



## THE APPLICATION OF MULTI-CRITERIA ANALYSIS TO DECISION SUPPORT FOR THE FACILITY MANAGEMENT OF A RESIDENTIAL DISTRICT

Tatjana Vilutienė, Edmundas Kazimieras Zavadskas

*Dept of Construction Technology and Management, Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-2040 Vilnius, Lithuania. E-mail: tatjana.vilutiene@st.vtu.lt*

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**Abstract.** The article deals with the problem of dwelling maintenance. In this paper the process of building maintenance in Lithuania is analysed, the activities of subjects carrying out maintenance work described, and a comparison of maintenance variants was made applying the methods WSM, WPM, AHP, Revised AHP and *Topsis*. A method of multi-criteria complex proportional evaluation of the projects was also applied for determining the efficient variant and the degree of its utility. The analysis of the application of the multi-criteria methods for solving the problems with multiple objectives was also made. In striving to prolong the existence of buildings the professional use of a property should be ensured. The article presents a model of property management with the participation of monitoring organisations. This model helps ensure a more effective facilities management process and the work quality in dwellings.

**Keywords:** dwellings, maintenance, multi-criteria analysis, decision-making methods, facility management organisations.

### 1. Introduction

The problems of multi-flat building maintenance in Lithuania cause a lot of debates, however, practically the ways of maintenance have not been analysed and the activities of maintenance participants not investigated. The variants of facility management were not motivated scientifically. The process of facility management can be defined by many criteria and according to different interested and participating parties. The members of the facility management process usually meet the problem of variant selection, therefore for solving such problems it is purposeful to use the methods of multi-criteria analysis.

These methods allow to find an effective way of the problem solution. As a result, the goals of all interested parties are met and the deterioration of buildings can be minimised.

What methods of multi-criteria analysis could be applied to determine the efficient process of a building's facility management and how can building owners and users influence a building's longevity?

Maintenance problems arise from the beginning of a building usage when its state starts to deteriorate. Buildings are affected by different internal and external environmental factors. As a result, a building sets, materials dilate or shrink and air/water and circulating chemicals frustrate wall surfaces. Finally, users can destroy the elements of a building due to its insufficient maintenance and neglect.

At present about 97 % of the total housing stock is private and in this respect Lithuania is unique. In comparison with foreign countries, this quantity is too large, because there are limitations for privately owned housing numbers – only about 50 %. For instance, in Poland ~ 50 %, in Denmark ~ 30 % (data on dwelling and town development stock were collected in 1999, November). Because of such a high number of private housing-stock in Lithuania specific facility management problems arise.

In Lithuania like in countries of Central and Eastern Europe the multi-story and multi-flat dwellings are prevalent. Cooperative societies, dwelling owners associations or condominiums maintain this stock of dwellings. Therefore it is very important to pay attention to how the problems related to facility management of such housing stock are being solved in these countries. Liias, Ždankova, Kursis (1998-2001) showed the failings of facility management of multi-story and multi-flat dwellings which are typical of Central and Eastern European countries [1-5]:

- There is no (or not enough) facility management and building maintenance legislation, legislative instruments and regulations;
- After housing stock privatisation, the conflicts between different interests and the avoidance of responsibility have developed;
- There are not enough legislative documents outlining the limits of responsibilities;
- The state of dwellings has not been investigated,

and the state of equipment almost everywhere has not been evaluated;

- Owners usually do not know how to maintain their property properly;
- For professional property maintenance owners need maintenance manuals;
- Facility management organisations sometimes have no experience of solving some specific problems that are related to facility management.

As a result, decline of a building state has appeared. The results of examining a set of five-story large-panel dwellings showed that the majority of buildings have broken constructions. The research made in 1998 [6, 7] showed that in multi-story and multi-flat dwellings the following damages prevail: in external walls (22 %), in roofs (25 %), in landings (19 %). Internal walls (10 %) and inter-story coverings (10 %) are less damaged [6–8]. Bojko *et al* in 1993 determined that damages were differently distributed in storeys [9].

Continual decay of buildings is unavoidable. But this process can be controlled by means of maintenance. Maintenance planning has to be started at a building's design stage and continued throughout the building life. Building owners and users must take part in this process.

The aim of paper is to apply the methods of multi-criteria analysis for an efficient building maintenance variant determination and the degree of its utility calculation, and to offer the property management form when the private property management organisations are participating.

The research methods are classic multi-criteria methods that apply to problems with a cardinal type of information on the attributes (i.e. WSM, WPM, AHP, Revised AHP, Topsis). In this paper the example of the application of a method of multi-criteria complex proportional evaluation of the projects for solving the problems of facility management is presented.

## 2. Review of applying multi-criteria decision-making methods for solving multi-objective problems

The process of building maintenance is related to the problem of coordination of different goals of the interested parties involved in this process. For different goal coordination and an efficient variant substantiation this multi-criteria decision-making methods can be applied.

Classical methods of multi-criteria optimisation, priority and the degree of utility determination were started to apply in 1896 by Pareto and in 1959 were improved by Debreu [10, 11]. These methods were strongly related to an economical theory, which is concerned with the averages of thousands of decisions and the individual consumer. Similarly, in this theory, as in a mathematical construction, which averaged out institutional constraints and dependencies there are relations to economic theories.

Multi-criteria analysis systems have been developed since the 1960's in accordance with the increasing requirements of human societies and the environment. Firstly, the main intention was the multi-objective extensions of mathematical programming. In this way Cochrane and Zeleny provided researches in 1973 with some essential data and Keeny in 1974 developed multi-criteria decision analysis with conflicting objectives [11, 12]. Scientists provided representation theorems for determining multi-criteria utility functions under preferential and utility independence assumptions [12]. Seo in 1980 provided multi-criteria decision-making method that was concerned with balancing conflicting objectives in a hierarchical structure. In this work, Seo presented a quantitative analysis for multi-objective extension of organisations and a theoretical approach where decision-making problems are related to different interests of individuals or groups [13].

The problem of the coordination of different goals and interests of interested parties was resolved in 1980 by Tanino, Nakayama and Swaragi [14]. They used the ECR method that extended the contributive rule method.

Wierzbicki in his works analysed problems related to the decision-making process in a simple organisation, also the relation between satisfying decision-making and utility or value maximisation [11]. Zanakis in 1980 used the IGP (integer goal programming) method for solving real world multi-objective problems. Today, problems with hundreds or even thousands of variables and constraints could be solved using this method [15].

Caballero *et al* in 2002 worked with problems that are typical of organisations with a hierarchical structure and those that have different decision levels and complex relations. The scientist has suggested an algorithm of hierarchical multiple aims model for different goal optimization. This model allows to solve the problem according to criteria and those that are in a conflict situation. The model can be applied to solve really difficult problems and those with complex relations [16].

Colson in 2000 analyzed the theoretical and practical aspects of multi-criteria decision-making systems [17]. Many scientists have described the application of multiple criteria procedures for quality and priority of variant determination.

Saati in 1977 showed the global importance of solving problems with conflicting goals by using multi-criteria models. The scientist also presented some decision-making models with incomplete information for solving political and economical problems [18].

Urli ir Nadeau in 1999 marked the importance of multi-criteria analysis. Their researches showed that the area of decision-support systems could be attached to the most important problems by significance and insufficiently developed. The scientists examined more than 800 European scientific editions that were published in period 1985–96. From the beginning of this period the quantity of articles related to multi-criteria analysis has

continuously increased [19]. Besides, the scientist has noted the dispersion of multi-criteria analysis in different areas. The methods of multi-criteria analysis were tried and applied to different disciplines and for solving specific problems.

In spite of these facts, the area of multi-criteria analysis is not sufficiently developed, methods are not perfect, and scientists constantly raise the question, “Which is the best method for a given problem?” (E. Triantaphyllou, 2000).

Triantaphyllou analysed the most popular multi-criteria decision-making methods (MCDM): WSM – weighted the sum model, WPM – weighted the product model, AHP – the analytic hierarchy process and the variants of it and the ELECTRE and TOPSIS methods [20]. The scientist has distinguished two main theoretical streams of multi-criteria decision-making area. These streams include the most popular and usable methods of multi-criteria analysis.

The first stream covers multi-objective decision making models (MODM), which assume continuous solution spaces, try to determine the optimal compromise solutions. This stream allows for many modifications of the basic model or method. However, it is difficult to apply these methods in practice, because the models do not solve the majority of MCDM problems.

The second stream focuses on problems with discrete decision spaces (i.e. those with countable few decision alternatives) and use approaches from discrete mathematics. This stream is often called “Multi-Attribute Decision Making” or MADM. These models do not try to compute an optimal solution, but try to determine a rank of decision alternatives that is optimal with respect to several criteria, or they try to find optimal actions among the existing solutions. Though these models are frequent in practice, the quality of applying the methods and determining the best one is hard to do. The main conclusion that can be made from the comparative study of MCDM methods made by Triantaphyllou is that there may not be a single MADM method, which can always ensure the best decision [20].

Most methods of the second stream enable one to determine the priority rank for comparing alternatives, but do not allow to evaluate the level on which one alternative can be better than another.

Zavadskas and Kaklauskas in 1996 have created a method of multi-criteria complex proportional evaluation of projects, which present a possibility to coordinate different objectives and determine the rank of priorities. This method allows one to compare alternatives and evaluate how much one variant is better than another. Lithuanian scientists Zavadskas, Kaklauskas, Kvederytė, Malienė, Lepkova, Malinauskas *et al.* in 1996–2001 had applied this method for solving different multi-objective problems [21–27].

### 3. The tasks formulation for solving the problems of facility management of a residential district

While solving the problems of increasing the effectiveness of property management, the main task was the implementation of new property management forms in the housing sector.

Different property management forms were analysed and their advantages and disadvantages were noted. It appears from this that the most effective property management form is when it manages not only buildings and land, but also all the objects of common use like the entity of a vast complex of property [28].

One of the conditions and abidance by it ensures effective property maintenance and is professionally fulfilled by the work and services that are done. Building owners and users expect skilled and professional maintenance work to be carried out. Building maintenance is usually a minor and short-term, so it is difficult to choose the skilled worker and later to evaluate the quality of his/her work.

When analysing the process of a building maintenance (the exact form of the work’s performance), the following variants can be noted:

1. Maintenance and renovation are performed by directly employed labour (when the process is organised directly by tenants);
2. Making a contract with a joint-stock company that has been selected by a contest to perform maintenance and renovation.

Thus the first task is to determine the most efficient form of *maintenance work and performance*. The effectiveness of a building maintenance process depends more on qualitative criteria than on quantitative aspects, because in evaluating the effectiveness of a maintenance process it is important to evaluate the level of a customer’s needs being met, not only costs or other quantitative parameters. Therefore, for comparison of the alternatives, costs as quantitative criteria were not included in the list of criteria. A qualitative description of the project provides information about various aspects of a building facility process (i.e. convenience, work quality, level of insurance of materials to health and environment, noise level, mastery level and continuance of work, etc). In striving for the determination of the most effective alternative and coordinating the different goals of the processes participators, the multi-criteria decision-making methods were applied.

### 4. The application of MCDM methods for enlarging the effectiveness of a building maintenance process

#### 4.1. Stages of multi-criteria analysis of a building maintenance process and the general scheme

Multi-criteria analysis of a building maintenance process can be separated into the following stages [21, 22]:

- Determination of typical interested parties affecting the effectiveness of the building maintenance process and information about the initial data.
  - Determining the variants a building maintenance process.
  - Determination of qualitative criteria list, their values and significances.
  - Determination of significances of criteria.
  - Determination of reliability of the expertise.
  - Multi-criteria analysis for the selection of the optimal variant and utility degree determination of projects.
  - Analysis of results and recommendations.
- Multi-criteria analysis scheme for building maintenance process is presented in Fig 1. The basic element of these stages is the application of a decision-making matrix and multi-criteria analysis of alternative projects.

The decision-making matrix for the maintenance process of a building is presented in Table 1, where columns contain  $n$  alternative projects that are being considered, while all qualitative information pertaining to them is found in the lines. Qualitative information is based on the criteria systems, units of measure, values and initial weights as well as the data on the alternative projects that are being development. In order to select the best project, it is necessary, having formed the decision-making matrix, to perform the multi-criteria analysis of the projects.

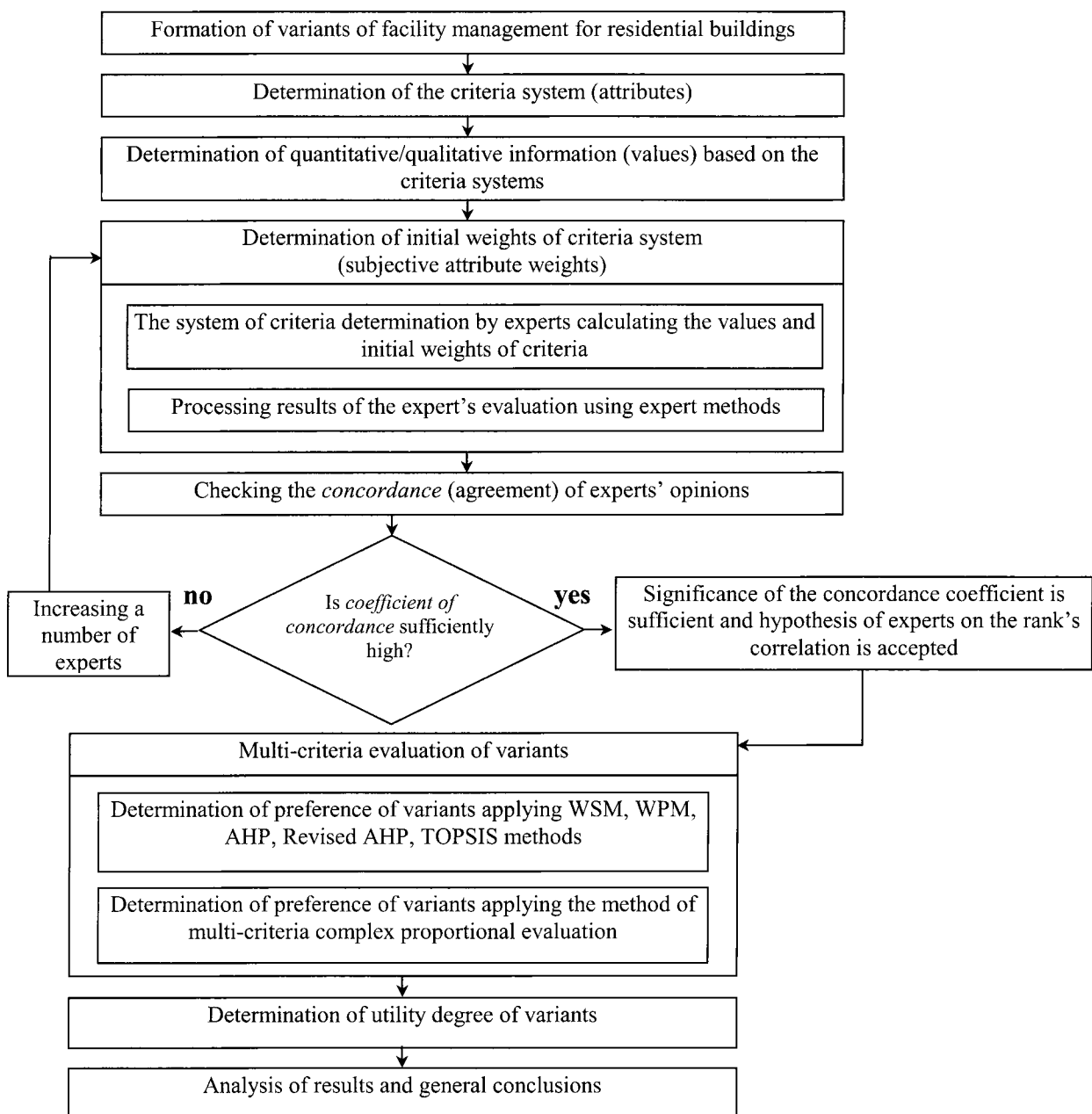


Fig 1. Block-scheme of multi-criteria analysis of a residential building maintenance process

**Table 1.** Decision making matrix M1 for the maintenance process of a building

Analysing criteria system		*	Weights	Units of measure	Evaluating alternatives					
					1	2	...	<i>j</i>	...	<i>n</i>
Qualitative criteria	$X_1$	$z_1$	$q_1$	$m_1$	$x_{11}$	$x_{12}$	...	$x_{1j}$	...	$x_{1n}$
	$X_2$	$z_2$	$q_2$	$m_2$	$x_{21}$	$x_{22}$	...	$x_{2j}$	...	$x_{2n}$
	...	...	...	...	...	...	...	...	...	...
	$X_i$	$z_i$	$q_i$	$m_i$	$x_{i1}$	$x_{i2}$	...	$x_{ij}$	...	$x_{in}$
	...	...	...	...	...	...	...	...	...	...
	$X_m$	$z_m$	$q_m$	$m_m$	$x_{m1}$	$x_{m2}$	...	$x_{mj}$	...	$x_{mn}$

\* Symbol  $z_i$  indicates accordingly the greater (less) value of criterion, which conforms to a customer's requirements

With reference to Table 1 the decision-making matrix of a building maintenance process is determined, where the data about this process is presented (available variants, system of criteria, units of measurements, values and initial weights of the criteria).

By comparing criteria numerical values and weights and analysing the conceptual information of the investigated project the above mentioned is performed. One of the major tasks is to determine the weights of the criteria. The significances of all criteria must be coordinated among themselves.

The system of criteria is determined and then experts calculate the values and initial weights of criteria. All this information can be corrected by the interested parties (customer, users, etc) by taking into consideration their pursued goals and the existing capabilities.

**4.2. Expert evaluation method application for determining the criteria weights**

To determine the weights of the criteria the expert evaluation method was used [21]. The block scheme of this method is presented in Fig 2. After the expert's examination estimate sets  $t_{jk}$  for statistical processing were obtained. The average of criteria value  $\bar{t}_j$  is calculated by the formula:

$$\bar{t}_j = \frac{\sum_{k=1}^r t_{jk}}{r}, \tag{1}$$

where  $t_{jk}$  – the estimate of  $j$ -th criterion by the  $k$ -th expert;  $r$  – number of experts.

Weights of criteria calculated dividing sum of criteria average values by each average value of the criterion:

$$\frac{\sum_{j=1}^n \bar{t}_j}{\bar{t}_j} \tag{2}$$

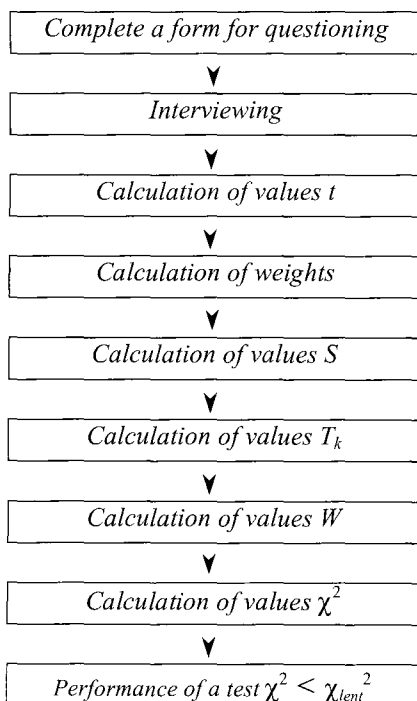
Weights sum of all criteria must be equal to one:

$$\sum_{j=1}^n \frac{\bar{t}_j}{\sum_{j=1}^n \bar{t}_j} = 1,0. \tag{3}$$

Reliability of the expertise can also be expressed by the coefficient of concordance (agreement) of experts' opinions by describing the extent of proximity of individual views that are determined according to the formula:

$$W = \frac{12S}{r^2(n^3 - n) - r \sum_{k=1}^r T_k}, \tag{4}$$

where  $S$  – sum of squares of deviation of total estimates of each criterion,  $T_k$  – index of related ranks in the  $k$ -th rank correlation;  $k$  – number of experts;  $n$  – number of evaluating criteria. This criterion must be equal or close to 1.



**Fig 2.** Block-scheme of an expert's evaluation method [21]

Deviation of criterion evaluation:

$$S = \sum_{j=1}^n \left[ \sum_{k=1}^r t_{jk} - \frac{1}{n} \sum_{j=1}^n \sum_{k=1}^r t_{jk} \right]^2, \quad (5)$$

where  $t_{jk}$  – the rank conferred by the  $k$ -th expert on the  $j$ -th criteria.

Significance of the concordance coefficient is calculated by the formula:

$$\chi^2 = \frac{12S}{rn(n+1) - \frac{1}{n-1} \sum_{k=1}^r T_k}. \quad (6)$$

This value must be greater than  $\chi_{lent}^2$  that is related to a number of freedom degrees and the adopted level of significance, then the hypothesis of experts on the rank's correlation is accepted.

Otherwise, when  $\chi^2 < \chi_{lent}^2$  is regarded, opinions or experts are not in agreement and they differ substantially.

## 5. Multi-criteria evaluation of dwelling facility management process

### 5.1. Determination of preference of variants applying WSM, WPM, AHP, Revised AHP and *Topsis* methods

When the weights of criteria have been calculated, the priority of variants is determined. For the problem with cardinal information on attributes, the efficient variant can be determined by applying WSM, WPM, AHP, Revised AHP and *Topsis* methods [20]. The weighted sum model (WSM) is the earliest and probably the most commonly applied. This method can be used in single dimensional problems, for calculations using actual values of criteria. The weighted product model (WPM) is very similar to the WSM and can be considered as a modification of the WSM, where the weaknesses of WSM method were eliminated. The WPM is sometimes called a dimensionless analysis because its structure eliminates any units of measure. An advantage of the method is that instead of the actual values it can use relative ones. The analytic hierarchy process (AHP), as proposed by Saaty (1980, 1994), decomposes a complex MCDM problem into a system of hierarchies. This method is more suitable to solving qualitative problems. Belton and Gear in 1983 proposed a model of a revised version of the original AHP method.

According to [20], when using classic AHP method the ranking can be incorrect, because the sum of relative values adds up to one. Therefore, the scientist proposed dividing each relative value by the maximum value of the relative values. Yoon and Hwang in 1980 developed the *Topsis* method as an alternative to the *Electre* method.

The basic concept of this method is that the selected alternative should have the shortest distance from the ideal solution and the farthest distance from the negative one.

When applying enumerated methods using the following steps, makes the ranking of a variant [20]:

- 1) Determination of alternatives and relevant criteria.
- 2) Attachment of numerical measures to the relative importance of the criteria and to the impacts of the alternatives on these criteria.

Processing the numerical values determines a ranking of each alternative.

### The application of the WSM method to determine the efficient variant of maintenance work and performance

One-dimensional problems are solved applying the weighted sum model (WSM) with calculations were actual values of criteria are used. If there are  $m$  alternatives and  $n$  criteria, then the best alternative is the one that satisfies (in maximisation case) the following expression (Fishburn, 1967) [20]:

$$A^*_{WSM-score} = \max_i \sum_{j=1}^n x_{ij} q_j \quad \text{for } i = 1, 2, 3, \dots, m. \quad (7)$$

By using the initial data from Table 2 the following results were calculated:

$$A^1_{WSM-score} = 6,1846345,$$

$$A^2_{WSM-score} = 8,3230241.$$

The results show that  $A_2 \succ A_1$ , where symbol  $\succ$  means "better than". Then, the best variant by priority is the second one ( $A_2 = 8,3230$ ).

### The application of the WPM method to determine the efficient variant of maintenance work and performance

The weighted product model WPM can be considered as a modification of the WSM. The WPM is sometimes called dimensionless analysis because its structure eliminates any units of measure (instead of the actual values it uses relative ones). For the most efficient alternative ( $A_k$  or  $A_j$ ) determination Bridgman in 1922, Miller and Starr in 1969 offered the following formula [20]:

$$R(A_k / A_L) = \prod_{j=1}^n \left( a_{kj} / a_{Lj} \right)^{q_j}. \quad (8)$$

Using the same data, the calculated result was:

$$R(A_1 / A_2) = 0,7418819 < 1.$$

The result shows that  $A_2 \succ A_1$ .

### The application of the AHP method to determine the efficient variant of maintenance work and performance

**Table 2.** Initial data for a building maintenance process multi-criteria analysis implementation

The criteria considered	*	Measuring units of criteria	Weights of criteria, $q_i$	Value of criteria, $x_{ij}$	
				Variant $A_1$ (directly employed labor)	Variant $A_2$ (joint stock company)
1. Work quality	+	points	0,1555	6,3793	8,9310
2. Convenience	+	points	0,0861	7,5862	7,7586
3. Beginning of the work	+	points	0,0833	6,0690	8,4483
4. Continuance of work	+	points	0,1335	6,2759	8,6207
5. Work fulfilling regularity	+	points	0,0717	6,0000	7,4483
6. Mastery level	+	points	0,1506	6,2069	8,6207
7. Safety assurance	+	points	0,1495	5,6207	8,4483
8. Level of insurance to health	-	points	0,0877	5,4483	7,4138
9. Environment cleaning	+	points	0,0822	6,2414	8,1034

\* The sign +(-) indicates that accordingly greater (less) value of criterion conforms to customers' requirements

By applying the AHP method for ranking, the expression analogous to WSM condition was used. The difference is that AHP uses relative values instead of the actual ones. Relative values are calculated by dividing each actual value by the sum of the criteria actual values [20]:

$$A^*_{AHP-score} = \max_i \sum_{j=1}^n x_{ij} q_j \text{ for } i = 1, 2, 3, \dots, m. \quad (9)$$

The result of the calculations was:  $A_1 = 0,4261$  and  $A_2 = 0,5740$ .

The result shows that  $A_2 > A_1$ . Then the best variant by priority is the second one ( $A_2 = 0,5740$ ).

**The application of the revised AHP method to determine the efficient variant of maintenance work and performance**

The authors of this method proposed dividing each relative value by the maximum value of the relative values to find the correct (revised) relative values. Next, a new alternative,  $A_3$ , must be introduced, which is an identical copy of the existing alternative  $A_2$  ( $A_2 \equiv A_3$ ). Then the new matrix was formed and applying the expression of the classic AHP method made the calculations [20]. The results calculated were:

$$A^1_{Revised AHP-score} = 0,2710217$$

$$A^2_{Revised AHP-score} = 0,3645392$$

The results show that  $A_2 \equiv A_3 > A_1$ . Then, the best variant by priority is the second one ( $A_2 = 0,3645392$ ).

**The application of the Topsis method to determine the efficient variant of maintenance work and performance**

The developers of the Topsis method state that each criterion has a tendency of monotonically increasing or decreasing the utility. Therefore it is easy to define the ideal and negative-ideal solutions. The Euclidean distance approach was proposed to evaluate the relative close-

ness of the alternatives to the ideal solution. Seeing that the Topsis method is widely applied, its steps are not given here [20]. Using the same initial data made the calculations and the results were:

The relative closeness to the ideal solution of first variant is:

$$C_{1*} = 0,1977208.$$

The relative closeness to the ideal solution of second variant is:

$$C_{2*} = 0,8023216,$$

$$C_{2*} / C_{1*} = 4,0578515.$$

The results show that the second variant is better than the first one, because its value of the relative closeness to the ideal solution is four times larger than the same value of the second variant. Moreover, the given value of first variant is nearer to 1, and the best following condition is met:

$$1 \geq C_{i*} \geq 0, \text{ were } i = 1, 2, 3, \dots, m,$$

$$C_{i*} = 1, \text{ if } A_i = A^* \text{ and } C_{ix} = 0, \text{ if } A_i = A^-.$$

The results of applying the methods have been put into Table 3. By analysing the results a conclusion can be made that the best variant is the second, when maintenance and renovation are performed by making a contract with the joint-stock company, which was selected by competition. Moreover, a greater difference between the results of the comparison was given by applying the Topsis method. It shows that this method can be considered as the best of those applied to solve the earlier defined problem.

**5.2. A method of multiple criteria complex proportional evaluation of a building lifetime**

After calculating the weights of criteria has been done, a method of multiple criteria complex proportional evaluation is applied for determining the priority and degree of the utility of alternatives [21, 22].

**Table 3.** The results of applying WSM, WPM, AHP, Revised AHP and *Topsis* methods

Variants	Methods				
	WSM ( $A_i^*$ )	WPM ( $R(A_k / A_L)$ )	AHP ( $A_i^*$ )	Revised AHP	<i>Topsis</i>
$A_1$ (directly employed labor)	6,1846	0,7419	0,4261	0,2710	0,1977
$A_2$ (joint stock company)	8,3230	1,3479	0,5740	0,3645	0,8023
Difference ( $A_2 / A_1$ )	<b>1,3458</b>	<b>1,8169</b>	<b>1,3471</b>	<b>1,3451</b>	<b>4,0579</b>
Percentage distance $A_2$ from $A_1$	<b>25,6924</b>	<b>44,9611</b>	<b>25,7676</b>	<b>25,6537</b>	<b>75,3564</b>
First variant degree of utility in comparison with second variant ( $A_1/A_2 \cdot 100\%$ )	<b>74,3%</b>	<b>55,0%</b>	<b>74,21%</b>	<b>74,4%</b>	<b>24,6%</b>

This method assumes direct and proportional dependence of significance and priority of the investigated versions on a system of criteria that adequately describes the alternatives and is based on the criteria values and significances. The criteria system is determined and then the experts calculate criteria values and initial weights. The information can be corrected by the interested groups by taking into account their goals and opportunities. By using the method of multi-criteria complex proportional evaluation, priority and significances of alternatives are determined by completing four steps.

**Step 1.** Evaluated normalised decision make matrix  $D$  is formed (Table 4). The aim of this step is to get unmeasured evaluated values from the compared indexes. If these values are known, all the criteria with different units of measure can be compared among them. It will gain by applying this formula:

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

where  $x_{ij}$  – the value of  $i$ -th criterion in  $j$ -th decision variant;  $m$  – number of criteria;  $n$  – number of comparative variants;  $q_i$  – the significance of  $i$ -th criterion.

The sum of the unmeasured estimated values  $d_{ij}$ -th of each  $x_i$ -th criterion must always be equal to significance  $q_i$  of the criterion:

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

In other words, the weights  $q_i$  of the criterion distributed in proportion to all the alternatives  $a_j$  takes into account it values  $x_{ij}$ .

**Step 2.** The sum of the evaluated normalised minimising (their less value) is better, for example, the price of a building  $S_{-j}$  and maximising (their greater value) is better, for example, workmanship level, safety assurance  $S_{+j}$  indexes characterising the  $j$ -th alternative and is calculated by:

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

In this case  $S_{+j}$  (the greater this value, the more goals of the interested groups is carried out) and  $S_{-j}$  (the less this value, the more goals of interested groups is carried out) values express the level of goals of the interested groups achievements.

In any case, the sums of  $S_{+j}$  and the sums of  $S_{-j}$  are always equal to the sums of significances of all minimising and maximising criteria:

$$S_{+} = \sum_{j=1}^n S_{+j} = \sum_{i=1}^m \sum_{j=1}^n d_{+ij},$$

$$S_{-} = \sum_{j=1}^n S_{-j} = \sum_{i=1}^m \sum_{j=1}^n d_{-ij}, \quad i = 1, m \quad j = 1, n. \quad (13)$$

Thus, in this way the calculation correction control could be made once more.

**Step 3.** The relative significance of comparative variants is determined according to positive  $S_{+j}$  and negative  $S_{-j}$  properties that characterise these alternatives. The relative significance  $Q_j$  of each alternative  $a_j$  is determined according to the formula:

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

**Step 4.** The priority  $Q_j$  of alternatives was calculated. The greater  $Q_j$ , the more effective it is on the alternatives.

Analysing the results, the author came to the conclusion that it is easy to evaluate and select a more effective alternative when this method of multi-criteria complex proportional evaluation is used. In addition, generalising criterion  $Q_j$  has a direct and proportional dependence on significance  $q_i$  and values  $x_{ij}$  of the investigated criteria and influences the final result.



**Table 4.** Evaluated normalised decision making matrix *D* and multi-criteria analysis results

The criteria considered	Measuring units of criteria	*	Weights of criteria	Numerical value of normalised evaluated criteria (matrix <i>D</i> )					
				1	2	...	<i>j</i>	...	<i>n</i>
$X_1$	$m_1$	$z_1$	$q_1$	$d_{11}$	$d_{12}$	...	$d_{1j}$	...	$d_{1n}$
$X_2$	$m_2$	$z_2$	$q_2$	$d_{21}$	$d_{22}$	...	$d_{2j}$	...	$d_{2n}$
...	...	...	...	...	...	...	...	...	...
$X_i$	$m_i$	$z_i$	$q_i$	$d_{i1}$	$d_{i2}$	...	$d_{ij}$	...	$d_{in}$
...	...	...	...	...	...	...	...	...	...
$X_m$	$m_m$	$z_m$	$q_m$	$d_{m1}$	$d_{m2}$	...	$d_{mj}$	...	$d_{mn}$
Sum of normalised evaluated criteria maximising values				$S_{+1}$	$S_{+2}$	...	$S_{+j}$	...	$S_{+n}$
Sum of normalised evaluated criteria minimising values				$S_{-1}$	$S_{-2}$	...	$S_{-j}$	...	$S_{-n}$
Significance of the alternative				$Q_1$	$Q_2$	...	$Q_j$	...	$Q_n$
Priority of the alternative				$Pr_1$	$Pr_2$	...	$Pr_j$	...	$Pr_n$
Utility degree of the alternative				$N_1$	$N_2$	...	$N_j$	...	$N_n$

\* The sign +(-) indicates that accordingly greater (less) value of criteria conforms to customers' requirements

Further, the example of solving the task of a building maintenance process effectiveness and enlargement by using the describing method is presented here. The initial data of the task described earlier is shown in Table 3.

**5.3. Practical application of the method of multi-criteria complex proportional evaluation on a building maintenance process**

According to (12)–(16) formulas presented in section 5.2 the results of multiple criteria analysis of a building maintenance process were calculated (Table 5).

Sums of  $S_{+j}$  and  $S_{-j}$  properties of all alternatives are equal according to the sums of significances of all minimising and maximising criteria ((15) formula). Solving the mentioned problem the values were calculated as:

$$S_+ = 0,9123, \quad S_- = 0,0877,$$

According to results presented in Table 5, the  $Q_2 \succ Q_1$ , where symbol  $\succ$  mean "better than". So, in accordance with the priority level of the alternatives, the better one is the second variant of the building's maintenance process ( $Q_2 = 0,6352$ ). The better and most efficient version is the one when maintenance work is carried out by contracts with joint-stock companies.

**5.4. Utility degree of variants of a building maintenance process**

Since a customer is more interested in the effectiveness level of one or an other alternative (especially

when it meets their interests), then when selecting the most efficient decision, it is better not to use the significance but the utility degree conception. By determining the utility degree of a building's maintenance process the variants are compared with the most efficient one. The degree of utility  $N_j$  of  $a_j$  alternative shows the level of goals reached by interested groups. The more and significant the goals reached the higher degree of the variant utility.

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

$$N_i = (Q_i / Q_{\max}) \cdot 100 \%, \quad (15)$$

where  $Q_i$  and  $Q_{\max}$  are significances of alternatives determined by the formula (15).

The degree of utility  $N_j$  of a building's life cycle is directly associated with the qualitative information that is related to it (criteria system, criteria values and weights). The higher (less) the significances of examining variant, the greater the increase (decrease) of its utility degree.

The degree of utility of examining variants was calculated by applying the multiple-criteria method for determining the utility degree of the projects (Table 4).

From the calculation it can be seen that the more efficient is the second variant, when the maintenance work is carried out by contracts with joint-stock companies. The degree of utility of this variant is  $N_2 = 100\%$  (Table 5) and is by 15 % higher than the first one, ie the second variant meets the requirements and goals of the interested parties more than the other.

**Table 5.** Dwelling facilities process alternatives multi-criteria analysis results and determination of the priority and utility degree of alternatives

The criteria considered	*	Measuring units of criteria	Weights of criteria $q_i$	Numerical value of criterion $d_{ij}$	
				1 variant	2 variant
1. Work quality	+	Points	0,1555	0,0648	0,0907
2. Convenience	+	Points	0,0861	0,0425	0,0435
3. Beginning of the work	+	Points	0,0833	0,0348	0,0485
4. Continuance of work	+	Points	0,1335	0,0562	0,0772
5. Work fulfilling regularity	+	Points	0,0717	0,0320	0,0397
6. Mastery level	+	Points	0,1506	0,0630	0,0875
7. Safety assurance	+	Points	0,1495	0,0597	0,0898
8. Level of health insurance	-	Points	0,0877	0,0371	0,0506
9. Environment cleaning	+	Points	0,0822	0,0358	0,0464
Sum of normalised evaluated criteria maximising values $S_{+i}$				0,3889	0,5234
Sum of normalised evaluated criteria minimising values $S_{-i}$				0,0371	0,0506
Significance of the alternative $Q_i$				0,5410	0,6352
Priority of the alternative				2	1
Utility degree of the alternative $N_i$				85 %	100 %

\* The sign +(-) indicates that accordingly greater (less) value of criteria conforms to customers' requirements

## 6. The concept of housing maintenance when the proprietary property management organisations are participating in the building maintenance

One of the conditions and abundance by it ensures the effective property maintenance, is the professionally fulfilled work and services. Constant changes are found in the property market.

Authors Liias, Ždankova, Kursis, Fine in 1998, Malinauskas in 2001 noticed that recently the main feature of changes is the transition from a regulated and centralised market to an uncontrolled and divided one that separates unprofessional units with conflicting attitudes and interests [1–5, 27]. To improve the situation in dwellings, consulting services have been organised. However, unprofessional individuals have the final possibility of choosing alternative actions. Liias states that the Dwelling Owners Associations (DOA) cannot fulfill their main function, ie to maintain the building properly and professionally [1, 2, 5]. Nonetheless, when implementing their defined activities the DOA can also be the cause of potential problems for the society. These problems include the rapid process of a building's deterioration and the irreversible recession of housing stocks. Finally, the situation can require high investments from a society. For solving the recent problems it is necessary to create universal logistics, which will ensure sequential housing management that will maintain the property's value. Dwelling Owners Association (DOA) is not only the building and its owners; it is also communications, equipment and land. Managing property the need of complex services for property management occurs.

Building exploitation and maintenance, property evaluation, facility management, mediator's services in

market and consulting are on the list of these services [29]. The principles of activities of facility management organisations were widely described in 2001 in the works of Swistock [30] and McGregor [29]. Recently facility management organisations in Lithuania offer two kinds of services: first – executive maintenance, second – technical maintenance. Therefore the owner of a building is constrained to make the building maintenance on his/her own. In this situation a building's owner has to make contracts with many organisations for different kinds of maintenance services. This requests additional resources as well as work and time expenditures. The new scheme for a building maintenance and its facility management (Fig 3) lets one use rational resources and better work and time expenditures. This can be easily applied to different property types: eg the housing sector, commercial and public buildings, industrial buildings, uninhabitable buildings and others [28, 31–32].

According to this model, owners of a building should have another way of solving maintenance problems. Then the distribution of maintenance functions will be as follows:

- The owner implements only customer's functions making payments for services;
- The facility management organisation fulfills all work related to a building's maintenance and repairing, perspective strategies of inspections management occurs, renovations, and all the total complex of services that were stipulated in the contract.

Then the main task of a facility management organisation would be effective building maintenance and management. Swistock states that it is worthwhile making a contract with facility management organisation for the following reasons:

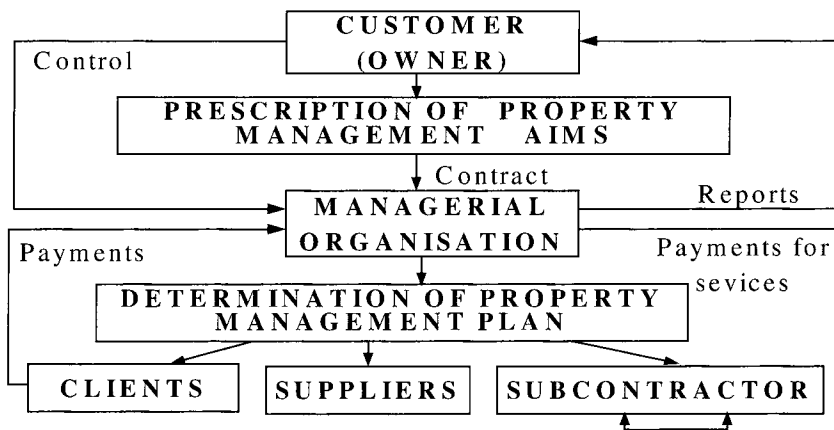


Fig 3. Scheme for facility management when the managerial organisation participates

- Often DOA members or workers on a building maintenance subdivisions in organisations cannot fulfil special work because they do not have enough competencies in the maintenance field. The quality of the same work fulfilled by a facility management organisation would be better and the work organisation more efficient.
- The specifics of a building maintenance process and quickly changing technologies require new investments in special staff preparation, equipment, materials and information technologies.
- For the DOA and not maintenance organisations, it is not expedient to make large investments for specific maintenance purposes.
- Work processes of low technology require a larger work force. Routine work would be cheaper if the facility management staff and organisations fulfil these functions.

## 7. Conclusions

1. The multiple analysis of a building maintenance process allows one to evaluate how different decisions meet the requirements and possibilities of the customers, users and others participants in this process. Using a quantitative and qualitative criteria system, values and the importance of criteria that have been evaluated by their weights and express their requirements.

2. For determining an effective variant of a dwelling maintenance work and performance, the methods WSM, WPM, AHP, Revised AHP, *Topsis* were applied. The method of multi-criteria complex proportional evaluation was offered to determine the effective variant of a dwelling maintenance work and performance. The results of the calculations were compared.

3. The initial weights of criteria were calculated by using the method of an expert's evaluation.

4. According to results presented in Table 3 and 5, the better and most efficient variant is the one when maintenance is carried out by contracts with joint-stock companies. Taking into account the requirements of the

building's users, the analysis of a building maintenance process, was performed.

5. Using the offered method of multi-criteria complex proportional an evaluation of the variants the relative significance  $Q_j$  was calculated. It shows the relative influence of the values of the compared criteria that are made for the complex effectiveness of different decisions.

6. The utility degree  $N_j$  of the variant evaluates, in a complex way, the positive and negative properties of different decisions. The degree of utility  $N_j$  of a building maintenance process directly depends on the qualitative information that is related to it (eg criteria system, criteria values and weights).

7. Leading results of the analysis the maintenance problems was enumerated and factors, which determine the appearance of problems, were indicated and problem decisions methods were offered.

8. Property management has to be a field of private managerial structures, because competition in the market stimulates them to raise the work quality and its effectiveness. Professional property management ensures the solving of problems related to building maintenance in complex way.

9. There are few facility management specialists in Lithuania and people who work in the facility management field need more experience. Facility management in Lithuania needs more opportunities and a correct legislative system, property accounting, standard maintenance procedures and a control system. When these aspects will be implemented, the best property usage can be achieved.

10. A new scheme for building maintenance and facility management, ie when the facility management organisation is participating, has been offered. By implementing the maintenance by this model the work can be organised more efficiently. The given scheme allows one to use more rational resources, better work and time expenditures. It can be easily applied to different property types: the housing sector, commercial and public buildings, industrial buildings, uninhabitable buildings etc.

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