



## CONTRACTOR SELECTION OF CONSTRUCTION IN A COMPETITIVE ENVIRONMENT

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**Abstract.** Contractor selection is a vital part of the project management cycle and deals with risk and risk management. This paper presents contractors' assessment and selection based on the multi-attribute methods in a competitive and risky environment. The model is based on a multi-attribute evaluation of contractors, the determination of their optimality criterion values according to Hodges-Lehmann rule. The proposed model could be applied to assessment of construction operations. The attributes of contractor evaluation are selected taking into consideration the interests and goals of the stakeholders as well as factors that influence the process of construction efficiency. The model is based on metric scores. A background and a description of the proposed model are provided and a few key findings from the data analyses are presented.

**Keywords:** attribute, contractor, risk level, Hodges – Lehmann rule.

## 1. Introduction

The efficiency of construction process is often associated with the successful choice of a contractor. Various contractors' selection procedures are applied in practice. A single attribute cannot give a full expression of goals purposed by various stakeholders. Contractors choice was analyzed by Skitmore (1989), Hatush and Skitmore (1998), Olson (1998), Fong and Choi (2000), Andruškevičius (2005), Cheng *et al.* (2006), Turskis (2008). The importance of contractor selection is mostly underestimated and neglected in construction (Kumaraswamy and Matthews 2000; Ng and Wan 2005). It is hard to analyze many trade-offs involved in decision making, especially in times with so many uncertainties presented by environmental considerations. Insufficient time for execution, complicated procedures or poor information channels may be the reasons of problems in the selection of contractors. Contractor evaluation has been recognized as a particularly complex task due to its ambiguity and difficult formalization (Albino and Garavelli 1998; Cheng *et al.* 2006; Schieg 2007). It is usually based on intuition and past experience and carried out by the general

contractor management (Albino and Garavelli 1998; Luu and Sher 2006). There have been no generalized sets of rules for the evaluation process. The importance of non-price factors is well recognized in the literature. Various scientists offer different models for a contractor's evaluation. Multi-attribute decision aid provides several powerful and effective tools (Triantaphyllou 2000; Figueira *et al.* 2005; Peldschus and Zavadskas 2005; Antuchevičienė *et al.* 2006; Kaklauskas *et al.* 2006; Kaplinski and Janusz 2006; Mitkus and Trinkūnienė 2006; Su *et al.* 2006; Turskis *et al.* 2006; Zagorskas and Turskis 2006; Zavadskas *et al.* 2006; Ginevičius and Podvezko 2007; Kaklauskas *et al.* 2007; Viteikiene and Zavadskas 2007; Banaitiene *et al.* 2008; Ginevičius 2008; Zavadskas *et al.* 2008) for confronting sorting problems. In Turkey, a two-stage procedure is used, but at the end, the lowest price determines the selection (Topcu 2004). In Lithuania, the “lowest bidder” is selected as in Canada and the USA (Cheng *et al.* 2006). Hence, it may be concluded that price attribute is decisive in contractor selection. Lately the “lowest bid” selection practice has been criticized because it involves high-risk exposure of the client. The selection based on the low price basis can

be one of the reasons for project completion delays, poor quality and/or financial losses, etc. Hatush and Skitmore (1998), Topcu (2004) stated, that in seeking to minimize risk, the pre-qualification procedure is often chosen. Topcu (2004) proposed a multi-attribute decision model based on time, price and quality attributes evaluation for eligible contractor selection. Hatush and Skitmore (1998) suggested determining the client's needs and aims of a particular project to set the proper contractor evaluation attributes. The proposed attributes involve price, time, quality parameters, uncertainty level, flexibility to make changes, the allocation of risks and the ability of a contractor to cope with the levels of complexity that are involved. Hatush and Skitmore (1998) proposed the application of the multi-attribute utility theory for contractor selection. By applying an additive model, they compared four contractors against different attributes.

## 2. Methodology

The problems of rational construction variants selection are solved under various conditions, which are characterized by many efficiency attributes (Ginevičius *et al.* 2007; Zavadskas *et al.* 2007; Banaitiene *et al.* 2008; Zavadskas and Turskis 2008; Zavadskas *et al.* 2008). The attributes for each of the variants being compared (projects, strategies, alternatives) are calculated or set by means of experiments, then upon assessing environmental conditions, these attributes are characterized by the information available. Decisions may be made under totally definite conditions (for a determined problem), upon evaluating one or several efficiency attributes.

All these procedures are aimed at selecting a qualified contractor on a competitive basis, but in reality a decision is usually based on a single criterion (Hatush and Skitmore 1998). Siskos *et al.* (2000) described their methodological approach based on the principles of multi-attribute modelling and the application of the original preference disaggregation method as used in MUSA (Multi-criteria Satisfaction Analysis) for data analysis and interpretation.

The contractor pre-qualification process involves the establishment of a standard for measuring and assessing the capabilities of potential contractors (Ng *et al.* 1999).

Jaselskis and Russel (1992), Crowley and Hancher (1995), Russel (1996), Kumaraswamy (1996) have identified commonly used attribute for prequalification and bid evaluation and have proposed methodologies for contractor selection.

Zavadskas and Kaklauskas (1996) selected 25 attributes for contractor selection and applied COPRAS method. Hatush and Skitmore (1998) have initiated the use of systematic multi-attribute decision analysis techniques for contractor selection and bid evaluation based on additive multi-attribute utility function model. Banaitienė *et al.* (2008) performed an analysis of criteria for contractors' evaluation. Dikmen *et al.* (2007) after conducting a thorough research, selected 44 candidate factors affecting the bid mark-up decisions as factors having potential impact on bid mark-up size for a project.

Every problem to be solved is represented by a matrix, which contains variants (rows) and attributes (columns). The variants represent a set of situations for a problem that really exists. All variants considered are evaluated using the same attributes. The evaluation results are put in a matrix  $x_{ij}$ ,  $i = \overline{1, m}$ ,  $j = \overline{1, n}$ . Usually the attributes have different dimensions. That is why their effectiveness cannot be compared directly. An exception is the application of evaluation numbers without any dimensions according to a points system. This, however, involves subjective influences to a great extent. Hence, it should only be used in exceptional cases. In order to avoid the difficulties due to different dimensions of the attributes, the ratio of the optimal value is used (Figueira *et al.* 2005; Turskis *et al.* 2006; Zavadskas and Vilutienė 2006; Ginevičius and Podvezko 2007; Ginevičius 2008.). In this way the discrepancy between different dimensions of optimal values is also eliminated. There are various theories about the ratio of the optimal value. Note that the decision for a theory may affect the solution. However, the values are mapped either on the interval  $[0; 1]$  or on the interval  $[0, \text{infinity})$  by the transformation. Only those well-known theories of transformation are used that are appropriate for both problems of maximisation and minimization.

The linear normalization uses a scale of the existing values Weitendorf (1976). The calculated values are dependent on the size of the interval and thus change if the interval is altered.

$$\bar{x}_{ij} = \frac{x_{ij} - \min_j x_{ij}}{\max_j x_{ij} - \min_j x_{ij}}, \text{ when } \max_j x_j \text{ is optimal, (1)}$$

$$\bar{x}_{ij} = \frac{\max_j x_{ij} - x_{ij}}{\max_j x_{ij} - \min_j x_{ij}}, \text{ when } \min_j x_j \text{ is optimal. (2)}$$

The calculation of the relative deviation is a well performing linear transformation.

**Hodges-Lehmann rule.** With this rule (Hodges and Lehmann 1952) confidence in the knowledge of the probabilities of the strategies of the opponent can be expressed by the parameter  $\lambda$ :

$$K_i = \lambda \sum_{j=1}^n q_j x_{ij} + (1-\lambda) \min_j \overline{x_{ij}}, \quad (3)$$

$K_i$  – optimality criterion;  
 $\lambda$  – risk assessment factor;  
 $q_i$  – attribute weight.

$$K_{opt} = \max_i K_i, \quad (4)$$

$K_{opt}$  – optimal alternative.

$\lambda = 0$  (no confidence) gives the solution according to Wald’s rule.  $\lambda = 1$  (great confidence) gives the solution according to Bayes’s rule.

### 3. Model of the contractor selection

The model is described by discrete values: construction time, quality of performed projects, bid estimates, communication level with stakeholders, and capacity influence based on the different stakeholders sectors risks and uncertainties. The model of problem is presented in Fig. 1. The subject of investigation is a nine-storeyed administration and business complex building in Vilnius city. Each contractor is described by 8 at-

tributes. Attributes and their weights were determined on the basis of performed questionnaires. The attributes of contractor selection are as follows:

$x_1$  – **bid estimates [million €]**. For the contractor, a bid estimate submitted to the stakeholder either for competitive bidding or negotiation consists of direct construction cost including field supervision, plus a mark-up to cover general overhead and profits. The direct cost of construction for bid estimates is usually derived from a combination of the following approaches:

- Subcontractor quotations;
- Quantity take-offs;
- Construction procedures.

$x_2$  – **construction duration [months]**. Most contracts are quite specific regarding the amount of construction time allowed to complete the work, and many provide for the payment of “liquidated damages” by the contractor to the owner for failure to complete on time or, in some cases, to complete portions of the work that interface with other contract schedules where multiple prime contracts have been executed.

The work covered in a construction contract includes a stated guarantee period. The contractors according to valid regulations and rules must give construction works certain guarantees:

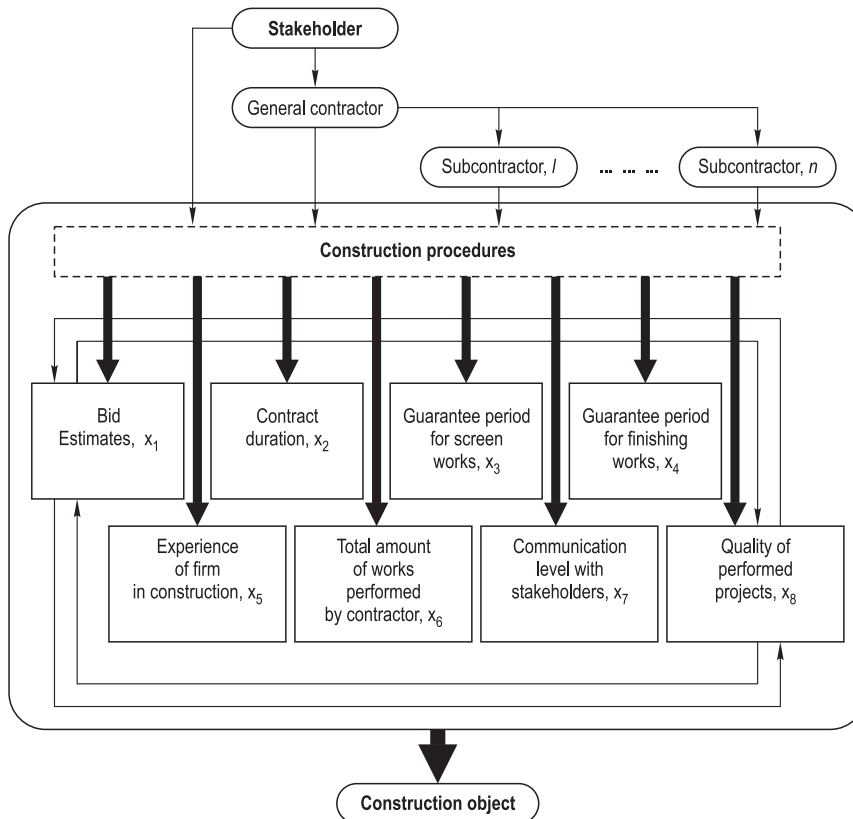


Fig. 1. Determinants of construction problems’ model

- $x_3$  – **guarantee period for screen works [year]**, must be not less than 10 years.
- $x_4$  – **guarantee period for finishing works [year]**, must be not less than 5 years. The contractor is responsible for the quality workmanship, the quality of the materials used, and for performance of the contract only.
- $x_5$  – **experience of firm in construction [year]**. This attribute assesses contractor’s activity in construction sector.
- $x_6$  – **total amount of works performed by contractor [rate]**, the contractor must at the few, like a fifty percent work fill their intensity.
- $x_7$  – **communication level with stakeholders [point]**, is very important all through a construction period and after finishing construction work.
- $x_8$  – **quality of performed projects [point]**.

The algorithm for the ranking of alternatives by applying Hodges-Lehmann rule is shown in Fig. 2. In order to establish the indicators importance, a survey has been carried out and 20 experts have been questioned. The experts, basing their answers on their knowledge, experience and intuition, had to rate indicators of effectiveness starting with the most important ones. The rating was done on a scale from 1 to 8, where 8 meant “very important” and 1 “not important at all”. The importance of indicators was established according to the

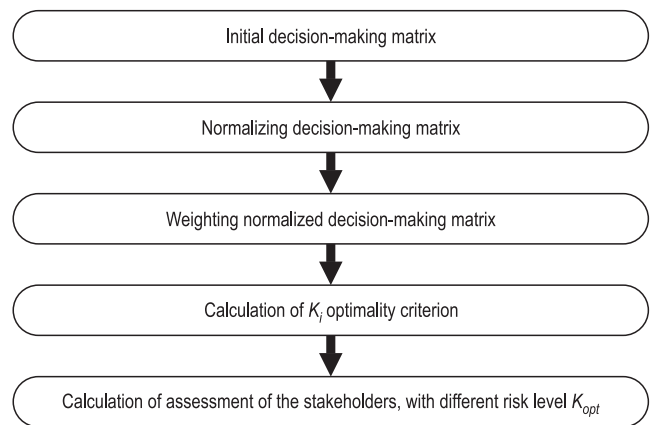


Fig. 2. Ranking of alternatives using Hodges-Lehmann rule

rating methods (Zavadskas and Turskis 2008) of these experts and also demonstrated the priorities of the user (stakeholder).

If we scrutinize initial decision-making matrix (Table 1) we can find that no one alternative has all optimal attribute values. The best price is in alternative 7, the shortest construction duration is in alternative 9, and so on.

In Table 2 weighting normalized decision-making matrix is presented. The results of the assessment are presented in Table 3. According to the solution results

Table 1. Initial decision-making matrix with values

Alternative	Attribute							
	$x_1$	$x_2$	$x_3$	$x_4$	$x_5$	$x_6$	$x_7$	$x_8$
	min	min	max	max	max	max	max	max
<b>Attribute weight – <math>q_j</math></b>	<b>0.18</b>	<b>0.14</b>	<b>0.12</b>	<b>0.09</b>	<b>0.14</b>	<b>0.09</b>	<b>0.10</b>	<b>0.14</b>
$A_1$	5.00	26	10	5	13	0.74	8.00	9.01
$A_2$	5.54	23	10	10	13	0.61	7.21	9.24
$A_3$	4.63	30	10	2	13	0.55	8.51	8.38
$A_4$	5.56	22	15	10	18	0.71	9.22	8.15
$A_5$	5.14	24	15	2	57	0.77	7.32	8.08
$A_6$	4.99	28	10	5	48	0.79	8.48	7.51
$A_7$	4.57	29	10	2	15	0.65	7.21	7.84
$A_8$	5.15	27	15	5	13	0.72	7.72	7.35
$A_9$	5.25	19	10	5	50	0.85	8.50	8.61
$A_{10}$	5.31	25	10	10	56	0.72	7.36	8.45
$A_{11}$	4.60	25	15	5	4	0.56	7.20	8.32
$A_{12}$	4.89	23	10	5	5	0.59	7.45	8.22
$A_{13}$	4.74	28	10	5	9	0.54	7.80	8.54
$A_{14}$	4.82	28	10	5	15	0.57	8.04	7.08
$A_{15}$	5.04	26	15	5	13	0.60	8.13	8.01

**Table 2.** Weighting normalized decision-making matrix

Alternative	Attribute							
	$x_1$	$x_2$	$x_3$	$x_4$	$x_5$	$x_6$	$x_7$	$x_8$
	min	min	max	max	max	max	max	max
<b>Attribute weight – <math>q_j</math></b>	<b>0.18</b>	<b>0.14</b>	<b>0.12</b>	<b>0.09</b>	<b>0.14</b>	<b>0.09</b>	<b>0.10</b>	<b>0.14</b>
$A_1$	0.57	0.36	0.00	0.38	0.17	0.65	0.40	0.89
$A_2$	0.11	0.64	0.00	1.00	0.17	0.23	0.00	1.00
$A_3$	0.94	0.00	0.00	0.00	0.17	0.03	0.65	0.60
$A_4$	0.00	0.73	1.00	1.00	0.26	0.55	1.00	0.50
$A_5$	0.42	0.55	1.00	0.00	1.00	0.74	0.06	0.46
$A_6$	0.58	0.18	0.00	0.38	0.83	0.81	0.63	0.20
$A_7$	1.00	0.09	0.00	0.00	0.21	0.35	0.00	0.35
$A_8$	0.41	0.27	1.00	0.38	0.17	0.58	0.26	0.12
$A_9$	0.31	1.00	0.00	0.38	0.87	1.00	0.64	0.71
$A_{10}$	0.25	0.45	0.00	1.00	0.98	0.58	0.08	0.63
$A_{11}$	0.97	0.45	1.00	0.38	0.00	0.06	0.00	0.57
$A_{12}$	0.68	0.64	0.00	0.38	0.02	0.16	0.12	0.53
$A_{13}$	0.83	0.18	0.00	0.38	0.09	0.00	0.30	0.68
$A_{14}$	0.75	0.18	0.00	0.38	0.21	0.10	0.42	0.00
$A_{15}$	0.53	0.36	1.00	0.38	0.17	0.19	0.46	0.43

**Table 3.** Optimality attributes values of optimality criterion  $K_j$  at different risk level

	$\lambda$						
	<b>0.000</b>	<b>0.167</b>	<b>0.333</b>	<b>0.500</b>	<b>0.667</b>	<b>0.833</b>	<b>1.000</b>
<b>The best alternative</b>	1	15	15	15	15	15	9
<b>Score of the best alternative</b>	0.00	0.26	0.45	0.56	0.60	0.56	0.61

it is clear, that according to all risk levels the best alternative is the 15<sup>th</sup> alternative, with one exception (risk level 0.00). When there is no risk the best alternative is the 1<sup>st</sup> alternative. In very risky environment and situation the risk level equals to 1.00. In this case the best alternative is the 9<sup>th</sup> alternative.

The best 15<sup>th</sup> alternative was selected according to the calculated optimality criterion values at different risk level.

#### 4. Conclusions

In construction process an important role is the best contractor and subcontractor selection.

Traditional selection of contractors such as choosing those with whom the stakeholder had already done business can lead to inefficiencies in projects and poor project performance.

A contractor’s assessment and selection always deals with risk and a single attribute – price can be used in certain cases only.

In competitive and risky environment contractor selection must be performed according to multiple attributes.

The application of the model offered at this paper may reduce the risk involved in the selection of a contractor and can lead to the elimination of unqualified contractors during the bidding process.

The selection of contractor can be with different risk level. Hodges-Lehmann rule allows stakeholders to select contractor taking into account different risk levels.

Knowing the risk level stakeholders can effectively manage the risk.

This model can be applied to select alternatives in construction under risky environment.

## References

- Albino, V.; Garavelli, A. C. 1998. A neural network application to subcontractor rating in construction firms, *International Journal of Project Management* 16(1): 9–14.
- Andruškevičius, A. 2005. Evaluation of contractors by using COPRAS - the multiple criteria method, *Technological and Economic Development of Economy* 11(3): 158–169.
- Antuchevičienė, J.; Turskis, Z.; Zavadskas, E. K. 2006. Modelling renewal of construction objects applying methods of the game theory, *Technological and Economic Development of Economy* 12(4): 263–268.
- Banaitienė, N.; Banaitis, A.; Kaklauskas, A.; Zavadskas, E. K. 2008. Evaluating the life cycle of a building: A multivariate and multiple criteria approach, *Omega* 36(3): 429–441.
- Cheng, M.-Y.; Tsai, M.-H.; Xiao, Z.-W. 2006. Construction management process reengineering: Organizational human resource planning for multiple projects, *Automation in Construction* 15(6): 785–799.
- Crowley, L. G.; Hancher, D. E. 1995. Evaluation of competitive bids, *Journal of Construction Engineering and Management*, ASCE 121(2): 238–245.
- Dikmen, I.; Birgonul, M. T.; Gur, A. K. 2007. A case-based decision support tool for bid mark-up estimation of international construction projects, *Automation in Construction* 17(1): 30–44.
- Figueira, J.; Greco, S.; Ehrgott, M. 2005. *Multiple Criteria Decision Analysis: State of the Art Surveys*. Springer, Berlin.
- Fong, S. W.; Choi, K. Y. 2000. Final contractor selection using the analytical hierarchy process, *Construction Management and Economics* 18: 547–557.
- Ginevičius, R.; Podvezko, V. 2007. Some problems of evaluating multicriteria decision methods, *International Journal of Management Decision Making* 8(5/6): 527–539.
- Ginevičius, R.; Podvezko, V.; Andruskevicius, A. 2007. Quantitative evaluation of building technology, *International Journal of Technology Management* 40(1/2/3): 192–214.
- Ginevičius, R. 2008. Normalization of quantities of various dimensions, *Journal of Business Economics and Management* 9(1): 79–86.
- Hatush, Z.; Skitmore, M. 1998. Contractor selection using multi-criteria utility theory: an additive model, *Building and Environment* 33(2/3): 105–115.
- Hodges, J. L.; Lehmann, E. L. 1952. The use of previous experience in reaching statistical decision, *Annals of Mathematics Statistic* 23: 396–407.
- Jaselskis, E. J.; Russell, J. S. 1992. Risk analysis approach to selection of contractor evaluation method, *Journal of Construction Engineering and Management*, ASCE 118(4): 814–821.
- Kaklauskas, A.; Zavadskas, E. K.; Raslanas, S.; Ginevičius, R.; Komka, A.; Malinauskas, P. 2006. Selection of low-e windows in retrofit of public buildings by applying multiple criteria method COPRAS: A Lithuanian case, *Energy and Buildings* 38(5): 454–462.
- Kaklauskas, A.; Zavadskas, E.K.; Trinkūnas, V. 2007. A multiple criteria decision support on-line system for construction, *Engineering Applications of Artificial Intelligence* 20(2): 163–175.
- Kaplinski, O.; Janusz, L. 2006. Three phases of multifactor modelling of construction processes, *Journal of Civil Engineering and Management* 12(2): 127–134.
- Kumaraswamy, M. M. 1996. Contractor evaluation and selection – a Hong Kong perspective, *Building and Environment* 31(3): 273–282.
- Kumaraswamy, M. M.; Matthews, J. 2000. Improved subcontractor selection employing partnering principles, *Journal of Management in Engineering*, ASCE 16(3): 47–57.
- Luu, D. T.; Sher, W. 2006. Construction tender subcontract selection using case-based reasoning, *Australian Journal of Construction Economics and Building* 6(2): 31–43.
- Mitkus, S.; Trinkūnienė, E. 2006. Models of indicator systems of construction contraction agreements, *Journal of Civil Engineering and Management* 12(4): 327–335.
- Ng, S. T.; Skitmore, R. M.; Smith, N. J. 1999. Decision-makers perceptions in the formulation of prequalification criteria, *Engineering Construction & Architectural Management* 6(2): 155–165.
- Ng, S. T.; Wan, W. Y. 2005. Appraisal of subcontractor performance — criteria and their importance, in A. S. Kazi (Editor). *Proceedings of CIB2005—Advancing Facilities Management and Construction through Innovation*, Finlandia Hall, Helsinki, Finland, 305–314.
- Olson, R. 1998. Subcontract coordination in construction, *International Journal of Production Economics* 56–57: 503–509.
- Peldschus, F.; Zavadskas, E. K. 2005. Fuzzy matrix games multi-criteria model for decision-making in engineering, *Informatica* 16(1): 107–120.
- Russell, J. S. 1996. *Constructor prequalification—choosing the best constructor and avoiding constructor failure*, ASCE Press, New York.
- Schieg, M. 2007. Post-mortem analysis on the analysis and evaluation of risks in construction project management, *Journal of Business Economics and Management* 8(2): 145–153.
- Siskos, Y.; Grigoroudis, E.; Politis, Y.; Malandrakis, Y. 2000. Customer satisfaction evaluation: some real experiences, in *Selection of papers presented at the 49th (Italy) and 50th (France) meetings of the EURO working group in multiple criteria decision aiding*. Luxembourg: Office for Official Publications of the European Communities, 297–314.
- Skitmore, R. M. 1989. *Contract Bidding in Construction: Strategic Management and Modelling*. Longman Scientific and Technical, Harlow.

- Su, C.-W.; Cheng, M.-Y.; Lin, F.-B. 2006. Simulation-enhanced approach for ranking major transport projects, *Journal of Civil Engineering and Management* 12(4): 285–291.
- Topcu, YI. 2004. A decision model proposal for construction contractor selection in Turkey, *Building and Environment* 39(4): 469–481.
- Triantaphyllou, E. 2000. *Multi-Criteria Decision Making Methods: A Comparative Study*. Kluwer Academic Publishers, Dordrecht.
- Turskis, Z.; Zavadskas, E. K.; Zagorskas, J. 2006. Sustainable city compactness evaluation on the basis of GIS and Bayes rule, *International Journal of Strategic Property Management* 10(3): 185–207.
- Turskis, Z. 2008. Multi-attribute contractors ranking method by applying ordering of feasible alternatives of solutions in terms of preferability technique, *Technological and Economic Development of Economy* 14(2): 224–239.
- Viteikienė, M.; Zavadskas, E. K. 2007. Evaluating the sustainability of Vilnius city residential areas, *Journal of Civil Engineering and Management* 13(2): 149–155.
- Weitendorf, D. 1976. *Beitrag zur Optimierung der räumlichen Struktur eines Gebäudes*. Dissertation, Hochschule für Architektur und Bauwesen, Weimar.
- Zagorskas, J.; Turskis, Z. 2006. Multi-attribute model for estimation of retail centres influence on the city structure. Kaunas city case study, *Technological and Economic Development of Economy* 12(4): 347–352.
- Zavadskas, E. K.; Kaklauskas, A. 1996. *Pastatų sistemo techninis įvertinimas* [Multiple criteria evaluation of buildings]. Vilnius: Technika.
- Zavadskas, E. K.; Vilotienė, T. 2006. A multiple criteria evaluation of multi-family apartment block's maintenance contractors: I-Model for maintenance contractor evaluation and determination of its selection criteria, *Building and Environment* 41(5): 621–632.
- Zavadskas, E. K.; Zakarevičius, A.; Antuchevičienė, J. 2006. Evaluation of ranking accuracy in multi-criteria decisions, *Informatica* 17(4): 601–618.
- Zavadskas, E. K.; Turskis, Z.; Dejus, T.; Viteikienė, M. 2007. Sensitivity analysis of a simple additive weight method, *International Journal of Management and Decision Making* 8(5/6): 555–574.
- Zavadskas, E. K.; Kaklauskas, A.; Turskis, Z.; Tamošaitienė, J. 2008. Selection of the effective dwelling house walls by applying attribute values determined at intervals, *Journal of Civil Engineering and Management* (14)2: 85–93.
- Zavadskas, E. K.; Turskis, Z. 2008. A new logarithmic normalization method in game theory, *Informatica* 19(2): 303–314.