The Use of Mathematical Tools to Determine the Importance of Multimedia Products Design Elements

Oleksandr Tymchenko[1[0000-0003-2052-5165]], Svitlana Vasiuta[2[0000-0003-0079-9740]], Olha Sosnovska[2[0000-0001-5413-2517]], Andriy Konyukhov[2[0000-0002-4643-9620]], Marek Dudzik[3[0000-0002-2475-5489]] and Anna Romanska-Zapala[3[0000-0003-2303-4337]]

[1.] University of Warmia and Mazury, Olsztyn, Poland
o_tymch@ukr.net
[2.] Ukrainian Academy of Printing, Lviv, Ukraine
lanapavliv@gmail.com, olhakh@gmail.com, konyukhow@gmail.com
[3.] Cracow University of Technology, Cracow, Poland
mdudzik@pk.edu.pl, a.romanska@pk.edu.pl

Abstract. The development of digital technology has led to the creation of new ways of transmitting information. These changes are particularly noticeable in the field of education, namely the widespread introduction into the educational process of multimedia products that promote learning in universities and research institutions. Their attractive features significantly affect the interest of students and better perception of the received information. This leads to the constant modernization of information and functionalities used. That is why this work presents a study of design elements that influence the creation of high-quality multimedia products. Experts highlight the following main multimedia product design elements: color palette, contrast, composition, background, font, plasticity, and rhythm. We the use of the theory of graphs, mathematical calculations are performed to rank the priority of the importance of the described elements. As a result of mathematical calculations, we constructed a hierarchical model of the importance of design elements that affect the quality of the information in multimedia products. To optimize the obtained structured multilevel model, we used the Saaty pairwise comparison method. The key objective of this method is to investigate the presence and consistency of pairwise comparisons of the weights of the elements and to obtain a numerical estimate of the connection between them in the original graph. Finally, suggestions are made for further research with the use of multimedia products.

Keywords: Multimedia Product, Graph Theory, Saaty Method, Pairwise Comparison Method, Design Elements, Multilevel Model.

1. Introduction

The rapid development of computer technologies encourages developers to introduce new models of cooperation and possibilities in the design of multimedia products. A

2019 DCSMart Workshop.

striking example is the dynamics of publications on media products and their widespread use in the learning process.

As noted in a study [1], in the so-called information society, the relations resulting from the interaction of its technological bases with the consumer have changed the perception of information in general. The Internet is considered as the multimedia backbone and acts as the source of information. These changes put professors and students in the new educational conditions and require teamwork to solve technological challenges.

Today multimedia products face the task of addressing these challenges. These products provide opportunities for both professors and students to rely on attractive cognitive and effective resources for the development of the educational process. As a result, the educational process became more interesting, and the use of multimedia products increased students' motivation and creativity, which are considered to be two key aspects of success.

However, it should be noted that the research that would be conducted to determine how the elements of a multimedia product design affect one another and, in general, how these elements affect a student's perception of information is rather limited and is rare in literature. In our opinion, this indicates the feasibility and relevance of these studies.

2. Formal Problem Statement

The vast majority of all multimedia products consist of the same set of design elements, which, depending on the scope, may differ in their "weight" and feature feed.

One of the most important points in the multimedia product design is determining which design element should take priority. Moreover, to which elements we need to pay more attention to and highlight multimedia design. Given the above, to evaluate the importance of the design elements of a multimedia product, we proposed to use a mathematical tool called the graph theory. This theory is one of the modern direction of mathematics, which is rapidly developing. To determine the optimality of decisions in terms of multicriteria, as noted in the literature, a special place is taken by the analytic hierarchy process by T. Saaty. This technique has qualitative advantages over others, as it allows to evaluate higher levels based on the interaction of different levels of the hierarchy.

The main problem that is determined in the framework of this study is solved by the pairwise comparison and development of a certain importance priority ranking.

3. Literature Review

The work [2], among the other interesting studies in this area, concerns the studies of cognitive component and multimedia learning from 2015 to 2019. We analyzed 94 articles in terms of types of cognitive component and its measurements, multimedia learning principles, dependent and independent variables, cognitive processes, types of multimedia learning environments, and demographic characteristics of research. Most of the peer-reviewed multimedia cognitive studies have been conducted by researchers from Europe, especially from Germany, then Asia, the USA, Australia, and Africa. In this paper, it is noted that those studies are more dominated by subjective than objective methods of measuring the cognitive component. The main elements studied were design, material type, presentation format, and individual differences. These studies have elaborated and identified a number of gaps in the cognitive study of content related to multimedia learning.

The research [3] is considered as valuable work in this field. We analyzed 52 articles and 58 studies related to the study of cognitive processes in multimedia learning with the help of certain variables using eye movement tracking technologies. By using the eye movement tracking method, we came to the conclusion that there is a certain link between cognitive processes and learning performance. Also, in work based on the research, some inaccuracies were identified in existing conclusions regarding multimedia learning design. The suggestions were made for further research and practice.

In [4], [5] it is noted that the use of information technology in the educational process is not new, and studies in this direction have been conducted by many researchers. The use of multimedia products in this process is effective since it involves different media with an interactive and informative connection with the material. Their effectiveness lies in engagement and motivation, as well as reduction of the mistakes in the learning process. It is also noted that the student sometimes lacks sufficient cognitive awareness and skills in understanding the material presented. Therefore, the pedagogical factor is an important moment in the presentation of the material in a multimedia product. It serves to increase students' cognitive awareness of what they know and what they need to learn from a particular topic.

The usefulness of using multimedia products in the educational process is shown in work [6]. In particular, multimedia products provide teachers with a great opportunity to demonstrate and visualize their subject matter, as well as allow them to prepare course material in a way that optimizes student learning skills. It also describes the utility of using animation in multimedia products, which enables students to become self-trained in subject learning. It gives the structure of animation and advantages in its use. The issue of creating a virtual learning environment is also considered important in work.

There are a number of other publications that discuss the multimedia features in the educational process. For example, the study [7] shows the advantages of using such multimedia elements in education as images, video, and multidimensionality. And study [8], show that the use of gestures in combination with multimedia products is useful for the education and student perception of the information provided. Literary sources include works such as [9] concerning the review of networks and their structure for multimedia transmission and development of a specialized software product.

4. Materials and Methods

In order to highlight the main design elements and their weight in a multimedia product, we conducted a survey that included students and professors as respondents. Surveys results are the following important elements of the multimedia design:

- *composition*, this design element is responsible for the elements balance in the multimedia product, which in turn allows the user to correctly define the hierarchy of objects, the sequence of actions, and allows the developer to control the user's view;
- *the color palette*, when the color is oversaturated in the multimedia product design it is more difficult for the consumer to navigate in the product, and accordingly, it is harder to gather the required information;
- *contrast*, this design element is responsible for the interaction of opposite elements of the composition, it allows to distinguish differences and similarities, to attract the attention of the consumer;
- *background properties*, the inconsistency of correct submission of background parameters leads to compositional problems, often drawing unnecessary attention, or the inability to read the text;
- *font properties*, this parameter strongly affects the readability of the text, which is usually the main content in a multimedia product;
- *plasticity and rhythm*, these elements are used to achieve a certain purpose, for example, to set the view direction or for continuity of attention, which in turn will give the integrity, adjust the appearance, help in finding the necessary materials.

The survey responses serve for further elaboration and ultimately clarification what multimedia product design elements are important and which elements should be given particular attention when using them.

5. Experiments, Results and Discussions

In the conducted surveys, respondents identified a number of elements that provide a convenient perception of information from multimedia products. The next task for the respondents was to indicate which element is more important and how they are related, that is, to indicate how the elements interact. For further work, we use graph theory and construct a hierarchical model of the importance of design elements. By using this method, we can rank the importance of the elements, and we can determine the impact among them. The expediency of using this mathematical tool has been proved in our previous similar studies [10 - 13].

To solve this problem, using the graph theory, we must assume that the elements considered are a certain set $B=\{b_1, b_2, ..., b_n\}$. From this set, we define the subset $B_1 \in B$ of the most essential elements. To simplify the information presented and further mathematical calculations, we supplement our mathematical notation with certain mnemonic names, namely:

b_1 – composition (COM);

b_2 – color palette (CP);
b_3 – background properties (BP);
b_4 – plasticity (PL);
b_5 – rhythm (R);
b_6 – contrast (CONT);
b_7 – font properties (FP).

A subset of the elements B_1 and the interaction indicated by the respondents between them are represented as an indicative graph (see Fig. 1).

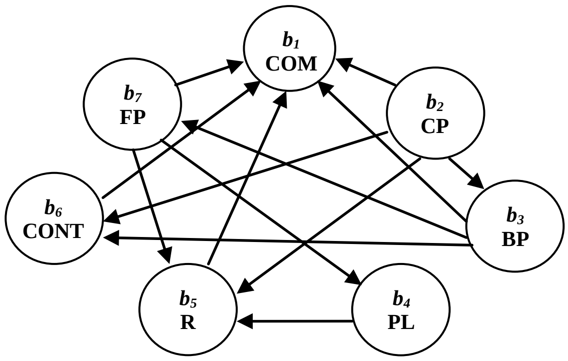

Fig.1. The graph of the relationship between the elements of influence in the multimedia product design.

Taking into account the graphs theory and the graph above, we construct a binary dependence matrix A for the set of vertices B with the following condition [14]:

$$a_{ij} = \begin{cases} 0, \text{ if the factor } i \text{ does not depend on the factor } j \\ 1, \text{ if the factor } i \text{ depends on the factor } j \end{cases} \quad (1)$$

For better display, we place the dependency matrix in Table 1 by adding an information row and a column with mnemonic element names.

Table 1. The element dependency matrix.

	COM	CP	BP	PL	R	CONT	FP
COM	0	0	0	0	0	0	0
CP	1	0	1	0	1	1	0
BP	1	0	0	0	0	1	1
PL	0	0	0	0	1	0	0
R	1	0	0	0	0	0	0
CONT	1	0	0	0	0	0	0
FP	1	0	0	1	1	0	0

Based on the graph and the obtained binary matrix A, we form the reachability matrix by this rule ($I+A$), (where I – identity matrix), which is raised to a power n to satisfy the condition:

$$(I+A)^{n-1} \leq (I+A)^{n} = (I+A)^{n+1} \tag{2}$$

We are filling the reachability matrix (Table 2) with binary elements on rows (from left to right) according to the following rule:

$$d_{ij} = \begin{cases} 1, \text{ if we can reach the vertex } i \text{ from the vertex } j \\ 0, \text{ in anothe case} \end{cases} \tag{3}$$

Table 2. The reachability matrix.

	COM	CP	BP	PL	R	CONT	FP
COM	1	0	0	0	0	0	0
CP	1	1	1	1	1	1	1
BP	1	0	1	1	1	1	1
PL	1	0	0	1	1	0	0
R	1	0	0	0	1	0	0
CONT	1	0	0	0	0	1	0
FP	1	0	0	1	1	0	1

The reachability matrix is necessary for dividing the set of vertices B into a subset of levels. For this, all the vertices of our graph must be divided by the vertices of the precursors and reached. The vertex b_i is called reached from vertex b_j, if there is a path from b_j to b_i in the indicative graph. We denote this subset of the reached vertices as $R(b_i)$. The vertex b_j is called the precursor of the vertex b_i, if it is possible to reach b_i from b_j. We denote this subset of precursors vertices as $A(b_i)$. The intersection of these subsets will be a subset

$$A(b_i)=R(b_i) \cap A(b_i) \tag{4}$$

The set of vertices $A(b_i)=R(b_i) \cap A(b_i)$, for which the condition of inaccessibility from any of the vertices of the remaining set B is satisfied, will be defined as the level of the hierarchy [10, 14].

Performing the sets of actions above enables us to determine the first level of the element hierarchy and to form Table 3. In this table, a subset of $R(b_i)$ is formed from the elements of the *i-th* row of the reachability matrix, if equal to one. The subset formation $A(b_i)$ comes from the elements of the *i-th* column of the reachability matrix, again, if it is equal to one. According to this theory, a subset $R(b_i) \cap A(b_i)$ forms as a logical intersection of element subsets $R(b_i)$ and $A(b_i)$.

Table 3. Defining the first level of the element hierarchy.

b_i	$R(b_i)$	$A(b_i)$	$R(b_i) \cap A(b_i)$	
1	1	1, 2, 3, 4, 5, 6, 7	1	
2	1, 2, 3, 4, 5, 6, 7	2	2	←
3	1, 3, 4, 5, 6, 7	2, 3	3	
4	1, 4, 5	2, 3, 4, 7	4	
5	1, 5	2, 3, 4, 5, 7	5	
6	1, 6	2, 3, 6	6	
7	1, 4, 5, 7	2, 3, 7	7	

From the obtained results of the construction of Table 3, we can state that equality $A(b_i)=R(b_i) \cap A(b_i)$ holds for the element under number 2. This number corresponds to the color palette used in the multimedia product. According to graph theory, this element is considered to be the lowest ranking of importance. We remove the second row and exclude from the table the value of 2. Similarly, how we determined the first level of the element hierarchy, we obtain all the following levels (Tables 4-7):

Table 4. Defining the second level of the element hierarchy.

b_i	$R(b_i)$	$A(b_i)$	$R(b_i) \cap A(b_i)$	
1	1	1, 3, 4, 5, 6, 7	1	
3	1, 3, 4, 5, 6, 7	3	3	←
4	1, 4, 5	3, 4, 7	4	
5	1, 5	3, 4, 5, 7	5	
6	1, 6	3, 6	6	
7	1, 4, 5, 7	3, 7	7	

Table 5. Defining the third level of the element hierarchy.

b_i	$R(b_i)$	$A(b_i)$	$R(b_i) \cap A(b_i)$	
1	1	1, 4, 5, 6, 7	1	
4	1, 4, 5	4, 7	4	
5	1, 5	4, 5, 7	5	
6	1, 6	6	6	←
7	1, 4, 5, 7	7	7	←

Table 6. Defining the fourth level of the element hierarchy.

b_i	$R(b_i)$	$A(b_i)$	$R(b_i) \cap A(b_i)$	
1	1	1, 4, 5	1	
4	1, 4, 5	4	4	←
5	1, 5	4, 5	5	

Table 7. Defining the fifth level of the element hierarchy.

b_i	$R(b_i)$	$A(b_i)$	$R(b_i) \cap A(b_i)$	
1	1	1, 5	1	
5	1, 5	5	5	←

From the results of determining the hierarchy of importance of the multimedia product design elements, we see that the highest level (level 6) corresponds to the composition. According to the results obtained, we construct a hierarchical model of the importance of the elements (see Fig. 2).

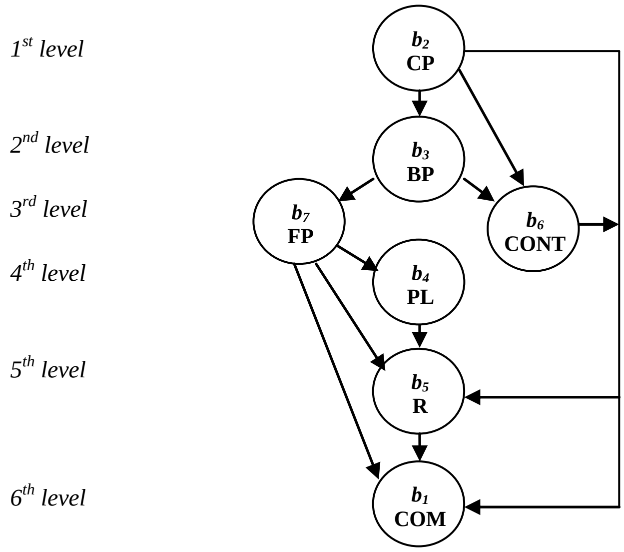

Fig.2. The hierarchical model of the element importance

The resulting hierarchical structured model simulates the priority of the importance of the individual elements of multimedia product design. From the results obtained, we can say that the composition is the most important element in the multimedia product design. The aforementioned makes it possible to argue that it is a key element in the construction, and it provides visual contact between the user and the multimedia product. As we can see from the obtained model, the rhythm and plasticity in the multimedia product design should also be considered as important elements. These two elements make it possible to build the necessary hierarchy of the representation of all components of a given product. At the lower level is a color palette.

The next mathematical action is to solve the problem of optimizing the resulting model. A special place for this is given to the method of analytic hierarchy by T. Saaty. This method has certain advantages over others, as it allows to take full account of all the criteria that have been put forward to determine the optimal solution. The main task of using this method is the challenge of experts to determine how much the use of one element outweighs the other [15]. In other words, we need to give numerical weights to the elements of a product's multimedia design.

For the following mathematical calculations, we use the scale of relative importance by Saaty [16, 17].

Using this scale, to determine the numerical weight of the design elements, we create a matrix of pairwise comparisons $B=(b_{ij})$ that is equal to $b_{ij}=1/b_{ji}$ (Table 8):

Table 8. The pairwise comparison matrix.

	COM	CP	BP	PL	R	CONT	FP
COM	1	6	5	3	2	4	4
CP	1/6	1	1/2	1/4	1/5	1/3	1/3
BP	1/5	2	1	1/3	1/4	1/2	1/2
PL	1/3	4	3	1	1/2	2	2
R	1/2	5	4	2	1	3	3
CONT	1/4	3	2	1/2	1/3	1	2
FP	1/4	3	2	1/2	1/3	1/2	1

The pairwise comparison matrix enables pairwise comparisons of elements at a certain level of the hierarchical structure in terms of their importance to the element at the highest level of the hierarchy.

According to this method, experts give more weight to the elements that are more significant by the results of the calculations, and accordingly, less weight is given to elements with less importance. With the obtained hierarchical model (Fig. 2) and using this method of experts, we give the following number of official registration data, namely: COM (b_1) – 60; CP (b_2) – 10; BP (b_3) – 20; PL (b_4) – 40; R (b_5) – 50; CONT (b_6) – 30; FP (b_7) – 30.

The principal eigenvector, by this method, is calculated as the geometric mean in the row of the resulting matrix and, in our case is equal to:

E_0= (3,12; 0,333; 0,504; 1,345; 2,099; 0,905; 0,742).

The priority vector component can be calculated by the following equality:

$$E_n = E_i \Big/ \sum_{i=1}^{n} E_i \qquad (5)$$

Accordingly, we obtain the following values of the normalized vector:

E_n = (0,344; 0,036; 0,055; 0,148; 0,231; 0,1; 0,082).

For a better representation of the components of this vector, we can multiply by a factor k, for our case we can make it equal to 1000. Accordingly, we obtain:

E_n x k= (344; 36; 55; 148; 231; 100; 82).

To assess the consistency of expert judgment, we calculate $\lambda_{\max}$:

$$\lambda_{\max} = \sum_{j=1}^{n} M_j E_j \, , \qquad (6)$$

where $M_j = \sum_{i=1}^{n} z_{ij}$ – is the sum of the elements of the *ith* column of the matrix; E_j – vector of priorities of the analyzed matrix. In our case, we obtain λ_{max} = 7,18.

By the method described in the literature [12, 16], we can say that the value $\lambda_{\max}$ is the main characteristic, used to establish the consistency of expert judgment, regarding pairwise comparisons of items in tasks with undetermined factors. The result of the decision is determined by the consistency index, in our case, it is *IU* = 0,03. For the proper consistency of expert judgment, the following inequality must be satisfied *IU<0,1*x*WI*. Where *WI* – the reference value of the consistency index, in our case for 7 elements, it is 1.32. Substituting the data obtained into this inequality, we can say that there is proper consistency (0,03< 0,1 x 1,32).

The weights of the design elements that are obtained as a result of using this technique can be entered in Table 9.

Table 9. The factor weights.

	b_1	b_2	b_3	b_4	b_5	b_6	b_7
E_0	60	10	20	40	50	30	30
E_n	0,344	0,036	0,055	0,148	0,231	0,1	0,082
E_n x k	344	36	55	148	231	100	82

The obtained values of the components of the normalized vector are the optimized weights of the considered elements of the multimedia product design used to build the optimized model (see Fig. 3).

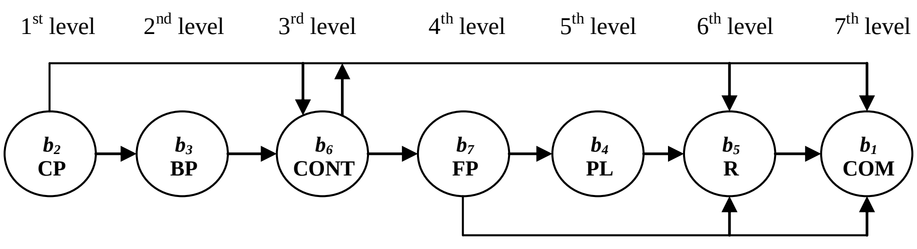

Fig.3. The optimized model of the hierarchy of importance of the multimedia product design elements

Therefore, the obtained multilevel optimized model of the hierarchy importance of the multimedia product design elements confirms that the most important element in the design is the composition. The next priority is rhythm and plasticity, which are also important. The less important design elements are the background and color properties.

6. Conclusions

The proposed use of mathematical tools, namely graph theory made it possible to evaluate and calculate the importance of multimedia product design elements that are useful and highly regarded by students. As a result of the research, we constructed a hierarchical multilevel model of the relative importance of the design elements. The adequacy of the calculation is confirmed by the permissible consistency index. Based on weight values, we constructed an optimized multilevel model of the importance hierarchy of multimedia product design elements as a result of the expert survey. This method of calculation can be used when the parameters of a certain process have different numerical and qualitative characteristics, which does not allow to obtain an adequate relation between them and influence them on the process itself.

References

1. Fernandez, R. F. F., Goodova, M., Rubtsova, E.: Multimedia Resources as Examples of Polymorphic Educational Hypertexts in the Post-Literacy Era. Procedia – Social and Behavioral Sciences, vol. 214, pp. 952-957 (2015) doi: 10.1016/j.sbspro.2015.11.679
2. Mutlu-Bayraktar, D., Cosgun, V., Altan, T.: Cognitive load in multimedia learning environments: A systematic review. Computers & Education, vol. 141, art. no. 103618 (2019) doi: 10.1016/j.compedu.2019.103618
3. Alemdag, E., Cagiltay, K.: A systematic review of eye tracking research on multimedia learning. Computers & Education, vol. 125, pp. 413-428 (2018) doi: 10.1016/j.compedu.2018.06.023
4. Tien Tien, L., Osman, K.: Pedagogical Agents in Interactive Multimedia Modules: Issues of Variability. Procedia - Social and Behavioral Sciences, vol. 7, pp. 605-612 (2010) doi: 10.1016/j.sbspro.2010.10.082
5. Navarro, O., Molina, A. I., Lacruz, M., Ortega, M.: Evaluation of multimedia educational materials using eye tracking. Procedia – Social and Behavioral Sciences, vol. 197, pp. 2236-2243 (2015) doi: 10.1016/j.sbspro.2015.07.366
6. Milková, E.: Multimedia application for educational purposes: Development of algorithmic thinking. Applied Computing and Informatics, 11 (1), pp. 76-88 (2015) doi: 10.1016/j.aci.2014.05.001
7. Hayat, K.: Multimedia super-resolution via deep learning: A survey. Digital Signal Processing, vol. 81, pp. 198-217 (2018) doi: 10.1016/j.dsp.2018.07.005
8. Davis, R. O.: The impact of pedagogical agent gesturing in multimedia learning environments: A meta-analysis. Educational Research Review, vol. 24, pp. 193-209 (2018) doi: 10.1016/j.edurev.2018.05.002
9. Muhammad, F. M., Syed, H. A., Siraj, M., Houbing, S., Danda, B. R.: Multimedia streaming in information-centric networking: A survey and future perspectives. Computer Networks, vol. 125, pp. 103-121 (2017) doi: 10.1016/j.comnet.2017.05.030
10. Vasiuta, S., Soroka, N., Khamula, O.: Factors of influence of interface use based on mobile applications. Scientific Papers, 2 (53), Lviv, pp. 28–36 (2016)

11. Vasiuta, S., Soroka, N., Khamula, O.: Optimization of mathematical model of the impact factors hierarchy of the interface use based on mobile. Scientific and technical collection “Printing and Publishing”, 2 (72), Lviv, pp. 28–35 (2016)
12. Tymchenko, O., Vasiuta, S., Khamula, O.: Optimization of the Mathematical Model of Factors of Composite Design of Infographic. The materials at the 2018 IEEE 13th International scientific and technical conference Computer Science and Information Technologies CSIT 2018 in Lviv, Ukraine, vol. 2, pp. 58-61 (2018) doi: 10.1109/STC-CSIT.2018.8526673
13. Tymchenko, O., Vasiuta, S., Khamula, O., Sosnovska, O., Dudzik, M.: Using the method of pairwise comparisons for the multifactor selection of infographics design alternatives. The materials at the 2019 IEEE 20th International Conference on Research and Education in Mechatronics (REM), Date of Conference: Wels, Austria, art. no. 8744108 (2019) doi: 10.1109/REM.2019.8744108
14. Vasiuta, S., Khamula, O.: Syntez modeli faktoriv kompozytsiinoho oformlennia infohrafiky. Polihrafiia i vydavnycha sprava, 2 (74), pp. 59–65 (2017)
15. Saaty, T.: What is the Analytic Hierarchy Process? Univ. Pittsburgh, 287 p. (1988)
16. Saaty, T.: Prinyatie resheniy. Metod analiza ierarhiy. Moskow, 278 p. (1993)
17. Skiter, I., Tkalenko, N., Trunova, O.: Matematychni metody pryiniattia upravlinskykh rishen: Navchalnyi posibnyk. Chernihiv, 250 p. (2011)