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SUPPLIER ASSESSMENT USING THE AHP METHOD AND COST-QUALITY ANALYSIS

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Abstract:

Analyzes of multi-criteria decision support are applied to solve complex logistics problems, including supply problems from the industry sector. Organizations struggle with various decision problems that arise during the activities of organizations such as production logistics, supply logistics, transport logistics. Therefore, sometimes is necessary to make multi-criteria analysis, in which except the quality criteria, the costs are included. The problem with making the best decision in terms of quality and cost occurred in a production and service enterprise localized in south-eastern Poland. The problem was the selection and purchase of the most favorable in terms of quality and cost of fluorescent penetrant for non-destructive testing characterized by the so-called medium level of sensitivity. The aim was to integrate the AHP method and quality-cost analyze to select the most favorable for the enterprise the fluorescent penetrant to non-destructive test. The fluorescent penetrants, which were selected to analysis were: ZL-61, ZL19, ZL60C, ZL-61 from Magnaflux; FP-22B from Sherwin and Ardrox 9812 from Chemetall. Penetrants were analyzed in terms of criteria, i.e. the environment, flammability, reactivity, available packaging capacities and the cost of purchasing penetrant. The analysis carried out using the integrated methods (AHP and cost-quality analysis) which has not been practiced until now, has allowed indicating the most favorable fluorescent penetrant in terms of quality and costs It has been shown that the implementation of cost-quality analysis in the AHP method is effective in analyzing logistic problems regarding the selection of the most advantageous solution, taking into account quality and costs. The analysis proved that not always the highest quality and the lowest price guarantee the best choice. Therefore, it becomes effective to practice the proposed methodology (AHP and cost-quality analysis) in organizations for analyzing various logistic problems, in which it is important to make the most-favorable decision taking into account qualitative criteria and costs.

Keywords: *AHP, supply, mechanical engineering, quality, logistic, fluorescent penetrant, non-destructive test*

INTRODUCTION

Analyses of multi-criteria decision support are applied to solve complex logistics problems, including problems from the industry sector. Organizations struggle with various decision problems that arise during the activities of organizations such as production logistics, supply logistics, transport logistics [1, 24]. In addition, progress in the development of science and technology has resulted in the need to use numerical quality and cost estimates [26, 33]. Quality management conditions the need decision making in an organization has in order to make a level of quality products. Therefore, in organizations is important to make a comprehensive analysis with including various type of resources [1, 23, 25]. One of the methods, which allows solving the decision problem is the AHP method (Analytic Hierarchy Process). AHP method has an application to solving different decision problems, in which the choice is dependent on more than one criteria [30, 35, 36]. The problem is analysed in terms of the relationship of pairs of given criteria, in accordance with the adopted assessment scale. According to Saaty, in AHP method is preferred to use of scale 1-9, in which 1 is the lowest rating and means a very unfavourable condition, and 9 is the highest rating and indicates a very favourable condition [29]. In the AHP method, assessing criteria is a subjective assessment of the decision maker (the person who analyses the problem). Therefore, the results of the analysis may vary depending on the type of problem, criteria, and grades awarded which were being analysed.

A review of the literature on the subject of the latest literature indicates that the AHP method was used, among others to:

- comparison of the importance and weight of criteria [5, 10, 12],
- making decisions in the area of sustainable development and analysis of issues related to society [5, 13, 19],
- selection of objects, devices and machines or analysis of their failure [11, 23],
- cost-dependent choices [9, 13, 39].

The AHP method was integrated with other methods, i.e.:

- FAHP (Fuzzy Analytical Hierarchy Process) [21, 22, 27],
- TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) or Fuzzy TOPSIS [6, 28, 38],
- Fuzzy Logic [14, 17],
- GRA (Grey Relational Analysis) or PSO (Particle Swarm Optimization) [2, 6, 18],
- AHP-GP or FCE (Fuzzy Comprehensive Evaluation [3, 41],
- GIS (Geographical Information Systems) [24, 31, 35],
- PCA (Principal Component Analysis) [10, 43],
- SWOT (Strengths, Weaknesses, Opportunities and Threats) [4, 38].

After reviewing the literature, it was concluded that the AHP method was used to analyse the problem of cost-dependent decision making [9, 13, 39]. However, it was not integrated with cost-quality analysis, which enables making decisions based on many criteria, including quality and costs [1, 16, 33]. In turn, the cost-quality analysis was used with other methods to determine quality, i.e.:

- Average Transformed Quality,
- Group Selection of States,
- Formalized Scoring,
- Accelerated Three-Stage Evaluation,
- Alternate-Point Method [32].

By using these methods, the quality was determined. However, this quality was not calculated using the AHP method, which, enriched by the possibility of computational analysis with the Matlab computer program, is an effective tool for multi-criteria analysis. Therefore, it was order to demonstrate that implement the cost-quality analysis in the AHP method is effective in case of analysing the logistics problems regarding the selection of the most advantageous solution taking into account quality and costs. The aim was to integrate the AHP method and quality-cost analyse to select the most favourable for the enterprise the fluorescent penetrant to non-destructive test. Cost-quality analyse allows making the best to analysis problem decision (with taking into account known quality and costs). Cost-quality analyze has applies mainly in case of a problem, in which a few criteria are comparison [1, 16, 33]. In the cost-quality analysis, the calculation are made based on example the level of quality, which is calculated using other, adequate method, and also basic on cost (in this example – purchase of penetrant) [16, 24, 33]. Therefore, it was considered, that this analysis (cost-quality) will be effective to solve the multi-criteria problem (choice the most favorable for the enterprise the fluorescent penetrant to non-destructive test), which was in enterprise localized in south-eastern Poland.

In the selected enterprise, the problem was the selection and purchase of the most favourable in terms of quality and cost of fluorescent penetrant for non-destructive testing characterized by the so-called medium level of sensitivity. Was proposed to the enterprise the use of AHP method with cost-quality analysis, in due to a large number of types of fluorescent penetrants available on the market, which were taken into account during the analysis, and the need to analyse more than two criteria characterizing fluorescent penetrants. Due to the criterion which was the cost of purchasing penetrant, which was not a qualitative criterion, it became necessary to carry out additional cost-quality analysis (adequate to the analysis of multi-criteria problems), which takes into account both quality and cost. In enterprise the research with the fluorescent method (FPI) was made, using penetrant in a low and high level of sensitivity. In view of making NDT research for different types of product and needs to improve the services offered, it was necessary to purchase the fluorescent penetrant about the average level of sensitivity. In addition to this criterion (sensitivity level 2), it was important for the company to take into account the criteria i. e: environment, flammability, reactivity, available packaging capacities and the cost of purchasing penetrant. The fluorescent penetrants, which were selected to analysis were: ZL-61, ZL19, ZL60C, ZL-61 from Magnaflux; FP-22B from Sherwin and Ardrox 9812 from Chemetall.

1 MATERIAL

Six types of fluorescent penetrants were analysed, which are using in industrial non-destructive testing by fluorescence. The choice was determined by the individual preferences of the decision-maker (quality control manager). The quality control manager was guided by his opinion and experience in the area of analyses conducted by FPI research during the choice of the number and types of fluorescent penetrants. The fluorescent penetrants, which were selected to analysis were: ZL-61, ZL19, ZL60C, ZL-61 from Magnaflux; FP-22B from Sherwin and Ardrox 9812 from Chemetall. Selected substances for FPI tests were characterized by the so-called "Medium" sensitivity level. Information on selected fluorescent penetrants for analysis is available in publicly available safety data sheets for these chemicals.

2 METHOD

Method to analysis the logistic problem (choice the most favourable for the enterprise the fluorescent penetrant to non-destructive test) were two methods, which were not integrated techniques so far, i.e. AHP method and cost-quality analysis. Additionally, with the aim of improving the process of problem analysis using the AHP method, the Matlab (computer program) was used to calculate, which allow to relative and quickly make calculate, which very improved the process of making an analysis.

The first step of the integrated method to solve the logistic problem (choice the most favourable for the enterprise the fluorescent penetrant to non-destructive test) was an analysis of the problem using the AHP method. The quality control manager, appointed both as an expert and a decision-maker, selected six types of fluorescent penetrants. On the need for research, the selected penetrants were marked from P1 to P6. During the brainstorm moderated by an expert, four criteria were selected to assess selected penetrants. These criteria were: environment, flammability, reactivity, available packaging capacities and cost purchase of penetrant. Then the quality control manager determined the importance of each of the criteria selected for analysis against the others. The validity of each criterion was determined according to a nine-point scale (according to preferred scale by Saaty) in which 1 is the lowest rating and means a very unfavourable condition, and 9 is the highest rating and indicates a very favourable condition. The most important criterium was the environment, then flammability, reactivity, and the least important available packaging capacities. During the validity of the criteria, the cost of purchasing penetrant, which was not a qualitative criterion and was included in the cost-quality analysis, was omitted. Next, the expert (quality control manager) evaluated each penetrant in accordance with the adopted nine-point scale, each penetrant in terms of selected criteria (environment, flammability, reactivity, available packaging capacities). Based on assessments of the penetrants and criteria, calculations were made in accordance with the AHP methodology. To calculate the Matlab program was used. Simulation in the Matlab program was ended, when the result from the difference of values from the quotients of the matrix values for the criteria and from the quotients of the values of the created matrix was smaller than the assumed precision (1.0e-003*), which is three decimal places. The results obtained from the AHP calculations in the Matlab program indicated which penetrant was the most beneficial in quality (Q [%] - maximum value) for the enterprise in terms of selected criteria.

The second step of the integrated method to solve the logistic problem is to analyse the problem using cost-quality analysis. This method is based on the value of the quality of penetrants, which was calculated during the AHP method, and based on the cost (cost of purchase the penetrant). For the enterprise was important to purchase the maximum available capacity of fluorescent penetrant (i.e. about 208 l), therefore to need the cost-quality analysis the approximate cost of purchasing the analysed penetrants was estimated. The choice of packaging size (i.e. 208 litres - maximum available capacity) resulted from the average annual consumption of penetrants for fluorescence testing in the selected enterprise (i.e. on average 400 - 600 litres/year).

The quality cost index was calculated [32]:

$$C_p = \frac{P}{Q} \tag{1}$$

where: P – cost [zlotys],
Q – level of quality [%].

Relative cost was calculated [32]:

$$P = \frac{P_{max} - P_{product}}{P_{max} - P_{min}} \tag{2}$$

where: P_{max} *– largest cost [zlotys],*
P_{min} *– lowest cost [zlotys],*
$P_{product}$ *– product cost [zlotys].*

The cost-quality proportionality index was calculated [32]:

$$E = \frac{P}{q} \quad (3)$$

where: q – level of quality expressed as a decimal fraction.

The relativised cost index C was calculated from the formula [32]:

$$C = \frac{C_{pa} - C_p}{C_{pa} - C_{pi}} \quad (4)$$

where: C_{pa} *– maximum cost-quality ratio,*
C_{pi} *– minimum cost-quality ratio,*
C_p *– cost-quality ratio of the product.*

The resolution indicator for technical preference was calculated [32]:

$$R_t = 0{,}167\ (3q + 2D + C) \quad (5)$$

The settlement indicator for economic preference was calculated [32]:

$$R_e = 0{,}167\ (3C + 2D + q) \quad (6)$$

The average decision-making indicator was calculated [32]:

$$R_d = 0{,}5\ (R_t + R_e) \quad (7)$$

The last stage of the methodology was the selection of fluorescent penetrant characterized by the desired cost-quality criteria. According to the methodology of cost-quality analysis, a penetrant with the highest value of the decision-making indicator was selected (R_d).

3 RESULTS

The expert (quality control manager) was assessments the six different fluorescent penetrants selected for analysis (Table 1).

Tab. 1 *Penetrant assessment by criteria.*

Criteria	**Type of penetrant and assessment**					
	P1	**P2**	**P3**	**P4**	**P5**	**P6**
natural environment	3	7	1	3	5	5
flammability	9	3	5	9	7	7
reactivity	7	7	3	7	5	7
capacity	3	5	5	5	1	5

Source: Own study.

In table 2 was shown the way of validity criteria, which was made by quality control manager, where the most important criterium was the environment, then flammability, reactivity, and the least important available packaging capacities.

Tab. 2 *Preference matrix for selected criteria.*

Criteria	natural environment	flammability	reactivity	capacity
natural environment	1	3	5	7
flammability	1/3	1	3	5
reactivity	1/5	1/3	1	3
capacity	1/7	1/5	1/3	1

Source: Own study.

The quality control assessment given by the quality control manager for each penetrant in terms of its criteria is presented in Table 3.

Tab. 3 *Preference matrix for selected fluorescent penetrants.*

natural environment	P1	P2	P3	P4	P5	P6
P1	1	3/7	3	1	3/5	3/5
P2	7/3	1	7	7/3	7/5	7/5
P3	1/3	1/7	1	1/3	1/5	1/5
P4	1	3/7	3	1	3/5	3/5
P5	5/3	5/7	5	5/3	1	1
P6	5/3	5/7	5	5/3	1	1
flammability	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
P1	1	9/3	9/5	1	9/7	9/7
P2	3/9	1	3/6	3/9	3/7	3/7
P3	5/9	5/3	1	5/9	5/7	5/7
P4	1	9/3	9/5	1	9/7	9/7
P5	7/9	7/3	7/5	7/9	1	1
P6	7/9	7/3	7/5	7/9	1	1
reactivity	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
P1	1	1	7/3	1	7/5	1
P2	1	1	7/3	1	7/5	1
P3	3/7	3/7	1	3/7	3/5	3/7
P4	1	1	7/3	1	7/5	1
P5	5/7	5/7	5/3	5/7	1	5/7
P6	1	1	7/3	1	7/5	1
capacity	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
P1	1	3/5	3/5	3/5	3	3/5
P2	5/3	1	1	1	5	1
P3	5/3	1	1	1	5	1
P4	5/3	1	1	1	5	1
P5	1/3	1/5	1/5	1/5	1	1/5
P6	5/3	1	1	1	1	1

Source: Own study.

After the AHP analysis using the Matlab computer program, the quality level of the six types of penetrants analysed was calculated in terms of selected quality criteria, the results of which are presented in Table 4.

***Tab. 4** The AHP calculation results for penetrants according to selected criteria.*

Criterium	**Type of the penetrant and result of the assessment [%]**					
	P1	**P2**	**P3**	**P4**	**P5**	**P6**
natural environment	14,318	33,408	4,773	14,318	23,863	23,863
flammability	19,947	6,464	11,082	19,947	15,515	15,515
reactivity	16,704	16,704	7,159	16,704	11,931	16,704
capacity	12,365	20,608	20,608	20,608	4,122	17,796
SUM [%]	63,334	77,184	43,622	71,577	55,431	73,878

Source: Own study.

After analysis the problem using the AHP method it was shown, that the advantageous penetrant for the enterprise during selected quality criteria is penetrant P2, which was characterized by the maximum value Q [%]. Quality of penetrant P2 was assessment the best (Q=77,184%), in comparison to other penetrants, which is shown in Table 5.

***Tab. 5** Assessment of the quality level of fluorescent penetrants according to selected criteria and scale 1-9.*

Criterium	**Penetrant type and number of points**					
	P1	**P2**	**P3**	**P4**	**P5**	**P6**
natural environment	3	7	1	3	5	5
flammability	9	3	5	9	7	7
reactivity	7	7	3	7	5	7
capacity	3	5	5	5	1	5
Quality Q [%]	63,334	77,184	43,622	71,577	55,431	73,878
Place in the ranking	4	1	6	3	5	2

Source: Own study.

The results from the cost-quality analysis, taking into account the quality level calculated by the AHP method, are presented in Table 6.

***Tab. 6** The results of the cost-quality analysis taking into account the level of quality calculated by the AHP method.*

Criterium	**Penetrant type and number of points**					
	P1	**P2**	**P3**	**P4**	**P5**	**P6**
Purchase P, zl/ package	227106,3	1478450	1719550	2398892	1881013	137723,7
Quality Q [%]	63,334	77,184	43,622	71,577	55,431	73,878
Cp	3585,85	19154,88	39419,33	33514,84	33934,32	1864,20
P	0,96	0,41	0,30	0,00	0,23	1,00
E	1,52	0,53	0,69	0,00	0,41	1,35
D	0,76	0,26	0,34	0,00	0,21	0,68
C	0,95	0,54	0,00	0,16	0,15	1,00
R_t	0,73	0,56	0,33	0,38	0,37	0,76
R_e	0,84	0,49	0,19	0,20	0,23	0,85
R_d	0,78	0,53	0,26	0,29	0,30	0,81
Place according to R_d	2	3	6	5	4	1

Source: Own study.

After considering the quality and costs (purchase of the desired size of the penetrant packaging, i.e. 208 l - maximum available capacity), it was concluded that the most advantageous penetrant in terms of the cost-quality and quality is penetrant P6 (Rd = 0.81). Penetrant P6 was second in the quality (Q = 73, 878%).

In the AHP method, assessing criteria is a subjective assessment of the decision-maker (the person who analyses the problem). Therefore, the results of the analysis may vary depending on the type of problem, criteria, and grades awarded which were being analysed.

3 CONCLUSIONS

In organizations origin with various decision problems that arise during the activities of organizations such as production logistics, supply logistics, transport logistics. The problem with making the best decision in terms of quality and cost occurred in a production and service enterprise localized in south-eastern Poland, and concerned the selection and purchase of penetrant. The problem was the selection and purchase of the most favourable in terms of quality and cost of fluorescent penetrant for non-destructive testing characterized by the so-called medium level of sensitivity. To solve the problem and identify the penetrant with the desired quality, the simple method like the AHP method with the computer program Matlab was proposed in the enterprise.

In order to take into account, the costs of penetrant purchase significant for the company, it was proposed to use cost-quality analysis. The aim was to integrate the AHP method and quality-cost analyze to select the most favourable for the enterprise the fluorescent penetrant to non-destructive test.

The analysis carried out using the integrated methods (AHP and cost-quality analysis) which has not been practiced until now, has allowed indicating that the most favourable fluorescent penetrant in terms of quality was penetrant marked P2 (Q=77,184%). After considering the quality and cost of purchasing penetrant, it was shown that the most cost-effective penetrant in terms of cost and quality was penetrant P6 (R_d = 73.878%). In the AHP method, assessing criteria is a subjective assessment of the decision maker (the person who analyses the problem). Therefore, the results of the analysis may vary depending on the type of problem, criteria, and grades awarded which were being analysed.

The analysis proved that not always the highest quality and the lowest price guarantee the best choice. It was shown that implemented the cost-quality analysis in the AHP method is effective in logistic problem analysis, about choice the best solution with taking into account the costs and quality. Therefore, it becomes effective to practice the proposed methodology (AHP and cost-quality analysis) in organizations for analysing various logistic problems, in which it is important to make the most-favourable decision taking into account qualitative criteria and costs.

References

[1] Adamczyk J., Pacana A., 2012, „Doskonalenie logistyki zaopatrzenia z wykorzystaniem analizy kosztowo-jakościowej,” Rachunkowość w logistyce przedsiębiorstw, red. G. Lew, Rzeszów, pp. 13-14.

[2] Amohadi M., Fotuhi-Firuzabad M., 2019, „Optimal placement of switching and protection devices in radial distribution networks to enhance system reliability using the AHP-PSO method, ” TURKISH JOURNAL OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCES, 27(1), pp. 181-196.

[3] Andres J., Soto R., Garduno S., 2019, „Determination of the Weightings of Hydroelectric Sustainability Criteria by Combining AHP and GP Extended Methods,” INGENIERIA, 24(2), pp. 116-142.

[4] Basset M. A., Mohamed M., Sangaiah A. K. et al., 2018, „An integrated neutrosophic AHP and SWOT method for strategic planning methodology selection, ” BENCHMARKING-AN INTERNATIONAL JOURNAL, 25(7), pp. 2546-2564.

[5] Ding J-F., Kuo J.-F., Tai W.-H., 2019, „Using Fuzzy AHP Method to Evaluate Key Competency and Capabilities of Selecting Middle Managers for Global Shipping Logistics Service Providers, ” POMORSTVO-SCIENTIFIC JOURNAL OF MARITIME RESEARCH, 33(1), pp. 3-10.

[6] Ersoy M., 2019, „Classification of Marble Blocks Using AHP Assisted TOPSIS and GRA Methods,” Journal Of Polytechnic-Politeknik Dergisi, 22(2), pp. 303-317

[7] Goh K. C., Goh H. H, Chong H.-Y., 2019, „Integration Model of Fuzzy AHP and Life-Cycle Cost Analysis for Evaluating Highway Infrastructure Investments,” JOURNAL OF INFRASTRUCTURE SYSTEMS, 25(1).

[8] Hadef H., Djebabra M., 2019, „PCA-I and AHP Methods: Unavoidable Arguments in Accident Scenario Classification,” Journal Of Failure Analysis And Prevention, 19(2), pp. 496-503.

[9] Hadef H., Djebabra M., 2019, „PCA-I and AHP Methods: Unavoidable Arguments in Accident Scenario Classification,” Journal Of Failure Analysis And Prevention, 19(2), pp. 496-503.

[10] He H., Hu D., Sun Q. et al., 2019, „A Landslide Susceptibility Assessment Method Based on GIS Technology and an AHP-Weighted Information Content Method: A Case Study of Southern Anhui, China,” Isprs International Journal Of Geo-Information, 8(6).

[11] Horvathova P., Copikova A., Mokra K., 2091, „Methodology proposal of the creation of competency models and competency model for the position of a sales manager in an industrial organisation using the AHP method and Saaty's method of determining weights,” ECONOMIC RESEARCH-EKONOMSKA ISTRAZIVANJA, 32(1), pp. 2594-2613.

[12] Justino N. J. M., Ragoni I. G., Frezzatto S. L. E. et al., 2019, „Selecting low-cost 3D printers using the AHP method: a case study,” SN APPLIED SCIENCES, 1(4).

[13] Justino N. J. M., Ragoni I. G., Frezzatto S. L. E. et al., 2019, „Selecting low-cost 3D printers using the AHP method: a case study,” SN APPLIED SCIENCES, 1(4).

[14] Kadam A., Karnewar A. S., Umrikar B. et al., 2019, „Hydrological response-based watershed prioritization in semiarid, basaltic region of western India using frequency ratio, fuzzy logic and AHP method," ENVIRONMENT DEVELOPMENT AND SUSTAINABILITY, 21(4), pp. 1809-1833.

[15] Khoshi A., Gooshki H. S., Mahmoudi N., 2018, „The data on the effective qualifications of teachers in medical sciences: An application of combined fuzzy AHP and fuzzy TOPSIS methods," DATA IN BRIEF, 21, pp. 2689-2693.

[16] Kolman R. 1992, „Inżynieria jakości, " PWE, Warszawa, pp. 6.

[17] Lad S., Ayachit R., Kadam A. et al., 2019, „Groundwater vulnerability assessment using DRASTIC model: a comparative analysis of conventional, AHP, Fuzzy logic and Frequency ratio method," MODELING EARTH SYSTEMS AND ENVIRONMENT , 5(2), pp. 543-553.

[18] Li J., Zhang H., Sun T. et al., 2019, „Method For Designing The Optimal Trajectory For Drilling A Horizontal Well, Based On Particle Swarm Optimization (Pso) And Analytic Hierarchy Process (Ahp)," Chemistry And Technology Of Fuels And Oils, 55(1), Pp. 105-115.

[19] Li J., Zhang H., Sun T. et al., 2019, „Method for designing the optimal trajectory for drilling a horizontal well, based on particle swarm optimization (PSO) and analytic hierarchy process (AHP)," CHEMISTRY AND TECHNOLOGY OF FUELS AND OILS, 55(1), pp. 105-115.

[20] Morimoto R. M., de Oliveira F. H., 2019, „analysis of the constructed space for infant education network by ahp and gis methods: a case study in camboriu (brazil), " arquitetura revista, 15(1), pp. 15-38.

[21] Muhsen D. H., Haider H. T., Al-Nidawi Y. M. et al., 2019, „Domestic load management based on integration of MODE and AHP-TOPSIS decision making methods, " SUSTAINABLE CITIES AND SOCIETY, 50.

[22] Omidvar M., Nirumand F., 2019, „Risk assessment of heat stress using the AHP and TOPSIS methods in fuzzy environment - A case study in a foundry shop, " JOURNAL OF HEALTH AND SAFETY AT WORK, 8(4), pp. 397.

[23] Pacana A., Bednarova, L., Liberko, I., Woźny, A., 2014, „Effect of selected production factors of the stretch film on its extensibility, " Przemysl Chemiczny, 93(7).

[24] Pacana A., Pasternak-Malicka M., Zawada M., Radoń-Cholewa A., 2016, „Wspomaganie podejmowania decyzji w produkcji folii opakowaniowej z wykorzystaniem analizy kosztowo-jakościowej," Przemysł Chemiczny, 95(5), pp. 1042-1044.

[25] Pacana A., Siwiec D., Bednarova L., 2019, „Analysis of the incompatibility of the product with fluorescent method, " METALURGIJA, 58 (3-4), pp. 337-340.

[26] Pacana A., Siwiec D., Bednarova L., Hajduova Z., 2019, „The selected methods of quality management used for the evaluation of label printing," Przemysł Chemiczny, 98(1), pp. 110-112.

[27] Rodcha R., T., Nitin K., Shrestha R. P., 2019, „Comparison of Cash Crop Suitability Assessment Using Parametric, AHP, and FAHP Methods," LAND, 8(5).

[28] Roy T., Dutta R. K., 2019, „Integrated fuzzy AHP and fuzzy TOPSIS methods for multi-objective optimization of electro discharge machining process,” SOFT COMPUTING, 23(13), pp. 5053-5063.

[29] Saaty T.L., 1980, „The Analytic Hierarchy Process,” New York: McGraw-Hill.

[30] Sahin Y., Aydemir E., 2019, „An AHP-Weighted Gray Relational Analysis Method to Determine the Technical Characteristics' Importance Levels of the Smartphone,” Eskisehir Osmangazi Universitesi Iibf Dergisi-Eskisehir Osmangazi University Journal Of Economics And Administrative Sciences, 14(1), pp. 225-238.

[31] Santhosh L. G., Babu G. L. S., 2018, „Landfill site selection based on reliability concepts using the DRASTIC method and AHP integrated with GIS - a case study of Bengaluru city, India”, Georisk-Assessment And Management Of Risk For Engineered Systems And Geohazards, 12(3), pp. 234-252.

[32] Sęp J., Perłowski R., Pacana A., „Techniki Wspomagania Zarządzania Jakością,” Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów, 2006.

[33] Siwiec D., Bednarova L., Pacana A., Zawada M., Rusko M., 2019, „Decision support in the selection of fluorescent penetrants for industrial non-destructive testing, ” Przemysł Chemiczny, 98(10), pp. 1594-1596.

[34] Stojcetovic B. V., Nikolic D. M. Zivkovic Z. D. et al., 2019, „Swot-Ahp Method Application To Determine Current Energy Situation And Define Strategies For Energy Security Improvement, ” THERMAL SCIENCE, 23(2), pp. 861-872.

[35] Strojny J., 2015, „Implementation of the AHP and benchmarking in Strategic Analysis of Polish Regions,” Procedia Social and Behavioral Sciences, 213, pp. 229-235.

[36] Strojny J., 2016, „Application Methods AHP and Benchmarking in the Strategic Management of Local Development: The Key Procedural Aspects Through the Example of Polish Districts,” Entrepreneurship. Business and Economics, 2-3(2).

[37] Sun B., Tang J., Yu D. et al., 2019, „Ecosystem health assessment: A PSR analysis combining AHP and FCE methods for Jiaozhou Bay, China, ” OCEAN & COASTAL MANAGEMENT, 168, pp. 41-50.

[38] Turker Y. A., Baynal K., Turker T., 2019, „THE EVALUATION OF LEARNING MANAGEMENT SYSTEMS BY USING FUZZY AHP, FUZZY TOPSIS AND AN INTEGRATED METHOD: A CASE STUDY,” TURKISH ONLINE JOURNAL OF DISTANCE EDUCATION, 20(2), pp. 195-218.

[39] Zhou J. L., Xu Q. Q., Zhang X. Y., 2018, „Water Resources and Sustainability Assessment Based on Group AHP-PCA Method: A Case Study in the Jinsha River Basin,” WATER, 10(12).

[40] Strojny J., 2016, „Application Methods AHP and Benchmarking in the Strategic Management of Local Development: The Key Procedural Aspects Through the Example of Polish Districts,” Entrepreneurship. Business and Economics, 2-3(2).

[41] Sun B., Tang J., Yu D. et al., 2019, „Ecosystem health assessment: A PSR analysis combining AHP and FCE methods for Jiaozhou Bay, China, ” OCEAN & COASTAL MANAGEMENT, 168, pp. 41-50.

[42] Zhou J. L., Xu Q. Q., Zhang X. Y., 2018, „Water Resources and Sustainability Assessment Based on Group AHP-PCA Method: A Case Study in the Jinsha River Basin,” WATER, 10(12).

[43] Turker Y. A., Baynal K., Turker T., 2019, „The Evaluation Of Learning Management Systems By Using Fuzzy Ahp, Fuzzy Topsis And An Integrated Method: A Case Study," Turkish Online Journal Of Distance Education, 20(2), pp. 195-218.