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NORMALIZATION OF QUANTITIES OF VARIOUS DIMENSIONS

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Abstract. Currently used methods of multiple criteria evaluation (MEM) based on the values obtained allow us to establish the priority order of the considered object's alternatives. However, they do not allow us to determine the values of multicriteria evaluation of a particular alternative taken out of their context. This restricts the range of MEM applications. To expand the application area of the methods, we should know how the criteria of a particular alternative describing the object considered which are expressed in different dimensions, can be normalized. This can be achieved by dividing any different value by the respective quantity of the same dimension. The task is complicated by the fact that these quantities should be comparable for all the criteria.

Keywords: multicriteria evaluation methods, data normalization.

1. Introduction

In recent years, multicriteria evaluation methods have been widely used in solving both theoretical and practical problems. Actually, these methods are universal because they allow us to quantitatively evaluate any complicated object described by a set of criteria. Another advantage of these methods is their ability to combine both maximizing and minimizing criteria expressed in various dimensions into one integrated criterion. The maximizing criteria imply that, if their values are growing, the situation is getting better, while for minimizing criteria this means a worsening situation. The integration is achieved by normalization which helps to convert all the criteria values into non-dimensional, i.e. comparable quantities.

Many similar assignments, involving various technical, social and other problems have been solved. For example, the following problems have been solved in construction: evaluation of the efficiency of rural buildings' projects (Ustinovičius *et al.* 2006), the efficiency of investments (Ustinovičius, Ševčenko, Kočin 2006; Zavadskas *et al.* 2006; Ustinovičius, Ševčenko 2007; Ustinovičius, Kočin, Ševčenko 2007), economical efficiency of plots for building construction of a particular type (Šarka, Budinas, Šarkienė 2004; Šarka, Šarkienė, Budinas 2005), the efficiency of investments into multi-storied residential buildings (Ustinovičius, Šarkienė 2006), the efficiency of architectural solutions and investments into the construction of individual dwelling houses (Ustinovičius, Šarkienė, Šarka 2003; Šarkienė, Ustinovičius, Šarka 2005, 2006), the efficiency of construction contracts and the selection of contractors (Ustinovičius *et al.* 2005a, 2005b, 2007; Ashikhmin *et al.* 2006; Turskis *et al.* 2008; Ustinovičius, Barvidas, Ashikhmin 2007), the comparison of the available construction alternatives (Migilinskas, Ustinovichius 2004, 2006a, 2006b; Popovas, Ustinovichius, Mikalauskas 2004), the alternatives of the repair and selling of office premises (Ustinovichius, Podvezko, Ginevičius 2006), selection of building sites for commercial buildings (Ustinovichius, Kochin, Narkevičiūtė 2004; Larichev, Kochin, Ustinovichius 2003; Zavadskas, Ustinovichius, Stasiulionis 2004; Stasiulionis, Ustinovičius 2003a, 2003b; Karablikovas, Ustinovičius 2002), etc.

A great number of social and economic problems have been solved applying multicriteria evaluation methods and commonly used normalization (Ginevičius, Podvezko 2000, 2001, 2003, 2004a, 2004b, 2004c, 2005, 2007a, 2007b; Ginevičius, Mikelis 2002; Podvezko, Ginevičius 2003; Ginevičius, Podvezko, Mikelis 2004, 2006; Гинявичюс, Подвезько 2004; Gineičius, Podvezko, Ustinovičius 2005a, 2005b; Ginevičius, Podvezko, Andruškevičius 2007).

A number of these publications consider the problems of education (Ginevičius, Podvezko, Ginevičienė 2004a, 2004b, 2004c; Гинявичюс, Подвезько, Гинявичене 2005).

Multicriteria methods are even used in the analysis of medical problems (Kochin, Ustinovichius, Sliesoraitiene 2005; Ustinovichius *et al.* 2005, 2006).

On the other hand, the currently used methods of multicriteria evaluation have some drawbacks, limiting the range of their application. These drawbacks do not negatively affect calculations only if multicriteria evaluation is aimed at establishing the priority order of the considered object's alternatives. Normalization methods of the criteria of various dimensions are also used for this purpose, when their normalized values are obtained, for example, by dividing the value of the j-th criterion by the sum of all its values for all the alternatives of the object considered. In this case, the normalized value of the j-th criterion for one particular alternative can be determined from the context, i.e. it is influenced by the values of the same criterion of other alternatives. However, the need often arises to get the value of multicriteria evaluation of one particular alternative. The alternatives may represent the level of economic and social development in various regions of the country as an object of consideration. It may also be the level of higher school development as an object of consideration in a particular school, the efficiency of an enterprise's commercial and economic activities as an object of consideration, etc. This would allow us to consider the effect of various factors on these criteria and to assess the state of the considered object separately, not taking into account other alternatives. This approach could reveal a new area of practical and theoretical application. The present paper addresses this problem.

2. Currently used multicriteria evaluation and data normalization methods

In recent years, many various multicriteria quantitative and qualitative evaluation methods of different complexity have been used (Zavadskas 1991; Ustinovičius 2001a, 2001b; Hwang, Yoon 1981; Hwang, Lin 1987; Saaty 1994, 1980; Beuthe, Scannella 2001). Qualitative methods based on expert judgement can be used to determine the best of the suggested alternatives or several best options (Hokkannen, Salminen 1997; Ginevičius, Podvezko 2001, 2003; Ginevičius, Podvezko, Mikelis 2004; Beshelev, Gurvich 1974; Yevlanov 1984; Fan, Ma, Tian 1977; Zavadskas 1991; Ustinovičius 2001a, 2001b; Hwang, Yoon 1981; Hwang, Lin 1987; Saaty 1994, 1980; Beuthe, Scannella 2001; Brans, Vincke, Mareschal 1986; Opricovič, Tzeng 2004; Roy 1996; Zavadskas, Kaklauskas 1996; Larichev, Moshkovich 1977; Larichev 1979). Quantitative methods quantitatively evaluate each alternative determining the differences in the values obtained for the alternatives considered. The essence of multicriteria evaluation can be clearly shown by the so-called SAW (Simple Additive Weighting) method expressed as:

$$S_j = \sum_{i=1}^{m} \omega_i \tilde{r}_{ij}, \tag{1}$$

where S_j is the value obtained in multicriteria evaluation of the j-th alternative; ω_i is the i-th criterion weight; $\tilde{r}_{ij}$ is normalized value of the i-th criterion for the j-th alternative.

As can be seen from the formula (1), you should have normalized values of the criteria to determine the quantity of multicriteria evaluation. The sequence of normalization operations depends on the methods of multicriteria evaluation used. Calculating by SAW, normalization is based on the formula (Ginevičius, Podvezko 2004b; Ginevičius, Butkevičius, Podvezko 2005):

$$\tilde{r}_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}}, \tag{2}$$

where r_{ij} is the i-th value of the j-th alternative.

SAW can also rely on the following method of maximizing criteria normalization (Zavadskas 1991; Ustinovičius 2001a, 2001b; Hwang, Yoon 1981):

$$\tilde{r}_{ij} = \frac{r_{ij}}{\max_j r_{ij}}, \tag{3}$$

where $\max_j r_{ij}$ is the largest value of the criterion considered.

Multicriteria evaluation by using complex proportional assessment method (COPRAS) relies on the formula (Zavadskas *et al.* 2004):

$$K_j = S_{+j} + \frac{S_{-\min}\sum_{j=1}^{n} S_{-j}}{S_{-j}\sum_{j=1}^{n}\frac{S_{-\min}}{S_{-j}}}, \quad (4)$$

where K_j is the value obtained by COPRAS for the j-th alternative; $S_{+j} = \sum_{i=1}^{m}\tilde{r}_{+ij}$ is the largest sum of the weighted values $\tilde{r}_{+ij}$ of the j-th maximizing criteria (i.e. those whose largest value is the best) for all m alternatives; $S_{-j} = \sum_{i=1}^{m}\tilde{r}_{-ij}$ is the same for the j-th minimizing criteria (i.e. those whose smallest value is the best).

When calculating by COPRAS, data normalization is performed in this way:

$$\tilde{r}_{ij} = \frac{r_{ij}\omega_i}{\sum_{j=1}^{n} r_{ij}}. \quad (5)$$

Multicriteria evaluation method TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) is based on the criterion C_j^* (Hwang, Yoon 1981; Hwang, Lin 1987; Opricovič, Tzeng 2004):

$$C_j^* = \frac{D_j^-}{D_j^* + D_j^-} \; (j = 1, \ldots, n), \quad (6)$$

where C_j^* is the value obtained by TOPSIS for the j-th alternative; D_j^- is the total distance of the j-th alternative to the worst solutions; D_j^* is the same for the best solutions.

When calculating by TOPSIS, vector normalization of data is used:

$$\tilde{r}_{ij} = \frac{r_{ij}}{\sqrt{\sum_{j=1}^{n} r_{ij}^2}} \; (i = 1, \ldots, m; j = 1, \ldots, n). \quad (7)$$

The following type of normalization is actually provided for by TOPSIS (Hwang, Yoon 1981; Hwang, Lin 1987; Opricovič, Tzeng 2004):

$$\omega_i r_{ij} = \frac{\omega_i r_{ij}}{\sqrt{\sum_{j=1}^{n} r_{ij}^2}}. \quad (8)$$

Multicriteria evaluation method VIKOR (Opricovič, Tzeng 2004; Ginevičius, Podvezk 2004) relies on the main generalizing criterion Q_j calculated by the formula:

$$Q_j = \frac{\nu (S_j - S^*)}{S^- - S^*} + \frac{(1-\nu)(R_j - R^*)}{R^- - R^*}, \quad (9)$$

where Q_j is the value of the j-th alternative obtained by VIKOR; $S^* = \min_j S_j$, $S^- = \max_j S_j$, $R^* = \min_j R_j$, $R^- = \max_j R_j$, v is the weighted value of the most criteria.

VIKOR uses the following method of data normalization:

$$\tilde{r}_{ij} = \frac{\max_j r_{ij} - r_{ij}}{\max_j r_{ij} - \min_j r_{ij}}, \; (0 \le \tilde{r}_{ij} \le 1). \quad (10)$$

As shown by the formulas (2, 3, 5, 7, 8 and 10), in all cases, the normalized value of the i-th criterion of the j-th alternative is derived from the i-th criterion values of all other alternatives. Therefore, this normalization logic is well suited when the aim of multicriteria evaluation is ranking of the alternatives referring to the object considered. However, this approach is not suitable when it is aimed at assessing one particular alternative by a multicriteria evaluation method because, in this case, every value of the considered alternative should be converted into a non-dimensional quantity.

3. Normalizing the criteria of one particular alternative of the considered object

Assume that we have four alternatives of the considered object. Every alternative is described by eight criteria. Their weights as well as the initial, non-normalized values are given in Table 1.

Table 1. The data on the alternatives of the considered object

Criteria	Criteria weights	Units of criteria measurement	Alternatives			
			1st	2nd	3rd	4th
1st	0,23	lt.	800	5 000	1 200	12 000
2nd	0,20	kg	50	150	10	90
3rd	0,18	km	256	145	340	100
4th	0,13	units	4	1	2	9
5th	0,10	%	36	48	32	78
6th	0,08	lt.	80	52	161	314
7th	0,05	%	12	36	45	78
8th	0,03	t	18	3,6	4,1	5,6

Let us normalize the data from Table 1 for multicriteria evaluation by SAW method aimed at determining the priority order of the alternatives (Table 2). The calculations will be made by formula 2.

Table 2. Normalized data on the considered object's alternatives

Criteria	Criteria weights	Alternatives			
		1st	2nd	3rd	4th
1st	0,23	0,042	0,2632	0,0632	0,6316
2nd	0,20	0,167	0,5	0,033	0,3
3rd	0,18	0,3044	0,1724	0,4042	0,1190
4th	0,13	0,25	0,0625	0,125	0,5625
5th	0,10	0,1856	0,2474	0,1649	0,4021
6th	0,08	0,1318	0,0857	0,2652	0,5173
7th	0,05	0,0702	0,2105	0,2632	0,4561
8th	0,03	0,1192	0,2384	0,2715	0,3709

Let us evaluate by SAW method the alternatives of the object considered, based on Table 2. The following results were obtained (Table 3).

Table 3. The data obtained in multicriteria evaluation of the considered object's alternatives by SAW method

Criteria	Alternatives			
	1st	2nd	3rd	4th
Value	0,1634	0,2538	0,1692	0,4153
Rank	4th	2nd	3rd	1st

As shown in Table 2, normalization was made horizontally, i.e. the values of the alternatives of each criterion were summed up, and, then, all criterion values of these alternatives were divided by this number. Our aim was to make vertical data normalization, i.e. to convert all values of the considered alternative to non-dimensional quantities, not taking into account the criteria values of other alternatives. The formula (2) is not suited because we cannot sum up the criteria values of various dimensions.

To turn a quantity of a particular dimension into a dimensionless value, it should be divided by a value of the same dimension. In the case considered, this number should be found for each criterion. The question arises, what number it should be. Since we want to perform normalization, the normalized value should be smaller than or at least equal to one (unity). Therefore, this number may be equal to or larger than the largest possible criterion value. There are several methods of solving this problem. The first one relies on the largest value of the criterion which is taken as the largest quantity. The second method is based on the values determined by experts. In this paper, we use a simple first method. Thus, basing ourselves on the data presented in Table 1, we will get the following largest values of the alternatives (Table 4).

Table 4. The largest possible values of the criteria

Indicators	Criteria							
	1st	2nd	3rd	4th	5th	6th	7th	8th
Unit of measurement	lt.	kg	km	units	%	lt	%	t
The largest criterion value	12 000	150	340	9	78	314	78	5,6

Based on the data from Table 4, we can turn the values from Table 1 into non-dimensional quantities. This can be achieved by applying a data normalization method based on the formula (3) (see Table 5).

Table 5. Non-dimensional values of the considered object's alternatives

Criteria	Criteria weights	Alternatives			
		1st	2nd	3rd	4th
1st	0,23	0,0667	0,4167	0,1	1,0
2nd	0,20	0,3334	1,0	0,0667	0,6
3rd	0,18	0,7794	0,4265	1,0	0,2942
4th	0,13	0,4444	0,1111	0,2222	1,0
5th	0,10	0,4615	0,6154	0,4102	1,0
6th	0,08	0,2548	0,1656	0,5127	1,0
7th	0,05	0,1538	0,4615	0,5769	1,0
8th	0,03	0,3214	0,6429	0,7321	1,0

Now, we can perform multicriteria evaluation of the considered object's alternatives by using the method SAW (Ginevičius, Podvezko 2005). The calculation results are given in Table 6.

Table 6. The results obtained in multicriteria evaluation of the considered object's alternatives

Criteria	Alternatives			
	1st	2nd	3rd	4th
Value	0,3640	0,5041	0,3780	0,7930
Rank	4th	2nd	3rd	1st

As shown in Table 6, the sequence of the considered value's alternatives based on their advantages has not changed compared to that presented in Table 3. However, we are interested in the fact how much the alternative evaluation values have changed, depending on the multicriteria evaluation method used, rather than in the priority order of the alternatives. We can easily see that they have increased. The relationship between the values is given in Table 7.

Table 7. Comparison of the results obtained in multicriteria evaluation of the considered object's alternatives, depending on the normalization method used

Criterion	Alternatives			
	1st	2nd	3rd	4th
The relationship between the respective numbers from Table 7 and Table 3	2,228	1,986	2,235	1,909

As seen in Table 7, the results of multicriteria evaluation differ by about two times, depending on the normalization method applied. This is a considerable difference, therefore, the use of some results in further research can be of particular importance. Thus, the suggested data normalization method is a valuable option.

4. Conclusions

1. Depending on the aim of multicriteria evaluation of the available alternatives, two groups of objects can be distinguished. The first group includes the cases when multicriteria evaluation is aimed at establishing the priority order of the alternatives, while the second group embraces the cases when multicriteria method is aimed at assessing one particular alternative. Therefore, the above cases differ in the final aim of applying multicriteria methods to the evaluation of alternatives. In one case, the final aim is to arrange the alternatives in the priority order, while in the second – to use the value obtained as a basis for further research.
2. Now, methods of normalizing the data describing the alternatives of the object considered are clear if multicriteria evaluation is aimed at establishing the priority order of alternatives. In this case, the values of all the alternatives of a particular criterion are compared with each other in unit fractures, implying that normalization is horizontal. However, for only one available alternative of the considered object the problem of normalization has not been solved yet. It is necessary to normalize the criteria values of various dimensions in this case if we want to apply multicriteria evaluation methods, and data normalization is vertical.
3. In order to combine the data on the criteria describing the considered object into a single integrated quantity, i.e. to perform multicriteria evaluation, all the data should be non-dimensional. This can be achieved by dividing each criterion expressed in a particular dimension by a particular value of the same dimension. Therefore, the main problem in this case is to find such a value for performing normalization of quantities having various dimensions. This problem is complicated because the values expressed in different dimensions should be compared, otherwise, normalized values of various criteria would not be compared.
4. The above values can be found in two ways. In the first case, the values considered are determined by experts. In the second case, we take the largest criteria values of all considered alternatives. The largest values recorded over a certain period of time can be taken.
5. The results obtained in multicriteria evaluation of the considered object's alternatives show that the values differ by about two times depending on the normalization method used. This shows that it is necessary to use one of normalization methods, depending on the aim of multicriteria evaluation.
6. The suggested method of data normalization indicates a new trend of applying multicriteria evaluation methods to solving various complicated problems, e.g. determining the relationship between two complex quantities which are described by a number of criteria expressed in various dimensions.

References

Ashikhmin, V.; Kocin, D.; Ustinovichius, L.; Barvidas, A. 2006. DSS UniComBOS for engineering and construction contracts, *Akademicka oficina wydawnica EXIT,* BOS 2006, Warzawa, 117–130.

Beshelev, S. D.; Gurvich, S. D. 1974. *Mathematical-statistical expert methods*. Moscow: Statistics.

Beuthe, M.; Scannella, G. 2001. Comparative analysis of UTA multicriteria methods, *European Journal of Operational Research* 130: 246–262.

Brans, J. P.; Vincke, PH.; Mareschal, B. 1986. How to select and how to rank projects: The PROMETHEE method, *European Journal of Operational Research* 24: 228–238.

Fan, Z.; Ma, J.; Tian, P. 1977. A subjective and objective integrated approach for the determination of attribute weights, in *Materials of 4th Conference of International Society for Decision Support Systems*.

Ginevičius, R.; Butkevičius, A., Podvezko, V. 2005. Multicriteria evaluation of economic development of new EU member-states, *Verslas: teorija ir praktika* [*Business: theory and practice*] 6(2): 85–93.

Ginevičius, R.; Mikelis, D. 2002. Efficiency of investments into socio-economic development of regions, *Verslas: teorija ir praktika* [*Business: theory and practice*] 2(2): 89–95.

Ginevičius, R., Podvezko, V. 2003. Quantitative evaluation of significance of hierarchically structured indexes, in *Modeling and Simulation of Business Systems international conference, May 13-14, 2003, Vilnius, Lithuania / Kaunas University of Technology, Vilnius Gediminas Technical University, Institute of Mathematics and Informatics, Law University of Lithuania, Lithuanian Operational Research Society within EURO (LitORS), The Association of European Operational Research Societies, Baltic Operational Research Society (BaltORS).* Kaunas: Technologija, 22–25.

Ginevičius, R.; Podvezko, V. 2004a. Assessing the accuracy of expert methods, *Inžinerinė ekonomika* 5(40): 7–12.

Ginevičius, R.; Podvezko, V. 2004b. Complex evaluation of the use of information technologies in the Countries of Eastern and Central Europe, *Journal of Business and Economics Management* 5(4): 183–191.

Ginevičius, R.; Podvezko, V. 2004c. Quantitative assessment of regional development, *Aplinkos tyrimai, inžinerija ir vadyba* 1(27): 10–14.

Ginevičius, R.; Podvezko, V. 2001. Complex evaluation of economic-social development of Lithuanian regions, *Statyba* [Civil Engineering] 7(4): 304–309.

Ginevičius, R.; Podvezko, V. 2000. Complex evaluation of efficiency of economic activities at construction enterprises, *Statyba* [Civil Engineering] 6(4): 278–288.

Ginevičius, R.; Podvezko, V. 2005. Complex evaluation of the financing activities of construction enterprises, in *Podium: 10 Internationales Kolloquium Planungsinstrumente für das Projektmanagement am 19 und 20 Mai 2005 in Leipzig: Sonderheft 2005. 11 Jahrgang* Jg. 11, Sonderheft 1, 13–15.

Ginevičius, R.; Podvezko, V.2003. Determination of weightiness of cascade-structured organisation according to the indices of its commercial activity, in *9th German--Lithuanian-Polish Colloquium „Planning Instruments in Construction Management“. Poznan-Kolobrzeg, 28-31 May 2003*, *Program and abstracts*. Poznan, 19.

Ginevičius, R.; Podvezko, V. 2007a. Some problems of evaluating multicriteria decision methods, *International Journal of Management and Decision Making* 8(5/6): 527–539.

Ginevičius, R.; Podvezko, V. 2007b. Complex assessment of sustainable development of state regions with emphasis on ecological and dwelling conditions, *Ekologija* 53(Supplement): 41–48.

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

Ginevičius, R.; Podvezko, V.; Ginevičienė, V. B. 2004a. A complex evaluation of the work productivity of university teaching staff, in *8th Baltic Region Seminar on Engineering Education. Kaunas University of Technology, Kaunas, Lithuania, 2-4 September 2004: seminar proceedings*. Clayton : Monash University, 44–46.

Ginevičius, R.; Podvezko, V.; Ginevičienė, V. B. 2004b. The multicriteria evaluation of university subdivisions, in *International Symposium on New Methods and Curricula in Engineering Education in a New Europe. Valladolid 14-16th October 2004: abstracts.* Universidad de Valladolid, Escuela Universitaria Politécnica. Valladolid, 1.

Ginevičius, R.; Podvezko, V.; Ginevičienė, V. B. 2004c. Quantitative evaluation of university teaching staff work efficiency, in *New Teaching and Learning Methods: How Effective Are They?: New Methods and Curricula in Engineering Education in a New Europe.* Valladolid, 82–93.

Ginevičius, R.; Podvezko, V.; Mikelis, D. 2004. Quantitative Evaluation of Economic and Social Development of Lithuanian Regions, *Economics: scientific publications* 65: 67–81.

Гинявичюс, Р.; Подвезько, В.; Микялис, Д. 2006. Система оценки социально-экономического развития регионов, in *Polityka rozwoju państw Europy Środkowowschodniej. Aspekty makroekonomiczne i regionalne*. Włocławek: Lega, 211–224.

Ginevičius, R.; Podvezko, V.; Ustinovičius, L. 2005a. Complex evaluation of the development of „New Economy“ in transition economy states, in *SMRSSL'05. The International Symposium on Stochastic Models in Reliability Safety, Security and Logistics: Sami Shamoon College of Engineering. Beer Sheva, February 15-17, 2005: proceedings.* Beer Sheva–Riga, 132–136.

Ginevičius, R.; Podvezko, V.; Ustinovičius, L. 2005b. Complex evaluation of the development of „New Economy“ in transition economy states, in *SMRSSL'05. International Symposium on Stochastic Models in Reliability Safety, Security and Logistics: Sami Shamoon College of Engineering. Beer Sheva, February 15-17, 2005: program and book of abstracts*. Beer Sheva–Riga, 51.

Hokkannen, J.; Salminen, P. 1997. ELECTRE III and IV decision aids in an environmental problem. *Journal of Multi–Criteria Decision Analysis* 5(6): 215–226.

Hwang, C. L.; Yoon, K. 1981. *Multiple attribute decision making-methods and applications. A state of the art survey*. Springer Verlag, Berlin, Heidelberg, New York.

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

Yevlanov, L. G. 1984. *Theory and practice of decision-making*. Moscow: Economics.

Karablikovas, A.; Ustinovičius, L. 2002. Daugiabučių namų stogų racionalių remonto būdų parinkimas, taikant daugiakriterinius įvertinimo metodus, *Inžinerinė ekonomika* 3(29): 24–31.

Kochin, D.; Ustinovichius, L.; Sliesoraitiene, V. 2005. Implicit learning system for teaching the art of acute cardiac infarction diagnosis, *Lecture Notes in Artificial Intelligence (Subseries of Lecture Notes in Computer Science* 3581: 395–399.

Larichev, O. I. 1979. *Know-how of decision-making*. Moscow, Science.

Larichev, O. I.; Moshkovich, H. M. 1977. *Verbal decision analysis for unstructured problems.* Kluwer Academic Publishers Boston.

Larichev, O.; Kochin, D.; Ustinovichius, L. 2003. Multicriteria method of choosing the best alternative for investments, *International Journal of Strategic Property Management* 7(1): 33–43.

Migilinskas, D.; Ustinovichius, L. 2006a. Computer-aided modelling, evaluation and management of construction projects according to PLM concept, *Lecture Notes in Computer Science* 4101: 242–250.

Migilinskas, D.; Ustinovichius, L. 2006b. Uncertainties in construction's decision making. Simulation and optimization in business and industry, in *Proceedings of the International Conference held in Talinn, Estonia 17–20th May 2006*, 17–22. ISBN 9955-25-061-5.

Migilinskas, D.; Ustinovičius, L. 2004. An analysis of inaccuracy effect in solving construction technology and economy problems, applying games theory, in *The 8th International conference MODERN BUILDING MATERIALS, STRUCTURES AND TECHNIQUES. Selected papers, 2004, 229–235.* ISBN 9986-05-757-4.

Opricovič, S.; Tzeng, G.-H. 2004. Compromise solution by MCDM methods: A comparative analysis of VIKON and TOPSIS, EJOR, *European Journal of Operational Research* 156: 445–455.

Podviezko, V.; Ginevičius, R. 2003. Issues of the quantitative assessment of regional development, in *SIID-2003. International Conference on Sustainability Indicators and Intelligent Decisions. 9-11 October 2003, Vilnius, Lithuania: abstracts of papers. Baltic Ecological Information Dissemination System (BEIDS), National Commission of Sustainable Development of Lithuania, Institute of Geology and Geography, Vilnius*. Vilnius, 21–22.

Popovas, V.; Ustinovichius, L.; Mikalauskas, S. 2004. Technique for computer aided evaluation of economic indicators of a construction project, in *Modern Building Materials, Structures and Techniques. The 8th International conference MODERN BUILDING MATERIALS, STRUCTURES AND TECHNIQUES*. Selected papers, 290–297. ISBN 9986-05-757-4.

Roy, B. 1996. *Multicriteria methodology for decision aiding*. Kluwer Academic Publishers Dortrecht.

Saaty, T. L. 1994. *Fundamentals of decision making and priority theory with the AHP*. RWS Publication, Pittsburgh, PA, USA.

Saaty, T. L. 1980. *The analytic hierarchy process*. M.Graw-Hill, New York.

Stasiulionis, A.; Ustinovičius, L. 2003a. Komercinių objektų konstrukcijų ir statybos projektų daugiakriterinė analizė ir raida, *Ūkio technologinis ir ekonominis vystymas* 9(1): 3–12.

Stasiulionis, A.; Ustinovičius, L.2003b. Komercinės paskirties objektų rodiklių sistema ir analizė investicijų aspektu, *Ūkio technologinis ir ekonominis vystymas* 9(3): 105–115.

Šarka, V.; Budinas, S.; Šarkienė, E. 2004. Model of economic evaluation of hotel construction based on multiple criteria decision synthesis methods, in *The 8th International conference „Modern building materials, structures and techniques“*: Selected papers, ed. by E. K. Zavadskas, P. Vainiūnas, F. M. Mazzolani, Vilnius: Technika, 260–267.

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

Šarkienė, E.; Ustinovičius, L.; Šarka, V. 2006. A Model for evaluating the investment in the construction of dwelling houses based on multiple criteria decision synthesis methods, in *Multiple Criteria Decision Making '05*, scientific publications, edited by Tadeusz Trzaskalik, Katowice: The Karol Adamiecki University of Economics in Katowicie, 233–250.

Šarkienė, E.; Ustinovičius, L.; Šarka, V. 2005. Model of selection architectural solutions in housing construction based on multiple criteria decision synthesis methods, *Foundations of civil and environmental engineering*, Poznan: Publishing House of Poznan University of Technology 6: 191–202.

Turskis, Z.; Ambrasas, G.; Kalibatas, D.; Barvidas, A. 2008. Multiple criteria decision support system model for construction works technological cards designing, in P. Vainiūnas (ed.). *Proc. of the 9th International Conference „Modern Building Materials, Structures and Techniques“ 2007*. Vilnius, Lithuania, Technica, 381–391.

Ustinovichius, L.; Balcevich, R.; Kochin, D.; Sliesoraityte, I. 2005. The use of verbal classification in determining the course of medical treatment by medicinal herbs, *Lecture Notes in Artificial Intelligence (Subseries of Lecture Notes in Computer Science)* 3581: 276–285.

Ustinovichius, L.; Barvidas, A.; Ashikhmin, I. 2008. Verbal analysis of DSS UniComBOS for engineering project models, in P. Vainiūnas (ed.). *Proc. of the 9th International Conference „Modern Building Materials, Structures and Techniques“ 2007*. Vilnius, Lithuania, Technica, 392–400.

Ustinovichius, L.; Kochin, D.; Narkevičiūtė, M. 2004. The enhancement of the method SNOD to choose the best object for investment, in *The 8th International conference MODERN BUILDING MATERIALS, STRUCTURES AND TECHNIQUES. Selected papers*, 290–297. ISBN 9986-05-757-4.

Ustinovichius, L.; Zavadskas, E. K..; Lunkevichius, S.; Shevchenko, G. 2006. Multiple criteria analysis for assessing the investment projects ir rural property revitalization, in *Ternational Conference "Simulation and Optimization in*

Business and Industry". May 17–20, 2006, *Tallin, Estonia*, 194–199.

Ustinovichius, L.; Podvezko, V.; Ginevicius, R. 2006. A method of determining risk zones of investment in real estate, *Control and Cybernetics* 35(2): 471–486.

Ustinovichius, L.; Šarkienė, E. 2006. The analysis of apartment house construction investment efficiency applying mathematical modelling, *Transport and Telecommunications* 7(1): 97–105.

Ustinovičius, L. 2001. Determining integrated weights of attributes, *Statyba* [Civil Engineering] 7(4): 321–326.

Ustinovičius, L. 2001. Multicriteria analysis of the efficiency of construction investments, *Almanach des praktischen Managements in Mitell–und Ost–Europa,* Band Nr.3, Nordic Academy of Informatization e.V.i.G. mit Sitz in Stralsund, 4. Quartal, 107–114.

Ustinovičius, L.; Andruškevičius, A.; Kutut, V.; Balcevič, R.; Barvidas, A. 2005a. Verbal analysis of contracts of engineering and design of buildings, *Technological and Economic Development of Economy* 11(1): 36–49.

Ustinovičius, L.; Andruškevičius, A.; Kutut, V.; Balcevič, R.; Barvidas, A. 2005b. Verbal analysis of engineering and construction solutions, *Technological and Economic Development of Economy* 11(3): 220–231.

Ustinovičius, L.; Andruškevičius, A.; Kutut, V.; Migilinskas, D.; Barvidas, A. 2007. Verbal analysis of engineering and construction contracts, *Engenharia Civil*, Portugal 28: 5–18.

Ustinovičius, L.; Kochin, D.; Ševčenko, G. 2007. CLARA – expert verbal method of determining investment risk in construction, in *9 th International Conference "Modern Building Materials, Structures and Techniques". May 16–18, 2007, Vilnius, Lithuania*.

Ustinovičius, L.; Šarkienė, E.; Šarka, V. 2003. Individualių namų architektūrinių sprendimų modelis, taikant daugiakriterinius sintezės metodus, *Ūkio technologinis ir ekonominis vystymas* [*Technological and Economic Development of Economy*] 9(1): 18–26.

Ustinovičius, L.; Ševčenko, G. 2007. Method CLARA – new approach to expert verbal classification, in *International Workshop On Multi – Criteria Desicion Making. Ustron, Poland. 14–18 April 2007.*

Ustinovičius, L.; Ševčenko, G.; Kočin, D. 2006. Classification of real alternatives and its application to the investment risk in construction, in *Multicriteria desicion making'05*. Ed. by T. Trzaskalik, Katowice, 299–318. ISBN 83-7246-843-5.

Zavadskas, E. K. 1991. *Multicriteria evaluation of technological solutions in construction*. Leningrad: Stroyizdat.

Zavadskas, E. K.; Kaklauskas, A. 1996. *Technical evaluation of a system of buildings*. Vilnius: Technika. 280 p.

Zavadskas, E. K.; Kaklauskas, A.; Banaitis, A.; Kvederytė, N. 2004. Housing credit access model: the case for Lithuania, *European Journal of Operational Research* 155: 335–352.

Zavadskas, E. K.; Ustinovichius, L.; Kochin, D.; Ševčenko, G. 2006. Verbal analysis – effective instrument of investment risk management in construction, in *Proceedings of the 6th International Conference „RELIABILITY and STATISTICS in TRANSPORTATION and communication (RelStat'06) held in Riga, Latvija. 25-28th October 2006*, 320–326. ISBN 9984-9865-9-4.

Zavadskas, E.K.; Ustinovichius, L.; Stasiulionis, A. 2004. Multicriteria evaluation of commercial construction projects for investment purposes, *Journal of Civil Engineering and Management* 10(2): 151–166.

Гинявичюс, Р.; Подвезько, В. 2004. Объективные и субъективные оценки значимости показателей в многокритериальных моделях, in *The International Conference „Reliability and Statistics in Transportation and Communication" (RelStat' 04), 14–15 October 2004, Riga, Latvia: programme and abstracts,* Riga: Transport and Telecommunication Institute, 51–52.

Гинявичюс, Р.; Подвезько, В.; Гинявичене, В. Б. 2005. Комплексная оценка эффективности деятельности инженерных факультетов технических университетов, в *Машиностроение и техносфера XXI века: сборник трудов XII международной научно-технической конференции: 12–17 сентября 2005 г. в городе Севастополе*. Донецк: ДонНТУ 1: 188–191.

Устиновичюс, Л.; Бальцевич, Р.; Кочин, Д.; Слесорайтене, В.; Слесорайтите, Е. 2006. Применение вербальной классификации для определения курса лечения с использованием лекарственных растений, *Искусственный интеллект*. Киев: Труды НАН 2: 448–451.