ISSN 1819-5377 print / ISSN 1993-3509 online
ЕКОНОМІКА БУДІВНИЦТВА І МІСЬКОГО ГОСПОДАРСТВА
ЭКОНОМИКА СТРОИТЕЛЬСТВА И ГОРОДСКОГО ХОЗЯЙСТВА
ECONOMICS OF CIVIL ENGINEERING AND MUNICIPAL ECONOMY
ТОМ 4, НОМЕР 2, 2008, 61-72
УДК 338.24:669

БАГАТОЦІЛЬОВИЙ ВИБІР ПІДРЯДНИКІВ НА ОСНОВІ ПРАВИЛИ БАЙЄСА

З. Турскис
Вільнюський Технчний Університет Гедимінаса
Солетекайо ал. 11, LT-10223, Вільнюс.
E-mail: zenonas.turskis@st.vgtu.lt

Received 11 May 2008, accepted 16 May 2008

Анотація. Оцінка підрядника – життєво важлива частина циклу керівництва проектом і пов'язана з управлінням ризиками. Однією з важливих фаз в процесі існування будівельного проекту – процес встановлення ціни. Для того, щоб обрати найкращого підрядника для здійснення проекту и отримати максимально реалістичну і точну пропозицію ціни інвестори повинні мати достовірну фінансову, технічну і загальну інформацію про претендентів у підрядники. Інформація може бути у вигляді якісних або кількісних даних. Багато сучасних вчених вважають складними алгоритми великою кількістю даних. Найчастіше кількість показників перевищує 40. Отримати таку кількість точних даних у великій кількості в переважній більшості випадків неможливо. Дана стаття містить методику, що містить систему показників ефективності. Запропонований метод дозволяє використовувати якісні і кількісні показники. Дана методика апробована автором на реальному прикладі.

Ключові слова: будівництво, підрядник, показники ефективності, оцінка, передкваліфікація, прийняття рішення, правило Байєса.

МНОГОЦЕЛЕВОЙ ВЫБОР ПОДРЯДЧИКОВ НА ОСНОВЕ ПРАВИЛА БАЙЕСА

З. Турскис
Вильнюсский Технический Университет Гедиминаса
Солетекайо ал. 11, LT-10223, Вильнюс.
E-mail: zenonas.turskis@st.vgtu.lt

Получена 12 мая 2008, принята 16 мая 2008

Аннотация. Оценка подрядчика - жизненная часть цикла руководства проектом и имеет дело с управлением рисками. Одна из самых важных фаз в процессе существования строительного проекта - процесс установления цены. Чтобы выбирать наилучшего подрядчика для осуществления проекта и получить самое реалистическое и точное предложение цены инвесторы должны иметь достоверную финансовую, техническую и общую информацию об претендентах в подрядчики. Информация может быть определена как качественные или количественные данные. Многие современные ученые предлагают очень сложные алгоритмы с большими количествами данных. Часто количество показателей достигает более 40. Получить такое большое количество точных данных в большинстве случаев невозможно. Эта статья представляет методику описывается системой показателей эффективности. Представленный метод позволяет иметь дело как с качественным так и с количественными данными. В конце статьи представлен реальный пример выбора подрядчика используя предложенную модель.

Ключевые слова: строительство, подрядчик, показатели эффективности, оценка, предквалификация, принятие решения, правило Байеса.

MULTI-ATTRIBUTE CONTRACTORS SELECTION ON THE BASIS OF BAYES RULE

Z. Turskis
Vilnius Gediminas Technical University,
Sauletekio al. 11, LT-10223, Vilnius, Lithuania.
E-mail: zenonas.turskis@st.vgtu.lt

Received 11 May 2008, accepted 16 May 2008

Abstract. Contractor evaluation is a vital part of the project management cycle and deals with risk and risk management. One of the most important phases in the construction industry is the bidding process. In order to select the most appropriate contractor for the project and prepare the most realistic and accurate bid proposal, stakeholders have to know all financial, technical and general information about these contractors. The information can be determined as qualitative or quantitative data. This paper presents the multi-attribute contractors ranking method by applying Bayes rule. This method allows dealing with qualitative as well as with quantitative data. Finally, an illustrative example of contractor selection is used to demonstrate the feasibility and practicability of the proposed model.

Keywords: construction, contractor, multi-attribute, evaluation, pre-qualification, decision-making, Bayes rule.

1. Introduction

The growth of the economy calls for development of infrastructures and assets. Construction projects are one-off endeavours with many unique features such as long period, complicated processes, changing environment. Contractor evaluation is a vital part of the project management cycle. As construction projects become more complex, the need for evaluating contractor performance becomes more crucial. Organizational and technological complexity of construction projects generates enormous risks. Contractor selection is the process of selecting the most appropriate contractor to deliver the project as specified so that the achievement of the best value for money is ensured. The selection of a qualified contractor gives confidence to the stakeholder that the selected contractor can achieve the project goals. However, the importance of contractor selection is mostly underestimated and neglected in construction [1, 2]. It is hard to analyze many tradeoffs 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 [3]. Contractor evaluation has been recognized as a particularly complex task due to its ambiguity and difficult formalisation [3 - 5]. It is usually based on intuition and past experience and carried out by the general contractor management [5, 6]. There have been no generalized sets of rules for the evaluation process.

Cotractor selection deals with risk and risk management. Zou et al [7] argues that the risks in construction projects can be classified as follows: cost overrun, time delay, quality, safety, environmental sustainability and funding, contractors' poor management ability, contractors' difficulty in reimbursement, poor competency of labourers, not buying insurance for major equipments and employees, inadequate safety measures or unsafe operations, lack of readily available utilities on site, prosecution due to unlawful disposal of construction waste and serious air and water pollution due to construction activities, suppliers' incompetency to deliver materials on time.

Many construction contracts are awarded to the lowest bidder. An offered bid price is undoubtedly an important factor in choosing a contractor, but there are many other important ones playing a vital role in project implementation that have to be incorporated in the contractor's evaluation process.

2. Multi-attribute contractor selection models

Many researches [8-11] have pointed out that in construction it is essential to be able to take into account the impacts of cultural, social, moral, legislative, demographic, economic, environmental, governmental and technological change, as well as changes in the business world on international, national, regional and local real estate markets. Evaluation of contractors based on multi-attributes is becoming more popular and is, in essence, largely dependent on the uncertainty inherent in the nature of construction projects and subjective judgment of decision makers.

Multi-attribute decision making is defined by processes that involve designing the best alternative or selecting the best one from a set of alternatives, that has the most attractive overall attributes, and that involves the selection of the optimal alternative, handled via preference models [12-17]. Multi-attribute analysis is widely used in selecting the best alternative from a finite set of decision alternatives with respect to multiple, usually conflicting attributes. Many methods have been proposed to model the decision making phase. Multi-attribute decision-making methods have different characteristics [18].

Multi-attribute decision making can be classified as follows:

a) Multi-attribute decision making (MADM) for the sorting or the ranking of alternatives according to several attributes and
b) Multi-objective decision making (MODM), for driving a vector optimization-based design process to a solution [19].

There are different ways to classify them. Multi-attribute methods can be classified by the type of initial information (deterministic, stochastic, fuzzy set theory methods) or by the number of decision-makers (one or group). Scientists classify deterministic MADM methods differently. Lin and Wu [20] presented classification of the methodology which can be used for qualitative and quantitative methods aimed at technology management. The classification of MADM methods according to the type of information proposed by Larichev [21] is given here:

1) Methods based on quantitative measurements. The methods based on multi-attribute utility theory may be referred to this group (TOPSIS – Technique for Order preference by Similarity to Ideal Solution [17, 22], SAW – Simple Additive Weighting [23, 24], LINMAP – Linear Programming Techniques for Multidimensional Analysis of Preference [25], COPRAS – COmplex PRoportional ASsessment [26] and other new methods [27].
2) Methods based on qualitative initial measurements. These include two widely known groups of methods, i.e. analytic hierarchy methods (AHP) [28] and fuzzy set theory methods [29].
3) Comparative preference methods based on pairwise comparison of alternatives. This group comprises the modifications of the ELECTRE [30], PROMETHEE I and II [31], and other methods.
4) Methods based on qualitative measurements not converted to quantitative variables. This group includes methods of verbal decision making analysis [32-35] and uses qualitative data for decision environments involving high levels of uncertainty.

A major criticism of MADM is that different techniques may yield different results when applied to the same problem.

A special feature of the model is the determination of attributes weights. Many methods in multi-attribute decision making require information about the relative importance of each attribute [17]. Multi-attribute analysis methods that generate a cardinal preference of the alternatives require the decision maker to provide information in specific ways on:

- Relative importance (weights) of the attributes with respect to the objectives of the decision problem;
- Performance ratings of the alternatives in relation to each attribute [17, 19, 36-39]. Theoretical and practical aspects of expert methods have been dealt with in various research papers by many authors [22, 40-45]. To determine the significances of the attributes, the expert judgement method proposed by Kendall [46] was used. Zavadskas *et al.* [47], Kaklauskas *et al.* [48, 49], Vilutiene and Zavadskas [11] discussed the application of this method in the construction field.

A number of methods for determining attributes weights in multi-attribute analysis have been developed. It is usually given by a set of weights which is normalized to sum to 1. Eckelrode [50] suggests six techniques for collection of the judgements of decision makers concerning the relative value of attributes. Keeney and Raiffa [36] first present a value trade off approach. In eigenvector method the Saaty [51] scale ratio gives an intensity of importance. A weighted least square method is proposed by Chu *et al.* [52] to obtain the weight. Zavadskas [53, 54] describes and applies methods of weight assessment based on the Entropy method, evaluating the weights of attributes on the basis of the relative losses method and weight assessment according to expert opinion.

Different decision makers using the same approach may give different weights due to their subjective judgements [55]. As a result, inconsistent ranking outcomes may be produced, leading to ineffective decisions being made. Figueira and Roy [56] explain a very simple procedure using a set of cards, allowing to determine indirectly numerical values for weights. Smolнkovб and Wachowiak [57] discussed a heuristic method for determining weights for Multi Expert-Multi Attribute decision-making.

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 attribute [58]. Siskos et al. [59] 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 [60]. According to Hatush and Skitmore [61] and Holt [62] the information used for the assessment of attributes for pre-qualification falls into the following groups:

- General information that is used mainly for administrative purposes;
- Financial information;
- Technical information;
- Managerial information;
- Experience attributes;
- Performance attributes;
- Safety information;
- Environmental concerns.

Jaselskis and Russel [63], Crowley and Hancher [64], Russel [65] and Kumaraswamy [66] have identified commonly used attributes for prequalification and bid evaluation and have proposed methodologies for contractor selection.

Zavadskas and Kaklauskas [67] selected 25 attributes of contractor selection and applied COPRAS method to contractor selection. Hatush and Skitmore [58] 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. Banaitiene and Banaitis [68] performed an analysis of attributes for contractors' evaluation. Dikmen et al [69] after conducting a thorough research, 44 candidate factors affecting the bid markup decisions selected as factors having potential impact on bid mark-up size for a project. The factors are divided into 4 groups, namely: general features about company and project, risk factors, opportunity factors and competition factors.

Vilnius Gediminas Technical University (VGTU) and Leipzig University of Applied Sciences (HTKW) have been investigating the application of games theory principles to civil engineering technology and management problems about 30 years [70-77]. The program LEVI 3.0 was a result of the co-operation between VGTU and HTKW.

An extensive literature review by the researchers revealed that the most acceptable contractor's pre-qualification attributes are financial stability, management and technical ability, contractor's experience, contractor's performance, resources, quality management and health and safety concerns. Therefore, the contractor's attributes corresponding to these attributes should be evaluated.

Ustinovichius et al [78] presented a systematic procedure based on fuzzy set theory to evaluate the capability of a contractor to deliver the project as per the owner's requirements. The notion of Shapley value is used to determine the global value or relative importance of each attribute in accomplishing the overall objective of the decision-making process. One major advantage of the proposed method is that it makes the selection process more systematic and realistic as the use of fuzzy set theory allows the decision makers to express their assessment of contractors' performance on decision attributes in linguistic terms rather than as crisp values.

Another approach suggested by Al-Harbi [79] and Topcu [80] used Analytical Hierarchy Process methods to select contractors. Shiau et al. [4] developed an sub-contractor selection management aid system. Pongpeng and Liston [81] addressed the use of a combination of utility function and social welfare function to evaluate the contractor ability when assessing tenders. Wong et al [82] explored the use of a multivariate discernment technique for developing a contractor classification model for the project specific attributes.

Mitkus and Trinkuniene [83] analyzed three models of multi-attribute attributes systems of construction contraction agreements. They in 2007 [84] proposed to use analytic hierarchical model for structural evaluation of construction contracts.

El-Sawalhi et al [85] presented model by using a hybrid model, combining the merits of Analytical Hierarchy Process, Neural Network and Genetic Algorithm in one consolidated model which is able to overcome the published models limitations.

Kersuliene [86] proposed analysis model of construction process parties during dispute settlement. She stated that with the use of optimism and asymmetric information models it is possible to determine the most economically advantageous behavioral pattern for both parties.

Selection of contractor is an important issue in the field of construction management [9, 24, 26, 87, 88] for the success or failure of a project is usually influenced by the quality of contractor.

Murtoaro and Kujala [89] pointed that the client and contractor face significant difficulties in negotiating major projects, project negotiations have not attracted much attention in the academia. The basic idea is to embrace both the buyer and seller perspectives in a single continuum of recurring negotiations, oriented around the zone of possible agreement.

Researches listed above had significantly improved the contractor selection process in the construction industry. However, some of the proposed methods and approaches could be complex and difficult to apply in practice. The construction industry needs simple but effective methods in contractor selection process due to the limited time intervals of the bidding periods. For these and many other reasons, selection of a construction contractor requires the contractor selection model that should be able to meet the critical characteristics of the pre-qualification:

- a multi-attribute problem.
- risks inherited from different decision maker's opinion.
- noisy and uncertain date given by different contractors.
- subjective judgement made by decision makers.
- non-linear relationships between contractor's attributes and their corresponding pre-qualification decisions.
- to deal with qualitative as well as quantitative data.

The multi-attribute contractors selection model is shown in Fig. 1.

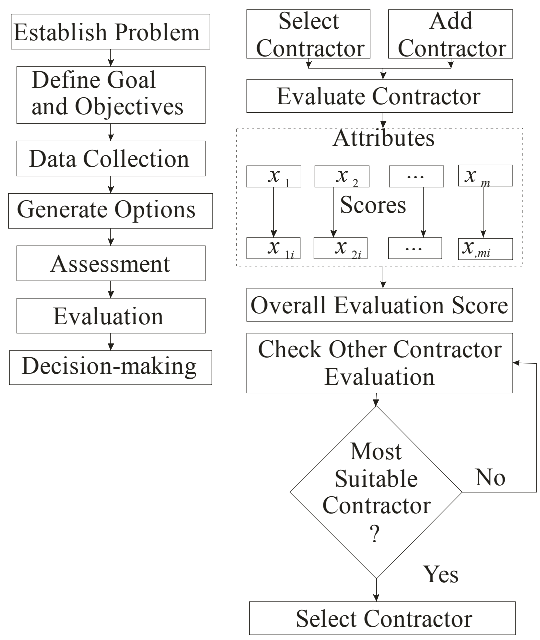

Fig. 1. Contractors evaluating and selecting process.

Decision maker using the expert methods determines the system of attributes and calculates the values and initial weights of qualitative attributes. Following decision matrix the weighted normalized decision making matrix is formed. The purpose here is to receive dimensionless weighted values from comparative indexes. When the dimensionless values of the indexes are known, all attributes can be compared.

It should be noted that the stakeholders must adjust the attributes depending on the demand of each project. The critical point is that the selected attributes should have a direct effect on performance. In addition, the selected evaluation attributes should also based on the measurement culture of the stakeholder.

3. Description of bayes method and applying it to assess contractors

Various decision methods can be applied to the decision of such problems. One of such methods is the attribute of optimality. If parameters of efficiency w_j are not equivalent, but the importance of these parameters w_j is known, the best variant can be determined by average success criterion of the decision made K_i under the formula:

$$K_i = \left\{ v_i \middle| \max_i \left(\frac{1}{n} \sum_{j=1}^{n} w_i \bar{x}_{ij} \right) \right\}. \qquad (1)$$

where: v_i alternative; $\bar{x}_{ij}$ - normalized attribute values of *j*-th attribute for *i*-th variant.

The given criterion refers K_i to Bayes rule or Bayes – Laplace principle. Most often parameters of the importance pay off in such a manner that $\sum_{j=1}^{n} w_j = 1$, therefore the variant with the greatest weighed sum of parameters values in this case gets out. Criterion K_i in the literature is named on a miscellaneous. Hwang and Yonn [17] refer to Bayes rule or Bayes – Laplace principle as a Simple Additive Weighting method (SAW) and Zavadskas [53, 54] – average success criterion of the made decision.

The expert judgement method algorithm of attributes weight establishment is applied [9, 53, 54, 88]. After performed calculations were established attributes weights as presented in table 1.

In applying the Bayes rule (SAW method) [10, 53, 54, 67, 72, 73, 75, 77] the decision matrix elements are normalized according to the formula (2) or (3) (Table 1) [8]:

$$b_{ij} = \frac{\ln\left(a_{ij}\right)}{\ln\left(\prod_{i=1}^{n} a_{ij}\right)}, \qquad (2)$$

when preferable value $a_{ij} = \min a_{ij}$;

$$b_{ij} = \frac{1 - \dfrac{\ln\left(a_{ij}\right)}{\ln\left(\prod_{i=1}^{n} a_{ij}\right)}}{n-1} \qquad (3)$$

when preferable value $a_{ij} = \max a_{ij}$.

It can be noted that the sum of normalized criterion values is always equal to 1.

4. Case study

Stakeholders wishes to emphasize that construction work is open to any firm that desires construction work, provided it meets qualifying standards, actively participates in the bid process, and demonstrates high measures of performance on the job. The Informal Contracts process is designed by stakeholders to ensure that the best-qualified contractors perform construction work. This means that contractors who have worked for many years with stakeholders will enjoy preferred bidding status so long as an active degree of bid participation and high quality of work continues. This also means that new contractors can quickly establish the same consideration for bid work as a contractor who has worked with stakeholders for many years. Conversely, the process also ensures that both "old" and "new" contractors must continue to perform well and offer reasonably priced construction services in order to maintain their invitational status. Contractors are invited to bid on individual projects based upon attributes that include but are not limited to:

1. A history of reasonable bid price submissions.
2. A work history that indicates specialization and quality of workmanship in a particular construction skill, including the extent to which the Contractor follows project specifications and drawings provided by stakeholders.
3. Degree of participation in the stakeholders bid process, i.e., demonstrating a high degree of attendance at pre-bid meetings and submitting competitive bids when invited to bid.
4. Contractor's degree of quality control, i.e., identification and correction of deficient work or plan conflicts in a timely manner.
5. Decorum, conduct, and non-disruptiveness of contractor staff and subcontractors.

Table 1. Initial decision–making matrix.

Alternatives ↓	Initial decision- making matrix						Normalized weighted decision- making matrix						K	***Rank***
	Attributes ↔						***Attributes*** ↔							
	a_1	a_2	a_3	a_4	a_5	a_6	b_1	b_2	b_3	b_4	b_5	b_6		
Weights → ***w***	0.29	0.23	0.19	0.1	0.05	0.14								
Optimum →	*min*	*min*	*max*	*max*	*max*	*min*								
v_1	1	7.5	11	11	5	9	0.097	0.059	0.048	0.025	0.013	0.030	0.068	2
v_2	1.25	10.5	10	13	3	3	-0.004	0.056	0.046	0.027	0.009	0.038	0.043	4
v_3	0.9	10	12	9	7	5	0.144	0.057	0.049	0.023	0.016	0.034	0.081	1
v_4	1.1	9	11	10	5	3	0.053	0.058	0.048	0.024	0.013	0.038	0.058	3

6. Cooperation with other contractors on the project and in the vicinity.
7. Degree to which Contractor is considerate of building occupants and the construction management project manager with regard to notification, scheduling, and coordination of operations that will cause noise, vibrations, dust, odors, safety concerns, and other activities that can potentially interrupt the normal conduct of business.
8. Responsiveness to warranty issues.
9. Safety consciousness on the job site.
10. Job site cleanliness during projects and upon leaving job sites.
11. Flexibility and cooperation when resolving delays
12. Ability to meet project schedule, given size of full-time staff and the ability to subcontract quickly.
13. Work load at the time of a project solicitation.

Contractor ratings play a direct role in determining whether a contractor will be invited for construction work. Contractors rating is performed according to following proposed attributes (Table 1): $\boldsymbol{x_1}$– price [mln. $]; $\boldsymbol{x_2}$– time [months]; $\boldsymbol{x_3}$– quaranty period [years]; $\boldsymbol{x_4}$– qualification (experience time in construction); $\boldsymbol{x_5}$– relations with client [points]; $\boldsymbol{x_6}$– risk (ammount of works per year own:

$$if\ x_6 \prec x_1\ then\ x_6 = 9;$$
$$if\ x_1 \le x_6 \prec 1.5x_1\ then\ x_6 = 8;$$
$$if\ 1.5x_1 \le x_6 \prec 2.0x_1\ then\ x_6 = 7;$$
$$if\ 2.0x_1 \le x_6 \prec 3.0x_1\ then\ x_6 = 5;$$
$$if\ 3.0x_1 \le x_6 \prec 4.0x_1\ then\ x_6 = 3;$$
$$if\ 4.0x_1 \le x_6 \prec 5.0x_1\ then\ x_6 = 2;$$
$$if\ 5.0x_1 \le x_6\ then\ x_6 = 1.$$

Stakeholders rated contractors for performance on a project by applying Bayes rule.

The initial decision-making matrix have been formed according to these attributes values. The weights $\boldsymbol{w_i}$ of attributes presented in Table 1 were determined by application of the expert judgment method proposed by Kendall (Kendall, 1970; Turskis et al, 2006). The decision-making matrix was normalized by applying logarithm normalization method [8].

The calculation process and results shortly are presented in Table 1.

The rationality of the alternatives is obtained by the formula (1) (Table 1). The solution results show that K_i varies from 0.043 to 0.081.

According to the results of Table 1, we can find the priority of considered alternatives is $a_3 \succ a_1 \succ a_4 \succ a_2$. The best alternative (third contractor) was selected.

5. Conclusion

Making decisions play an important role in the construction management, such as investment, contractor or subcontractor selection, construction technique alternative evaluation and human resource arrangement.

The overall benefit of selecting the most suitable contractor can be the improvement of the stakeholders overall performance. Choosing the right contractor for the right job influences the quality of work as well as the construction progress. Especially during the bidding process optimum selection of contractors is vital for an accurate and realistic bid proposal.

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.

The proposed model is based on multi-attribute evaluation of potential contractors, the determination of their ranks by taking into account the results obtained in the applied multi-attribute analysis. Following the suggested model, the evaluation attributes are selected by taking into consideration the objectives and interests of the stakeholders.

As construction projects and contract works become more complex, a combined assessment of various attributes should be considered by the stakeholders in order to select the most suitable one.

The model presented in this research is a feasible tool to aid in decision making for contractor pre-qualification. This model can help to improve the selection process and obtain the best decision of selecting a contractor.

The application of the model offered in 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.

It should be noted that the stakeholders must adjust the attributes depending on the demand of each project. The critical point is that the selected attributes should have a direct effect on performance.

The method described in this article can be used as a basis for further development. A simple set of six attributes describing basic characteristics of a contractor can be easy changed.

References

1. Kumaraswamy, M.M.; Matthews, J. Improved subcontractor selection employing partnering principles, *ASCE Journal of Management in Engineering,* 2000 –Vol.16, No. 3, p.47–57.
2. Ng, S.T.; Wan, W.Y. 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,* 2005 – 305–314.
3. Tserng, H.P.; Lin, P.H. An accelerated subcontracting and procuring model for construction projects, *Automation in Construction,* 2002 - Vol.11, No. 1, p.105–125.
4. Shiau, Y.C.;Tsai, T.P.; Wang W.C.; Huang, M.L. Use questionnaire and AHP techniques to develop subcontractor selection system, *International Symposium on Automation and Robotics in Construction, 19th (ISARC) Proceedings*, National Institute of Standards and Technology, Gaithersburg, Maryland , 2002 – 35-40.
5. Albino, V.; Garavelli, A.C. A neural network application to subcontractor rating in construction firms, *International Journal of Project Management,* 1998 – Vol.16, No. 1, p.9-14.
6. Luu, D.T.; Sher, W. Construction tender subcontract selection using case-based reasoning, *Australian Journal of Construction Economics and Building,* 2006 – Vol. 6, No. 2, p.31-43.
7. Zou, P. X.W.; Zhang, G.; Wang, J. Understanding the key risks in construction projects in China, *International Journal of Project Management,* 2007 – Vol. 25, No. 6, p. 601-614.
8. Zavadskas, E.K.; Turskis, Z. A new normalization method in games theory , *Informatica***,** 2008 – Vol. 19, No. 2: 303-314
9. Zavadskas, E. K.; Vilutienл, T. A multiple criteria evaluation of multi-family apartment block's maintenance contractors : I—Model for maintenance contractor evaluation and the determination of its selection criteria, *Building and environment,* 2006 - Vol. 41, No. 5, p. 621-632.
10. Zavadskas, E.K.; Kaklauskas, A. Mehrzielselektion fьr Entscheidungen im Bauwesen. Fraunhofer IRB Verlag. 2007.
11. Vilutienл, T.; Zavadskas, E.K. The application of multi-criteria analysis to decision support for the facility management of a city's residential district, *Journal of Civil Engineering and Management,* 2003 – Vol. 9, No. 4, p. 241-252.
12. Sage, A. P. Methodology for Large Scale Systems. New York: McGraw-Hill. 1977.
13. Bui, T. X.Co-oP—A group decision support system for cooperative multiple criteria decision making, in Lecture Notes in Computer Science. Berlin, Germany: Springer-Verlag. 1987.
14. Chankong, V.; Haimes, Y. Y. Multiobjective Decision Making- Theory and Methodology. New York: North-Holland. 1983.
15. French, S.; Simpson, L.; Atherton, E.; Belton, V.; Dawes, R.; Edwards, W.; Hдmдlдinen, R.P.; Larichev, O.; Lootsma, A.; Pearman, A.; Vlek, C. Problem formulation for Journal of Multi-Criteria Decision Analysis : report of a workshop,*Journal of Multi-Criteria Decision Analysis,* 1998 – Vol. 7, No. 5, p.242-262.
16. Hwang, C. L.; Lin, M. J. Group Decision Making Under Multiple Criteria. Berlin: Springer-Verlag. 1987.
17. Hwang C. L., Yoon K. S. Multiple Attribute Decision Making // Methods and Applications. Springer-Verlag. Berlin, Heidelberg, New York. 1981.
18. Triantaphyllou, E. Multi-Criteria Decision Making Methodologies: A Comparative Study, volume 44 of *Applied Optimization*. Kluwer Academic, Dordrecht. 2000.
19. Colson, G.; Bruyn, C. D. Models and Methods in Multiple Criteria Decision Making. New York: Pergamon. 1989.

20. Lin C.-T.; Wu, C.-R. Editorial: qualitative and quantitative methods aimed at technology management. *International Journal of Technology Management (IJTM),* 2007 – Vol. 40, Nos. 1/2/3, p. 1-6.
21. Larichev , O. Decision-making theory and methods. Moscow: Logos 2000. (in Russian) Ларичев О.И. Теория и методы принятия решений. М.: Логос, 2000.
22. Arditi, D, Gьnaydэn, H.M. Perceptions of Process Quality in Building Projects. *Journal of Management in Engineering*; ASCE, 1998 – Vol. 15, No. 2, p.43-53.
23. MacCrimmon, K.R. Decisionmaking Among Multiple-Attribute Alternatives: A Survey and Consolidated Approach, Memorandum RM-4823 -ARPA. The Rand Corporation, Santa Monica, Calif. 1968.
24. Zavadskas, E.K.; Turskis, Z.; Dejus, T.; Viteikiene, M. Sensitivity analysis of a simple additive weight method, *International Journal of Management and Decision Making (IJMDM),* 2007 – Vol. 8, Nos. 5/6, p. 555-574.
25. Srinivasan, V.; Shocker, A. D. Linear Programming techniques for multidimensional analysis of privileged. *Psychometrika,* 1973 – Vol. 38, p.337-369.
26. Zavadskas, E. K.; Kaklauskas, A.; Peldschus, F.; Turskis, Z.. Multi-attribute Assessment of Road Design Solutions by Using the COPRAS Method, *The Baltic Journal of Road and Bridge Engineering,* 2007 – Vol. 2, No. 4, p. 195-203.
27. Zavadskas, E.K.; Kaklauskas, A.; Turskis, Z.; Tamosaitiene, J. Selection of the effective dwelling house walls applying attributes determined in intervals, *Journal of Civil Engineering and Management,* 2008 – Vol.14 No.2. (Article in press).
28. Saaty,T. L. Highlights and critical points in theory and application of the Analytic Hierarchy Process. *European Journal of Operational Research,* 1994 – Vol. 74, p.426-447.
29. Zimmermann, H.-J. An application-oriented view of modelling uncertainty, *European Journal of Operational Research,* 2000 – Vol. 122, No. 2, p. 190-198.
30. Roy, B. Multicriteria Methodology for Decision Aiding. Kluwer Academic Publishers, Dortrecht. 1996.
31. Brans, J. P., Mareschal ,B., Vincke, P. PROMETHEE: anew family of outranking methods in multicriteria analysis. In Brans, J.P. (ed.), *IFORS 84*. North Holland, Amsterdam, 1984 – Vol. 477-490.
32. Berkeley, D., Humphreys, P., Larichev, O., and Moshkovich, H. Aiding strategic decision making: Derivation and development of ASTRIDA. In Y. Vecsenyi and H. Sol, eds., Environment for Supporting Decision Processes, North-Holland, Amsterdam. 1991.
33. Andre'eva, Y., Larichev, O., Flanders, N. & Brown, R. Complexity and uncertainty in Arctic resource decision: The example of the Yamal pipeline. *Polar Geography and Geology,* 1995 – Vol. 19, p. 22-35.
34. Larichev O., Moshkovich , E. Qualitative decision-making methods. Moscow: Fizmalit. 1996. (in Russian) Ларичев О.И., Мошкович Е.М. Качественные методы принятия решений. М.: Наука, 1996.
35. Flanders, N.E., Brown, R.V., Andre'eva, Y. and Larichev, O. Justifying public decisions in Arctic oil and gas development: American and Russian aproaches. *Arctic,* 1998 – Vol. 51, No. 3, p. 262-279.
36. Keeney, R.L. and Raiffa, H. *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, John Wiley & Sons, New York. 1976
37. Zeleny, M. *Multiple Criteria Decision Making*. McGraw-Hill, New York. 1982.
38. Chen, S.J. and Hwang, C.L. *Fuzzy Multiple Attribute Decision Making: Methods and Applications*. Springer, New York. 1992
39. Vincke, P. *Multicriteria Decision-Aid*. Wiley, New York. 1992.
40. Kale, S. and Arditi, D. General Contractors' relationships with subcontractors: a strategic asset. *Construction Management and Economics*, 2001 – Vol. 19, No. 5, p. 541-549.
41. Bana e Costa, C.A. and Vansnick, J.C. Applications of the MACBETH approach in the framework of an additive aggregation model. *Journal of Multicriteria Decision Analysis*, 1997 – Vol. 6, p. 107-114.
42. Bana e Costa, C.A., Ensslin, L., Correa, E.C. and Vansnick, J.C. Decision support systems in action: integrated application in a multicriteria decision aid process. *European Journal of Operational Research*, 1999 – Vol. 113, p. 315-335.
43. Chinyio, E.A., Olomolaiye, P.O., Kometa, S.T. and Harris, F.C. A Needs – Based Methodology for Classifying Clients and Selecting Contractors. *Construction Management and Economics*, 1998 – Vol. 16, No. 1, p. 91-98
44. Ustinovichius, L. Determining integrated weights of attributes. *Statyba (Civil Engineering)*, 2001 – Vol.7, No. 4, p. 321–326.
45. Ustinovichius, L. Determination of efficiency of investments in construction. *International Journal of Strategic Property Management*, 2004 – Vol. 8, No. 1, p. 28–44.
46. Kendall, M.G. Rank correlation methods (4th ed.) London Griffin. 1970.
47. Zavadskas, E.K.; Peldschus, F.; Kaklauskas, A. Multiple criteria evaluation of projects in construction, Vilnius: Technika. 1994.
48. Kaklauskas, A., Zavadskas, E.K. and Raslanas, S. Multivariant design and multiple criteria analysis of building refurbishement. *Energy and Buildings*, 2005 – Vol. 37, No. 4, p. 361-372.
49. Kaklauskas, A., Zavadskas, E.K., Raslanas, S., Ginevicius, R., Komka, A. and Malinauskas, P. Selection of low-e windows in retrofit of public buildings by applying multiple criteria method COPRAS: A Lithuanian case. *Energy and Buildings*, 2006 – Vol. 38, p. 454-462.
50. Eckenrode, R.T. Weighting Multiple Criteria. *Management science*, 1965 – Vol. 12(3), p. 180–192.
51. Saaty, T.L. A Scaling Method for Priorities in Hierarchical Structures. *Journal of Mathematical Psychology*, 1977 – Vol. 15, No. (3), p. 234-281.

52. Chu, A.T.W., Kalaba, R.E. and Spingarn, K. A comparison of Two Methods for Determining the Weights of Belonging to Fuzzy Sets. *Journal of Optimization Theory and Applications*, 1979 – Vol. 27, No. 4, p. 531–538.
53. Zavadskas, E.K. *Complex evaluation and solution of resourse-saving decisions in civil engineering.* Vilnius: Mokslas 1987 (In Russian). Завадскас Э.К. Комплексная оценка и выбор ресурсосберегающих решений в строительстве. – Вильнюс: Мокслас, 1987.
54. Zavadskas, E. K. Systems of Estimation of Technological Solutions in Building Construction. Strojizdat, Leningrad 1991 (in Russian). [Завадскас, Э.-К. 1991. Системотехническая оценка технологических решений строительного производства. Ленинград: Стройиздат, 1991.
55. Diakoulaki, D., Mavrotas, G. and Papayannakis, L. Determining objective weights in multiple criteria problems: The CRITIC method. *Computer and Operations Research*, 1995 – Vol. 22, No. 7, p. 763-770.
56. Figueira, J. and Roy, B. Determining the weights of criteria in the ELECTRE type methods with a revised Simos' procedure. *European Journal of Operational Research*, 2002 – Vol. 139, p. 317-326.
57. Smolнkovб, R. and Wachowiak, M.P. Aggregation operators for selection problems. *Fuzzy Sets and Systems*, 2002 – Vol. 131, p. 23-34.
58. Hatush, Z.; Skitmore, R.M. Contractor selection using multi-criteria utility theory: an additive model *Building and Environment,* 1998 – Vol. 33, Nos. 2/3, p.105-115.
59. Siskos, Y.; Grigoroudis, E.; Politis, Y.; Malandrakis, Y. 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, 2000 – p. 297-314.
60. Ng, S.T.; Skitmore, R.M.; Smith, N.J. 1999. Decision-makers perceptions in the formulation of prequalification criteria, *Engineering Construction & Architectural Management,* Vol. 6, No. 2, p. 155-165.
61. Hatush, Z.; Skitmore, R.M. Assessment and evaluation of contractor data against client goals using PERT approach. *Construction Management and Economics,* 1997 – Vol. 15, No. 4, p. 327-340.
62. Holt, G.D. Applying cluster analysis to construction contractor classification, *Building and Environment,* 1996 – Vol. 31, No. 6, p.557–568.
63. Jaselskis, E.J.; Russell, J.S. Risk analysis approach to selection of contractor evaluation method, *ASCE Journal of Construction Engineering and Management*, 1992 – Vol. 118, No. 4, p. 814–821.
64. Crowley, L.G.; Hancher, D.E. Evaluation of competitive bids, *ASCE Journal of Construction Engineering and Management,* 1995 – Vol. 121, No. 2, p. 238–245.
65. Russell, J.S. Constructor prequalification-choosing the best contractor and avoiding constructor failure, ASCE Press, New York. 1996.
66. Kumaraswamy, M.M. Contractor evaluation and selection — a Hong Kong perspective, *Building and Environment,* 1996 – Vol. 31, No. 3, p. 273–282.
67. Zavadskas, E.K.; Kaklauskas, A. Determination of an efficient contractor by using the new method of multicriteria assessment . *International Symposium for "The Organisation and Management of Construction". Shaping Theory and Practice. Vol. 2: Managing the Construction Project and Managing Risk.* /edited by D.A.Langford and A.Retik CIB W 65; London, Weinheim, New York, Tokyo, Melbourne, Madras. - London: E and FN SPON 2, 1996 – p. 94-104.
68. Banaitiene, N.; Banaitis, A. Analysis of criteria for contractors' evaluation, *Technological and economic development of economy,* 2006 – Vol. 12, No. 4, p. 276-282.
69. Dikmen, I.;, Birgonul, M. T.; Gur, A. K. A case-based decision support tool for bid mark-up estimation of international construction projects. *Automation in Construction,* 2007 – Vol. 17, No. 1, p. 30-44.
70. Zavadskas, E.K.; Peldschus, F.; Ustinovichius, L. Development of software for multiple criteria evaluation, *Informatica,* 2003 – Vol. 14 , No. 2, p.259-272.
71. Peldschus, F.; Vaigauskas, E.; Zavadskas, E.K. Technologische Entscheidungenbei der Berьcksichtigung mehrerer Ziehle, *Bauplanung–Bautechnik*, 1983 Vol. 37, No. 4, p. 173-175.
72. Zavadskas, E. K. ; Ustinovichius, L. ; Turskis, Z.; Peldschus, F.; Messing, D. LEVI 3.0 – Multiple criteria evaluation program for construction solutions,*Journal of Civil Engineering and Management,* 2002 – Vol. 8 , No. 3, p. 184–191.
73. Peldschus, F.; Messing, D.; Zavadskas, E.K.; Ustinovichius, L.; Turskis, Z. LEVI 3.0 – multiple criteria evaluation program under uncertainty. *Technological and Economic Development of Economy,* 2002 – Vol. 8, No. 1, p. 3 – 12.
74. Peldschus, F.The effectiveness of assessment in multiple criteria decisions, *International Journal of Management and Decision Making*, 2007 – Vol. 8, Nos. 5-6, p. 519-526.
75. Peldschus, F.; Zavadskas, E.K. Matrix games in building technology and management. Vilnius: Technika, 1997. (In Lithuanian) .
76. Peldschus, F.; Zavadskas, E.K. Fuzzy matrix game multi-criteria model for decision-making in engineering, *Informatica*, 2005 – Vol. 16 , No. 1, p. 107-120.
77. Zavadskas, E.K.; Peldschus, F.; Ustinovichius, L.; Turskis, Z. Game theory in building technology and management. Vilnius: Technika, 2004. (In Lithuanian)
78. Ustinovichius, L.; Zavadskas, E.K.; Migilinskas, D.; Malewska, A.; Nowak, P.; Minasowicz, A. Verbal analysis of risk elements in construction contracts, *Cooperative Design, Visualization, and Engineering: third International Conference, CDVE 2006, Mallorca, Spain, September 17-20, 2006: proceedings. Lecture Notes in Computer Science,* 2006 - Vol. 4101, p. 295-302.

79. Al-Harbi, K. Application of the AHP in project management, *International Journal of Project Management,* 2001 – Vol. 19, p. 19–27.
80. Topcu, Y.I. A decision model proposal for construction contractor selection in Turkey *Building and Environment,* 2004 – Vol. 39, p. 469–481.
81. Pongpeng, J.; Liston, J. A multi-criteria model's survey: state of the art and some necessary capabilities of future models, *Construction Management & Economics,* 2003 – Vol. 21, No. 7, p. 665–670.
82 Wong, C.H.; Nicholas, J.; Holt, G.D. Using multivariate techniques for developing contractor classification models, *Engineering, Construction and Architectural Management,* 2003 – Vol.10, No. 2, p. 99–116.
83 Mitkus, S; Trinkuniene, E. Models of indicator systems of construction contraction agreements, *Journal of civil engineering and management,* 2006 – Vol. 12, No. 4, p. 327-335.
84 Mitkus, S.; Trinkuniene, E. Analysis of criteria system model for construction contract evaluation, *Technological and economic development of economy,* 2007 – Vol. 13, No. 3, p. 244-252.
85 El-Sawalhi, N.; Eaton, D.; Rustom, R. Contractor pre-qualification model: State-of-the-art. *International Journal of Project Management,* 2007 – Vol. 25, No. 5, p. 465-474.
86 Zagorskas, J.; Turskis, Z. Multi-attribute model for estimation of retail centres influence on the city structure. Kaunas city case study, *Technological and economic development of economy,* 2006 – Vol. 12, No. 4, p.347-352.
87. Kersuliene, V. Possibilities of clients and contractor's disputes settlement at the pretrial stage. *Technological and economic development of economy,* 2007 – Vol. 13, No. 2, p. 139-143.
88. Turskis, Z.; Zavadskas, E.K; Zagorskas, J. Sustainable city compactness evaluation on the basis of GIS and Bayes rule, *International Journal of Strategic Property management,* 2006 – Vol.10, p.185-207.
89. Murtoaro, J.; Kujala, J. Project negotiation analysis. *International Journal of Project Management,* 2007– Vol. 25, No.7, p.722-733.

Зенонас Турскіс – кандидат технічних наук, старший науковий співробітник либораторії будівельних технологій Вільнюського Технічного Університету Гедемінаса. Наукові інтереси: будівельна техніка і управління, теорія прийняття рішень.

Зенонас Турскис – кандидат технических наук, старший научный сотрудник лаборатории строительных технологий и управления Вильнюсского Техническиого Университета Гедеминаса (Литва). Научные интересы: строительная техника и управление, теория принятия решений.

Zenonas Turskis – PHD, senior research fellow of Construction Technology and Management laboratory of Vilnius Gediminas Technical University (Lithuania). Research interests: building technology and management, decision-making theory, computer-aided automation in design, expert systems.