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МОДЕЛЮВАННЯ ТА ВИБІР СИСТЕМИ ДИСТАНЦІЙНОГО НАВЧАННЯ ВИЩОГО НАВЧАЛЬНОГО ЗАКЛАДУ НА ОСНОВІ МЕТОДУ ІЄРАРХІЧНОГО АНАЛІЗУ З ВИКОРИСТАННЯМ СППР

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MODELING AND SELECTION OF A DISTANCE LEARNING SYSTEM FOR A HIGHER EDUCATION INSTITUTION BASED ON THE METHOD OF HIERARCHY ANALYSIS USING THE DSS

Abstract. *Today, one of the key global trends in the educational process is the expansion of the use of distance learning systems (DLS). The most popular DLS are gaining popularity among higher education students. Successful DLS is based on the correct choice of software that meets the specific requirements, goals and objectives of the higher education institution. The goal of the study is to substantiate the choice of a DSS that meets the needs of higher education institutions based on models and methods of hierarchy analysis and using a decision support system (DSS). The object of research is the processes of modeling and selecting a DSS among those available on the market. The subject of research is the models and methods of hierarchy analysis for selecting a distance learning system using a decision support system. The study of DLS was conducted on the basis of the factors that determine the peculiarities of their use in the educational process of higher education institutions (HEIs). To determine the criteria for selecting a DLS, the methods of grouping the most significant factors were used. The following main criteria were identified: technical aspects, adaptation, administration, course management, user data management, communication tools, learning objects, usability. The most popular Open Source systems on the market were selected for the analysis of LMS: Moodle, ATutor, Sakai, OpenUSS. The hierarchy analysis method was used to conduct an experiment to rank the LMS depending on their priority. The construction and experimental testing of the hierarchy analysis model was carried out using the DSS "Choice". In the course of the experiment, a hierarchy model was created for ranking the DLS, the values of their importance were determined for the previously selected criteria, a pairwise comparison of the hierarchy elements by their importance was carried out, and pairwise comparisons of alternatives were made for all criteria. The originality of the study is to determine the main criteria for selecting DLS and to create a model based on the method of hierarchy analysis for ranking DLS by priority. The practical value lies in the development of a methodology to justify the choice of DLS, as well as in determining the most suitable DLS among popular Open Source systems.*

Keywords: *distance learning system, Open Source system, selection criteria, hierarchy analysis method, decision support system.*

Анотація. *Сьогодні одними із ключових світових трендів освітнього процесу є розширення застосування систем дистанційного навчання (СДН). Найбільшою популярності СДН набувають серед здобувачів вищої освіти. Успішне СДН ґрунтується на правильному виборі програмного забезпечення, відповідного конкретним вимогам, цілям і завданням, які висуваються до нього вищим навчальним закладом. Метою роботи є обґрунтування вибору СДН, яка задовольняє потребам вищих навчальних закладів, на основі моделей та методів аналізу ієрархій та з застосуванням системи прийняття рішень (СППР). Об'єктом дослідження є процеси моделювання та вибору СДН серед наявних на ринку. Предметом дослідження є моделі і методи аналізу ієрархій для вибору системи дистанційного навчання с застуванням СППР. Дослідження СДН проводилося на основі на основі факторів, які визначають особливості їх використання в навчальному процесі вищих навчальних закладів. Для визначення критеріїв вибору СДН застосовувалися методи групування найбільш суттєвих факторів. Були визначені такі основні критерії: технічні аспекти, адаптація, адміністрування, управління курсами, управління даними користувачів, інструменти комунікації, навчальні об'єкти, зручність використання. Для аналізу СДН були обрані найбільш популярні на ринку Open Source системи: Moodle, ATutor, Sakai, OpenUSS. Для здійснення експерименту щодо ранжування СДН в залежності від їх пріоритету застосувався метод аналізу ієрархій. Побудова і експериментальна апробація моделі аналізу ієрархій здійснювалася за допомогою СППР «Вибір». В процесі експерименту було створено модель ієрархій для ранжування СДН, для обраних попередньо критеріїв були визначені значення їх важливості, здійснено парне порівняння елементів ієрархій за їх важливістю, здійснено парні порівняння альтернатив за всіма критеріями. Оригінальність дослідження полягає в визначенні основних критеріїв для вибору СДН та створенні моделі на основі*

методу аналізу ієрархій для ранжування за пріоритетом СДН. Практична цінність полягає в розробленні методики для обґрунтування вибору СДН, а також в визначені найбільш прийнятної СДН серед популярних Open Source систем.

Ключові слова: *система дистанційного навчання, Open Source система, критерії вибору, метод аналізу ієрархій, система підтримки прийняття рішень.*

Formulation of the problem. The events of recent years related to the pandemic and subsequent military actions in Ukraine have shifted the focus of the educational process to the use of distance learning platforms. One of the key global trends in the educational process is the expansion of the use of e-learning and distance learning technologies in all forms of education in all areas of study, the creation of e-learning courses and other types of electronic content for educational purposes, and standardization in the development of electronic content. Distance learning systems are gaining the most popularity among students of higher education and for professional development, which is related to the peculiarities of the organization of processes in these areas.

Flexibility and convenience are two of the most important deciding factors for students when choosing between online learning and traditional classroom learning. In the Online College Students 2022 survey conducted by Learning House, 87% of online bachelor's and master's students agreed or strongly agreed that online learning is worth the cost [8]. This is a 16% percentage point increase over the opinions of students five years ago, demonstrating the growing acceptance and interest in online programs in higher education. Modern students see the value of online learning as it allows students with special needs and working students of all ages to earn a degree while balancing their work, family, and study priorities. Forward-thinking colleges and universities are developing flexible online programs for their disciplines that are in demand.

Based on the relevant trends in distance learning, it can be assumed that as

the relevance of distance learning will continue after the pandemic and the war effort, and the interest and number of applicants with certain needs is constantly growing, higher education institutions will also expand their online program offerings as a strategic response to growing demand [1]. The current state of computing facilities and the widespread use of the Internet provide an opportunity to realize numerous advantages of e-learning technologies, such as: remoteness, mass participation, high level of interactivity, access to electronic libraries, formation of a single educational environment, etc.

Distance learning systems (DLS) are the basis of the modern educational process and are used to organize and conduct both classroom and distance learning, develop, manage and distribute learning materials with shared access. It is difficult to overestimate the importance of these platforms in the context of limited access of students to educational institutions and the organization of distance learning. Today, there are a large number of both paid and free learning management platforms.

The successful implementation of e-learning is based on the right choice of software that meets the specific requirements, goals and objectives set by the higher education institution. This choice is related to the need to take into account a certain number of criteria and the development of the software segment and the emergence of new e-learning systems. The need to take into account a large number of interrelated factors and a changing environment require the use of a systematic approach, mathematical methods and information technologies in decision-making to justify the choice of a distance learning system. In this regard, decision support systems (DSS) are widely used in the tasks of choosing alternatives in decision-making.

Choosing a distance learning platform is a very important issue for every institution that decides to implement distance learning. To implement informed decision-making, it is necessary to accurately define the area of knowledge in which information is often poorly structured and requires formalization and the formation of an ontological model of the subject area.

Analysis of recent research and publications. A lot of research is devoted to the problems related to the use and selection of a distance learning system that meets the basic requirements of educational institutions. Among the scientific publications are the following issues: the attitude of students and teachers to distance learning platforms [4, 13, 14], justification of the criteria for choosing a distance learning system and the choice of modeling methods and tools to justify the choice of a particular system [3, 15].

In the study [3] the research was aimed at ranking distance learning platforms based on the criteria of human-computer interaction to justify the decision to choose the best platform. The authors grouped the selection criteria into ease of use, mental load, interface design, presentation methods, and interactivity. Fuzzy logic was used as a method for ranking platforms. The results show that the most important criterion was the mental load when using the platform.

The authors of the study [4] analyzed the attitude of higher education students to receiving education through distance learning systems. A special questionnaire was created to obtain the data. The survey results showed a positive attitude towards the role of distance learning in education. The research provides recommendations for improving the use of learning platforms in distance higher education: the strengths, such as student exchange and self-study, and the weaknesses, such as delayed feedback and content storage.

Another study [12] was aimed at analyzing the perception of higher education teachers of the use of distance learning systems during the transition from the traditional educational model to distance learning. The study conducted a statistical analysis of teachers' attitudes toward changing educational scenarios from traditional to distance learning, as well as the main problems of the transition period. The data collection was developed through the Google Forms application and distributed among teachers of public and private higher education institutions. The survey results showed that more than 60% of respondents had experience using Moodle, Google Classroom, and Blackboard; 80% of teachers had been trained at their institution in the use of virtual platforms; and in 60% of cases,

higher education institutions allowed them to choose a distance learning system.

In the study [6] the research is directed at determining the assessment of e-learning models and trends. It is about the criteria that can be used in further research on e-learning and gives an idea of its current state. The authors used the System Literature Review (SLR) approach. Three main databases were used in the study: Science Direct, ACM, SCOPUS. The results of the research showed that there are 7 criteria for which the research was conducted, namely platform, evaluation model, assessment, model, approach, problem, trend and challenge. These criteria can be used for further research on e-learning. Thus, this study provides knowledge about the criteria that can be used in further research on e-learning and gives an insight into its current state.

In order to improve [7] the use of e-learning systems, it is proposed to identify the factors that have the greatest impact on their quality. The study focused on identifying and prioritizing factors related to the quality of e-learning system design through a hierarchical quality model. A literature review was conducted to identify the factors that most influence the quality of e-learning systems and the factors that have the most significant effect were identified. The authors ranked the criteria according to their relative importance based on a pairwise comparison. The remaining factors were then classified into four main categories. Content was identified as the most important factor, and design was identified as the least important factor.

In summary, the analysis of recent publications shows considerable interest in issues related to distance learning and distance learning systems. However, this problem requires further research, first of all, to justify the choice of a distance learning system based on a set of different criteria.

Purpose and task statement. So, the issue of choosing a distance learning system is relevant and determines the object, subject and purpose of the study.

The object of the study is the processes of modeling and selecting a distance learning system among those available on the market.

The subject of the study is models and methods of hierarchy analysis for

selecting a distance learning system using the DSS.

The purpose is to substantiate the choice of a distance learning system that meets the needs of higher education institutions based on models and methods of hierarchy analysis and using the DSS.

The methods proposed in this publication are brought to practical implementation using an appropriate decision support system. They make it possible to model the decision-making process in hierarchical problems of criterion selection, as well as to select the best e-learning system based on the system of expert assessments using the hierarchy analysis method and use it to implement e-learning in higher education institutions. Successful implementation of e-learning is based on the right choice of software that meets the specific requirements, goals and objectives of the organization.

Presentation of the main research material. To choose a decision-making method for selecting a distance learning system, the advantages and disadvantages of the most popular methods were considered [9, 10, 11]. Table 1 shows the comparative characteristics of the methods by the following features: visualization of results, expert evaluation, use of qualitative and quantitative factors, prioritization of criteria, assessment of the stability of the decision, whether some risk is allowed.

Based only on the pros and cons of each method, it is difficult to choose which method is best for solving a given problem. Therefore, to choose a specific method, an additional analysis of methods is required with the identification of the main comparative features that are needed to model the decision-making process.

Based on the analysis, the decision tree and hierarchy analysis methods turned out to be the most flexible according to the criteria considered. However, the hierarchy analysis method allows processing both quantitative and qualitative information, which is why this method was used to select a distance learning system.

Table 1

Comparative characteristics of the main decision-making methods

Method	Visualization of results	Expert evaluation	Qualitative and quantitative factors	Prioritization of criteria	Sustainability of the decision	Allowance for risk
Linear programming	-	-	-	-	-	-
Non-linear programming	-	-	-	-	-	-
Decision tree	+	+	-	+	+	+
Hierarchy analysis method	+	+	+	+	+	+
Mini maxi solution	-	+	-	-	-	-

Among the distance learning systems, the most popular Open Source systems were considered [2]. This is a decisive factor in choosing a distance learning system for the vast majority of higher education institutions, as it allows them to customize the platform to the needs of a particular educational institution. Four alternatives were selected among the distance learning systems: Moodle, ATutor, Sakai, OpenUSS.

To select a distance learning system, it was necessary to formulate selection criteria [3, 6, 7]. To reduce the dimensionality of the future model, it was necessary to group many factors characterizing different aspects of these systems. As a result, the following criteria (groups) were chosen to evaluate and select a distance learning system:

– Technical aspects (system requirements, security, scalability).

– Adaptation (adaptability, personalization, extensibility).

– Administration (user management, authorization management).

– Course management (course management, test scoring, organization of course objects).

– User data management (tracking, statistics, online user identification, personal user profiles).

– Communication tools (forums, chats, internal messages and mail, conferencing, synchronous and asynchronous tools).

– Learning objects (tests, training materials, training exercises, imported learning objects).

– Ease of use (user support, documentation, user-friendly design).

The implementation of the choice of educational programs by the method of hierarchy analysis was carried out using the DSS "Choice" [5]. This DSS allows structuring a task, setting a set of alternatives for its solution, identifying factors that characterize the alternatives, establishing the weight of these factors, evaluating alternatives by all the given factors, identifying contradictions in the expert's judgment, ranking alternatives and analyzing the resulting decisions. This system is based on the mathematically based method of hierarchy analysis by Thomas Saaty. The system is used to solve poorly structured and unstructured problems. The methodology for solving such problems is based on a systematic approach, in which the problem is viewed as the result of the interaction of the interdependence of many different objects, and not just as their isolated and autonomous set.

The model development for selecting a distance learning system using the hierarchy analysis method includes the following steps:

1. Creating a hierarchy model;

2. Pairwise comparison of hierarchy elements by their importance;

3. Pairwise comparison of alternatives by all criteria.

The first stage of solving the problem is its presentation in the form of a hierarchy model that contains the goal - the choice of DLS, criteria for evaluating alternatives and the alternatives to solve the problem, from which the choice is made. The resulting hierarchy model is shown in fig. 1.

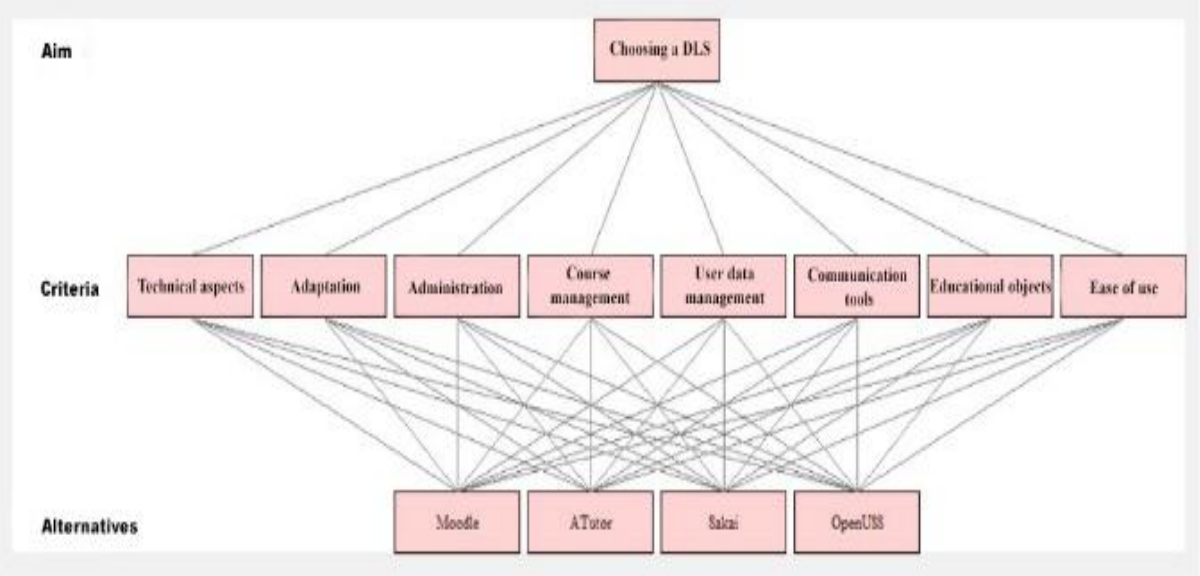

Figure 1. Hierarchy model for evaluating the choice of DLS

The next step is to compare the elements of the hierarchy in pairs. The comparison is based on the decision maker's reasoning about the superiority of some elements over others. In this case, when making pairwise comparisons, the following questions are mainly asked when comparing two elements: which one is more important or has more influence, which one is better, which one is most likely.

A decision maker's (DM) judgment is based on his or her preference system, which consists of many different factors, such as understanding of the problem, constraints, legal, economic, social, and psychological factors. A ranking scale for criteria and alternatives with an intensity from 1 to 9 is used to formally present the results of the comparison (Table 2) [13].

Table 2

Ranking scale for criteria and alternatives

Importance	Definition	Explanation
1	Equal importance	Both factors have the same impact on the goal
3	A bit more important	Assessment and personal experience show a slight preference for one over the other
5	More important	Evaluations and personal experience show a strong preference for one over the other
7	Much more important	Evaluation and personal experience show a significant advantage of one over the other. Its importance is demonstrated in practice
9	Absolutely more important	One is clearly superior to the other
2,4,6,8	Average values of importance	A compromise is needed

Based on the results of the criteria comparison, a matrix is created. The matrix of comparison of criteria is filled with quantitative values of the intensity of the manifestation of one element of the hierarchy relative to another element, which were evaluated on a scale. For the previously selected criteria, the values of their importance were determined (table 3).

Table 3

Importance of the criteria for the DLS

№	Criterion	Importance
1	Technical aspects	1
2	Adaptation	7
3	Administration	5
4	Course management	3
5	User data management	5
6	Communication tools	4
7	Learning objects	9
8	Ease of use	9

Then, these values are entered into the DSS "Choice", which forms a matrix of pairwise comparisons (fig. 2).

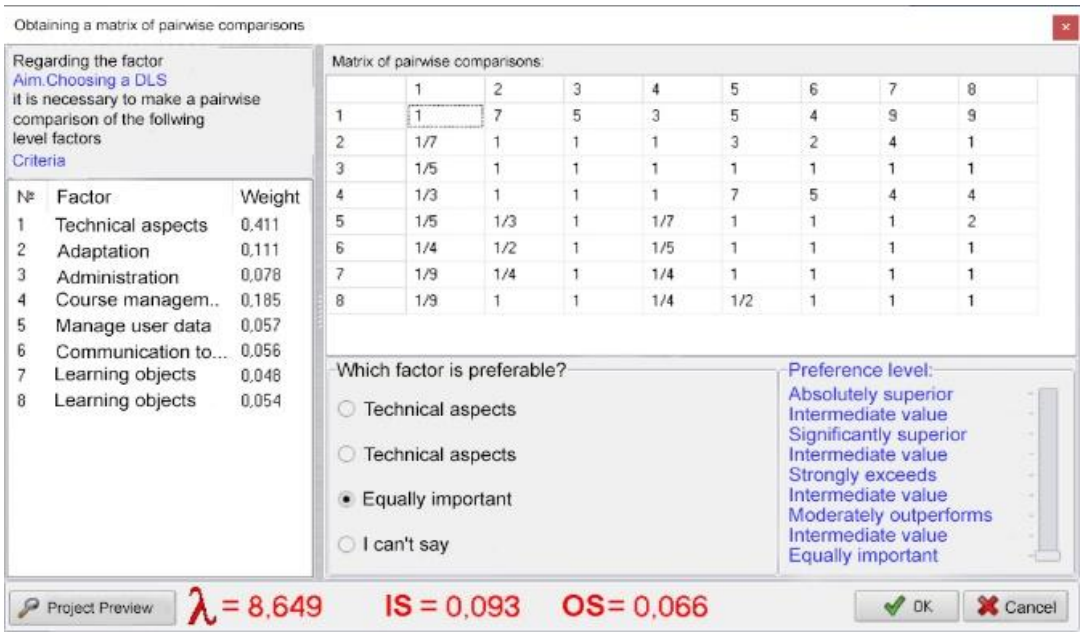

Figure 2. Matrix for comparing criteria

At this stage, the consistency of experts' judgments is also monitored. Inconsistency of judgments may arise as a result of expert errors, incorrectly asked

questions, or insufficient information, and when inconsistency occurs, it is not possible to determine the exact issues that caused it.

Consistency Index (CI) is a quantitative assessment of the contradictory nature of the results of comparisons. The consistency index is a positive value. The fewer contradictions in the comparison, the lower the value of the consistency index. When using the benchmarking method, the consistency index will be zero. The CI is determined by the following formula:

$$CI= (\lambda\_max-n)/((n-1)), \quad (1)$$

where λ_max - is the maximum eigenvalue,

n - is the dimension of the matrix

The calculation of the maximum eigenvalue λ_max is carried out using the pairwise comparison matrix as follows: each column of judgments is summed, then the sum of the first column is multiplied by the value of the first component of the normalized priority vector, the sum of the second column is multiplied by the second component, and so on, then the resulting numbers are summed.

The consistency ratio is calculated as the ratio of the calculated CI consistency index to the tabulated value of the TT. For an 8x8 matrix, this value is 1.40.

$$CR= CI/TT * 100\%. \quad (2)$$

In our case, the CR is 6.6%. If the CR is more than 10%, it is necessary to revise the judgment [13].

At the next stage, matrices of pairwise comparisons of alternatives were compiled for all criteria. Comparison of DLS by the criteria "Technical aspects", "Adaptation", "Administration", "Course management", "User data management", "Communication tools", "Learning objects", "Ease of use" are shown in fig. 3-10.

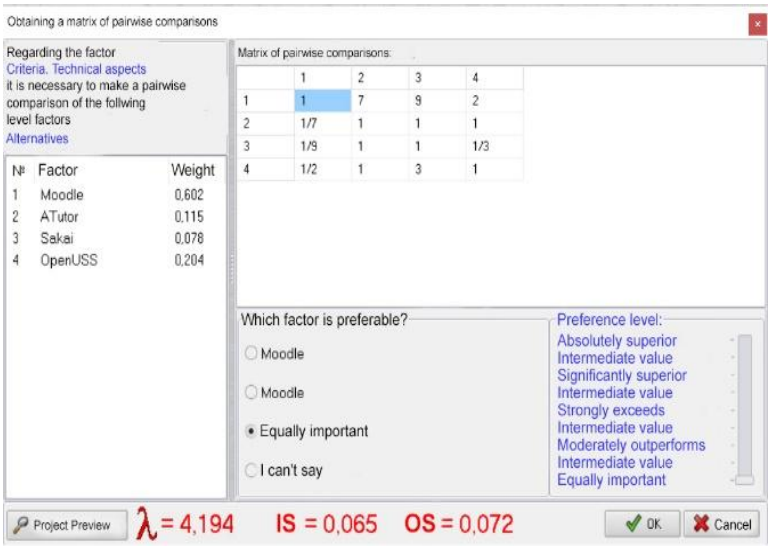

Fig. 3. Matrix for comparing solutions by the "Technical aspects" criterion

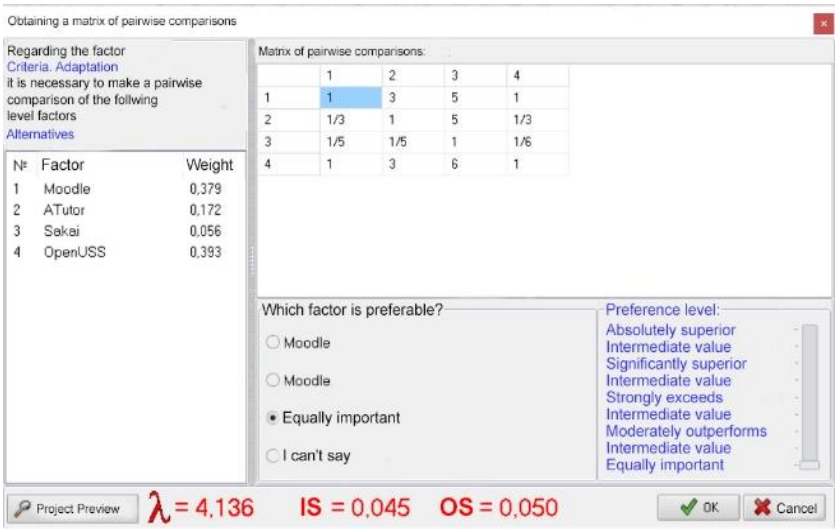

Fig. 4. Matrix for comparing solutions by the "Adaptation" criterion

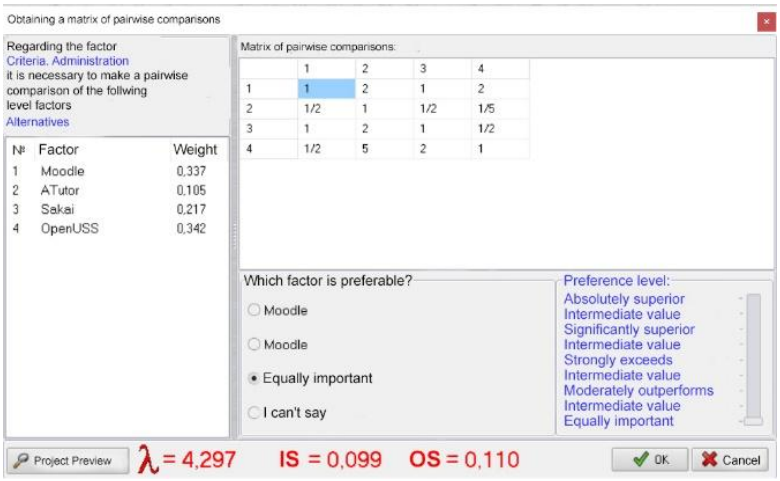

Fig. 5. Matrix for comparing solutions by the "Administration" criterion

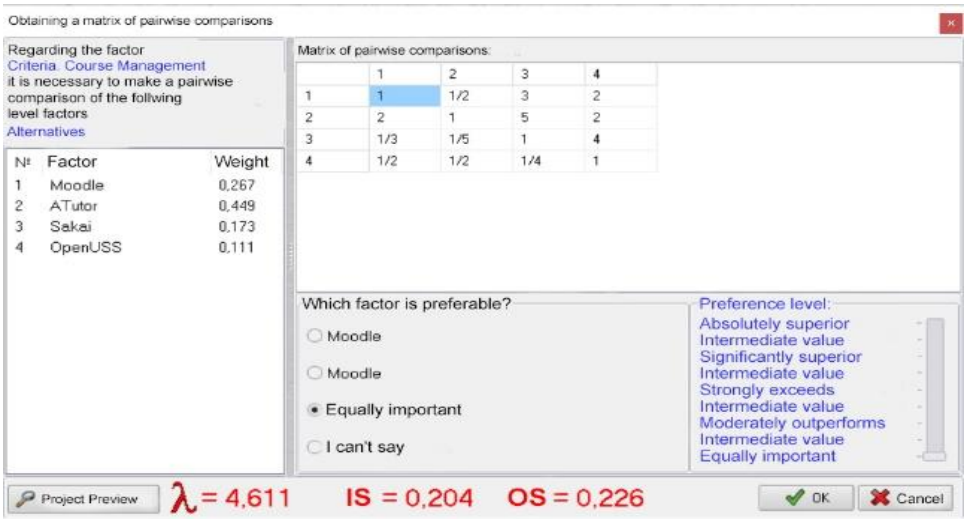

Fig. 6. Matrix for comparing solutions by the criterion "Course management"

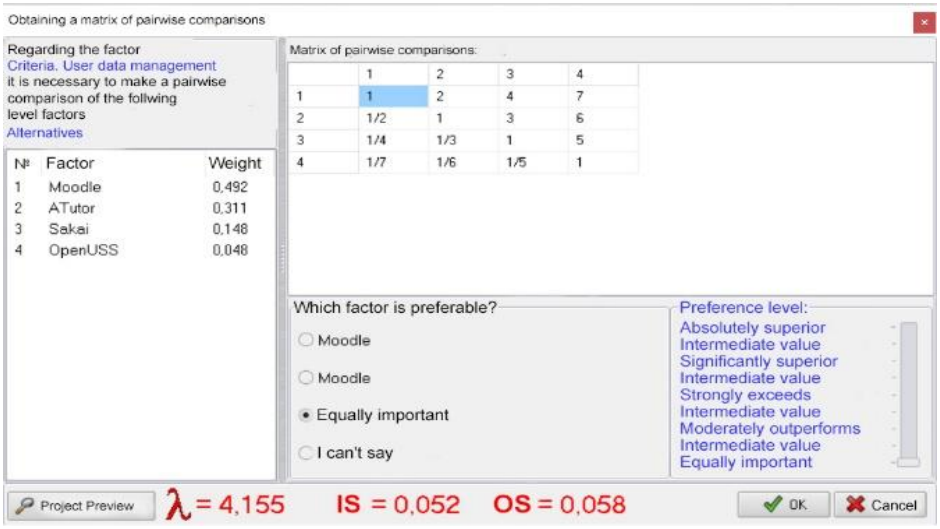

Fig. 7. Matrix for comparing solutions by the "User data management" criterion

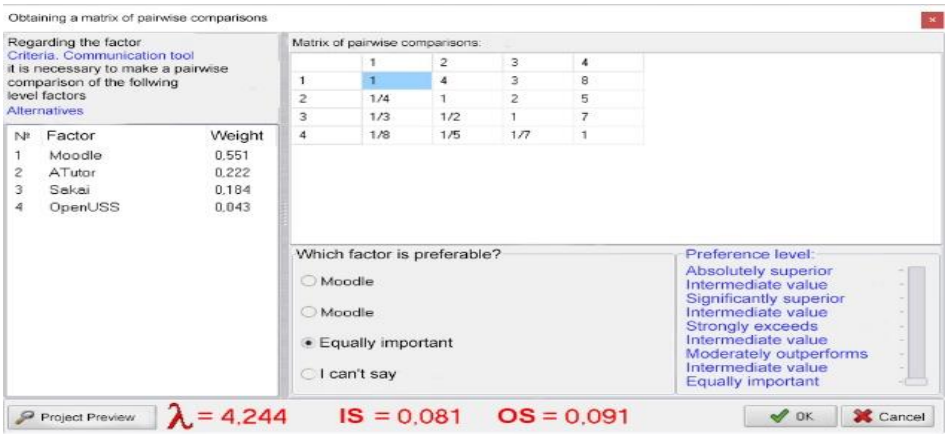

Fig. 8. Matrix for comparing solutions by the "Communication tools" criterion

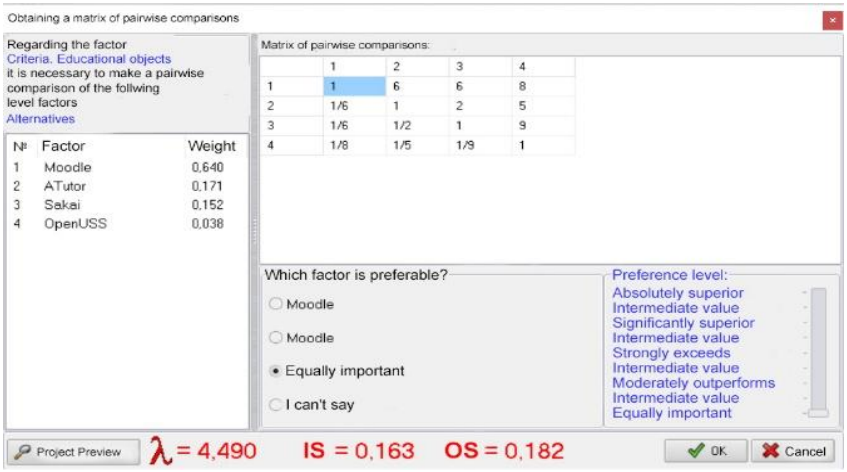

Fig. 9. Matrix of solutions comparison by the criterion "Educational objects"

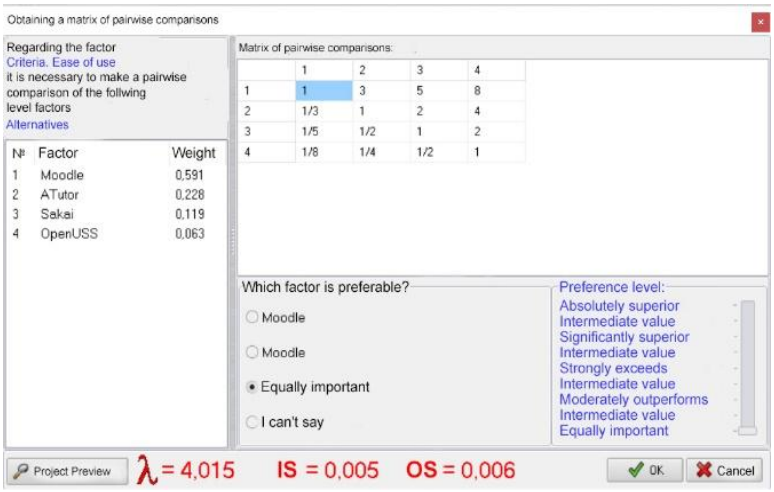

Fig. 10. Matrix of solutions comparison by the "Ease of use" criterion

Based on the results of the evaluation of alternatives for each of the criteria, the overall result is determined, which is expressed in the quantitative assessment of the priority of choosing each of the distance learning systems, which are presented in table 3.

Table 3

Results of choosing a distance learning platform

Platform	Percentage of preference	Priority
Moodle	48,7%	1
ATutor	20,8%	2
OpenUSS	18,5%	3
Sakai	12,0%	4

The visual results of the priority assessment of the analyzed DLSs in the form of pie and bar charts are shown in fig. 11-12.

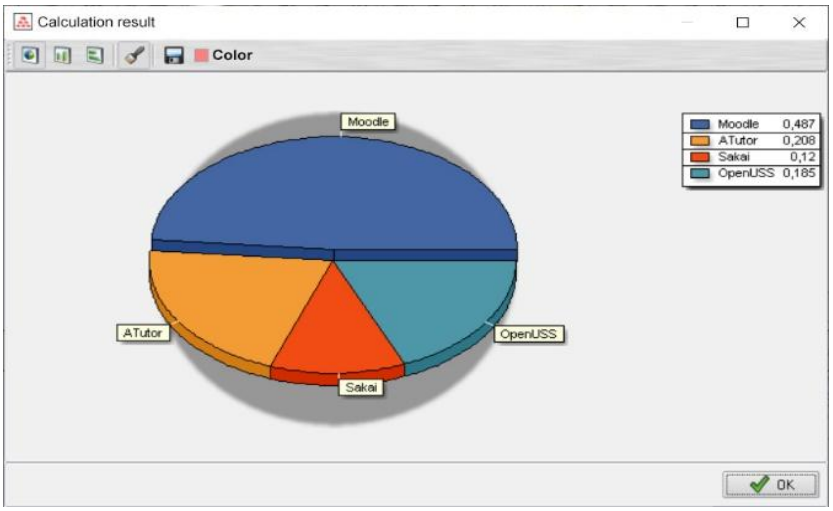

Fig. 11. Pie chart of the results of the assessment of DLS obtained in the DSS "Vybir"

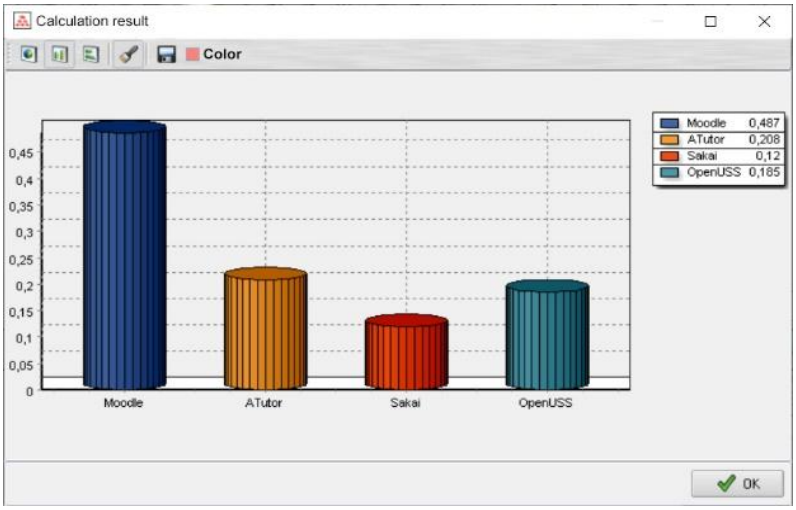

Fig. 12. Bar chart of the results of the assessment of the DLS obtained in the DSS "Vybir"

According to the survey, Moodle was found to be the best distance learning system. The percentage of preference for the Moodle alternative among all others is 48.7%. The second place is taken by the ATutor system with a percentage of 20.8%, the third and fourth places are taken by the OpenUSS and Sakai systems with a percentage of 18.5% and 12.0% respectively.

Conclusion. Therefore, based on the hierarchy analysis method and with the help of the "Choice" DSS, the selection of a DLS from four alternatives Moodle, ATutor, Sakai, OpenUSS was justified by the following criteria: technical aspects, adaptation, administration, course management, user data management, communication tools, learning objects, usability. The peculiarity of the task of choosing a distance learning system was that the selection criteria could not be expressed in quantitative form, this task belongs to the class of poorly structured tasks and was solved by applying a ranking scale for criteria and alternatives.

To select a platform using the hierarchy analysis method, hierarchy models were built, an expert survey was conducted to determine the importance of certain criteria for choosing a platform and their quantification using a ranking scale, and information was structured by pairwise comparison of criteria and alternatives. Based on the results obtained, the choice of the best alternative among the considered DLS was substantiated. It turned out to be the Moodle platform. The reliability of the obtained result is confirmed by determining the consistency index, the value of which does not exceed 0.1, which is a sign of data consistency.

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