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MODIFIED VIKOR METHOD AS A COMPONENT OF DECISION SUPPORT OF INFORMATION TECHNOLOGY OF THE DUAL FORM OF EDUCATION

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***Summary**. The model for supporting the student decision in choosing the subjects of specialty educational program based on VIKOR multi-criteria optimization method is developed in this paper. The developed model is the component of the dual education information system (when the student is trained in the company and educational institution at the same time on the basis of the contract). This component is a decision support tool for a student training by a dual education, taking into account the expert opinion of stakeholders in the learning process. The criteria of dual education stakeholders for ranking alternatives (subjects of the specialty program): student, educational institution, company are outlined. VIKOR method is modified by the selection of subsystems criteria in order to derive an integrated assessment of experts from different subsystems. The algorithm for integrating ratings of ranking subsystems is developed, taking into account the strategy of maximum group usefulness of VIKOR method. The weighting coefficients of subsystems and their criteria are determined by T. Saati method of hierarchies analysis. In order to take into account the uncertainty associated with the lack of information, intuitionistic fuzzy sets are used to assign assessments of the alternatives ranking by subsystem experts. The proposed modification of VIKOR method makes it possible to rank the alternatives with the involvement of different specialists with their own criteria system. This approach increases the accuracy of the obtained results, as the criteria are further divided into holders subsystems of the ranking problem. This approach enables to carry out deeper and broader analysis of ranking problem aspects. Numerical example of the developed model which confirms the acceptability of its application in practice in the dual educational process application is illustrated in this paper.*

***Key words**: VIKOR, information technology, MCDM, intuitionistic fuzzy sets, analytic hierarchy process.*

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Statement of the problem. Information technology in the educational institution is a required component of the learning process and its organization. The role of information technology is decisive in distance learning under COVID-19 pandemic conditions. The following components of the information technology complex of higher education can be distinguished Learning Management System (LMS), Knowledge Management System (KMS), Management Information System (MIS). As it is noted in paper [1] Education Management Information System (EMIS), Learning Management System (LMS) are the tools transforming educational institutions in both developed and developing countries. Dual education involves simultaneous training of the student in two locations i.e. educational institution and company. Thus, this form of education consists of two subsystems of learning locations. Taking into account this complexity and the fact that the dual form of education in the countries of introduction (Germany, Switzerland, Austria) uses, in particular, the means of information technology for distance education (MOODLE) or information technology (BLoK, Realto) [2, 3], which provide a certain aspect of the effective functioning of the dual form of education, such an education system requires the development of additional components of information technology to meet the needs of all stakeholders of the educational process (support for their decision-making): a company, an educational institution, a student. The component of the information technology complex of dual education Fig. 1 is developed in this paper.

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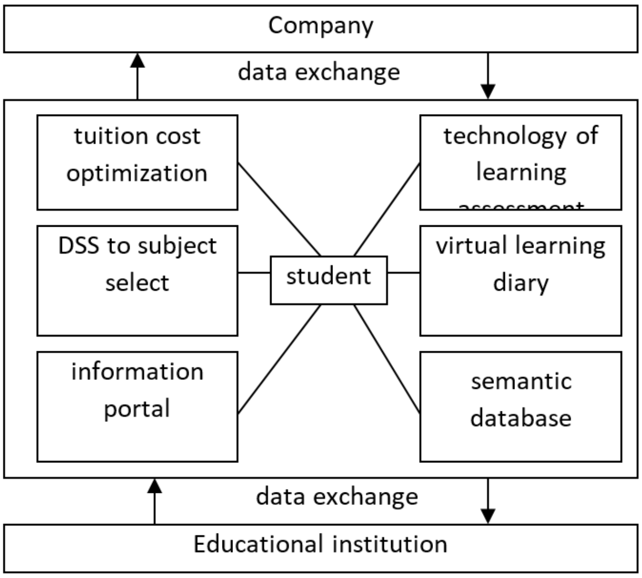

Figure 1. The components of informational technology of dual education

It is evident from Fig. 1 that information technology complex of the dual education includes the following components: tuition cost optimization, technology for assessing student learning in the company, virtual learning diary, information portal, database, decision support system for subject choice. The latter is developed in this paper and is aimed to help the student in choosing the subject taking into account the interests and knowledge of dual education stakeholders.

Decision support in the dual education system is a complex task, because the student in the dual system is at the same time the company employee. Given this fact, decisions made in the dual system should take into account the interests of all stakeholders. Stakeholders in this system, as already mentioned above, include: company, educational institution, student. One of the decisions that has a significant impact on the learning process and the student's work in dual system is the choice of additional subjects of the curriculum. Selected additional subjects should take into account not only the student's desire the but also the interests of the company and the educational institution and their advisory opinion. The decision made in such a way should be well considered and take into account the opinion of stakeholders, their knowledge.

Analysis of available results and investigations. In order to solve this problem, the best methods of multicriteria analysis of decision support are those, the structure of which makes it possible to determine comprehensively the recommended alternative. Methods of multicriteria analysis of decision making use a set of criteria for alternatives ranking. Alternatives priority is set by finding the distance from ideally negative, ideally positive value of the criterion in TOPSIS [4], VIKOR [5], CODAS [6] methods or determining the degree of alternatives dominance by comparing them by TODIM [7, 8], ELECTRE [9], PROMETHEE [10]. These methods consider criteria that are the same for all alternatives, i.e. when the ranked alternatives belong to the same criteria system. However, in practice, the alternatives assessment can be performed by experts, project teams, departments specializing in particular aspect of the integrated assessment problem (with its own system of criteria) or a limited set of assessment criteria due to narrow specialization. That is, alternatives can be ranked in different systems of specialization assessment. Taking into account this feature, there is a need to develop a method of multi-criteria analysis of decision-making that would aggregate various criteria assessed by experts of different subsystems and specializations. In order to solve this problem, let us consider VIKOR multicriteria optimization method, successful application of which can be found in more than 13 areas, such as: information technology, financial management; health, safety and medicine; construction and transport engineering; logistics and many others [11]. Various modifications of VIKOR method have been developed in scientific discourse. In the investigation [12], the authors consider VIKOR method using probabilistic linguistic terms of sets and their new modifications. In paper [13] VIKOR method is considered using probabilistic set of terms of the double hierarchy for the experts assessment appointment. In paper [14], VIKOR method is used with methods for determining subjective and objective weights. In the investigation [15], the authors use trapezoidal fuzzy numbers to rank alternatives by VIKOR method. In paper [16] the authors propose a new method for solving group multicriteria problems based on the idea of VIKOR method. In the paper trapezoidal fuzzy expert assessments are aggregated and dephasified into integers, in addition, individual expert assessment matrices are transformed into 2-tuple linguistic decision matrix. A compromise solution is found by comparing the values of 2-tuple linguistic values. In the analyzed papers VIKOR method is focused on the uncertainty overcoming and, accordingly, increasing the accuracy of the assessments assigned by experts for alternatives ranking by means of various modifications of the assessment assignment by experts. A well-known solution of increasing the objectivity of the results obtained in multi-criteria decision-making methods is to obtain the aggregate assessment determined by several experts. To reduce the degree of subjectivity, experts should meet the requirements of the subject area, the areas of alternative assessment before the group assessments aggregation stage. Taking into account this requirement, it should be noted that the expert not always have in-depth knowledge in several areas. Given this limitation, in this paper we present an algorithm for ensuring and fulfilling such requirement, ranking alternatives in individual subsystems of experts with subsequent derivation of the integrated assessment. We modify VIKOR method in order to implement such task using intuitionistic fuzzy sets.

The objective of the paper is to develop the model for supporting the decision-making in choosing the subjects of specialty educational program for dual education information technology.

Statement of the problem. Intuitionistic fuzzy sets were developed by Atanassov [17] for better notation, formalization of fuzzy information, uncertainty when it is difficult to determine the membership of the element in the set accurately. Intuitionistic fuzzy sets characterize the membership of an element as a function of belonging and non-belonging. The intuitionistic fuzzy set defines A in E as an object in the following form:

$$A = \{\langle x, \mu_A(x), v_A(x)\rangle | x \in E\}, \quad (1)$$

where $\mu_A : E \to [0,1], v_A : E \to [0,1]$

The sum of belonging and non-belonging functions is as follows:

$$0 \le \mu_A(x) + v_A(x) \le 1 \quad (2)$$

Ordinary fuzzy sets are written in the following way:

$$\{\langle x, \mu_A(x), 1-\mu_A(x))\rangle | x \in E\}, \quad (3)$$

The uncertainty coefficient of in intuitionistic sets is:

$$\pi_A = 1 - \mu_A(x) - v_A(x) \quad (4)$$

The algorithm of VIKOR method [5] is as follows:

1. Determination of the best and the worst values of all criteria functions i=1,2...,n. If the i-th function reflects positive criterion then:

$$f_i^* = \max_j f_{ij}, \quad f_i^- = \min_j f_{ij}.$$

2. Values determination:

$$S_j = \sum_{i=1}^{n} w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-), \tag{5}$$

$$R_j = \max_i [w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-)], \tag{6}$$

where w_i is the weight of relative criterion importance.

3. Calculation of values $Q_j,\ j = 1,2,...J$ by the ratio:

$$Q_j = \upsilon (S_j - S^*) / (S^- - S^*) + (1-\upsilon)(R_j - R^*)(R^- - R^*), \tag{7}$$

where

$$S^* = \min_j S_j, \quad S^- = \max_j S_j,$$
$$R^* = \min_j R_j, \quad R^- = \max_j R_j,$$

In this ratio υ is a weighting criterion of the «most criteria» strategy, i.e. «maximum group usefulness».

4. Alternatives ranking by sorting values *S*, *R* and *Q*y in descending order.

5. Selection of compromise solution of alternative (a') which is ranked as the best o Q (minimum) if the following conditions are met:

A) $Q(a'') - Q(a') \geq DQ$,

where a'' is the alternative of the second position in the ranked vector Q; $DQ = 1/(J-1)$; where *J* is the number of alternatives.

B) Alternative a' should also have better values *S*i/or *R.*

If one of the conditions is not met then a set of compromise solutions is proposed:

- Alternatives a' and a'' if only condition B is not met;
- Alternatives $a', a'', ...a^{(M)}$ if condition A is not met. $a^{(M)}$ is determined by ratio $Q(a^{(M)}) - Q(a') \leq DQ$ for maximum M (positions of these alternatives are close)

Let's develop and apply modified VIKOR method on the example of multicriteria model for decision support of additional subjects choice by educational institution student training by dual education. This model is a component of dual education information technology. Decisions made in dual education system require coherence, as their consequences affect all stakeholders: the student, the institution, the company. While studying in two locations at the same time at the educational institution and company, the student when choosing the educational program subjects should take into account not only his/her opinion, but the advice of educational institution representatives, mentor of the group and instructor from the company where the student studies. Besides, the student has limited information about the characteristics of the courses he chooses and can be guided by a certain informal single-criteria choice, particularly intuitive. Let us formulate the criteria for choosing the subject for the student and the criteria for the institution mentor and the company instructor advise (for the fourth-year cybersecurity student of Ternopil Ivan Puluj National Technical University who studies by dual education at Cyberoo company):

Student.

- Interest in the subject;
- Course content;
- The level of basic knowledge for course studies;

Instructor (company).

- Qualification of course staff;
- Course content;
- Technical support of the course;
- Course usefulness for the company;

Mentor (educational institution).

- Qualification of course staff ;
- Course content;
- Course structure;
- Relationship between the course and specialization.

Let us modify VIKOR method by structuring the assessment of alternatives set (selective disciplines) into three subsystems of assessment for student, mentor and instructor with their own assessment criteria (some of them can be duplicated in the subsystems). Each of experts the student, the mentor and the instructor rank the alternatives according to the specified criteria of their subsystem. Coefficient v_i from formula (7) characterizing the strategy of maximum group usefulness is selected in each ranking subsystem depending on the subsystems weights coefficients. The algorithm for coefficient selection v is as follows: 1. Divide the scale from 0.00 to 1.00 into such number of intervals which reflects the number of ranking subsystems (in this case 3). 2. Within these intervals, choose the coefficients values in each subsystem, each interval belongs to separate subsystem in ascending order with decreasing values of the subsystems weighting coefficients. Thus, with subsystem weighting factor 0.53, we choose the values within the interval from 0.00 to 0.33; with the value of subsystem weighting factor 0.36, the value v is within the range from 0.33 to 0.66. Such an algorithm will ensure, with the highest weighting factor, to focus attention on an alternative in which there will be no critically small values in the set of criteria, given its importance. Let us rank the alternatives in each subsystem using the intuitionistic fuzzy sets and the scale presented in [18] table 1:

Table 1

Scale for alternatives assessment

Linguistic terms	IFNs
Extremely Good (EG)	[1.00; 0.00; 0.00]
Very Good (VG)	[0.85; 0,05; 0.10]
Good (G)	[0.70; 0.20; 0.10]
Medium Bad (MB)	[0.50; 0.50; 0.00]
Bad (B)	[0.40; 0.50; 0.10]
Very Bad (VB)	[0.25; 0.60; 0.15]
Extremely Bad (EB)	[0.00; 0.90; 0.10]

The distances between the alternatives assessments by intuitionistic fuzzy sets are calculated by formulas [19] by modifying components (5), (6):

$$(f_i^* - f_{ij}) = \left[\sqrt{(\mu_A^* - \mu_A)^2 + (v_A - v_A^*)^2}\right],$$
$$(f_i^* - f_{ij}^-) = \left[\sqrt{(\mu_A^* - \mu_A^-)^2 + (v_A^- - v_A^*)^2}\right] \quad (8)$$

The weighting criteria of alternatives and subsystems are determined by means of T. Saati AHP method of [20]. Let us add the additional step to VIKOR algorithm after determining the final values Q_j and the subsystems weighting coefficients w_s. Then let's calculate the average weighted values R_l for each subsystem (company, student and educational institution) by the formula:

$$R_l = \frac{\sum Q_j (1 - w_s)}{m} \quad (9)$$

where m is the number of alternatives.

Analysis of numericall data and results of the investigations. In Table. 2 we present the alternatives assessment by intuitionistic sets in three subsystems the company, the student and the educational institution.

Table 2

Intuitionistic fuzzy assessments of ranking alternatives

Criteria/subjects	Data base and knowledge organization	Architecture of computer systems	Fundamentals and tools of analytical data processing	System programming and operational systems
Student				
Interest in the subject	[0.40; 0.50; 0.10]	[0.70; 0.20; 0.10]	[0.50; 0.50; 0.00]	[0.70; 0.20; 0.10]
Course content	[0.50; 0.50; 0.00]	[0.85; 0,05; 0.10]	[0.70; 0.20; 0.10]	[0.50; 0.50; 0.00]
The level of basic knowledge for course studies	[0.40; 0.50; 0.10]	[0.50; 0.50; 0.00]	[0.25; 0.60; 0.15]	[0.50; 0.50; 0.00]
Company				
Qualification of course staff	[0.50; 0.50; 0.00]	[0.70; 0.20; 0.10]	[0.85; 0,05; 0.10]	[0.50; 0.50; 0.00]
Course content	[0.70; 0.20; 0.10]	[0.85; 0,05; 0.10]	[0.50; 0.50; 0.00]	[0.70; 0.20; 0.10]
Technical support of the course	[0.70; 0.20; 0.10]	[0.50; 0.50; 0.00]	[0.50; 0.50; 0.00]	[0.70; 0.20; 0.10]
Course usefulness for the company	[0.25; 0.60; 0.15]	[0.50; 0.50; 0.00]	[0.70; 0.20; 0.10]	[0.85; 0,05; 0.10]
Educational institution				
Qualification of course staff	[0.70; 0.20; 0.10]	[0.50; 0.50; 0.00]	[0.70; 0.20; 0.10]	[0.85; 0,05; 0.10]
Course content	[0.70; 0.20; 0.10]	[0.70; 0.20; 0.10]	[0.70; 0.20; 0.10]	[0.85; 0,05; 0.10]
Course structure	[0.50; 0.50; 0.00]	[0.70; 0.20; 0.10]	[0.50; 0.50; 0.00]	[0.50; 0.50; 0.00]
Relationship between the course and specialization	[0.50; 0.50; 0.00]	[0.50; 0.50; 0.00]	[0.70; 0.20; 0.10]	[0.70; 0.20; 0.10]

The criteria weighting coefficients in each subsystem are given in Table 3.

Table 3

Weighting coefficients of subsystem criteria

Student	
Interest in the subject	0,43
Course content	0,32
The level of basic knowledge for course studies	0,23
Company	
Qualification of course staff	0,22
Course content	0,28
Technical support of the course	0,18
Course usefulness for the company	0,30
Educational institution	
Qualification of course staff	0,22
Course content	0,27
Course structure	0,17
Relationship between the course and specialization	0,32

The values of coefficients S_j, R_jта Q_j are calculated by formulas (5) and (6) in different subsystems are presented in Table. 4. Coefficient v in each subsystem is selected according to the weights of the subsystems $w_1>w_2>w_3$. Accordingly, the first priority is 0–0.33; the second 0.33–0.66; the third 0.66–100 (according to the modification we divide the scale from 0 to 1.00 into the number of the ranking criteria subsystems). Thus, coefficient v of the company subsystem is 0.30; of the student is 0.43; the educational institution 0.67. At their weights: company (57)> student (0.30)> educational institution (0.11).

Table 4

Data of alternatives coefficients

Coefficients/ alternatives	Data base and knowledge organization	Architecture of computer systems	Fundamentals and tools of analytical data processing	System programming and operational systems
Student				
S	0,67	0,40	0,49	0,56
R	0,43	0,24	0,26	0,32
Q	1	0	0,19	0,50
Company				
S	0,44	0,57	0,58	0,40
R	0,30	0,30	0,28	0,22
Q	0,76	0,98	0,80	0
Educational institution				
S	0,49	0,54	0,17	0,46
R	0,32	0,32	0,17	0,17
Q	0,91	1	0	0,52

Let us calculate the integrated values Q using weighting coefficients w_s by formula (9). As a result, at weighting coefficients of the company's subsystems – 0.57; of the educational institution 0.11; of the student 0.30 we get the following values Q: databases and knowledge organization is 0.60; architecture of computer systems is 0.43; fundamentals and tools of analytical data processing is 0, 15; system programming and operational systems is 0.27. According to the values of the presented coefficients, the most acceptable is the alternative «Fundamentals and tools of analytical data processing».

Conclusions. The conceptual model of the student decision support in the system of dual education for specialty additional subjects choice is developed. This model is a component of dual education information technology. Multicriteria optimization VIKOR method is modified by the selection of individual subsystems and their criteria. In each subsystem, experts have a different set of criteria by which they assess common alternatives for different subsystems, followed by the derivation of the integrated assessment. This approach makes it possible to assess alternatives professionally and accurately by specialists in a particular field and then derive the integrated assessment taking into account assessment results for each subsystem with its own criteria. With such method modification, experts are able to give more accurate results because the assessment criteria belong to their professional field or interests. In order to implement this modification, the strategy for selecting the coefficient v in VIKOR method for each subsystem of ranking alternatives is developed. Method for deriving the alternatives integrated assessment of the presented VIKOR method modification is developed. The numerical example of the developed model application confirming the acceptability of its application is shown.

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МОДИФІКОВАНИЙ МЕТОД VIKOR ЯК КОМПОНЕНТ ПІДТРИМКИ ПРИЙНЯТТЯ РІШЕННЯ ІНФОРМАЦІЙНОЇ ТЕХНОЛОГІЇ ДУАЛЬНОЇ ФОРМИ ОСВІТИ

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Резюме. *Розроблено концептуальну модель підтримки прийняття рішення обрання студентом вищого навчального закладу предметів за вибором освітньої програми спеціальності на основі методу багатокритеріального аналізу VIKOR. Розроблена модель є компонентом інформаційної технології дуальної форми освіти (коли студент навчається паралельно в компанії та навчальному закладі на основі договору). Даний компонент є інструментом підтримки прийняття рішення для студента, що навчається за дуальною формою освіти із урахуванням експертної думки стейкхолдерів навчального процесу. Окреслено критерії стейкхолдерів дуальної форми освіти для ранжування альтернатив (дисциплін програми спеціальності): студента, навчального закладу, компанії. Метод VIKOR, який використаний в основі моделі, був модифікований із виділенням критеріїв підсистем для виведення інтегральної оцінки експертів різних підсистем. Розроблено алгоритм інтеграції оцінок підсистем ранжування із урахуванням стратегії максимальної групової корисності методу VIKOR. Вагові коефіцієнти підсистем та їх критеріїв визначенні методом аналізу ієрархій Т. Сааті. Для врахування невизначеності, пов'язаної із недостатністю інформації, інтуїціоністські нечіткі множини були застосовані для призначення оцінок ранжування альтернатив експертами підсистем. Запропонована модифікація методу VIKOR дозволить ранжувати альтернативи із залученням різних фахівців із власною системою критеріїв. При даному підході збільшиться точність отриманих результатів, оскільки критерії будуть додатково поділені на підсистеми стейкхолдерів задачі ранжування. Такий підхід уможливить проводити глибший та ширший аналіз аспектів проблеми ранжування. Продемонстровано числовий приклад застосування розробленої моделі, який підтверджує прийнятність її застосування на практиці в навчальному процесі дуальної форми навчання.*

Ключові слова: *VIKOR, інформаційні технології, багатокритеріальний аналіз, інтуїціоністські нечіткі множини, метод аналізу ієрархій.*

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