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Selection of the best aggregates to be used in road construction with TOPSIS method

Introduction

Road construction in parallel with growing urbanization in the world work is increasing day by day. For this reason, the construction of high-speed and high-quality roads with heavy loads is an important issue. Building quality, economical and long-lasting roads are one of the important requirements of living a more comfortable life. Most of the asphalt material used in road construction (90–95%) consists of aggregate. Aggregates are used as raw materials in engineering applications such as roads, bridges, ports, airports, and water structures. Also, they are the most important raw material for the manufacture of concrete and asphalt, which is a significant part of the construction sector (Bilim et al. 2017).

Asphalt is a heterogeneous multiphase material that consists of aggregates, asphalt binder, and air voids (Sefidmazgi et al. 2012). Aggregate is the most produced and used mineral in the world. Aggregates must have physical, chemical, petrographic, and mechanical prop-

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erties suitable for their intended use (concrete, construction, road, mortar, railway ballast, facings, decoration, etc.). Limestone is the most used aggregate in the world. The use of artificial aggregate is far below that of natural aggregate.

Table 1. Some multi-criteria decision-making techniques and explanations

Tabela 1. Niektóre wielokryterialne techniki podejmowania decyzji i wyjaśnienia

Method name	Explanation	Developer
AHP (Analytic Hierarchy Process)	AHP is a structured technique for organizing and analyzing complex decisions based on mathematics and psychology. It is a technique that facilitates the decision-making process by sorting the alternatives given according to their relative weight obtained with the help of binary comparison matrices.	Saaty 1980
ANP (Analytic Network Process)	ANP was developed as a new theory with the expansion of AHP. It is a technique that considers the feedback between criteria or alternatives and the inter-cluster and inter-cluster dependency between them while following similar steps as in AHP.	Saaty 1996
TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution)	This is based on determining the alternatives closest to the positive ideal solution and the furthest from the negative ideal solution and ranking among the alternatives accordingly.	Hwang and Yoon 1981
VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje)	VIKOR is a technique that offers the decision-maker consensus solutions among the options that are closest to the ideal solution. VIKOR ranks alternatives and determines the solution named compromise that is the closest to the ideal.	Opricovic 1998; Opricovic and Tzeng 2004
ELECTRE (ELimination and Et Choice Translating REality)	Usually, the ELECTRE Methods are used to discard some alternatives to the problem which are unacceptable. According to the principle of superiority, it is a technique that supports decision-making by classifying alternatives, reducing non-superior alternatives to the decision-maker.	Roy and Vincke 1981
DEMATEL (The Decision-Making Trial and Evaluation Laboratory)	The DEMATEL method helps decision-makers prioritize improvement processes. It is a technique that reveals the relationships between criteria to build and analyze a complex structural problem.	Gabus and Fontela 1972
PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations)	This is a technique based on the principle of superiority to sort and select a finite number of alternatives according to criteria.	Brans and Vincke 1985
MOORA (Multi-Objective Optimization by Ratio Analysis)	MOORA uses non-subjective, non-directional values instead of the subjectively weighted normalization. It is a technique that considers and evaluates all goals and considers all interactions between alternatives and goals simultaneously, not piecemeal.	Brauers and Zavadskas 2006
EATWOS (Efficiency Analysis Technique With Output Satisficing)	This is an efficiency analysis method that supports the orientation towards satisfactory solutions instead of optimum solutions.	Peters and Zelewski 2007

The increase in the quality of aggregates used in road construction also increases the duration of road use. The performance of the aggregate layer depends on its intrinsic properties, i.e., the particle shape, grading, composition, and physical, mechanical, and chemical properties (Khanal and Tamrakar 1970). Aggregates and hot-mix asphalt used in road construction significantly impact road quality. The right choice of these materials directly affects the lifetime of the road.

It is necessary to make choices on different subjects many times in daily life. Everyone has their criteria when choosing. Experience, research, knowledge, skills, economic situation, comfort, security, etc. are factors that affect the choices of individuals. Although people face the consequences of their choices, workplaces may face serious gains or losses due to wrong decisions. A correct choice brings with it important advantages.

For this reason, scientists have developed many selection methods. Thanks to these methods, many parameters can be analyzed and scientific methods can be used for decision making. Among these methods, some of the multi-criteria decision-making methods (MCDM) which are frequently used today are presented in Table 1. The use of MCDM methods is changing rapidly and continuously today. In recent years, MCDM has been used frequently and successfully in the selection and decision-making processes in mining works.

In this study, the TOPSIS method, which is one of the multi-criteria decision-making methods, was used for the selection of the ideal aggregates to be used in road construction. The suitability of aggregates obtained from six different quarries that provide aggregates for the constructing urban roads in Ankara was investigated by the TOPSIS method. However, the fact that there is no scientific study in the literature on the selection of aggregates used in road pavement construction with MCDM adds originality to this study.

1. Materials and method

One of the most basic ways to reduce road construction costs is to choose the best quarry to supply aggregate. The selection of the best quarry will ensure suitable aggregate production, and appropriate aggregate production will ensure that comfortable and long-lasting roads are built.

This study was conducted in six crushed-stone quarries in the Ankara province. Ankara is the capital and second-most populous city is Turkey. Its population was 5,663,322 people as of 2020. These citizens live in twenty-five districts and 1425 neighborhoods connected to these districts. The population density in the province is 215. The list of cities according to their population is in the fifty-seventh place in the world according to the ranking made by considering the municipal borders. Geographically, it is located close to the center of Turkey, and most of it is in the Central Anatolia Region, except for the northern parts in the Western Black Sea Region. It is Turkey's third-largest province in terms of surface area.

Aggregates used in hot-mix asphalt production worldwide are generally selected from limestones with $CACO_3$ content. There are six limestone quarries in Ankara Province. All the hot-mix asphalt roads in the Ankara Province are produced with aggregates crushed from those six stone quarries is produced from aggregates supplied. The research question of this study was that the hot-mix asphalt, is from which of these size quarries will the obtained aggregate ensure that the roads in Ankara will be the most economical and comfortable , and of high quality. All aggregates obtained from these six crushed stone quarries, which are used to supply aggregates in the construction of urban asphalt roads in Ankara, meet all the standards required for hot-mix asphalt road construction. Although these aggregates meet the road construction standards, the main theme of this study is from which quarry will the aggregate produced be more ideal for quality and long-lasting road construction.

Ankara Province is divided into three main regions as equally as possible, taking into account the diversity of crushed stone. In order to represent the aggregate properties of each region, two different crushed stone quarries were determined in each region. Aggregate and bitumen tests were performed on samples obtained from two crushed stone quarries in each region. The created regions to represent the aggregate properties of Ankara Province are presented in Figure 1. By using the test results, studies were conducted to determine which aggregates produced from crushed stone quarries are suitable for hot-mix asphalt.

The selected six different stone quarries have been determined to reflect Ankara's city in general and be indifferent to distances and regions. Each quarry site is a field that consists of

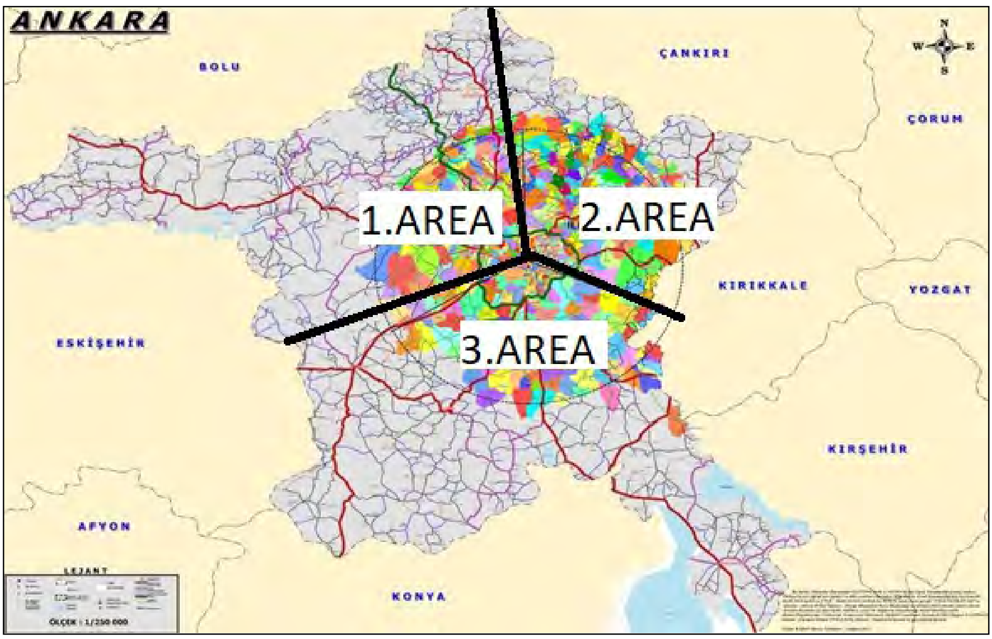

Fig. 1. Locations of quarries in Ankara Province

Rys. 1. Lokalizacje kamieniołomów w prowincji Ankara rocks containing $CACO_3$ and is produced by drilling-blasting methods. Additionally, there is a crushing-screening facility at each location. Aggregates produced in different fractions are processed in asphalt plant facilities to produce hot-mix asphalt. MCDM was used to rank the aggregates from these six quarries from the most ideal to the least ideal. It has been decided that TOPSIS, which can evaluate the closest to the positive ideal solution and the farthest distance from the negative ideal solution is the most appropriate method among the MCDM.

1.1. AHP and TOPSIS method

AHP is one of the most applied multi-criteria decision-making methods developed by Saaty (Saaty 1980). The analytical hierarchy process (AHP) was first introduced by Myers and Alpert (Myers and Alpert 1968) and was developed by Saaty (Saaty 1980) as a useful method for solving decision-making problems. The method determines how important, preferable or dominant the options and criteria are compared to each other through pairwise comparisons in the decision-making process (Özgörmüş et al. 2005).

AHP is an MCDM method that can evaluate quantitative and qualitative decision-making criteria, including the preferences, experiences, intuitions, knowledge, judgments and thoughts of the group or individual in the decision process, which allows solving complex problems by considering the decision process in a hierarchical structure. The decision-maker can include both objective and subjective thoughts in the decision process. In AHP, the hierarchy is established using at least at three levels. At the top level of AHP's decision problem, there is the purpose. A sub-level includes the main criteria and, if any, sub-criteria under the main criteria. At the bottom level, there are decision options.

The decision-making process can be evaluated in a class of deterministic modeling in which the data is known quantitatively, decision-making under risk where the data can be defined with probability distributions, and decision-making under uncertainty where the relative weights representing the degree of relationship of the data in the decision process cannot be assigned. AHP allows for the measurement of ideas, feelings and emotions, experiences, and judgments in such a way as to rank decision alternatives on a numerical scale. In other words, it is an important tool that ensures that both objective and subjective criteria can be included in the decision-making process.

The TOPSIS method is an MCDM that was first developed by Hwang and Yoon (Hwang and Yoon 1981) and has found application in many fields. This method can evaluate the options closest to the positive ideal solution and the options furthest from the negative ideal solution. The TOPSIS method aims to determine the option that is closest to the positive ideal solution and the option which is furthest from the negative ideal solution. The positive ideal solution is the one that minimizes the cost criterion and maximizes the benefit criterion. The negative ideal solution is evaluated as maximizing the cost criterion and minimizing the benefit criterion. The TOPSIS method reveals the distances from the positive and negative ideal solutions and reveals the ideal and non-ideal solutions. There must be at least two options for the method to be applicable. The TOPSIS method, which has an analysis process that does not contain complex algorithms and mathematical models, finds application in many areas due to its ease of use and the easy understanding and interpretation of the results.

The TOPSIS method, which was preferred in this study, has been frequently used in different mining areas (Table 2). However, a scientific study using TOPSIS and other MCDM in selecting aggregates used in road pavement construction, which is the main theme of this study, has not been found in the literature.

Table 2. Fields of study where the TOPSIS method is used in mining

Tabela 2. Kierunki studiów, na których stosowana jest metoda TOPSIS w górnictwie

Fields of study	Developer
Mining equipment selection	Acaroglu et al. 2006; Bazzazi et al. 2009; Ghasvareh et al. 2020; Kun et al. 2013; Rahimdel and Karamoozian 2014
Mining method selection	Ataei et al. 2008; Balusa and Gorai 2018; Chen et al. 2016; Iphar and Alpay 2019; Javanshirgiv et al. 2017; Mikaeil et al. 2009; Ooriad et al. 2018; Saki et al. 2020; Spanidis et al. 2020
Blast design	Monjezi et al. 2010; Yari et al. 2014
Work safety	Li et al. 2011; Mahdevari et al. 2014

2. Evaluation of the results

In this study, the experimental studies on the base layer and intermediate layer (binder) of asphalt were examined (Figure 2). The most important factor separating the layers forming the asphalt from each other is the aggregate sizes used during the production of the layers. For example, while aggregates in different fractions in the range of approximately 0–37 mm particle size are used in the bituminous base layer, this ratio is used in different fractions of 0–25 mm in the binder layer. In the wear layer with an asphalt surface, this ratio consists of aggregates used in different fractions of aggregates in the range of 0–19 mm. In summary, as you go from the ground to the surface, the size of the aggregate used decreases, and driving comfort increases accordingly.

In this study, AHP and TOPSIS methods were used together. The AHP method was used to determine the importance of the main criteria and sub-criteria, and the TOPSIS method was used to rank the suitability of aggregates for asphalt production.

The test results were first compared among themselves with the AHP method, and the effect weights were determined according to their properties, and weight matrices were

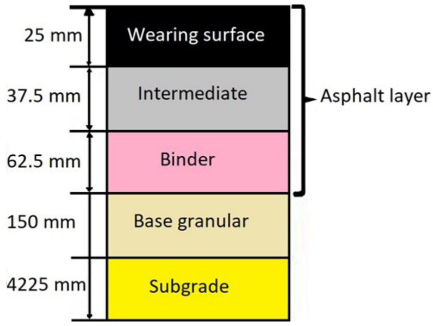

Fig. 2. Road layers

Rys. 2. Warstwy drogowe

formed. The test results of six different quarries were then compared with the standard best results based on the maximum and minimum limits of the aggregate and bitumen values specified in the relevant test standard. The best result is based on the range specified in the standard of the experiment. Table 3 shows the standards of the tests used in this study and the intervals used to determine the best result. The test results of six different quarries were indexed to the best result, and their weight scores were given. By using the values (matrices) of the impact weights obtained by the AHP method and the weight scores of each experiment, the suitability of the six different quarries for asphalt production was classified with the TOPSIS method. To evaluate the final result obtained by using the AHP and TOPSIS method together, to rank six different quarries. The best result number 1 was accepted.

Table 3. Experiments and standards in the study

Tabela 3. Eksperymenty i standardy w badaniu

Tests	Standarts	Intervals	
Stripping	ASTM D-1664	≥60	
Water absorption	ASTM D7172- 14	≤2.5	
Los Angeles	ASTM C-131	≤30	
Weather effect	ASTM C-127	≤18	
Methylene blue	ASTM D2330- 20	≤2.0	
Marshall Stability	ASTM D1559, D5581, D6927	Intermediate	Binder
		≥600	≥750
Size distribution	ASTM D2172	Intermediate (%)	Binder (%)
		3–5.5	3.5–6.5

The results were sorted according to their closeness to a value of 1. In short, after the test criteria, the weights of which were determined by the AHP method, the solution process was terminated with the TOPSIS method, which consists of six stages. In the AHP method, the 1–9 importance scale suggested by Saaty (Saaty 1980) was used to create pairwise comparison matrices and determine the importance weights (Table 4).

Table 4. Explanations and fundamental scale of AHP (Saaty 1990)

Tabela 4. Wyjaśnienia i podstawowa skala AHP

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgement strongly favor one activity over another
7	Very strong importance	An activity is strongly favored, and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	This is when compromise is needed

In this study, the tests to be performed on aggregates are listed in order of importance among themselves. Experience and current practices were considered while making this ranking. Comparison matrices prepared for this purpose are presented in Table 5.

As seen in Table 5, the stripping tests were compared with the methylene blue test, and 3 points were given to this comparison. In other words, it was emphasized that the first factor was more important than the second factor. Here, a comparison has been made by stating that the stripping test is more important than the methylene blue test for hot-mix asphalt. After creating Table 5 in this way, normalization operations were performed on the values in Table 5 (normalization is obtained by dividing each column value separately by the related column total) and after the normalized comparison matrices were created, the average of the row values of the matrix was taken and their weights were determined (Table 6). The TOPSIS method was applied under six different headings. These titles and the results obtained are given below.

Table 5. Comparison matrix of tests

Tabela 5. Macierz porównawcza testów

Tests	Stripping	Water absorption	Los Angeles	Density	Weather effect	Methylene blue	Stability	Flowing	Bitumen amount	Size distribution
Stripping	1.00	2.00	2.00	6.00	2.00	3.00	3.00	3.00	5.00	6.00
Water absorption	0.50	1.00	3.00	5.00	0.50	1.00	3.00	3.00	5.00	5.00
Los Angeles	0.50	0.33	1.00	4.00	1.00	4.00	3.00	3.00	5.00	5.00
Density	0.17	0.20	0.25	1.00	0.33	0.25	0.33	0.33	0.50	1.00
Weather effect	0.50	2.00	1.00	3.00	1.00	2.00	4.00	4.00	5.00	6.00
Methylene blue	0.33	2.00	0.25	4.00	0.50	1.00	3.00	3.00	5.00	5.00
Stability	0.33	0.33	0.33	3.00	0.25	0.33	1.00	1.00	3.00	5.00
Flowing	0.33	0.33	0.33	3.00	0.25	0.33	1.00	1.00	3.00	5.00
Bitumen amount	0.20	0.20	0.20	2.00	0.20	0.20	1.00	0.33	1.00	5.00
Size distribution	0.17	0.20	0.20	1.00	0.17	0.20	0.20	0.20	0.20	1.00
Total	4.03	8.60	8.57	32.00	6.20	12.32	19.53	18.87	32.70	44.00

Table 6. Weight matrix of tests

Tabela 6. Macierz wag testów

Tests	Weights of the tests
Stripping	0.21
Water absorption	0.15
Los Angeles	0.15
Density	0.03
Weather effect	0.16
Methylene blue	0.12
Stability	0.06
Flowing	0.06
Bitumen Amount	0.04
Size Distribution	0.02
Total	1.00

2.1. Creation of Decision Matrix (A) (Stage 1)

In the columns of the matrix, in the rows of the evaluation factors used in decision making, there are the decision points whose superiority is desired to be listed. This matrix is the initial matrix created by the decision-maker.

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & & & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}$$

A_{ij} gives the number of decision points, n gives the number of evaluation factors. Our decision points were used from six different quarries, and the evaluation factor was used from fourteen different experimental results. While creating the decision matrix values, each test result was evaluated in itself according to the relevant test standards, and the collective test results are presented in Table 7, and the evaluation of the test results according to the standards is presented in Table 8.

Table 7. Decision matrix created according to the test results

Tabela 7. Macierz decyzyjna utworzona na podstawie wyników testów

Crushed stone quarries	Stripping	Water absorption	Los Angeles	Density	Weather effect	Methylene blue	Marshall Stability		Flowing		Bitumen amount		Size distribution	
							B.Basis	Binder	B.Basis	Binder	B.Basis	Binder	B.Basis	Binder
Ayas-Oltan	0.750	0.740	0.203	0.993	0.555	0.000	0.838	0.398	0.067	0.000	0.819	0.425	0.830	0.910
Çayirhan	0.700	0.712	0.183	0.994	0.445	0.000	1.000	0.432	0.000	0.000	0.747	0.798	0.710	0.690
Eski Kibris	0.650	0.720	0.253	0.995	0.554	0.000	0.458	1.000	0.017	0.000	0.411	0.466	0.810	0.580
Yakupabtal	0.675	0.740	0.260	0.997	0.435	0.125	0.449	0.431	0.000	0.000	0.495	0.718	0.720	0.660
Saridegirmen	0.625	0.596	0.163	1.000	0.577	0.000	0.805	0.367	0.000	0.000	0.438	0.375	0.760	0.880
Sumer	0.725	0.700	0.087	0.991	0.343	0.375	0.596	0.427	0.356	0.000	0.672	0.300	0.930	0.910

Table 8. Standard decision matrix

Tabela 8. Standardowa macierz decyzji

Crushed stone quarries	Stripping	Water absorption	Los Angeles	Density	Weather effect	Methylene blue	Marshall Stability		Flowing		Bitumen amount		Size distribution	
							B.Basis	Binder	B.Basis	Binder	B.Basis	Binder	B.Basis	Binder
Ayas-Oltan	0.445	0.430	0.414	0.407	0.460	0.000	0.475	0.293	0.184	0.000	0.542	0.318	0.425	0.475
Çayirhan	0.415	0.413	0.374	0.408	0.369	0.000	0.566	0.318	0.000	0.000	0.494	0.598	0.364	0.360
Eski Kibris	0.385	0.418	0.516	0.408	0.460	0.000	0.259	0.736	0.047	0.000	0.272	0.349	0.415	0.302
Yakupabtal	0.400	0.430	0.530	0.409	0.361	0.316	0.255	0.317	0.000	0.000	0.328	0.538	0.369	0.344
Saridegirmen	0.370	0.346	0.333	0.410	0.479	0.000	0.456	0.270	0.000	0.000	0.290	0.281	0.389	0.459
Sumer	0.428	0.407	0.177	0.407	0.285	0.949	0.338	0.314	0.982	0.000	0.444	0.225	0.477	0.475

2.2. Creation of the standard decision matrix (R) (Stage 2)

The standard decision matrix, which is formed with the use of the elements in the A matrix, is calculated using Equation 1.

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \tag{1}$$

R matrix Equation:

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & & & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}$$

The standard decision matrix created by using the decision matrix values is presented in Table 8.

2.3. Creation of the weighted standard decision matrix (V) (Stage 3)

First of all, the weight values (W_i) for the evaluation factors are determined (W_i). The weight values obtained by the AHP method will be used. The elements in each column of the R matrix are then multiplied by their respective values to form the V matrix $\left(\sum_{i=1}^{n} w_i = 1\right)$.

In Table 9, the weighted standard decision matrix (v) created by multiplying the w_i weight values created by the AHP method is shown.

2.4. Creating Positive Ideal (A +) and Negative Ideal (A –) solutions (Stage 4)

It is assumed that the whole evaluation factor has a monotonically increasing or decreasing trend. In the ideal solution set created, weighted evaluation factors (the largest of the column values) are selected in the decision (V) matrix. If the evaluation is minimized, the smallest is chosen. Finding the positive ideal solution set is shown in Equation 2.

Table 9. Weighted standard decision matrix (v)

Tabela 9. Ważona standardowa macierz decyzyjna (v)

Crushed stone quarries	Stripping	Water absorption	Los Angeles	Density	Weather effect	Methylene blue	Marshall Stability		Flowing		Bitumen amount		Size distribution	
							B.Basis	Binder	B.Basis	Binder	B.Basis	Binder	B.Basis	Binder
Weight	0.21	0.15	0.15	0.03	0.16	0.12	0.06	0.06	0.06	0.06	0.04	0.04	0.02	0.02
Ayas-Oltan	0.093	0.065	0.062	0.012	0.074	0.000	0.029	0.018	0.007	0.000	0.022	0.013	0.009	0.009
Çayirhan	0.087	0.062	0.056	0.012	0.059	0.000	0.034	0.019	0.000	0.000	0.0199	0.024	0.00	0.008
Eski Kibris	0.081	0.063	0.077	0.012	0.074	0.000	0.016	0.044	0.002	0.000	0.011	0.014	0.009	0.006
Yakupabtal	0.084	0.065	0.079	0.012	0.058	0.038	0.015	0.019	0.00	0.000	0.013	0.022	0.008	0.007
Saridegirmen	0.078	0.052	0.050	0.012	0.077	0.000	0.027	0.016	0.0000	0.000	0.012	0.011	0.008	0.009
Sumer	0.090	0.061	0.027	0.012	0.046	0.114	0.020	0.019	0.039	0.000	0.018	0.009	0.009	0.009

Table 10. Positive and negative ideal solution sets

Tabela 10. Dodatnie i ujemne zestawy rozwiązań idealnych

	Stripping	Water absorption	Los Angeles	Density	Weather effect	Methylene blue	Marshall stability		Flowing		Bitumen amount		Size distribution	
							B.Basis	Binder	B.Basis	Binder	B.Basis	Binder	B.Basis	Binder
Minimum A–	0.0778	0.0519	0.0265	0.0122	0.0455	0.0000	0.0153	0.0162	0.0000	0.0090	0.0109	0.0090	0.0073	0.0060
Maximum A*	0.0933	0.0645	0.0795	0.0123	0.0766	0.1138	0.0340	0.0441	0.0393	0.0239	0.0217	0.0239	0.0095	0.0095

$$A^* = \left\{ \left(\max_i v_{ij} \middle| i \in J \right), \left(\min_i v_{ij} \middle| i \in J' \right) \right\} \tag{2}$$

The set to be calculated from the formula $A^* = \{v_1^*, v_2^*, ..., v_n^*\}$ is shown as

By contrast, the negative ideal solution set is created by choosing the smallest of the weighted evaluation factors in the V matrix, namely the column values (the largest if the relevant evaluation factor is towards maximization) (Table 10).

2.5. Calculation of separation measures (Stage 5)

In the TOPSIS method, the Euclidian distance approach is used to find the deviations of the evaluation factor value for each decision point from the ideal and negative ideal solution set. The deviation values of the decision points obtained here are called the ideal discrimination (S_i^*) and the negative ideal discrimination (S_i^-) measure. The calculation of the ideal separation (S_i^*) measure and the calculation of the negative ideal separation (S_i) measure are shown in Equations 3–4.

$$S_i^* = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^* \right)^2} \tag{3}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^- \right)^2} \tag{4}$$

The number of S_i^* and S_i^- to be calculated here will naturally be as much as the number of decision points.

2.6. Calculating the relative closeness to the ideal solution (Stage 6)

It is calculated as the relative closeness (C_i^*) of the decision point created using the negative ideal and positive ideal separation measures. The measure used in this process is the share of the negative ideal discrimination measure in the total discrimination. The calculation of the relative closeness value to the ideal solutions is shown in Equation 5.

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \tag{5}$$

Here the value C_i^* $0 \leq C_i^* \leq 1$ in and get value from $C_i^* = 1$ the point of decision about the ideal solution $C_i^* = 0$ indicates the proximity of the respective decision point necessarily a negative ideal solution. It was determined that the closest result to the value of 1, which was determined as the ideal solution by finding the distances to the positive and negative ideals, and the field that took the first place during the selection was the closest to the ideal (Table 11).

Table 11. Ideal solution results

Tabela 11. Wyniki rozwiązań idealnych

Crushed stone quarries	Distance from positive ideal solution	Distance from negative ideal solution	Distance from ideal solution	Order of preference
Sumer	0.0697	0.1218	0.6360	1
Yakupabtal	0.0939	0.0690	0.4236	2
Eski Kibris	0.1229	0.0657	0.3484	3
Ayas-Oltan	0.1231	0.0533	0.3021	4
Çayirhan	0.1267	0.0437	0.2564	5
Saridegirmen	0.1299	0.0409	0.2396	6

To classify the suitability of hot bituminous mixtures, first of all, the experiments were compared with the AHP method, and the effect weights were determined according to their properties, and these weights were used in the decision matrix created by the TOPSIS method, and the suitability degrees of the quarries were listed. According to the results obtained by the TOPSIS method, it was determined that the most suitable aggregate quarry for the hot-mix asphalt used in road construction is the Sumer quarry, which is the third region quarry.

Conclusions

In this study, the determination of the most ideal quarry by the TOPSIS method, with experimental studies on aggregates and hot-mix asphalt produced in two different quarries selected from each region with the city of Ankara being divided into three different regions. Because of the examination and research, it has been obtained that the TOPSIS method provides ease of use in the mining sector, the selection of the ideal quarry determined as a result of the applied method makes great contributions to the country's economy and contributes to the use of underground riches in the most ideal way.

The experimental parameters were first compared with the analytical hierarchy process (AHP) method, and the effect weights were determined according to their properties. By using these weights in the decision matrix created by the TOPSIS method, the suitability degrees of the quarries are listed.

Considering the transportation distances, the long service life of the asphalt produced and compacted, and the low maintenance and repair costs, considering the long road networks and the large amount of asphalt paving works in the budgets in Ankara, it is important to apply such a selection method and to determine the ideal site. Considering the burden and economic reasons, it provides great benefits.

In the TOPSIS method, the test results of six different quarries for each parameter were compared with the lower limit and upper limit values specified in the standards in Table 3, and the values of each quarries were determined. In accordance with the results found by the TOPSIS method, the seasonal conditions of hot-mix asphalt used in road construction and the test results made on the samples taken at the time of the works, it was determined that the most suitable aggregate quarry was the Sumer quarry, which is the third region quarry with the ideal solution distance value of 0.6360. This result was determined from the samples taken in this study and does not express certainty. It has been determined that the Saridegirmen quarry aggregate of the third region quarry, with a value of 0.2396 from the ideal solution, is more unsuitable for hot-mix asphalt than other quarries. This result was determined from the samples taken in this study and does not express certainty. The ranking from 1 to 6 made by the TOPSIS method has concluded that the aggregate to be used in Haymana and its immediate surroundings should be supplied from the Polatli Sumer quarry instead of the Haymana saridegirmen quarry, and the hot-mix asphalt to be produced would be more economical and long-lasting. Considering the weights determined by the AHP method, the hot-mix asphalt to be produced with the aggregate of the Polatli Sumer quarry, which ranks first in the TOPSIS ranking, will have a high bitumen wrapping rate (stripping and coating test), less abrasion, and deterioration (Los Angeles test), and the binder to be produced will be considered. It can be stated that the cost of hot-mix asphalt will decrease due to the fact that less bitumen will be used in the layer (extraction test). In this study, seven experiments were performed in six different quarries, and ten different results were obtained. It will not be possible to make a ranking based on the results obtained alone. For example, the Sarıdegirmen quarry, which is in the sixth place in the ranking obtained by the TOPSIS method, gave the best result in the weather resistance test. Since it is known that it will not be possible to make an evaluation and ranking according to the results of the experiments, a multi-criteria selection method was needed. This study aimed to make an ideal ranking by evaluating many criteria together. This aim has been achieved with the TOPSIS method; this method can be used successfully in the selection of the most suitable quarry for road construction.

As a result of this study, it has been proved that the TOPSIS method can be used successfully in the selection of the most suitable aggregate for quality and long-lasting road construction. With this study, it can also be determined which aggregate among the aggregates that meet the standards in the selection of ideal aggregates will be better for quality and long-lasting road construction. In addition, mining enterprises other than quarries can determine the ideal ore for the ideal product by using the systematics presented in this study in the selection of ore.

In future studies, the roads where the hot-mix asphalt produced from the selected (ranked) field is applied can be compared with the roads made with the hot-mix asphalt produced from other fields, and it can be observed whether or not the study will give correct results.

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SELECTION OF THE BEST AGGREGATES TO BE USED IN ROAD CONSTRUCTION WITH TOPSIS METHOD

K e y w o r d s

aggregate, quarry, analytical hierarchy process, MCDM, TOPSIS

A b s t r a c t

Road construction has been an ongoing engineering practice throughout human history. Although road construction technologies have changed over time, the raw material used has not changed for centuries, and it seems that it will not change in the upcoming centuries. Although some standards are used to determine the aggregate quality in road construction works, it is often complex and laborious to identify the aggregates that best meet the standards. Long-lasting and high-quality roads can be built and the most suitable aggregate is selected for the road. This study aims to select the most suitable aggregates used in hot-mix asphalt pavement production for road construction. In this study, multi-criteria decision-making methods were used for the selection of the aggregate that provides the best conditions. Aggregates used in constructing roads within the provincial borders of Ankara are produced from six stone quarries. To rank these aggregates and determine the ideal quarry for hot-mix asphalt production, the analytical hierarchy process (AHP) and the technique for order preference by similarity to an ideal solution (TOPSIS) method, which are multi-criteria decision making (MCDM) methods, were used. The results obtained from the tests on aggregates and hot-mix asphalts (HMA) were compared with the the best results based on the maximum and minimum limits determined in the standards. By comparing the the best results of the standards with the test results of the aggregates, weight scores were made for each test. Weight scores were scored and classified using the AHP and TOPSIS multi-criteria decision-making methods. As a result, the aggregate with the highest score and the quarry area represented by the aggregate were determined as the most suitable for hot-mix asphalt construction.

DOBÓR NAJLEPSZYCH KRUSZYW DO ZASTOSOWANIA W BUDOWNICTWIE DROGOWYM METODĄ TOPSIS

S ł o w a k l u c z o w e

kruszywo, kamieniołom, proces hierarchii analitycznej, MCDM, TOPSIS

S t r e s z c z e n i e

Budowa dróg była stałą praktyką inżynierską w całej historii ludzkości. Choć technologie budowy dróg zmieniały się na przestrzeni dziejów, to stosowany surowiec nie zmienia się od wieków i wydaje się, że nie zmieni się w kolejnych stuleciach. Chociaż niektóre normy są stosowane do określania jakości kruszyw w robotach drogowych, to często skomplikowane i pracochłonne jest uszeregowanie kruszyw spełniających te normy. Trwałe i wysokiej jakości drogi można budować przy użyciu najodpowiedniejszego kruszywa dobranego do drogi. Niniejsze opracowanie ma na celu wybór najodpowiedniejszych kruszyw do produkcji nawierzchni asfaltowych na gorąco do budowy dróg. W niniejszym badaniu zastosowano wielokryterialne metody decyzyjne do wyboru agregatu, który zapewnia najlepsze warunki. Kruszywa wykorzystywane do budowy dróg w granicach prowincji Ankary produkowane są w sześciu kamieniołomach. Aby uszeregować te agregaty i określić idealny kamieniołom do produkcji gorącej mieszanki asfaltowej, zostały użyte: analityczny proces hierarchiczny (AHP) i technika preferencji zamówień na podstawie podobieństwa do metody idealnego rozwiązania (TOPSIS), które są metodami wielokryterialnego podejmowania decyzji (MCDM). Wyniki uzyskane z badań kruszyw i asfaltów na gorąco (HMA) porównano z najlepszymi wynikami wynikającymi z maksymalnych i minimalnych limitów określonych w normach. Porównując najlepsze wyniki wzorców z wynikami testów agregatów, dla każdego testu wykonano oceny wagowe. Oceny wagowe zostały ocenione i sklasyfikowane przy użyciu wielokryterialnych metod podejmowania decyzji, AHP i TOPSIS. W rezultacie kruszywo z najwyższą punktacją i obszar kamieniołomu reprezentowany przez kruszywo zostały uznane za najbardziej odpowiednie do budowy gorących mieszanek mineralno-asfaltowych.