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SAW METHOD APPLICATION IN SELECTION OF ROADS CONSTRUCTION SUPPLIERS

The selection criteria for road construction suppliers are investigated in this study. Simple additive weighting (SAW) approach is applied to 9 selection criteria and simple additive weighting score was used to determine the best supplier. Three construction companies were selected as suppliers and, the values of partial selection criteria that determine the final index of suppliers' stability, are quantified. According to the results, suppliers' references was the most decisive criterion, and the selection process was the least important one.

Keywords: *SAW method; road construction; suppliers; selection criteria.*
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ЗАСТОСУВАННЯ ПРОСТОГО АДИТИВНОГО ЗВАЖУВАННЯ ПРИ ВИБОРІ ПОСТАЧАЛЬНИКІВ ДЛЯ БУДІВНИЦТВА ДОРІГ

У статті представлено критерії вибору постачальників при будівництві доріг. Показано застосування методу простого адитивного зважування, за якого найвищий бал отримує найкращий постачальник. На прикладі трьох компаній-постачальників продемонстровано, яким чином часткові критерії вибору формують фінальний індекс стабільності постачальника. За результатами дослідження, найбільш суттєвим фактором при виборі постачальника є його рекомендації, а найменш суттєвим — безпосередньо процес участі в тендері.

Ключові слова: *метод простого адитивного зважування; будівництво доріг; постачальники; критерії вибору.*
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ПРИМЕНЕНИЕ ПРОСТОГО АДДИТИВНОГО ВЗВЕШИВАНИЯ ПРИ ВЫБОРЕ ПОСТАВЩИКОВ В СТРОИТЕЛЬСТВЕ ДОРОГ

В статье представлены критерии выбора поставщиков при строительстве дорог. Показано применение метода простого аддитивного взвешивания, при котором наивысший балл получает лучший поставщик. На примере трёх компаний-поставщиков продемонстрировано, каким образом частичные критерии выбора формируют финальный индекс стабильности поставщика. Согласно результатам исследования, наиболее значимым фактором при выборе поставщика оказались его рекомендации, а наименее — непосредственно процесс участия в тендере.

Ключевые слова: *метод простого аддитивного взвешивания; строительство дорог; поставщики; критерии выбора.*

Introduction. The key element in the implementation of projects for building a road section is the selection of a suitable supplier. Success of implementation of a specific project within specified time and quality is determined by supplier. Inappropriate choice of a supplier for construction can lead to significant losses which can be difficult to reduce during the implementation as it often has an immediate and long-term negative impact on the ability of a particular supplier to respond

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to the needs of the customer. In recent years the realization, and also the selection of suppliers for road infrastructure building projects was mainly determined by state contracts and implementation of these projects is normally based on the results of public tenders. However, in public tenders the highest weight of the total score is often the final cost of construction works. There are also other factors directly affecting the amount of necessary investments which should be partially evaluated including prioritization in direct interaction with the selection of a contractor.

It is clear that the process of selection between suppliers must be systematic, comprehensive, and effective with the priority of meeting all clearly predefined circumstances and requirements, i.e. criteria set out in the framework of a public tender. For this reason it is necessary to quantify the importance (i.e. weight) of each request explicitly within a systematic approach and multi-criteria decision-making, including the terms of interval scoring of their realization by particular suppliers.

The simple additive weighting (SAW) method (Harsanyi, 1955, Churchman et al., 1957) is a direct method of multi-criteria decision-making. Under this method the decisive body decides about the input parameters and their dependencies. The most commonly used method, due to simplicity and good results, is proportionally index method and it can lead to specific choice by comparing overall evaluations (Hwang and Yoon, 1981; Chang and Yeh, 2001; Virvou and Kabassi, 2004). It uses all criterion values of alternatives and employs regular arithmetical operations of multiplication and addition (Chen, 2012; MacCrimmon, 1968; Chen and Hwang, 1992). In the study by (Einhorn and McCoach, 1977) the properties of SAW, including conditionally monotonic with utility and risk neutrality of decision behaviour, which is important for determining the weights of each criterion, were studied. SAW method was also applied to compare the fossil fuel (coal) power plants with nuclear power plants in (Shakouri et al., 2014). The results of that study showed that fossil fuel power plants with carbon capture and storage are slightly more efficient than nuclear power plants, with a remark on the disputability of input and output variables. SAW method was also combined with other fuzzy approaches, e.g. fuzzy set theory and the factor rating system to deal with both qualitative and quantitative dimensions (Chou et al., 2008), analytic hierarchy process, technique for order preference by similarity to ideal solution etc. to solve fuzzy multi-criteria decision-making problems and encompass decision-making messages under uncertainty and vagueness (Wang, 2015). SAW method has also been successfully used in determination of the optimum cocoa type or cocoa combination in physicochemical, sensory, and rheological properties of hot chocolate beverages (Dogan et al., 2015), in the study on the impact of anthropogenic risks on protected areas (Saffarian and Zaredar, 2015), in the selection of procurement methods for small building works (Griffith and Headley, 1997), in determining the overall framework and structure of responsibilities and authorities for participants of the building process (Love et al., 1998), in risk assessment and grading of pollution by metals in a copper sulphide mine in Iran (Rezaei et al., 2015), in non-cooperative competing game-theoretic model and strategy space based on user preference incorporated into the framework of noncooperative game theory (Salih et al., 2015), in spectrum handoff strategy to determine target channel to switch (Zhao et al., 2015), in assessment and monitoring of higher education institutions networking performance and supporting strategising (Nugaras and Ginevicius, 2015), in selecting the most suitable table grape variety intended for organic viticulture (Dragincic et al., 2015), in pharmaceutical supply chain risk assessment (Jaberidoost et al., 2015), in assessment of process management maturity in developing countries (Radosavljevic, 2014) and probably many other fields.

Possible application of SAW in selection of suppliers for road construction is analysed here. Selection of road construction suppliers was made on clear prioritization of selection criteria determined by implementation of quantification of their interacting links by an explicitly defined methodology. In combination with the assessment of each supplier selection criteria by interval evaluation followed by quantification in terms of SAW method the best road construction supplier was identified.

SAW method in selection of road construction suppliers. SAW method is characterized by an additive relationship using the weights of individual evaluation criteria (Balog and Straka, 2006):

$$U_m(x)=\sum_{m}^{n} a_i u_i(x_i), \tag{1}$$

where α_i – weight of the i-th criteria defined by the decisive body, for which $\sum_{i=1}^{n} a_i = 1$; $u_i(x_i)$ – usefulness of the i-th evaluation criteria for x_i, often $u_i(x_i) = x_i$; x_i – value of the result by the i-th criterion; $U_m(x)$ – total usefulness of supplier evaluation (stability index), $m = 1, 2, 3, ..., m$.

The drawback of the method is the possibility of compensation by reducing the quality of one evaluation criterion by increasing the quality by another. In summary valuation of the result the values according to different evaluation criteria are already indistinguishable and the same summary valuation of the usefulness result $U_m(x)$ corresponds to various cases of relations of values under each sub-criterion. Among these there may be some that are, in real terms, completely inappropriate for a deciding person (Ocelikova, 2011). The failure can be reduced by participation of several experts not only in identifying the criteria but also in quantifying their importance (α_i), including their objectification, in choosing the supplier for road construction.

For the purposes of applying the above described multi-criteria SAW method a schematic overview of the selection criteria of potential suppliers which were attributed weight α_i, accepting the general condition of $\Sigma\alpha_i = 1$, was created. The value of the weight creating a square matrix whose dimensions correspond to the number of defined criteria was quantified. The individual criteria were compared with each other. The values 1, 0, and 0.5 were used. To the diagonal of the matrix formed a value of 0 was plotted. In the case the considered factor is more important than the one compared with, a value of 1 was assigned, if it is less important, 0 was assigned, if they are of the same importance, a value of 0.5 was assigned. A partial sum of individual lines was created. Partial sums were summed for the final value that reflects interactions of the selection criteria that quantified the final value of individual weights α_i. The individual assessed selection criteria were assigned cardinal points of <0, 6> of interval point evaluation as follows:

0 – does not meet at all;

1 – meets significantly below average;

2 – meets below average;
3 – meets on average;
4 – meets above average;
5 – meets significantly above average;
6 – meets completely.

The points were multiplied with weights and the sum of multiplied points with the weights determines the final score of a particular supplier of the road section constructor. A supplier who has the greatest stability index (most points) is considered to be the most favourable for the needs of road construction according to the predefined selection criteria (Table 1).

Table 1. **Evaluation of potential suppliers for road construction by SAW method** (Balog and Straka, 2006; Ocelikova, 2011)

Factors	Factor weight	Supplier A	α_i x u_{1i}	Supplier B	α_i x u_{2i}	...
F_1	α_1	u_{11}	α_1 x u_{11}	u_{21}	α_1 x u_{21}	...
F_2	α_2	u_{12}	α_2 x u_{12}	u_{22}	α_2 x u_{22}	...
F_3	α_3	u_{13}	α_3 x u_{13}	u_{23}	α_3 x u_{23}	...
...	...	...	...	...	...	...
F_n	α_n	u_{1n}	α_n x u_{1n}	u_{2n}	α_n x u_{2n}	...
Index of stability	$\Sigma\alpha_I = 1$		$U_1 = \Sigma\alpha_i$ x u_{1i}		$U_2 = \Sigma\alpha_i$ x u_{2i}	

Model solution for selection of suppliers for road construction using SAW method. Selection of suppliers or contractors from individual road section is implemented through public tender with precisely defined requirements for future work of the contractor. The completed construction projects of expressways, highway sections, or 1st class roads in Slovakia were implemented by those suppliers (contractors) offering the lowest cost of making a particular work because in the tender the highest score was allocated to the total price of works.

According to the above data the selection criteria should be predefined in evaluation of potential suppliers with specified weights of importance that also provide a degree of influence of the selection criteria, i.e., the higher is the value of αi the more important would be the selection criterion in the selection process. For these reasons the following were included into the selection criteria:

- the cost of materials, material items' price according to the nature and requirements of a contractor;
- the cost of labour, cost of construction and other related works according to the nature and requirements of a contractor;
- the cost of delivery, i.e. the total cost of construction of a specific road section expressed by quotation;
- financial stability of a supplier, i.e. the ability to provide the required level of liquidity and profitability;
- solvency, i.e. supplier's ability to pay its due obligations for the requested period;
- references of a supplier;
- delivery reliability, i.e. probability of passing the delivery period with a primary role in the reliability of operating procedures and readiness of the supplier;

- warranty and post-conditions;
- charge conditions, i.e. due time.

By the above mentioned selection criteria the scales (Table 2) which reflect the importance of specific selection criteria in the actual process of choosing the right supplier were quantified. The results of weights' quantification of the selection criteria which form an integral part of the selection process by SAW method, pointed to the following partial conclusions (Figure 1):

- decisive partial criteria for the selection process of suppliers are their references and financial stability (α_i = 0.17, i.e. about 17% of the total criteria in the selection);
- less important partial criteria are warranty and post-conditions (α_i = 0.15, i.e. about 15% of the total criteria of the selection);
- delivery price which was the decisive criterion in the previously implemented public tender, was, together with solvency, given the importance of assessing the selection criteria to the third place (α_i = 0.14, i.e. about 14% of the total criteria of the selection).

Table 2. **Quantification of the weights of the selection criteria of suppliers,** *authors'*

Selection criterion	price of material	price of work	price of supply	financial stability	financial solvency	references	reliability of supply	warranty and post-conditions	payment terms	sum	α_i
price of material	0	0.5	0.0	0.0	0.0	0.0	0.5	0.0	0.0	1	**0.03**
price of work	0.5	0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	1	**0.03**
price of supply	1.0	1.0	0	0.5	0.5	0.5	0.5	0.5	0.5	5	**0.14**
financial stability	1.0	1.0	0.5	0	0.5	0.5	1.0	0.5	1.0	6	**0.17**
financial solvency	1.0	1.0	0.5	0.5	0	0.5	1.0	0.0	0.5	5	**0.14**
references	1.0	1.0	0.5	0.5	0.5	0	1.0	1.0	0.5	6	**0.17**
reliability of supply	0.5	0.5	0.5	0.0	0.0	0.0	0	0.0	0.5	2	**0.06**
warranty and post-conditions	1.0	1.0	0.5	0.5	0.0	0.5	1.0	0	1.0	6	**0.15**
payment terms	1.0	1.0	0.5	0.0	0.5	0.5	0.5	0.0	0	4	**0.11**
Sum										36	1.00

Having made quantification of weights of the selection criteria, scoring of 3 suppliers by the above-defined conditions was started. As suppliers 3 construction companies in Kosice (supplier A), Bratislava (supplier B), and Zilina (supplier C), have been chosen which were involved in the implementation of projects on construction on several sections of roads (highway sections, sections of expressways, 2nd and 3rd class roads), noise walls, gabion retaining walls, public lighting, including natural and electrical work, parking areas etc. The data were collected first on the Internet and then directly from the suppliers. The data were collected from September 2014 to August 2015.

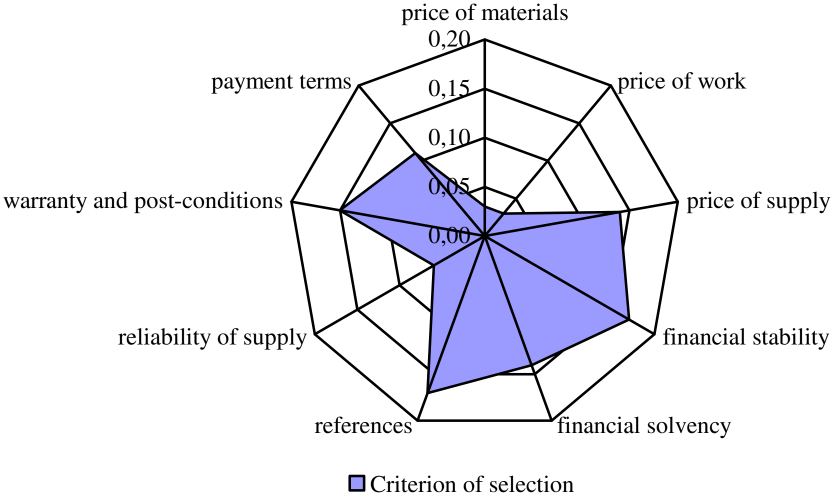

Figure 1. **Selection criteria of suppliers,** *authors'*

In terms of SAW methodology, the values of partial selection criteria determining the final index of the suppliers' stability were explicitly quantified. Based on the results of partial evaluation of the selection criteria it can be concluded that the decisive criteria for all 3 potential suppliers was their references, which ranged from 0.845 (supplier A) to 1.014 (suppliers B and C); on the other hand, the lowest potential showed the selection process (Figure 1). The average value of clearly defined selection criteria was met by the supplier A to the greatest extent with the average of 55.56% (delivery time, financial stability, references, warranty and post-conditions), while supplier C got the smallest extent with the average of 33.33% (financial stability, reference, warranty and post-conditions), as shown in Figure 2.

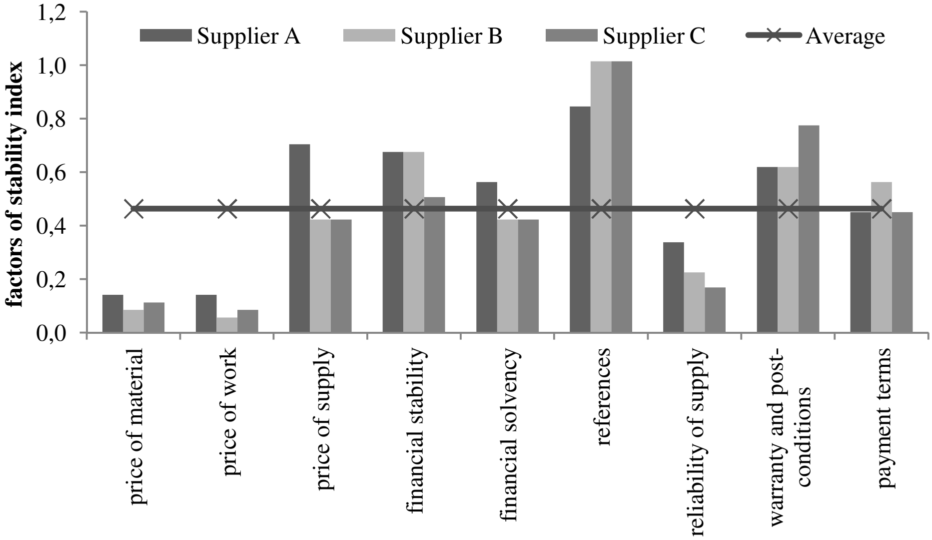

Figure 2. **Values of the selection criteria of potential suppliers,** *authors'*

Based on the results of multicriteria SAW method (Table 3) it can be stated that the optimum supplier for road construction under the above-defined selection criteria and conditions of interval scoring would be the company A located in Kosice whose stability index reached 4.479 and the least suitable company would be company C with the stability index of 3.958 (Table 3 and Figure 3).

Table 3. **Evaluation of the selected suppliers for road construction,** *authors'*

Selection criterion	α_i	Supplier A		Supplier B		Supplier C	
		u_i	α_i x u_{1i}	u_i	α_i x u_{2i}	u_i	α_i x u_{3i}
price of material	0.03	5	0.141	3	0.085	4	0.113
price of work	0.03	5	0.141	2	0.056	3	0.085
price of supply	0.14	5	0.704	3	0.423	3	0.423
financial stability	0.17	4	0.676	4	0.676	3	0.507
financial solvency	0.14	4	0.563	3	0.423	3	0.423
references	0.17	5	0.845	6	1.014	6	1.014
reliability of supply	0.06	6	0.338	4	0.225	3	0.169
warranty and post-conditions	0.15	4	0.620	4	0.620	5	0.775
payment terms	0.11	4	0.451	5	0.563	4	0.451
Index of stability	**4.479**			**4.085**		**3.958**	

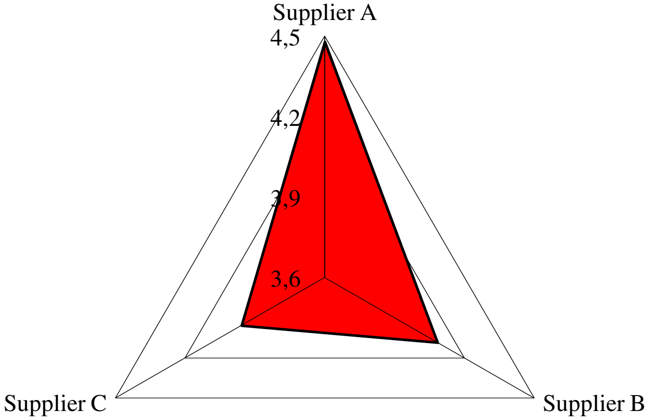

Figure 3. **The index of stability of the potential suppliers,** *authors'*

The realized above model of road construction supplier selection is designed as open, i.e. the number of selection criteria as well as the number of suppliers can be changed (reduced or increased) depending on the nature and the type of implementation of specific project of road construction and the number of candidates meeting the conditions of a particular tender.

Conclusions. Selection of suppliers in road making is a very sensitive process integrating the selection criteria and the extent of their compliance with suppliers which is determined by the character, nature and other specific requirements of a particular project. From this perspective there is a possibility of direct application of multicriteria methods including SAW. This method is a subjective one because the subject of decision-making is selecting the criteria. It is possible to objectify the method through participation of several experts and by explicit quantification of balance. SAW method is time-saving, easy, simple, and its results provide clearly quantifiable arguments for the selection of road making suppliers.

The main novel points and merits of the proposed evaluation method are the explicit quantification of selection criteria weights that also determine the priority in complex decision-making on the selection of a particular road construction supplier. In interaction with the implementation of interval evaluation of the selection criteria of each supplier with the objective of quantifying the stability index relevant arguments of the results of particular tender can be reached.

The proposed model was created as an open one, i.e. it can be flexibly adapted to particular circumstances (by extending the number of selection criteria or the interval scoring). The subjectivity of the method can be reduced by participation of several experts in quantifying the balance of the selection criteria.

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