AHP-TOPSIS METHOD AS A COMPONENT OF INFORMATION TECHNOLOGY FOR DUAL EDUCATION SYSTEM

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Conceptual mathematical model of human resource management (HRM) in the field of personnel training is developed in this paper. The developed model is the basis of information technology of dual education - a component evaluating the students training in the company. The information technology of dual education, which is being developed by us, will integrate education and work in the system of dual education, will solve the problem of cooperation between the company and the educational institution. By the methods of multicriteria analysis the proposed mathematical model of HRM describes the subsystems of dual education: companies, students' academic achievements, criteria for assessing the achievement of competencies by academic courses learning. Intuitionistic fuzzy sets for the determination of the subjectivity of assigning estimates by fuzzy trapezoidal numbers are modified, method of adjusting assigned ratings by experts, taking into account subjectivity is developed in this paper. The method for adjusting the subjectivity of final estimates of the multicriteria problem ranking depending on the aims of the integrating system of ranking alternatives subsystems is proposed. Numerical example of the TOPSIS method application taking into account the subjectivity of experts and without it is presented.

Key words: fuzzy logic, analytic hierarchy process, dual education, information technology, TOPSIS, Intuitionistic fuzzy sets

Problem statement. Information technology is an important component of effective development in the age of information and transformation economy.

There are problems of collaboration between the company and educational institution in the dual education system (domination of one of the stakeholders in the learning process) [1-3]. Companies in dual education system can tend to save money and want to develop in the student only those skills which are sufficient to perform his functional dutie, as a result productive profitable learning in the company in particular can be predominates and the academic component can be reduced. The statement of problem is to construct the mathematical model of learning evaluation in the company, which is based on the academic component of training and is a component of information technology of dual education system together with such components as: information portal, online learning diary, tuition cost optimization, LMS (learning management system), database, decision support in choosing a discipline.

The purpose and tasks of the article. The purpose of the paper is to develop the mathematical model of comprehensive assessment of the student's academic achievement in the enterprise. This model is based on the academic component, based on the method of multi-criteria analysis TOPSIS, taking into account subjectivism.

To achieve this purpose, it is necessary: 1. Determine subsystems and hierarchical structure for ranking alternatives; 2. Develop an algorithm for determining the subjectivity of experts; 3. Develop a method to account for the inconsistency of the ranking subsystems; 4. Test the developed model in practice.

The main material presentation. In this study, we use the TOPSIS method to build a model for assessing student learning in dual forms of education. The algorithm of TOPSIS method is described in papers [4, 5], investigations based on this method are conducted in papers [6, 7].

According to the developed modification it is proposed to supplement TOPSIS method by determination due to AHP of weight coefficients of inconsistency $v_p^s = (v_p^s, p = \overline{1,n})$ of the subsystems of ranking alternatives to the analysis purpose. After that it is necessary to calculate the adjusted indicators according to the formula:

$$\alpha(a_n^s) = (((1 - \phi(a_n^s))v_p^s) + 1)\phi(a_n^s) \qquad (1)$$

Improvement of the method in comparison with examples [6, 7] is necessary, because the ranking alternatives in this conceptual model belong to different assessment subsystems. The inconsistency of the assessment subsystems properties affects the goal of analysis, shifting the resulting indicators, requiring their adjustment. The conceptual model in this investigation is applied to the assessment process (that is, it involves repeated iterations of assessment during training) and is not the final stage as in papers [6, 7].

In TOPSIS [4, 5] method algorithm of determining the degree of alternatives belonging, we will add additional steps in order to determine the subjectivity of experts. To correct the membership functions of trapezoidal numbers of fuzzy sets, we take intuitionistic fuzzy sets as a basis [8], and call them subjective sets. Let's determine the subjectivity of the assigned assessments by experts-revisionists familiar with the subject area of assessment. The stages of subjectivity determination are as follows: 1.Assigned trapezoidal grades $R^a = (r_{ki}^a) = (a_{ki}^a, b_{ki}^a, c_{ki}^a, d_{ki}^a)$ in each subject $D = (d_{mz}^s) = (d_{mz}^s, z = \overline{1,n})$ of the students $À = (a_n^s) = (a_n^s, n = \overline{1,n})$ is evaluated for the subjectivity $A = \{\langle x, u_A(x), o_A(x) \rangle\}$ of underestimation and overestimation,

respectively. 2. Let us determine the accuracy of assessment using score(S) - the function of subjectivity:

$$score(S) = u_A(x) - o_A(x) \tag{2}$$

3. Let us correct values of trapezoidal numbers taking into account the assessment of subjectivity in the following way:

$$R^a = \begin{cases} (a_{ki}^a - o_A(x), b_{ki}^a - (S), c_{ki}^a - (S), d_{ki}^a + u_A(x)), & u_A(x) < o_A(x) \\ (a_{ki}^a + u_A(x), b_{ki}^a + (S), c_{ki}^a + (S), d_{ki}^a - o_A(x)), & u_A(x) > o_A(x) \end{cases} \tag{3}$$

The experiment was carried out in order to assess the learning outcomes of students majoring in 125 "Cybersecurity" of the dual education mode at Ternopil Ivan Puluj National Technical University for the academic year. The proposed method was tested in three IT companies UnderDefense, Cyberoo, Eleks for assessing student's training within companies. The assessment was carried out by experts from each company. In each company, using T. Saati AHP (Analytic Hierarchy Process) pairwise comparison, weights were determined by the relative importance of criteria and sub-criteria (Table 1) - competencies and subjects that form them - to solve the company's problems and, relatively, its specialization profile. In order to perform the assessment based on the TOPSIS method, it is necessary to eliminate the hierarchical structure of criteria, thus $w_p^S = w_{zk}^S \cdot w_{ml}^S$ [6].

Experts in each company assessed the alternatives (students outcomes, assignments (which relate to academic subjects) that they performs in the company) belonging to the sub-criteria using the linguistic variables of fuzzy trapezoidal numbers. Thus, the alternatives belonging to subcriteria in fuzzy trapezoidal numbers is represented in the form given in Table. 2.

Table 1

Coefficients of weighting criteria

UnderDefense				
Criteria (competencies)	Coefficient of relative criteria importance	Subcriteria (subjects)	Subcriteria coefficients	Private subcriteria weighting coefficients
GC1: Ability to apply knowledge in practical situations	0.09	Computer networks	0.37	0.03
		Programming Foundations	0.57	0.05
		Theory of probability and mathematical statistics	0.05	0.004
GC1: Ability to identify, pose and solve problems of professional purposes	0.03	Software development	0.68	0.02
		Foreign language	0.25	0.009
		Physics	0.06	0.002
PC2: Ability to use information and communication technologies, modern methods and models of information security and / or cybersecurity.	0.54	Foundations of computer technologies	0.80	0.44
		Mathematical analysis	0.07	0.04
		Discrete Mathematics	0.12	0.06
PC3: Ability to use software and software-hardware complexes of information security in information and telecommunication (automated) systems.	0.32	Numerical Methods	0.66	0.21
		Fundamentals of circuit theory, signals and processes in electronics	0.33	0.10
Cyberoo				
GC1: Ability to apply knowledge in practical situations	0.06	Computer networks	0.58	0.03
		Foundations of programming	0.35	0.02
		Theory of probability and mathematical statistics	0.05	0.03
GC4: Ability to identify, pose and solve problems of professional purposes.	0.05	Software development	0.75	0.03
		Foreign language	0.19	0.01
		Physics	0.04	0.002
PC2: Ability to use information and communication technologies, modern methods and models of information security and / or cybersecurity.	0.33	Foundations of computer technologies	0.80	0.26
		Mathematical analysis	0.06	0.02
		Discrete Mathematics	0.13	0.04
PC3: Ability to use software and software-	0.54	Numerical Methods	0.14	0.07
		Fundamentals of	0.85	0.46

hardware complexes of information security in information and telecommunication (automated) systems.		circuit theory, signals and processes in electronics		
Eleks				
GC1: Ability to apply knowledge in practical situations	0.18	Computer networks	0.18	0.03
		Foundationsof programming	0,.76	0.14
		Theory of probability and mathematical statistics	0.05	0.009
GC4: Ability to identify, pose and solve problems of professional purpose.	0.58	Software development	0.77	0.45
		Foreign language	0.17	0.10
		Physics	0.04	0.02
PC4: Ability to use information and communication technologies, modern methods and models of information security and / or cybersecurity.	0.17	Foundations of computer technologies	0.75	0.13
		Mathematical analysis	0.09	0.01
		Discrete Mathematics	0.15	0.02
PC3: Ability to use software and software-hardware complexes of information security in information and telecommunication (automated) systems.	0.05	Numerical Methods	0.8	0.04
		Fundamentals of circuit theory, signals and processes in electronics	0.2	0.01

When the values of belonging in fuzzy trapezoidal numbers are obtained, it is necessary to multiply them with the weighting coefficients of private criteria w_p^s as a result, we obtain weighted fuzzy trapezoidal numbers, the obtained values are normalized according to the method presented in paper [6] of expression

$$R_{nz}^N = \left[r_{nz}^N \right] \Leftrightarrow \left\{ a_{nz}^N, b_{nz}^N c_{nz}^N, d_{nz}^N \right\} \Leftrightarrow \left\{ \frac{a_{nz}^{sw}}{d_z^+}, \frac{b_{nz}^{sw}}{d_z^+}, \frac{c_{nz}^{sw}}{d_z^+}, \frac{d_{nz}^{sw}}{d_z^+} \right\}$$

$$d_z^+ = max\, d_{nz}^{sw}, n = 1,n \; ,$$

Table 2

Fuzzy trapezoidal numbers of alternatives belonging

Subcriteria (subjects)	UnderDefense c_1	Cyberoo c_2	Eleks c_3
	Student a_1^1	Student a_2^2	Student a_3^3
d_1	(8,9,10,10)	(7,8,8,9)	(8,9,10,10)
d_2	(7,8,8,9)	(7,8,8,9)	(7,8,8,9)

d_3	(7,8,8,9)	(5,6,7,8)	(5,6,7,8)
d_4	(4,5,5,6)	(7,8,8,9)	(4,5,5,6)
d_5	(4,5,5,6)	(8,9,10,10)	(4,5,5,6)
d_6	(8,9,10,10)	(4,5,5,6)	(8,9,10,10)
d_7	(8,9,10,10)	(8,9,10,10)	(8,9,10,10)
d_8	(5,6,7,8)	(4,5,5,6)	(8,9,10,10)
d_9	(5,6,7,8)	(7,8,8,9)	(5,6,7,8)
d_{10}	(4,5,5,6)	(7,8,8,9)	(2,3,4,5)
d_{11}	(7,8,8,9)	(5,6,7,8)	(7,8,8,9)

Using the normalized values, it is necessary to find fuzzy ideal positive and fuzzy ideal negative solutions x* and x- respectively, i.e. $d_z^* = \left\{ max\, d_{nz}^N, n = \overline{1,n} \right\}$ and $a_z^- = \left\{ max\, a_{nz}^N, n = \overline{1,n} \right\}$. Thus in, we obtained the matrix of ideally positive and negative solutions X* i X-. Let us find the distances of alternatives by individual criteria to perfectly negative and perfectly positive solution by formula [10]: $D_z^*(a_n^S, X^*) = \sqrt{\frac{1}{4}((a_{nz}^N - d_z^*)^2 + (b_{nz}^N - d_z^*)^2 + (c_{nz}^N - d_z^*)^2 + (d_{nz}^N - d_z^*)^2)}$. The distance to the

ideal negative solution is calculated similarly to the coefficient a_z^-. Let us determine the distance of alternatives to ideally positive and ideally negative solution by formulas: $D^*(a_n^S) = \sqrt{\sum_{z=1}^{z}(D_z^*(a_n^S, X^*))^2}$

$D^-(a_n^S) = \sqrt{\sum_{z=1}^{z}(D_z^-(a_n^S, X^-))^2}$ And let find the integral index

by formulas: $D(a_n^S) = D^*(a_n^S) + D^-(a_n^S)$, $\varphi(a_n^S) = \frac{D^-(a_n^S)}{D(a_n^S)}$. The calculation results are presented in Table 3.

According to TOPSIS methodology, the optimal alternative is a_2^2 with index 0.60, the next is a_1^1 with value 0.59 and a_3^3 having value 0.55. Let us recalculate TOPSIS algorithm taking into account the determination of experts subjectivity using the algorithm of subjective sets proposed above.

The assessment of experts on subjectivity using subjective sets is presented in Table. 4. The results of adjusting the experts assessment by subjective sets using formula (3) are presented in Table 5.

Table 3

Coefficients of alternatives approximation to the ideal solution

Alternatives	$D^*(a_n^s)$	$D^-(a_n^s)$	$D(a_n^s)$	$\varphi(a_n^s)$
UnderDefense, a_1^1	0.57	0.83	1.40	0.59
Cyberoo, a_2^2	0.55	0.84	1.40	0.60
Eleks, a_3^3	0.64	0.80	1.45	0.55

Table 4

Assessment of subjectivity of trapezoidal membership functions purpose

No	UnderDefense c_1	Cyberoo c_2	Eleks c_3
	Student a_1^1	Student a_2^2	Student a_3^3
d_1	(0.10;0.30)	(0.27;0.40)	(0.08;0.46)
d_2	(0.10;0.25;)	(0.19;0.38)	(0.55;0.45)
d_3	(0.05;0.40;)	(0.50;0.40)	(0.67;0.50)
d_4	(0.55;0.37)	(0.48;0.55)	(0.32;0.20)
d_5	(0.50;0.24)	(0.50;0.75)	(0.12;005)
d_6	(0.30;0.58)	(0.09;0.05)	(0.18;0.42)
d_7	(0.08;0.14)	(0.20;0.40)	(0.12;0.32)
d_8	(0.45;0.20)	(0.35;0.18)	(0.07;0.20)
d_9	(0.63;0.34)	(0.14;0.30)	(0.45;0.23)
d_{10}	(0.52;0.29)	(0.24;0.50)	(0.48;0.15)
d_{11}	(0.40;0.68)	(0.60;0.45)	(0.67;0.55)

The results of adjusted values from Table 4 using formula (3) are presented in Table 5. After reapplying TOPSIS algorithm and using the subjectivity-adjusted assessmenrs from Table. 5 we obtain the following results of ranking alternatives, the optimal alternative is a_1^1 with index 0.59,

the next is a_3^3 with value 0.58 and a_2^2 with value 0.54. Analyzing these indicators, it should be noted that in Ukraine the dual education system is new, so its implementation in educational institutions should be based on the adaptive basis. Due to this fact, the specialization of training in the company (including the position, performance of duties, training conditions) can not to some extent correspond to the students specialty or vice versa. In order to correct this discrepancy, it is necessary to assess the pairwise comparison of companies by AHP by competent experts from the educational institution. Thus, as a result of the analysis conducted by experts by AHP, the following coefficients of incompatibility of companies or positions held, specialties of students in the educational institution are established. The results of AHP application are as follows: v_1 - 0.19; v_2 - 0.17; v_3 - 0.63. In order to correct the final result of alternatives, we use the developed formula (1). Thus, after correction the alternative values the will be as follows: $\alpha(a_1^1)$ - 0, 64 (III rank); $\alpha(a_2^2)$ - 0, 59 (II rank); $\alpha(a_3^3)$ - 0, 73 (I rank);

Table 5

Corrected trapezoidal assessments based on subjectivity

No	UnderDefense c_1	Cyberoo c_2	Eleks c_3
	Student a_1^1	Student a_2^2	Student a_3^3
d_1	(7.70;8.80;9.80;10,10)	(6.60;7.87;7.87;9.27)	(7.54;8.62;9.62;10.08)
d_2	(6.75;7.85;7.85;9,10)	(6.62;7.81;7.81;9.19)	(7.55;8.10;8.10;8.55)
d_3	(6.60;7.65;7.65;9.05)	(5.50;6.10;7.107;7.6)	(5.67;6.17;7.17;7.50)
d_4	(4.55;5.18;5.18;5.63)	(6.45;7.93;7.93;9.48)	(4.32;5.12;5.12;5.8)
d_5	(4.50;5.26;5.26;5.76)	(7.25;8.75;9.75;10.5)	(4.12;5.07;5.07;5.95)
d_6	(7.42;8.72;9.72;10.3)	(4.09;5.04;5.04;5.95)	(7.58;8.76;9.76;10.18)
d_7	(7.86;8.94;9.94;10.08)	(7.6;8.8;9.8;10.2)	(7.68;8.80;9.80;10.12)
d_8	(5.45;6.25;7.25;7.8)	(4.35;5.17;5.17;5.82)	(7.80;8.87;9.87;10.07)
d_9	(5.63;6.29;7.29;7.66)	(6.70;7.84;7.84;9.14)	(5.45;6.22;7.22;7.77)
d_{10}	(4.52;5.23;5.23;5.71)	(6.50;7.75;7.75; 9.25)	(2.48;3.33;4.33;4.85)
d_{11}	(6.32;7.72;7.72;9.4)	(5.60;6.15;7.15;7.55)	(7.67;8.12;8.12;8.45)

The peculiarity of the presented model is the application of weighting coefficients for subjects and competencies of the curriculum, determination and consideration of experts subjectivity, correction of the final values of the mismatch of the alternatives ranking subsystems belonging, scales application for academic component adaptation to the company needs. That is, education in the educational institution should be based on the student's mastering the methods and skills of solving challenges, achieving goals in the work environment.

Taking into account the significant practical component of dual education system, the education model should be based on the competency-based approach.

The application of the constructed model makes it possible to adapt the educational process to the solution of practical tasks of the company. In turn, on-the-job training instructors will be able to determine the importance of the components of the specialty education program directly by student assessment.

As a result of the assessment by the modified TOPSIS method we receive estimates given in Table 6.

Table 6

The results of TOPSIS method application

Alternatives	Excluding subjectivity	Including experts subjectivity	External correction of subjectivism (inconsistency of subsystems)
UnderDefense, a_1^1	0.59	0.59	0.64
Cyberoo, a_2^2	0.60	0.54	0.59
Eleks, a_3^3	0.55	0.58	0.73

According to ECTS scale we get the following assessments $\alpha(a_3^3)$ - good (0.73), $\alpha(a_1^1)$ - satisfactory (0.64) and $\alpha(a_2^2)$ - sufficient (0.59).

Conclusions. As a result of the investigation, the conceptual model of human resources management in the system of dual education system is developed. This model is based on the academic component, based on the

method of multi-criteria analysis TOPSIS, taking into account subjectivism. The developed model is the conceptual unit of assessment in the information technology of dual education system. The investigation presented in this paper is the implementation of the integration technology component, other components of which will be implemented in further investigations.

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