Use of the TOPSIS technique to choose the best supplier of quarry natural aggregate

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Abstract

Purpose. All over the world, natural substance – the most consumed after water – is the aggregate. The aim of this paper is to select the best supplier of Quarry Natural Aggregate (QNA).

Methods. Selection of the best supplier of QNA is performed using the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) approach, and the method of weights based on ordinal ranking of criteria, and Lagrange multiplier.

Findings. In this article, the proposed Multi-Criteria Decision Making (MCDM) approach helps the decision maker(s) to choose the best supplier of QNA amongst the considered and evaluated suppliers.

Originality. During negotiation with suppliers, many are the decision makers which only attach an importance at two criteria (unit price and quality, or unit price and delivery time). Thereby, other criteria are not taken into account. Consequently, supplier selection would become not-efficient. The originality of this work is based on the multi-criteria approach to choose the best supplier of QNA.

Practical implications. The efficient choice of the best supplier of QNA represents a practical and economical value for the enterprises of the civil engineering, public works, railway and hydraulic works.

Keywords: lagrange multiplier, criteria weights, TOPSIS, supplier, aggregate, quarry

1. Introduction

Supplier selection problem of Quarry Natural Aggregate (QNA) is delicate. It is inter alia posed to the Enterprises of civil engineering, public works, bridges-and-roadways, construction of hydraulic dams, and railway.

Novelty of this article is the application of multi-criteria approach for choosing the best supplier of QNA. In the proposed methodology, as multi-criteria aggregation procedure, we propose the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) technique [1]. About the elicitation of criteria weights, we suggest the method of weights based on ordinal ranking of criteria, and Lagrange multiplier [2]. Decisional problems, resolved by the multi-criteria approach, are formalized by criteria as various as conflictual (not having the same units of measurement).

For identifying and defining the criteria to solve QNA supplier selection problem, we undertook a survey near construction and public works' enterprises in Algeria. After recapitulation and analysis of the collected responses, the retained criteria are:

– acquisition price per ton;
– transport price per ton per km;
– transport distance;
– quality;
– delivery time;
– guarantee policy;
– rejection level.

Among the seven criteria above-cited, one criterion (guarantee policy) is qualitative, six other criteria are quantitative. Conversion of the guarantee policy criterion, into quantitative criterion, is realized according to the recommendations of Bellut [3].

In this paper, a numerical example is accomplished to illustrate the proposed methodology. It is stated as follows: "select one supplier of QNA among a set of seven alternatives $\{a_1, …, a_7\}$ associated with seven criteria $\{C_1, …, C_7\}$". After aggregation of the considered alternatives' evaluations, final result indicates that the supplier of QNA $\{a_4\}$ represents the best solution.

2. Types of aggregates

Since the advent of industrialization at the beginning of the eighteenth century, aggregates are used in different domains such as civil engineering, bridges-and-roadways, construction of the hydraulic dams, railway, etc. Over twenty billions of tons of aggregates are yearly employed in the world for:

– hydraulic concretes;
– asphaltic concretes;

– bituminous mixes;
– pavements;
– railway (as ballast);
– surface treatment;
– abrasives; etc.

Aggregates generally come from two different sources: natural aggregates and artificial aggregates:

1. The natural aggregates are extracted from the sand deposits, the gravel deposits and the quarries. They are divided as follows:
   – river aggregate (sand);
   – sea aggregate (marine sand);
   – lake aggregate (sand);
   – desert aggregate (eolian sand);
   – glacial aggregate (sand);
   – fluvial aggregate (sand);
   – quarries' aggregates.

Concerning the aggregates of quarries, they are divided as follows [4]:

a) aggregates of calcareous origin: caliche, marl, coquina, limestone, dolomite;

b) aggregates of siliceous origin: flint, agate, chalcedony, chert, opal;

c) aggregates obtained starting from the metamorphic rocks: marble, gneiss, schist, quartzite, slate;

d) aggregates obtained starting from the igneous rocks: basalt, diorite, andesite, granite, and gabbro.

2. The artificial aggregates, which are of mineral origin emanating from an industrial treatment, can be slags, residues of mines and quarries, ashes and waste of bricks. There is equally another category of artificial aggregates. It is about the recycled and developed aggregates starting from the demolition of old constructions [5].

A natural aggregate, before its exploitation, must obligatorily satisfy standards of use which are generally required before the quarry is certified and authorized for production.

3. Problematic of suppliers' selection

A supplier is defined as being an executant of services in accordance with the schedule of conditions which inter alia specifies his duties and the rights of customer(s).

Services carried out by the suppliers are numerous, they concern the sale of materials, minerals, equipments, products, etc.; the repair of defective machines; the provisioning of the companies of spare parts; etc.

In construction and public works' sector, local enterprises or multinational corporations often pass contracts with one or more suppliers to be supplied by one or more products necessary to the realization of works.

By way of illustration, one Unit of works prefabrication in concrete (beams, attic-windows, cornices, longitudinal beams, etc.) is related to several suppliers. Amongst those latter, we can quote: the supplier of cements, the supplier of aggregates, the supplier of equipments, the supplier of electricity, the supplier of natural gas, etc.

The selection of suppliers becomes thus a strategic decision which has a crucial impact on the global performance for any enterprise [6]. The supplier evaluation-selection problem can be solved by using one of methods or approaches below:

1. Method based on the cost.
2. Method based on the artificial intelligence.
3. Method of categorization.
4. Mono-objective mathematical programming method.
5. Multi-objective mathematical programming method.
6. Probabilistic method.
7. Statistical method.
8. Multi-criteria approach with single criterion of synthesis.
9. Multi-criteria approach with outranking of alternatives.
10. Hybrid approach.

Let us note that several researchers consider the supplier selection problem as being of multi-criteria nature [7], [8]. The works relating to the supplier selection, using the multi-criteria approach and published those latter years, are numerous and relevant [9].

4. Overview on the multi-criteria decision making

4.1. Criteria weights' elicitation methods

In the multi-criteria decision making, weights of selection criteria are directly provided by the decision maker or indirectly determined starting from methods of calculation. According to the literature, there are various methods for eliciting criteria weights. The most relevant methods are presented in Table 1.

Table 1. Main methods of criteria weights' elicitation

Methods	Author(s)
Method of successive comparisons	Churchmann and Ackoff (1954)
Method of simple ranking	Kendall (1970)
Method of trade-offs	Keeny and Raiffa (1976)
Method of eigenvalues	Saaty (1980)
Method of reciprocal weights	Stillwell et al. (1981)
Method of rank sum linear weights	
Method of standard deviation	Fleiss (1981)
Method of entropy	Zeleny (1982)
Method of the centralized weights	Solymosi and Dombi (1985)
Method of ratio	Von Winterfeldet and Edwards (1986)
Method of probabilistic evaluation	Rietveld (1989)
Statistical method	Diakoulaki et al. (1992)
Method of "resistance to change" grid	Rogers and Bruen (1998)
Method of geometrical weights	Lootsma (1999)
Method based on the distance between partial preorders	Xu (2001)
Method of the revised Sismos' procedure	Figueira and Roy (2002)
Method based on the rank inclusion in criteria hierarchies	Salo and Punkka (2005)
Method of empirical weights	Alfares and Duffuaa (2009)
Method of total variation	Bouhedja and Pousin (2011)
Method of MGDA/Multiple Gradient Descent Algorithm	Désidéri (2012)
Method Q-Eval/Questioning-Evaluation	Eppe and De Smet (2014)
Method of KEMIRA/Kemeny Median Indicator Ranks Accordance	Krylovas et al. (2014)
Method based on the Data Envelopment Analysis	Bagherikahvarin and De Smet (2017)
Method based on the ordinal ranking of criteria and Lagrange multiplier	Bouhedja and Pousin (2017)

4.2. Multi-Criteria Decision Making methods

According to the literature, Multi-Criteria Decision Making (MCDM) methods are divided into two categories below:

The first category (belonging to the American school) is composed from the aggregation methods based on a single criterion of synthesis.

The second category (belonging to the European school) is constituted from the aggregation methods based on the outranking of alternatives.

The main methods of multi-criteria decision making are presented in Table 2.

Table 2. Main methods of multi-criteria decision making

MCDM Methods	Author(s)
SMART (Simple Multi-Attribute Ranking Technique) method	Edwards (1971)
MAUT (Multi-Attribute Utility Theory) method	Keeny and Raiffa (1976)
AHP (Analytical Hierarchy Process) method	Saaty (1980)
TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method	Hwang and Yoon (1981)
WSM (Weighted Sum Method)	In Timmermann (1986)
WPM (Weighted Product Method)	In Pomerol and Barba-Romeo (1993)
COPRAS (COmplex PRopotional ASsessment) method	Zavadskas et al. (1994)
SIR (Superiority and Inferiority Ranking) method	Xu (2001)
VIKOR* (VIseKriterijumska Optimizacija i kompromisno Resenje) method	In Oprocovic and Tzeng (2004)
ARAS (Additive Ratio ASsessment) method	Zavadskas and Turskis (2010)
ARAS-G (Additive Ratio Assessment-Grey) method	Turskis and Zavadskas (2010)
SAW (Simple Additive Weighting) method	In Afshari et al. (2010)
SWARA (Step-wise Weight Assessment Ratio Analysis) method	Keršuliene et al. (2010)
ELECTRE (ELimination Et Choix Traduisant la REalité) methods	Roy (1996)
PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluation) methods	Brans and Mareschal (2002)

*VIKOR: in English means "Multi-criteria optimization and compromise solution"

5. Proposed methodology

5.1. Identification of the selection criteria

When solving multi-criteria decisional problems, number of criteria is generally given by the decision maker(s). However, for helping as well decision maker(s) than analyst (technical expert), many researchers work on identification of the selection criteria.

The multiple criteria, used in the supplier selection framework, are identified and defined by numerous authors whose [10], [11].

The above-mentioned researchers' results, concerning the identification of criteria in relation to the supplier selection problem, show that the criteria represent strong and indispensible link in the multi-criteria decision making process. However, for each category of suppliers, it is necessary to identify and define the corresponding criteria.

For the supplier selection of quarry natural aggregate, we undertook a survey near construction and public works' enterprises in Algeria. After recapitulation and analysis of the collected responses, we have identified the criteria as shown in Table 3.

Table 3. Identification of the selection criteria

C_j	Definition of criteria	Ranks
C_1	Acquisition price per ton	1
C_2	Transport price per ton per km	2
C_3	Transport distance	3
C_4	Quality of QNA	4
C_5	Delivery time	5
C_6	Guarantee policy	6
C_7	Rejection level	7

Let us look at these criteria in a detailed way. The seven above-mentioned criteria form a family of criteria in relation with the economic and technical domain. This family of criteria satisfies five conditions imposed by Keeny and Raiffa (1976) which are: exhaustivity, non-redundancy, operability, decomposability and minimality.

The two first are criteria strictly economical: the first is related to the acquisition price of QNA, and the second concerns transport price per ton per kilometer.

The third criterion is related to the transport distance. It is considered by the ones as criterion of geographical localization, by others as economical criterion. Let us note that the quarries, which produce the aggregates, are generally far from the activity zones of the enterprises-consumers of QNA. Then, price of transport depends on the hauling distance. It can be higher or exceeds purchase in some cases.

The fourth criterion is technical, it characterizes quality of QNA. Natural aggregates, used for hydraulic concretes, asphaltic concretes or bituminous mixes, must obligatorily satisfy standards of use which are required before the quarries are certified and allowed for production. In this paper, we have retained clay fines' content as criterion of quality. The consequences of the presence of the argillaceous particles, in great quantity in the concrete, are numerous. We can quote for example: the expansion of hardened concrete, appearance of fissures, loss of resistance, and the decrease in durability.

In construction and public works' sector in Algeria, maximum content of clay fines' particles is regulated at 3% [12]. According to Reza and Wilde [13], maximum allowable percentages of clay lumps and friable particles are 2, 3 and 3% respectively for the weathering exposure categories: severe, moderate, and negligible.

When silt fines content is more than 5%, concrete exhibits higher chloride ion penetrability and decreases in durability [14]. In this work, for the criterion of quality of quarry natural aggregate, content of clay fines must not exceed 3%.

The fifth criterion is technico-temporal. It concerns delivery time. Let us mention that more the delivery time is respected by supplier, more the consumer(s) of QNA is (are) at ease in his (their) work organization. The delivery time can extend from one at some days. It depends on the availability of the quantities produced or stored by every supplier of QNA.

The sixth criterion concerns responsibility of the supplier. It is related to the guarantee policy ensured by supplier towards the customer(s). In this article, we perform the conversion of the guarantee policy criterion into quantitative criterion (Table 4).

Table 4. Ranks of guarantee policy

QNA suppliers' types	Guarantee policy	Ranks, (points)
Reliable supplier	Excellent	5
Credible supplier	Good	4
Acceptable supplier	Moderate	3
Recoverable supplier	Weak	2
Failing supplier	Bad	1

Conversion of the guarantee policy criterion, into quantitative criterion with five ranks, is accomplished according to the guidelines of Bellut [3]. Then, the five ranks, characterizing fives types of QNA suppliers, are presented as follows:

1. Reliable supplier (5 points): excellent performance, excellent management, excellent technical capacity, excellent turnover, thorough respect of contracts with the customers.

2. Credible supplier (4 points): good performance, good management, good technical capacity, good turnover, sure respect of contracts with the customers.

3. Acceptable supplier (3 points): moderate performance, moderate management, moderate technical capacity, moderate turnover, plausible respect of contracts with the customers.

4. Recoverable supplier if improvement will take place in the future (2 points): weak performance, weak management, weak technical capacity, weak turnover, possible respect of contracts with the customers.

5. Failing supplier (1 point): supplier in bankruptcy, very weak performance, catastrophic management, very weak technical capacity, unimportant turnover, probable respect of contracts with the customers.

Within the framework of invitation to tender, enterprise-customer asks every QNA supplier-tenderer to indicate expressly its guarantee policy. Enterprise-customer of QNA checks it in order to determine the rank of every considered supplier according to the Table 4. By using several ways suggested by Building Global Friendship [15].

The proposition, presented in Table 4, can be used for estimating guarantee policy of every considered QNA supplier-tenderer.

The seventh criterion is technico-organizational. It concerns rejection level. This last is determined by the number of orders for the returned QNA to the supplier(s) by enterprise-customer following a doubtful QNA, a QNA polluted by fine particles of dusty or argillaceous origin whose content is higher than 3%, or in case of a QNA not respecting the standards of use. In this article, we propose that the rejection level is rated every latest three months by basing on the collected information near business acquaintances, or by carrying out chemical and mineralogical tests (for a doubtful QNA), methylene blue test (for a polluted QNA), or geomechanical tests (for a QNA not satisfying standards of use) in the laboratory of the QNA enterprise-consumer itself. Else, at the level of a third laboratory in order to be sure of the tests' results.

5.2. Proposed method for eliciting the criteria weights

In this paper, for eliciting criteria weights, we propose the method of weights based on ordinal ranking of criteria, and Lagrange multiplier developed by Bouhedja and Pousin [2]. The proposed method is presented by three steps below:

Step 1. Ask to a decision maker to provide ascending ordinal ranking of criteria.

Step 2. Calculate the Lagrange multiplier (λ):

$$\lambda = \frac{2}{\left(\sum_{j=1}^{n} \frac{1}{\left[(n+1)-j\right]}\right) \cdot \left[n(n+1)\right]}, \tag{1}$$

where:

n – number of criteria;

$j = 1, \ldots n$ ($n \geq 3$).

Step 3. Determine the weight of criterion j (W_j):

$$W_j = \frac{\lambda \left[n(n+1)\right]}{2\left[(n+1)-j\right]}, \tag{2}$$

where:

λ – lagrange multiplier;

n – number of criteria;

$j = 1, \ldots n$ ($n \geq 3$).

5.3. Proposed method for multi-criteria decision making

TOPSIS technique is proposed in this article for the advantages which it has.

5.3.1. Argumentation of the choice of TOPSIS

TOPSIS is chosen in this research work for the reasons below:

1. It solves the dilemma relating to the choice of closeness to the positive-ideal solution, or remoteness to the negative-ideal solution.

2. It introduces the concepts of positive-ideal and negative-ideal in multi-criteria decision making.

3. It conforms with a logic of distance minimization to the positive-ideal solution, or with a logic of distance maximization to the negative-ideal solution.

4. It is a specific and operational method as multi-criteria aggregation procedure.

5. It uses three types of distance: i) rectilinear distance (P1); ii) Euclidean distance (P2) and iii) Tchebycheff distance (P∞). According to Olsen [16], the best result is obtained by Euclidean distance.

6. It permits to identify quickly best solution when aggregation of the alternatives' performances' values.

7. It finds broad application in various domains. Several articles, using the TOPSIS approach, are already published [17], [18].

5.3.2. Presentation of TOPSIS

TOPSIS approach assumes that we have: "*m*" alternatives and "*n*" criteria, and the performance value "*a_{ij}*" of each alternative i ($i = 1, \ldots, m$) with the respect of criterion j ($j = 1, \ldots, n$ ($n \geq 3$)).

TOPSIS is developed by Hwang and Yoon, it only admits selection criteria of quantitative type. TOPSIS is partially compensatory and presented by the following steps [1]:

Step 1. Calculate the normalized decision matrix. The normalized value r_{ij} is calculated as in expression (3):

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum a_{ij}^2}}, \tag{3}$$

where:

$i = 1, \ldots m$;

$j = 1, \ldots n$.

The normalized decision matrix ($R := r_{ij}$) is presented below:

$$R := r_{ij} \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}. \quad (4)$$

Step 2. Calculate the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as in expression (5):

$$v_{ij} = W_j \cdot r_{ij}, \quad (5)$$

where:
$i = 1, \ldots m$;
$j = 1, \ldots n$.
A set of weights $W = [W_1, \ldots, W_n]$ (satisfying $\sum_{j=1}^{n} W_j = 1$) defined by the decision maker is accommodated to the decision matrix to generate the weighted normalized decision matrix ($V := v_{ij}$):

$$V := v_{ij} \begin{bmatrix} W_1 r_{11} & W_2 r_{12} & \cdots & W_n r_{1n} \\ W_1 r_{21} & W_2 r_{22} & \cdots & W_n r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ W_1 r_{m1} & W_2 r_{m2} & \cdots & W_n r_{mn} \end{bmatrix}. \quad (6)$$

Step 3. The positive-ideal A^+ and the negative-ideal A^- solutions are defined as follows:

$$A^+ = \left\{ \max_j v_{ij}, j \in J; \min_j v_{ij}, j \in J' \right\}; \quad (7)$$

$$A^- = \left\{ \min_j v_{ij}, j \in J; \max_j v_{ij}, j \in J' \right\}. \quad (8)$$

For the benefit criteria J, the decision maker wants to have a maximum value among the alternatives. For the cost criteria J', the decision maker wants to have a minimum value among the alternatives.

Obviously, A^+ indicates the most preferable alternative or ideal solution. Similarly, A^- indicates the least preferable alternative or negative-ideal solution.

Step 4. Calculate the separation measure. In this step, the concept of the N-dimensional Euclidean distance is used to measure the separation distances of each alternative a_i to the ideal solution and negative-ideal solution. In expression (9), $S^+_{a_i}$ (distance to the ideal solution) and $S^-_{a_i}$ (distance to the negative-ideal solution) are calculated with given formula:

$$S^+_{a_i} = \sqrt{\left[\sum \left(v_{ij} - A^+_i \right)^2 \right]}; \quad (9)$$

$$S^-_{a_i} = \sqrt{\left[\sum \left(v_{ij} - A^-_j \right)^2 \right]}, \quad (10)$$

where:
$i = 1, \ldots, m$;
$j = 1, \ldots, n$.
Step 5. Calculate the relative closeness to the ideal solution. The relative closeness of the alternative a_i ($C^*_{a_i}$) with the respect A^+ is defined as in expression (11):

$$C^*_{a_i} = \frac{S^-_{a_i}}{S^-_{a_i} + S^+_{a_i}}, 0 \le C^*_{a_i} \le 1. \quad (11)$$

Step 6. After sorting the C^*_{ai} values, the maximum value corresponds to the best solution to the problem. The previous definition can also be used to demonstrate that any alternative which has the shortest distance from the ideal solution is also guaranteed to have the longest distance from the negative-ideal solution.

6. Numerical example

A Construction Enterprise (C.E.) launches an invitation to tender for selecting one supplier of QNA. The schedule of conditions, placed at the disposal of the tenderers by the C.E., inter alia stipulates that:

The requested aggregate must be manufactured starting from the limestone and must have a content of clay fines lower or equal to 3%.

The selection criteria of the suppliers of QNA are established as follows:

i) acquisition price per ton (C_1); ii) transport price per ton per kilometer (C_2); iii) transport distance (C_3); iv) quality of QNA (C_4); v) delivery time (C_5); vi) guarantee policy (C_6), and vii) rejection level (C_7).

The financial and technical offers, proposed by the suppliers-tenderers, are presented in Table 5. For solving this problem, we apply the methodology proposed in this article.

Table 5. Original decision matrix A (relating to the supplier selection of QNA)

Suppliers of QNA a_i	Selection criteria C_j						
	C_1 DA/t min	C_2 DA/t/km min	C_3 km min	C_4 % min	C_5 Day min	C_6 – max	C_7 – min
a_1	4000	125	25	3	1	Moderate	3
a_2	3850	140	24	2	4	Good	1
a_3	3800	135	15	3	4	Moderate	2
a_4	4100	120	10	1	2	Excellent	0
a_5	4250	150	12	3	5	Good	2
a_6	4200	145	18	2	1	Moderate	3
a_7	3950	130	20	3	3	Good	1

*DA: Algerian Dinar (Currency of Algeria).

6.1. Final results

6.1.1. Conversion of the guarantee policy criterion

The guarantee policy criterion must be converted into quantitative criterion. For that, we use the ranks proposed in Table 4. Then, we assign for moderate guarantee policy: (3 points); good guarantee policy: (4 points), and excellent guarantee policy: (5 points). The obtained values are inserted in their respective places at the level of the column of criterion C_6 (Table 6).

6.1.2. Normalized decision matrix R

The result of normalization of the considered suppliers' performances' values is presented in Table 7.

6.1.3. Result of the criteria weights

The criteria weights, elicited according to the method based on ordinal ranking of criteria, and Lagrange multiplier, are shown in Table 8.

Table 6. Original decision matrix A (all the considered criteria are quantitative)

Suppliers of QNA a_i	Selection criteria C_j						
	C_1 DA/t min	C_2 DA/t/km min	C_3 km min	C_4 % min	C_5 Day min	C_6 – max	C_7 – min
a_1	4000	125	25	3	1	3	3
a_2	3850	140	24	2	4	4	1
a_3	3800	135	15	3	4	3	2
a_4	4100	120	10	1	2	5	0
a_5	4250	150	12	3	5	4	2
a_6	4200	145	18	2	1	3	3
a_7	3950	130	20	3	3	4	1

*Min means criterion to be minimized and max means criterion to be maximized

Table 7. Normalized decision matrix R

Suppliers of QNA a_i	Selection criteria C_j						
	C_1 min	C_2 min	C_3 min	C_4 min	C_5 min	C_6 max	C_7 min
a_1	0.3756	0.3490	0.5109	0.4472	0.1178	0.3000	0.5669
a_2	0.3615	0.3908	0.4905	0.2981	0.4714	0.4000	0.1889
a_3	0.3568	0.3769	0.3065	0.4472	0.4714	0.3000	0.3779
a_4	0.3850	0.3350	0.2043	0.1490	0.2357	0.5000	0
a_5	0.3991	0.4188	0.2452	0.4472	0.5892	0.4000	0.3779
a_6	0.3944	0.4048	0.3678	0.2981	0.1178	0.3000	0.5669
a_7	0.3709	0.3629	0.4087	0.4472	0.3535	0.4000	0.1889

Table 8. Result of the criteria weights

Criteria C_j	Definition of criteria	Weights of criteria	
		W_j	Values
C_1	Acquisition price per ton	W_1	0.3856
C_2	Transport price per ton per kilometer	W_2	0.1928
C_3	Transport distance	W_3	0.1286
C_4	Quality of QNA	W_4	0.0964
C_5	Delivery time	W_5	0.0772
C_6	Guarantee policy	W_6	0.0643
C_7	Rejection level	W_7	0.0551

6.1.4. Weighted normalized decision matrix V

The weighted normalized decision matrix, according to the TOPSIS technique, is presented in Table 9.

Table 9. Weighted normalized decision matrix V

Suppliers of QNA a_i	Selection criteria C_j						
	C_1 min	C_2 min	C_3 min	C_4 min	C_5 min	C_6 max	C_7 min
a_1	0.1448	0.0672	0.0657	0.0431	0.0090	0.0192	0.0312
a_2	0.1393	0.0753	0.0630	0.0287	0.0363	0.0257	0.0104
a_3	0.1375	0.0726	0.0394	0.0431	0.0363	0.0192	0.0208
a_4	0.1484	0.0645	0.0262	0.0143	0.0181	0.0321	0
a_5	0.1538	0.0807	0.0315	0.0431	0.0454	0.0257	0.0208
a_6	0.1520	0.0780	0.0472	0.0287	0.0090	0.0192	0.0312
a_7	0.1430	0.0699	0.0525	0.0431	0.0272	0.0257	0.0104

6.1.5. Positive-ideal and negative-ideal solutions

For each considered criterion, the positive-ideal A^+ and negative-ideal A^- solutions, according to the TOPSIS technique, are presented in Table 10.

Table 10. Positive-ideal and negative-ideal solutions

Positive-ideal and negative-ideal solutions	Selection criteria C_j						
	C_1 min	C_2 min	C_3 min	C_4 min	C_5 min	C_6 max	C_7 min
A^+	0.1375	0.0645	0.0262	0.0143	0.0090	0.0321	0
A^-	0.1538	0.0807	0.0657	0.0431	0.0454	0.0192	0.0312

6.1.6. Result of evaluation of the QNA suppliers

The result of evaluation of the considered QNA suppliers, according to the TOPSIS technique, is presented in Table 11.

6.1.7. Result of ranking of the QNA suppliers

The result of ranking of the considered QNA suppliers, according to the TOPSIS technique, is shown in Table 12.

The obtained ranking of the considered QNA suppliers is established as follows:

$$a_4 > a_6 > a_7 > a_3 > a_1 > a_5 > a_2, \qquad (12)$$

Table 11. Evaluation result of the QNA suppliers

Suppliers of QNA a_i	S^+_{ai}	S^-_{ai}	C^*_{ai}
a_1	0.0574	0.0374	0.3945
a_2	0.0489	0.0282	0.3657
a_3	0.0458	0.0300	0.3957
a_4	0.0100	0.0648	0.8663
a_5	0.0538	0.0346	0.3914
a_6	0.0435	0.0424	0.4935
a_7	0.0424	0.0316	0.4270

Table 12. Ranking result of the QNA suppliers

Suppliers of QNA a_i	C^*_{ai}	Ranking
a_4	0.8663	1
a_6	0.4935	2
a_7	0.4270	3
a_3	0.3957	4
a_1	0.3945	5
a_5	0.3914	6
a_2	0.3657	7

The usage of the proposed methodology has enabled us to select the alternative {a_4} as being best supplier of quarry natural aggregate amongst the considered and evaluated suppliers (Tables 11 and 12).

7. Conclusions

At the end of this research work, the conclusions, which we drew, are presented below.

The resolution of the suppliers' selection problems constitutes an evident importance not only for the decision maker(s), but also for the researchers. According to the literature, several articles, concerning the suppliers' selection, are published those latter years (see www.biblio.promethee-gaia.net).

In this article, the proposed methodology is constituted from two parts:

1) elicitation of the criteria weights is performed by using the method of weights based on ordinal ranking of criteria, and Lagrange multiplier;

2) multi-criteria aggregation-evaluation of the performances of the QNA suppliers is realized by using the TOPSIS technique. Although TOPSIS is relatively old, it remains until the day of today usable for solving multi-criteria decisional problems in different domains.

The proposed methodology is easy to use. Whoever, having a basic level in mathematics, and having worked on software Excel, can use it.

By way of illustration, the proposed methodology is applied to the numerical example. It has enabled us:

– elicitation of the criteria weights (Table 8);

– evaluation of the performances' values of each QNA supplier considered (Table 11);

– establishment of the ranking of the QNA suppliers considered (Table 12);

– selection of the alternative $\{a_4\}$ as being best supplier of QNA (Tables 11 and 12).

In the numerical example, Construction Enterprise, as decision maker, can select the supplier $\{a_4\}$ in order to solve the problem of supply in QNA.

In the real-world, any decision maker or technical expert, concerned by the provisioning problem in QNA, can resolve it by using the methodology proposed in this paper.

The future extension of this research work consists to compare the proposed methodology with other approaches for the supplier selection of quarry natural aggregate.

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Використання багатокритеріального методу TOPSIS для вибору кращого постачальника природного заповнювача кар'єру

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Мета. Обґрунтування та вибір оптимального постачальника кар'єрного щебню як природного заповнювача на основі використання багатокритеріального методу.

Методика. Вибір найкращого постачальника кар'єрного природного заповнювача здійснювався за допомогою багатокритеріального методу аналізу варіантів за ступенем близькості до оптимального (TOPSIS) і методу вагових коефіцієнтів на основі порядкового ранжування критеріїв та множника Лагранжа.

Результати. Підхід, що описується в статті, заснований на багатокритеріальному прийнятті рішень і дозволяє обрати кращого постачальника природного заповнювача серед наявних та розглянутих на ринку компаній. В якості ілюстрації запропонована методологія застосована до чисельного прикладу. Це дозволило визначити вагу впливових на оцінку критеріїв, оцінку значень характеристик кожного розглянутого постачальника QNA, встановлення рейтингу розглянутих постачальників QNA і вибір альтернативи $\{a_4\}$ в якості кращого постачальника QNA.

Наукова новизна. Вперше для вибору оптимального постачальника природного заповнювача крім факторів ціни і якості встановлено характер впливу на загальну оцінку також ряду інших факторів: вартість транспортування, транспортна відстань, час доставки, гарантійна політика й рівень відхилення. У даній роботі вперше пропонується багатокритеріальний підхід до вибору оптимального постачальника природного заповнювача кар'єра.

Практична значимість. Ефективний вибір постачальника природного заповнювача кар'єра важливий з практичної та економічної точок зору для підприємств у галузі цивільного будівництва, громадських робіт, залізниці та гідротехнічних споруд.

Ключові слова: множник Лагранжа, метод вагових коефіцієнтів, TOPSIS, постачальник, щебінь, кар'єр

Использование многокритериального метода TOPSIS для выбора лучшего поставщика природного заполнителя карьера

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Цель. Обоснование и выбор оптимального поставщика карьерного щебня как природного заполнителя на основе использования многокритериального метода.

Методика. Выбор лучшего поставщика карьерного природного заполнителя осуществлялся с помощью многокритериального метода анализа вариантов по степени близости к оптимальному (TOPSIS) и метода весовых коэффициентов на основе порядкового ранжирования критериев и множителя Лагранжа.

Результаты. Подход, описываемый в статье, основан на многокритериальном принятии решений и позволяет выбрать лучшего поставщика природного заполнителя среди имеющихся и рассматриваемых на рынке компаний. В качестве иллюстрации предложенная методология применена к числовому примеру. Это позволило определить вес влияющих на оценку критериев, оценку значений характеристик каждого рассматриваемого поставщика QNA, установление рейтинга рассматриваемых поставщиков QNA и выбор альтернативы $\{a_4\}$ в качестве лучшего поставщика QNA.

Научная новизна. Впервые для выбора оптимального поставщика природного заполнителя кроме факторов цены и качества установлен характер влияния на общую оценку также ряда других факторов: стоимость транспортирования, транспортное расстояние, время доставки, гарантийная политика и уровень отклонения. В данной работе впервые предлагается многокритериальный подход к выбору оптимального поставщика природного заполнителя карьера.

Практическая значимость. Эффективный выбор поставщика природного заполнителя карьера важен с практической и экономической точек зрения для предприятий в области гражданского строительства, общественных работ, железной дороги и гидротехнических сооружений.

Ключевые слова: множитель Лагранжа, метод весовых коэффициентов, TOPSIS, поставщик, щебень, карьер

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