change aforementioned factors, but they can realize their impact and evaluate it during the implementation of different projects, herewith successfully organizing their current and future activities.

The term efficiency can be interpreted differently; therefore one has to evaluate all the needs of the participants of the maintenance process. Modelling and multicriteria analysis allow us to find a way to meet the goals of the participants of the maintenance process and to choose an optimal maintenance service supplier as well as the efficient ways of providing these services.

In the first part of the research Zavadskas and Vilutienė (2006) analyzed the factors influencing maintenance process efficiency and proposed the criteria characterizing the performance of maintenance contractors. Later Reichelt et al. (2008) for the proper maintenance of buildings suggested the theoretical model for rational maintenance strategy selection with the emphasis on rapidly changing environmental conditions. This paper describes the results obtained in optimal contractor selection based on multicriteria analysis. To compare the capabilities of maintenance contractors, the data obtained from 15 dwelling maintenance companies was used. A great amount of quantitative and qualitative information characterizes the work of maintenance contractors. Therefore, to evaluate the alternatives, a decision-maker has to apply method, allowing him/her to make a comprehensive analysis and to determine the utility level of contractor services for building user. The chosen method (applied in the present work) has following stages:

- determining the initial weights of the criteria (an expert method was applied in the first part);
- coordinating the initial weights of the criteria with calculated quantitative criteria (the method of multicriteria complex proportional assessment described in section 3.1);
- the application of multiple criteria analysis for determining the priorities of alternatives (the method of multicriteria complex proportional assessment described in section 3.2);
- the method for service price correction in competitive bidding, determining the degree of utility of each contractor (the method of multicriteria complex proportional assessment described in sections 3.3 and 3.4).

The results of calculations obtained previous stage serve as the initial data for next stage. The second and third stages are complex and have substages. To illustrate the efficiency of the model proposed, multicriteria analysis of maintenance contractor selection is presented in case study. Maintenance contractors were evaluated according to a set of criteria determined in the first part of the research (Zavadskas and Vilutienė, 2006).

2. A REVIEW OF MCDM METHODS APPLIED TO SOLVING MULTIOBJECTIVE PROBLEMS

Classical methods of multicriteria optimization and determination of priority and utility function were first applied by Pareto in 1896 (Pareto, 1971). In 1959 they were improved by Debreu (1959). These methods were strongly related to economic theory, concerning the averages of thousands of decisions. Methods of multicriteria analysis were developed in the 1960's to meet the increasing requirements of human society and the environment. First, the intention was multiobjective extension of mathematical programming. Working along this line, Cochrane and Zeleny (1973) provided a research report with some essential data in 1973. Seo (1981) suggested a multicriteria decision-making method that was concerned with balancing some conflicting objectives in a hierarchical structure. In 1980 Tanino et al. (1981) analyzed the problem of the coordination of different goals and objectives of various interested parties. Wierzbicki (1981) analyzed the problems related to decision-making in a simple organization. Zanakis (1981) used the IGP (integer goal programming) method in solving actual multiobjective problems in 1980. Keeney and Raiffa (1976) offered the representation theorems for determining multicriteria utility functions under preferential and utility independence assumptions. Keeney (1982) outlined the essential features and concepts of decision analysis and formulated axioms and major stages. Keeney and Winterfeldt (2001) suggested to follow the prudence principle in decision process, making decisions precisely and evaluating all possible alternatives, the aims of interested parties, subsequences of decision results and value changes, hereby minimizing the decision-making risk.

Saaty (1977) showed the global importance of solving problems with conflicting goals by using multicriteria models and presented decision-making models with incomplete information for solving political and economical problems. In his latest works Saaty analyzed measuring problems in assignments associated with uncertainty conditions and applied the AHP method to solve resource allocation problems (Saaty et al., 2003); he also analyzed the peculiarities of decision-making based on the AHP method and the necessity to use the eigenvector for priority determination (Saaty, 2003). For financial crisis forecasting he proposed the ANP (Analytic Network Process) model based on a new measuring system (Niemira and Saaty, 2004).

Skitmore and Pemberton (1994) applied a multivariate approach to determine the construction contract bidding mark-up strategies. Zavadskas et al. (1994) analyzed various multiple criteria methods, applying them to construction projects.

Later numerous researchers have pointed the importance of multicriteria assessment in decision-making processes. They analyzed the peculiarities of application of multi-criteria methods and proposed a lot of tools and techniques for multi-objective optimization.

Kumaraswamy and Dissanayaka (2001) developed a knowledge-based advisory DSS for assessing a contractor's competitiveness, which can help a contractor identify its strengths and weaknesses, thus allowing it to make more competitive bids. For multicriteria selection of an alternative under uncertainty conditions, in 2009 Turskis et al. (2009) created the software LEVI–4.0 based on different methods for criteria normalization and optimal variant selection. Cheung et al. (2002) developed a multicriteria evaluation model based on the analytic hierarchy process for the selection of a qualified architect. The results of expert surveying and similar projects analysis were used to establish a set of criteria to compare the alternatives and to determine the criteria values and weights. Dėjus (2002) analyzed the sensitivity of mathematical models of the methods SAW and TOPSIS and the influence of value changes of their segments on the final result. Shen et al. (2003) had developed a computer-aided decision support system for assessing a contractor's competitiveness based on a competitiveness scoring model. Topcu (2004) had proposed a multi-criteria decision model for construction contractor based on selection criteria related to cost, time, and quality concepts and has a process with two main stages: contractor prequalification and the choice of the eligible bidder among prequalified contractors. Egemen and Mohamed (2006) provided the set of criteria for the analysis needs, wants and expectations of private clients from contractor firms. Banaitienė and Banaitis (2006) performed an analysis of criteria for multi criteria evaluation of contractors. Straub and Mossel (2007) analysed selection of maintenance contractors for performance-based maintenance partnerships. Lambropoulos (2007) had proposed an award method which employs the criterion of the most economically advantageous tender and incorporates the use of client utility curves to evaluate both financial and time offers submitted. El-Sawalhi et al. (2007) suggested a state-of-the-art model by using a hybrid model, combining the merits of Analytical Hirarchy Process (AHP), Neural Network (NN) and Genetic Algorithm (GA) in one consolidated model which gives a chance to improve the accuracy of the model outputs and the prediction of the contractor's performance. Ko et al. (2007) study provides a Sub-contractor Performance Evaluation Model (SPEM) which accurately measures sub-contractor's performance enhancing the current practice of evaluation. Lahdenperä (2009) developed a novel multi-target competition process with special emphasis on the allocation algorithms that allow selecting the most qualified competitors for parallel follow-up competitions from among a large group of registered candidates. Kumaraswamy and Anvuur (2008) proposed the framework for decision-making based on technical, sustainability and relational criteria. Brauers et al. (2008) applied a MOORA method based on ratio analysis and dimensionless measurement to ranking the largest maintenance contractors of dwellings. Turskis (2008) for contractors ranking had applied the preferability technique. Ginevičius and Podvezko (2008a) presented the method of multicriteria graphical-analytical evaluation. It was applied to evaluation of the financial state of construction enterprises. Ginevičius et al. (2008) evaluated the alternative solutions of wall insulation by multicriteria methods. Study of Lai et al. (2008) presents a novel procedure for determining construction project budgets. The proposed procedure integrates an analytical hierarchy process (AHP)-based multi-criteria evaluation model with a simulation-based cost model. Arslan et al. (2008) proposed a web-based sub-contractor evaluation system called WEBSES by which the sub-contractors can be evaluated based on combined criteria - cost, quality, time and adequacy. These four main headings had their sub-headings which are identified as the sub-criteria in this proposed system. Liu (2009) proposed a method to resolve the multi-attribute decision-making problem using TOPSIS method based on attribute weights and attribute values are all interval vague value. The research of Lam et al. (2009) presents an overview of potential suitability of Support Vector Machine (SVM) method for contractor/consultant prequalification transactions in the construction project procurements. Furthermore, the performance of SVM is compared with specific artificial neural network outcomes. Brauers and Zavadskas (2009) in their study presented an application of the Multi-Objective Optimization by Ratio Analysis Method (MOORA) on the facilities sector. Investigation of human factors during multiple criteria optimization was performed by Petkus et al. (2009). They investigated the time necessary for human's training to solve this multiple criteria optimization problem, the dependence of human factors on the strategy of parallel solution and on the number of computers in a computer network.

Urli and Nadeau (1999) emphasized the importance of multicriteria analysis. Their studies have shown that the area of application of decision-support systems could embrace the most important problems and their significance is underestimated. Researchers examined more than 800 European scientific publications in the period from 1985 to 1996. Since then the amount of articles dealing with multicriteria analysis has considerably increased. Besides, the researchers noticed the dispersion of multicriteria analysis to different areas. The methods of multicriteria analysis were tested in many fields and applied to different disciplines as well as to solving many specific problems. In spite of these facts, multicriteria analysis is not sufficiently developed, the methods are not perfect, and scientists constantly raise the question, "Which is the best method for a given problem?" (Triantaphyllou, 2000). Most of the methods enable us to determine the priority rank for comparing the alternatives, not allowing, however, to establish the level at which one alternative can be better than another.

Zavadskas and Kaklauskas (1996) created a method of multicriteria COmplex PRoportional ASsessment of projects (COPRAS), which presents a possibility to coordinate different objectives and to determine their priorities. This method makes it possible to compare the alternatives evaluating the superiority of one alternative over another. Lepkova et al. (2008), Zavadskas et al. (2004, 2007), Zavadskas and Vilutienė (2004), Ginevičius and Podvezko (2008b), Ginevičius and Ginevičienė (2009), Šliogerienė et al. (2009), Vilutienė and Zavadskas (2003), Banaitiene et al. (2008), Banaitis and Banaitienė (2007), Kaklauskas et al. (2006, 2007), Urbanavičienė et al. (2009), Mickaitytė et al. (2008) and others successfully applied this method for solving different multiobjective problems.

3. CASE STUDY: MULTIPLE CRITERIA ANALYSIS OF MAINTENANCE CONTRACTORS

3.1. Determining the weights of criteria by a complex method

The initial weights of the criteria are determined by expert methods. The obtained data are put down in a decision-making matrix (Table 1).

When performing multiple criteria evaluation of the alternatives, the values of the criteria describing them should be normalized and weighted. This provides a possibility to compare the values of the criteria having different units of measurement and to determine the most efficient alternatives.

Table 1. Decision-making matrix for maintenance contractor evaluation

Criteria describing the alternative		Units of measurement	*	Weights	Compared alternatives					
					1	2	...	j	...	n
Quantitative criteria	X_1	m_1	z_1	q_1	x_{11}	x_{12}	...	x_{1j}	...	x_{1n}
	X_2	m_2	z_2	q_2	x_{21}	x_{22}	...	x_{2j}	...	x_{2n}
	...	...	...	...	...	...	...	...	...	...
	X_i	m_i	z_i	q_i	x_{i1}	x_{i2}	...	x_{ij}	...	x_{in}
	...	...	...	...	...	...	...	...	...	...
	X_t	m_t	z_t	q_t	x_{t1}	x_{t2}	...	x_{tj}	...	x_{tn}
Qualitative criteria	X_{t+1}	m_{t+1}	z_{t+1}	q_{t+1}	$x_{t+1\,1}$	$x_{t+1\,2}$	...	$x_{t+1\,j}$	...	$x_{t+1\,n}$
	X_{t+2}	m_{t+2}	z_{t+2}	q_{t+2}	$x_{t+2\,1}$	$x_{t+2\,2}$	...	$x_{t+2\,j}$	...	$x_{t+2\,n}$
	...	...	...	...	...	...	...	...	...	...
	X_i	m_i	z_i	q_i	x_{i1}	x_{i2}	...	x_{ij}	...	x_{in}
	...	...	...	...	...	...	...	...	...	...
	X_m	m_m	z_m	q_m	x_{m1}	x_{m2}	...	x_{mj}	...	x_{mn}

* The sign z_i (+/–) indicates that a greater/smaller criterion value corresponds to a greater significance for a client

It should be noted, that, unlike objective quantitative information, the values and initial weights of the qualitative criteria are usually rather subjective. Having determined the weights of the criteria by expert methods, we found how much one criterion is more significant than another. But the weights of all quantitative and qualitative characteristics are not coordinated. Though the assessment of the values and initial weights of the qualitative criteria may seem biased and even quite subjective, the solution finally made may fully meet the requirements, needs and objectives of the interested parties. The methods of measurement of qualitative criteria are not quite reliable because there are no rigorous rules for the assignment of a particular numerical value to a criterion. The application of expert methods allows us to increase the objectivity of evaluation to a certain extent. It is necessary to harmonize the conceptual information, primary qualitative rating scale and the quantitative scoring system. Therefore, more reliable methods of measuring qualitative criteria are required.

In the present paper it is proposed to combine qualitative rating scales and quantitative representation of the results. The weights of quantitative criteria can be coordinated, if the values of quantitative criteria are expressed through the same measurement unit (in this case, the equivalent monetary unit is suggested). Having performed a comprehensive mutual coordination of quantitative criteria weights, the same is done to the weights of qualitative criteria. Thus all the weights of qualitative and quantitative criteria are coordinated at the same time.

A method COPRAS (Zavadskas and Kaklauskas, 1996) takes into account quantitative and qualitative characteristics of the criteria. The application of the method to determine the criteria weights is efficient when the considered alternatives are based on certain quantitative criteria. When a set of criteria includes one quantitative criterion, it is simpler to apply expert methods to define the weights of the criteria.

The weighting of the criteria is performed by the multiplication of their normalized values and their weights. The weights of quantitative criteria can be coordinated if the values of quantitative criteria are expressed through the equivalent monetary units (Stages 1–4). Having performed mutual coordination of quantitative criteria weights, the same procedure is applied to the weights of qualitative criteria (Stages 5–7). The weights of qualitative and quantitative criteria are coordinated at stages 1 to 7.

When a list of criteria is made, and their values and initial weights are calculated and presented in the form of a matrix, the user can calculate the actual weights of the criteria.

Stage 1: Calculation of the sum of values for each quantitative criterion by:

$$S_i = \sum_{j=1}^{n} x_{ij}, \; i = 1, 2, \ldots, t; \; j = 1, 2, \ldots, n, \quad (1)$$

where: x_{ij} is the value of the i-th criterion in the j-th alternative; t is the number of quantitative criteria; n is the number of the alternatives compared.

Stage 2: The total monetary expression of every quantitative criterion describing the investigated project is obtained by the expression:

$$P_i = S_i \cdot p_i, \; i = 1, 2, \ldots, t, \quad (2)$$

where: p_i is the initial weight of the i-th criterion; p_i should be measured insomuch as having been multiplied by a quantitative criterion value, an equivalent monetary expression could be obtained.

According to the effect of quantitative criteria on the performance of the alternative projects in time, the quantitative criteria may be divided into:

- Short-term factors, affecting the project/process only for a certain period of time;

- Long-term factors, affecting the project/process throughout its life cycle.

The initial weights of long-term criteria, such as resources needed for heating and the environment protection depend on the project's repay time and on the evaluation, in financial terms, of a criterion's monetary unit of measure, which is:

$$p_i = e \cdot f_i, \quad (3)$$

where: e is repay time of project; f_i is monetary evaluation of a measure unit of the i-th criterion.

The initial weights of a single criterion reflecting, for example, the cost of services, or the cost of a plot, are equal in financial terms to monetary expression of the criterion measuring unit:

$$p_i = f_i. \quad (4)$$

The physical meaning of the initial weight of a quantitative criterion shows that multiplication of the initial weight by the value of a quantitative criterion yields its expression in monetary units, which is calculated over the whole life cycle of an object.

Stage 3: The total sum of quantitative criteria monetary expressions is determined according to the formula:

$$V = \sum_{i=1}^{t} P_i, \; i = 1, 2, \ldots, t; \quad (5)$$

Stage 4: The final weights of quantitative criteria, describing the alternatives, are determined as follows:

$$q_i = \frac{P_i}{V}, \; i = 1, 2, \ldots, t; \quad (6)$$

The total sum of quantitative criteria weights is always equal to 1:

$$\sum_{i=1}^{t} q_i = 1. \quad (7)$$

Stage 5: In order to achieve the coordination between the weights of quantitative and qualitative criteria, a standard value (E) is determined. E is equal to the sum of any selected weights of quantitative criteria. One of the main requirements to this standard value to be used in comparison is that according to its utility it should be easily comparable to all qualitative criteria. The weights of all qualitative criteria are determined by comparing their utility with the standard value. The weight of the comparative standard value E is determined by

$$E = \sum_{z=1}^{g} q_z, \quad (8)$$

where: g is the number of quantitative criteria; q_z is the weight of the z-th quantitative criterion.

Stage 6: The initial weight v_i of the qualitative criterion is determined by expert methods comparing its relative significance to the significance E of the selected standard. Relative weights of qualitative criteria should be expressed in percentages.

Stage 7: The weight of the i-th qualitative criterion is determined as follows:

$$q_i = \frac{\nu_i \cdot E}{100}, \; i = t + 1, \ldots, m. \quad (9)$$

The above method allows for the determination of the weights of criteria that are closely interrelated and depend on the type of criteria, which may be qualitative or quantitative.

Therefore, a balance should be achieved between qualitative aspects and the costs of the quantitative aspects after the establishment of the weight of each criterion.

Maintenance companies are compared against the following quantitative criteria: cost of building management, cost of common property management, HVAC system maintenance cost, courtyard territory cleaning (in summer), total service cost, number of maintained buildings, average floor space of maintained buildings, income from common property maintenance per employee (Table 2).

Table 2. Qualitative criteria for evaluating the alternatives

Quantitative criteria	Calculated weights of criteria
1. Cost of building management, Lt*/m^2	0.0455
2. Cost of common property management, Lt/m^2	0.1054
3. HVAC system maintenance cost, Lt/m^2	0.1195
4. Courtyard territory cleaning (in summer), Lt/m^2	0.1265
5. Total service cost, Lt/m^2	0.4018
6. Number of maintained buildings, units	0.0633
7. Average floor space of maintained buildings, m^2	0.0448
8. Income from common property maintenance per employee, Lt/prs	0.0929

* a basic monetary unit of Lithuania, containing 100 cents, 1 EUR = 3.4628 LTL (the exchange rate fixed by Lithuanian central bank in 2002-02-02)

The weights of the criteria pertaining to the alternatives being evaluated are found by a complex method used to determine weights of the criteria. The procedure is performed by using a decision-making matrix (Table 3).

To find the total monetary equivalent for all quantitative criteria, their initial weights should be determined. The considered quantitative criteria are short-term, therefore their initial significance is equal to the monetary equivalent of the criterion's unit of measurement. The initial weights of all costs are equal to the average calculated floor space of the maintained dwellings 306454.4 m^2 (Table 4). The weight of the number of dwellings being maintained is equal to the monthly expenses calculated for dwelling administration (184.464 Lt). In this case, the number is obtained by multiplying the average floor space (2502 m^2) of a standard five-floor residential house with three staircases by the average administration cost of the house (0.074 Lt/m^2).

Table 3. Decision-making matrix for multiple criteria analysis

Decision criteria	Units of measurement	*	Weights	Compared alternatives (matrix D)					
				1	2	...	j	...	n
X_1	m_1	z_1	q_1	d_{11}	d_{12}	...	d_{1j}	...	d_{1n}
X_2	m_2	z_2	q_2	d_{21}	d_{22}	...	d_{2j}	...	d_{2n}
...	...	...	...	...	...	...	...	...	...
X_i	m_i	z_i	q_i	d_{i1}	d_{i2}	...	d_{ij}	...	d_{in}
...	...	...	...	...	...	...	...	...	...
X_m	m_m	z_m	q_m	d_{m1}	d_{m2}	...	d_{mj}	...	d_{mn}
Weighted sums of normalized maximizing criteria of the alternatives				S_{+1}	S_{+2}	...	S_{+j}	...	S_{+n}
Weighted sums of normalized minimizing criteria of the alternatives				S_{-1}	S_{-2}	...	S_{-j}	...	S_{-n}
Significances of the alternatives				Q_1	Q_2	...	Q_j	...	Q_n
Priorities of the alternatives				Pr_1	Pr_2	...	Pr_j	...	Pr_n
Utility degree of the alternatives (%)				N_1	N_2	...	N_j	...	N_n

* The sign +(–) indicates that a higher (lower) value of criteria meets customers' requirements

Table 4. Initial data for contractor evaluation from the client's viewpoint

Decision criteria	Units of measurement	*	Alternatives									Initial weights, p_i	Calculation		
			Numerical values of criteria										Total qualitative criteria, S_i	Total monetary expression, P_i	Ultimate weights of criteria, q_i
			A	*B*	*C*	*D*	*E*	*F*	*G*	… *N*	*O*				
Quantitative criteria															
1. Cost of building management	Lt/m^2	–	0.064	0.06	0.0568	0.0582	0.0582	0.0712	0.11	… 0.056	0.12	306454.4	1.1059	338907.92	**0.04557**
2. Cost of common property management	Lt/m^2	–	0.11	0.14	0.11	0.12	0.1	0.3	0.14	… 0.14	0.14	306454.4	2.56	784523.26	**0.10549**
3. HVAC system maintenance cost	Lt/m^2	–	0.18	0.18	0.37	0.18	0.09	0.18	0.18	… 0.18	0.09	306454.4	2.9	888717.76	**0.11950**
4. Courtyard cleaning (in summer)	Lt/m^2	–	0.31	0.12	0.15	0.15	0.2	0.26	0.12	… 0.12	0.21	306454.4	3.07	940815.01	**0.12651**
5. Total service cost	Lt/m^2	–	0.67	0.5	0.69	0.57	0.45	0.82	0.55	… 0.5	0.56	306454.4	9.75	2987930.4	**0.40178**
6. Number of maintained buildings	units	–	300	10	134	181	142	680	72	… 68	1	184.464	2554	471121.06	**0.06335**
7. Average floor space of maintained buildings	m^2	+	356713	2060	462184	485890	400311	709298	172800	… 210000	5200	0.074	4519291	333192.26	**0.04480**
8. Income from common property maintenance per employee	Lt/prs	+	594.5	9.613	558.68	897.03	392.46	1773.25	403.20	… 735.00	24.27	63	10657	674202.8	**0.09299**
														V = 7419410	
Qualitative criteria															**E = 0,5396**
9. Length of time in maintenance business (experience)	years	+	12	3	12	12	12	13	5	… 11	3	0.020			**0.01087**
10. Market share for each contractor (in Vilnius)	%	+	11.75	0.39	5.25	7.09	5.56	26.62	2.82	… 2.66	0.04	0.023			**0.01251**
11. Number of projects per manager	obj./prs	+	4.6	0.33	1.47	2.78	1.39	5.67	1.20	… 1.70	0.03	0.013			**0.00708**

(Continued)

Decision criteria	Units of measure-ment	*	Alternatives									Initial weights, p_i	Calculation		
			Numerical values of criteria										Total qualitative criteria, S_i	Total monetary expression, P_i	Ultimate weights of criteria, q_i
			A	*B*	*C*	*D*	*E*	*F*	*G*	… *N*	*O*				
Qualitative criteria															
(*Continued*)															
12. Management cost (C_{min}/C_p)	–	+	0.83	0.885	0.935	0.912	0.912	0.746	0.483	… 0.948	0.531	0.037			**0.01984**
13. Quality standard of management services	points	+	7.625	6.167	6.458	6.417	7.25	6.833	8.417	… 6.354	8.792	0.036			**0.01959**
……..	…	…	…	…	…	…	…	…	…	… …	…	…	…	…	…
16. Quality standard of common property maintenance	points	+	6.539	7.154	8.269	7.423	7.923	8.269	8.308	… 7.577	8.5	0.037			**0.01971**
……….	…	…	…	…	…	…	…	…	…	… …	…	…	…	…	…
26. Work organization	points	+	7.875	6.75	7.733	7.417	7.667	7.625	8.558	… 7.708	8.767	0.025			**0.01365**
……….	…	…	…	…	…	…	…	…	…	… …	…	…	…	…	…
34 The efficiency of information use	points	+	7.788	6.525	6.688	6.813	7.875	7.025	7.75	… 7.463	8.55	0.019			**0.00998**
………….	…	…	…	…	…	…	…	…	…	… …	…	…	…	…	…
38. Certification of company	points	+	9	2	9	9	9	9	2	… 9	2	0.020			**0.01099**
39. Range of services	points	+	4	3	3.5	4.3	5.9	3.5	7.5	… 5.5	6.5	0.030			**0.01630**
40. Reliability of company	points	+	8	6	8	8	8.7	8	7	… 8	8	0.036			**0.01946**
41. Company reputation	points	+	6	5	7.5	8	8.5	9	8.7	… 5.5	9	0.035			**0.01883**
42. Staff qualification and past experience	points	+	8.4	7.5	8.4	8.4	8.4	8.5	7.7	… 8.4	7.5	0.036			**0.01933**
43. Communication skills	points	+	3	6	7	7	7.6	8	8.5	… 7	8.5	0.031			**0.01681**
44. Geographical market restrictions	points	-	8	8	8.5	8.5	8.5	6	3.5	… 8.5	3.5	0.018			**0.00985**

* The sign +(–) indicates that a higher (lower) value of criteria conforms to customers' requirements

The initial weight of the income obtained by service provider dealing with common assets is equal to the average number of employees providing maintenance services in a particular organization (63 persons).

In order to find a balance between the weights of quantitative and qualitative criteria, a standard value E is determined by formula (8). The experts have chosen the sum of weights of the criteria 'total cost of services', 'floor space of maintained dwellings and income of an employee from common spaces maintenance' as a standard for comparison. Therefore, the significance $E = 0.5396$ (Table 4) will be used in further calculations.

The initial weights of quantitative criteria are found by expert methods. The respondents specified the weights of the criteria. The completed questionnaires were then processed and the reliability of the expertise was determined by calculating the concordance coefficient showing the compatibility of experts' judgments.

By applying formula (9) of a complex method of determining the weights of criteria, the weights of the quantitative and qualitative criteria relating to maintenance contractor alternatives were established. As shown in Table 4, the criteria of the greatest weight are as follows: total cost of services ($q_5 = 0.4018$); courtyard cleaning in summer ($q_4 = 0.1265$); cost of using and maintenance of the heating system ($q_3 = 0.1195$); maintenance cost of common property ($q_2 = 0.1055$); income obtained by service provider from common property maintenance ($q_8 = 0.0929$).

3.2. Multiple criteria complex proportional assessment of maintenance contractors

When the weights of the criteria were determined, a method of multiple criteria complex proportional assessment was applied to establish the priority order and the utility degree of the alternatives.

This method assumes the existence of direct and proportional relationship between significance and priority of the investigated option considered against a set of criteria that adequately describe the alternatives and is based on the criteria values and weights. The set of criteria are determined and then the experts calculate their values and initial weights. The information can be updated by the interested groups by taking into account their goals and capabilities. By using the method of multicriteria complex proportional evaluation, the priorities and significances of the alternatives are determined in four steps.

Stage 1. A normalized decision-making matrix is constructed (Table 5). This step is aimed at getting the dimensionless weighted values based on the compared criteria. If these values are known, all the criteria can be compared. It is achieved by applying the following formula:

$$d_{ij} = \frac{x_{ij} \cdot q_i}{\sum_{j=1}^{n} x_{ij}}, \quad i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n, \qquad (10)$$

where: x_{ij} is the value of the i-th criterion of the j-th alternative; m is the number of criteria; n is the number of the alternatives compared; q_i is the weight of the i-th criterion.

The total of dimensionless weighted criteria values d_{ij} of each x_i criterion must always be equal to weight q_i of the criterion:

$$q_i = \sum_{j=1}^{n} d_{ij}, \quad i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n. \qquad (11)$$

In other words, the value of weight q_i of the investigated criterion is proportionally distributed among all alternatives a_j according to their value x_{ij}.

Stage 2. The sums of the weighted normalized criteria describing the j-th alternative are calculated. The alternatives are described by minimized values S_{-j} and maximized values S_{+j}. The lower the value of minimized criteria, such as the price of service, the better the attainment of goals. The greater the value of maximizing criteria, such as comfort, the better the attainment of goals.

S_{-j} and S_{+j} are the criteria characterizing the j-th alternative which are calculated according to the formulas:

$$S_{+j} = \sum_{i=1}^{m} d_{+ij}, \quad S_{-j} = \sum_{i=1}^{m} d_{-ij},$$
$$i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n, \qquad (12)$$

In this case, S_{+j} (the greater this value, the higher is the extent to which the needs of the interested groups are satisfied) and S_{-j} (the lower this value, the more goals of interested groups are attained) are the values expressing the attainment of the goals pursued by the interested groups.

In any case, the sums of S_{+j} and the sums of S_{-j} are equal to the weighted sums of all maximized and minimized criteria, respectively:

$$S_{+} = \sum_{j=1}^{n} S_{+j} = \sum_{i=1}^{m}\sum_{j=1}^{n} d_{+ij},$$
$$S_{-} = \sum_{j=1}^{n} S_{-j} = \sum_{i=1}^{m}\sum_{j=1}^{n} d_{-ij},$$
$$i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n. \qquad (13)$$

Thus, in this way, the calculations may be additionally checked.

Stage 3. The relative significance of the compared alternatives is determined by describing positive (S_{+j}) and negative (S_{-j}) characteristics of the alternatives.

The relative significance Q_j of each alternative a_j is determined from the formula:

$$Q_j = S_{+j} + \frac{S_{-\min} \cdot \sum_{j=1}^{n} S_{-j}}{S_{-j} \cdot \sum_{j=1}^{n} \frac{S_{-\min}}{S_{-j}}}, \; j = 1, 2, \ldots, n. \qquad (14)$$

Stage 4. Determination of priorities. The priorities Q_j of the alternatives are calculated. Significance Q_j of project a_j indicates the satisfaction degree of demands and goals pursued by the interested parties. The greater the value Q_j, the more effective is the alternative. The significance of all the remaining projects is lower compared to that of the most efficient project. Overall demands and goals of the interested parties will be satisfied to a smaller extent than in the case of the best project.

As mentioned above, maintenance contractors were evaluated and compared from the viewpoints of building users. The initial data for comparing the contractors are written down in a decision-making matrix (Table 5). The alternatives n considered in the paper are arranged in columns, while quantitative and qualitative information describing them is given in rows. The calculated aggregate criterion Q_j is directly proportional to the relative influence of values x_{ij} and weights q_i on the final results.

The expression $Q_5 \succ Q_4 \succ Q_{14} \succ Q_6 \succ Q_7 \succ Q_8 \succ Q_{15} \succ Q_2 \succ Q_1 \succ Q_3 \succ Q_{10} \succ Q_{11} \succ Q_{12} \succ Q_{13} \succ Q_9$ (the sign "$\succ$" means "better than") was obtained based on the building user (client) viewpoint. This implies that, according to the priority order, the 5-th alternative representing maintenance contractor 'E' is the best (Q_5 = 0.1172).

3.3. The utility degree of maintenance contractors

Since clients are more interested in the effectiveness of a particular alternative (especially when the quality of contractor services satisfies their needs and objectives), it is better to rely on the concept of the utility degree when selecting the most efficient option. In marketing terms, one of the factors influencing the client's decision to choose a particular alternative product or service is its utility. It is assumed that clients can measure various projects in terms of *utility*. In the proposed method, the utility of the alternatives is measured quantitatively.

Table 5. The results of multiple criteria evaluation of maintenance contractors from client's viewpoint (table presents the normalized values)

Decision criteria	Units of measurement	*	Alternatives														
			Numerical (normalized) values of criteria														
			A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*	*O*
Quantitative criteria																	
1. Cost of building management	Lt/m^2	–	0.00264	0.00247	0.00234	0.00240	0.00240	0.00293	0.00453	0.00239	0.00219	0.00293	0.00494	0.00293	0.00321	0.00231	0.00494
2. Cost of common property management	Lt/m^2	–	0.00453	0.00577	0.00453	0.00494	0.00412	0.01236	0.00577	0.00742	0.00577	0.01071	0.00824	0.01154	0.00824	0.00577	0.00577
3. HVAC system maintenance cost	Lt/m^2	–	0.00742	0.00742	0.01525	0.00742	0.00371	0.00742	0.00742	0.00742	0.01525	0.00659	0.01195	0.00371	0.00742	0.00742	0.00371
4. Courtyard cleaning (in summer)	Lt/m^2	–	0.01277	0.00495	0.00618	0.00618	0.00824	0.01071	0.00495	0.00783	0.00948	0.00948	0.00824	0.01154	0.01236	0.00495	0.00865
5. Total service cost	Lt/m^2	–	0.02761	0.02060	0.02843	0.02349	0.01854	0.03379	0.02266	0.02514	0.03297	0.03008	0.03338	0.03008	0.03132	0.02060	0.02308
6. Number of maintained buildings	units	–	0.00744	0.00025	0.00332	0.00449	0.00352	0.01687	0.00179	0.00600	0.00141	0.00853	0.00298	0.00149	0.00355	0.00169	0.00002
7. Average floor space of maintained buildings	m^2	+	0.00354	0.00002	0.00458	0.00482	0.00397	0.00703	0.00171	0.00638	0.00219	0.00119	0.00319	0.00134	0.00271	0.00208	0.00005
8. Income from common property maintenance per employee	Lt/prs	+	0.00001	0.00000	0.00001	0.00001	0.00000	0.00002	0.00000	0.00001	0.00000	0.00001	0.00001	0.00001	0.00001	0.00001	0.00000
Qualitative criteria																	
9. Length of time in maintenance business	years	+	0.00093	0.00023	0.00093	0.00093	0.00093	0.00101	0.00039	0.00085	0.00085	0.00085	0.00031	0.00093	0.00062	0.00085	0.00023
10. Market share for each contractor (in Vilnius)	%	+	0.00147	0.00005	0.00066	0.00089	0.00070	0.00333	0.00035	0.00119	0.00028	0.00169	0.00059	0.00029	0.00070	0.00033	0.00000
11. Number of projects per manager	obj./prs	+	0.00087	0.00006	0.00028	0.00052	0.00026	0.00107	0.00023	0.00057	0.00014	0.00170	0.00028	0.00016	0.00061	0.00032	0.00001
12. Management cost (C_{min}/C_p)	–	+	0.00141	0.00150	0.00158	0.00155	0.00155	0.00126	0.00082	0.00155	0.00169	0.00126	0.00075	0.00126	0.00115	0.00161	0.00090

(Continued)

Decision criteria	Units of measurement	*	Alternatives														
			Numerical (normalized) values of criteria														
			A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*	*O*
Qualitative criteria																	
(*Continued*)																	
13. Quality standard of management services	points	+	0.00139	0.00112	0.00118	0.00117	0.00132	0.00125	0.00154	0.00119	0.00119	0.00132	0.00161	0.00119	0.00135	0.00116	0.00160
....																	
16. Quality standard of common property maintenance	points	+	0.00113	0.00124	0.00143	0.00129	0.00137	0.00143	0.00144	0.00118	0.00121	0.00137	0.00149	0.00117	0.00115	0.00131	0.00147
....																	
26. Work organization	points	+	0.00092	0.00078	0.00090	0.00086	0.00089	0.00089	0.00100	0.00088	0.00092	0.00093	0.00102	0.00090	0.00085	0.00090	0.00102
....																	
34. The efficiency of information use	points	+	0.00070	0.00058	0.00060	0.00061	0.00071	0.00063	0.00069	0.00067	0.00066	0.00067	0.00080	0.00058	0.00064	0.00067	0.00077
....																	
38. Certification of company	points	+	0.00090	0.00067	0.00078	0.00096	0.00132	0.00078	0.00168	0.00067	0.00096	0.00112	0.00195	0.00112	0.00067	0.00123	0.00146
....																	
40. Reliability of company	points	+	0.00132	0.00118	0.00132	0.00132	0.00132	0.00134	0.00121	0.00130	0.00130	0.00130	0.00135	0.00132	0.00126	0.00132	0.00118
41. Company reputation	points	+	0.00047	0.00093	0.00109	0.00109	0.00118	0.00125	0.00132	0.00125	0.00117	0.00093	0.00139	0.00140	0.00093	0.00109	0.00132
42. Staff qualification and past experience	points	–	0.00073	0.00073	0.00077	0.00077	0.00077	0.00054	0.00032	0.00077	0.00073	0.00077	0.00032	0.00078	0.00078	0.00077	0.00032
....																	
Weighted sums of normalized maximizing criteria of the alternatives S_{+j}			0.0449	0.0284	0.0431	0.0437	0.0430	0.0628	0.0419	0.0468	0.0373	0.0472	0.0486	0.0361	0.0372	0.0386	0.0383
Weighted sums of normalized minimizing criteria of the alternatives S_{-j}			0.0557	0.0419	0.0575	0.0452	0.0378	0.0678	0.0456	0.0510	0.0664	0.0606	0.0671	0.0606	0.0633	0.0418	0.0465
Significances of the alternatives Q_j			**0.0953**	**0.0953**	**0.0919**	**0.1058**	**0.1172**	**0.1042**	**0.1034**	**0.1019**	**0.0796**	**0.0936**	**0.0904**	**0.0824**	**0.0815**	**0.1056**	**0.0987**
Priorities of the alternatives			**9**	**8**	**10**	**2**	**1**	**4**	**5**	**6**	**15**	**11**	**12**	**13**	**14**	**3**	**7**
Utility degree of the alternatives *Nj*			**81.291**	**81.339**	**78.387**	**90.230**	**100.000**	**88.875**	**88.193**	**86.906**	**67.922**	**79.818**	**77.157**	**70.297**	**69.552**	**90.134**	**84.175**

* The sign +(–) indicates that a higher (lower) value of criteria conforms to customers' requirements

With the increase/decrease of the significance of the analysed alternative, its degree of utility also increases/decreases. The degree of project utility is determined by comparing the analysed alternatives with the most efficient one. All utility values related to the considered projects will range from 0% to 100%.

The degree of utility N_j of the a_j-th alternative was determined according to the formula:

$$N_j = (Q_j : Q_{max}) \cdot 100\%, \quad (15)$$

where: Q_j and Q_{max} are significances of the alternatives calculated by formula (14).

The degree of utility N_j of a building's life cycle is associated with the qualitative information which is related to it (e.g. a set of criteria, criteria values and significances). The degree of utility N_j of the a_j-th alternative shows the attainment of goals pursued by the interested groups. The more goals are attained, the higher is the degree of the alternative utility.

By applying multicriteria analysis the utility functions of the considered maintenance contractors are determined (Table 5). The utility function N_5 = 100% of the 5-th alternative, i.e. cost and quality provided by the contractor in question better satisfy the needs and goals of the client.

3.4. Correction of service price offered in bidding

In order to determine the real competitive bid price, according to which the contract could be signed, the degree of effectiveness E_{xj} of choosing the alternatives a_j has to be calculated. It describes (in percent) how much better (or worse) it is to invest in the alternative a_x, compared with the alternative a_j (in choosing one of them). In our case, the degree of effectiveness is used in order to explain the rationale of the client's selection of a particular contractor.

The degree of efficiency of investments in all the alternatives E_{xj} is determined through the comparison of the alternative utility degree N_x with the remaining alternatives having the utility degrees N_j as follows:

$$E_{xj} = N_x - N_j, \quad (16)$$

N_j was calculated by formula (15).

Then the average deviation k_x of utility degree N_x of alternative a_x has to be calculated as follows:

$$k_x = \sum_{j=1}^{n} E_{xj} : (n-1), \quad (17)$$

The value V_x (competitive bid price) of alternative a_x is determined from the formula:

$$V_x = S_x(1 + k_x : 100), \quad (18)$$

where: S_x is the initial bid price of alternative a_x.

The calculations of contractual price are given in Table 6. The presented data indicate that the service price of the best contractor selected may be increased from 0.450 Lt/m^2 to 0.535 Lt/m^2. The comparison of the contractual cost computed with the initial cost for all contractors, taking into consideration the client's viewpoint, is provided in Figure 1.

4. CONCLUSIONS

Practical application of the suggested model for maintenance contractor selection could help all the interested groups to harmonize their diverse interests and objectives and to enhance the procedure of decision-making. Following the above model, decision criteria are chosen taking into account the interests and objectives of the client (building user) and other factors affecting the efficiency of the maintenance process. The application of the model offered in the present paper may also reduce the risk in choosing the appropriate maintenance contractor. The suggested model may be successfully applied not only to planning the maintenance work in multi-family apartment blocks but to choosing maintenance contractors for industrial and commercial buildings as well.

Table 6. Calculation of the contractual service price of an alternative

	Initial cost	Alternative efficiency E_{xj}, %															Average deviation of utility degree k_x, %	Offered competitive bid price V_x, Lt/m^2
		A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*	*O*		
A	0.670	0.000	–0.049	2.903	–8.939	–18.709	–7.584	–6.903	–5.616	13.369	1.472	4.133	10.994	11.739	–8.843	–2.885	–1.066	**0.663**
B	0.500	0.049	0.000	2.952	–8.891	–18.661	–7.535	–6.854	–5.567	13.418	1.521	4.182	11.043	11.787	–8.794	–2.836	–1.013	**0.495**
C	0.690	–2.903	–2.952	0.000	–11.842	–21.613	–10.487	–9.806	–8.519	10.466	–1.431	1.230	8.091	8.835	–11.746	–5.788	–4.176	**0.661**
D	0.570	8.939	8.891	11.842	0.000	–9.770	1.355	2.037	3.324	22.308	10.411	13.072	19.933	20.678	0.096	6.055	8.512	**0.619**
E	0.450	18.709	18.661	21.613	9.770	0.000	11.125	11.807	13.094	32.078	20.182	22.843	29.703	30.448	9.866	15.825	18.980	**0.535**
F	0.820	7.584	7.535	10.487	–1.355	–11.125	0.000	0.681	1.968	20.953	9.056	11.717	18.578	19.322	–1.259	4.699	7.060	**0.878**
G	0.550	6.903	6.854	9.806	–2.037	–11.807	–0.681	0.000	1.287	20.272	8.375	11.036	17.896	18.641	–1.940	4.018	6.330	**0.585**
H	0.610	5.616	5.567	8.519	–3.324	–13.094	–1.968	–1.287	0.000	18.985	7.088	9.749	16.610	17.354	–3.227	2.731	4.951	**0.640**
I	0.800	–13.369	–13.418	–10.466	–22.308	–32.078	–20.953	–20.272	–18.985	0.000	–11.897	–9.236	–2.375	–1.630	–22.212	–16.254	–15.389	**0.677**
J	0.730	–1.472	–1.521	1.431	–10.411	–20.182	–9.056	–8.375	–7.088	11.897	0.000	2.661	9.522	10.266	–10.315	–4.357	–2.643	**0.711**
K	0.810	–4.133	–4.182	–1.230	–13.072	–22.843	–11.717	–11.036	–9.749	9.236	–2.661	0.000	6.861	7.605	–12.976	–7.018	–5.494	**0.765**
L	0.730	–10.994	–11.043	–8.091	–19.933	–29.703	–18.578	–17.896	–16.610	2.375	–9.522	–6.861	0.000	0.745	–19.837	–13.879	–12.845	**0.636**
M	0.760	–11.739	–11.787	–8.835	–20.678	–30.448	–19.322	–18.641	–17.354	1.630	–10.266	–7.605	–0.745	0.000	–20.582	–14.623	–13.642	**0.656**
N	0.500	8.843	8.794	11.746	–0.096	–9.866	1.259	1.940	3.227	22.212	10.315	12.976	19.837	20.582	0.000	5.958	8.409	**0.542**
O	0.560	2.885	2.836	5.788	–6.055	–15.825	–4.699	–4.018	–2.731	16.254	4.357	7.018	13.879	14.623	–5.958	0.000	2.025	**0.571**

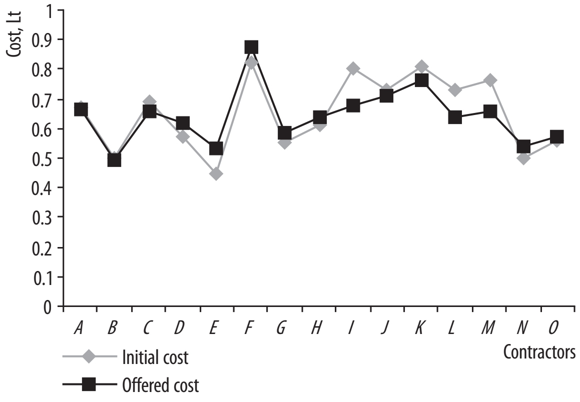

Figure 1. Comparison of initial and contractual cost calculated from the client's viewpoint

A complex method of determining the significances of the criteria suggested by the authors allows the significances of both quantitative and qualitative criteria to be calculated and balanced, taking into consideration the results of analysis of the quantitative and qualitative characteristics of the service life of the building.

The application of the proposed method of complex proportional multicriteria project assessment allowed the authors to calculate relative significances Q_j of the compared contractors reflecting the relative effect of values and significances of the compared criteria on the results of the comparative analysis of maintenance organizations. The suggested method may be used for evaluating a number of alternatives based on a set of quantitative and qualitative criteria in the environment where several decision-makers assess the projects. The method offered helps to determine the utility function of any alternative with respect to particular interested groups and to correct the cost of services based on the obtained utility value.

The results obtained in solving the problem reveal that the fifth alternative is more effective than other options not only in satisfying the needs and objectives of the client but from the viewpoint of maintenance manager as well. The utility functions of the concerned organizations are calculated and contractual costs are determined by applying the multicriteria analysis of project utility. Multicriteria analysis of maintenance contractor performance allows for complex evaluation of the criteria characterizing this issue from the perspective of their agreement with the needs and technical and financial capabilities of all parties interested in maintenance. The needs are described in terms of a set of quantitative and qualitative criteria and values, with the importance of the criteria expressed in terms of their significances. The application of multicriteria analysis to the selection of maintenance contractor helps to take the appropriate decision based on various criteria which may reduce the risk in the process of contractor selection. This confirms an assumption that the above method can be successfully used in maintenance contractor selection practice.

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SANTRAUKA

DAUGIABUČIŲ NAMŲ PRIEŽIŪROS ĮMONIŲ DAUGIAKRITERINIS VERTINIMAS: LIETUVOS ATVEJIS

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Straipsnyje pateikta daugiabučius namus administruojančių įmonių lyginamoji analizė. Tyrimo tikslas – nustatyti daugiabučius namus administruojančių įmonių paslaugų naudingumą namo naudotojams. Pavyzdžiui išspręsti buvo naudoti penkiolikos daugiabučius namus administruojančių įmonių paslaugų rodikliai. Įmonės pagal 44 juos apibūdinančius kriterijus vertino daugiabučių namų gyventojai. Pradiniai kokybinių rodiklių reikšmingumai nustatyti taikant ekspertinį metodą. Kokybinių ir kiekybinių rodiklių reikšmingumai suderinti, optimalus variantas ir variantų naudingumai nustatyti daugiakriterinio kompleksinio proporcingo vertinimo metodu (angl. *method of COmplex PRoportional ASsessment, COPRAS*). Pagal taikytą metodą derybų metu galima koreguoti pasiūlymų kainas, atsižvelgiant į nustatytą alternatyvų naudingumą. Daugiakriterinė analizė leidžia nustatyti konkretaus rangovo rodiklių reikšmingumus, įvertinus skirtingus daugiabučių namų priežiūros proceso dalyvių poreikius.