Models and Approaches to Flexible Adaptation of Educational Processes in the Era of Digital Economy

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ABSTRACT

In the era of growing digital economy education plays a crucial role in training qualified specialists having and demonstrating digital competencies needed on the labor market for a dynamically developing business.
In order to develop mechanisms for optimizing the management of educational processes and improving the compliance of educational results with the needs of the economy this paper offers such formalized tools as mathematical models, methods and algorithms that allow you to obtain generalized competence assessments of the results of completing educational programmes and form strategies for curricula changes that flexibly adapt them to the current and projected requirements of the economy.
The research also suggests the models for assessing the impact of providing and developing the digital economy competencies by educational structures on the development of the region. It is assumed that various educational structures in the region train specialists with different levels of digital competence development, and the personnel distribution according to the level of these competencies affects the main sub-indices which are the indicators of the region's performance efficiency in the digital economy. There has been considered the possibility of using neural network technologies to study this impact.

Keywords: *digital economy, digital competencies, integrated assessment mechanism, neural network technologies*

1. INTRODUCTION

A key feature of any economic system tends to be the interaction of market mechanism with expectations of agents trying to forecast the future evolution of the economy. Today the digital economy based on advanced information technologies requires the educational systems of secondary, higher and further education to work out innovative methods of teaching. Great attention has been paid to the issue of developing special competencies for working in the digital economy, which are digital competencies.

Depending on the area of the use the main digital competencies involve information literacy; communication and collaboration; digital content creation; security and problem solving.

In order to develop these competencies and train personnel there is the necessity for modernizing both educational and training systems. New educational programmes are being offered taking into account the needs of the digital economy. As a result, digital tools for educational activities are being introduced and fresh approaches to organize an individual way of lifelong learning for citizens are being developed.

The system of new IT education is to be aimed at forming and developing digital competencies in interactive dynamics that will be able to meet the needs of economy. It is necessary to define the relevant competencies for each structural element of the education system, digitize them, clearly identify the levels of competence formation and build a training system for each level with the appropriate methodology and instrument support. Such an approach will provide digital modernization of the main training processes with guaranteed achievement of diagnostic learning outcomes.

The formation of digital competencies, however, has a number of complex aspects related to the need:

– to justify the logical relationship between the competencies formed during the learning process and the general labor functions of professional standards;

– to develop efficient methods for assessing the levels of competence formation during the learning process and when involved in activities (competencies);

– to develop methods for comprehensive assessment of student's ability to work in a certain segment of the digital economy;

– to develop methods for flexible adaptation of the educational process to dynamic changes in the digital economy;

– to develop methods for distributing educational resources among the tasks of forming various competencies of the digital economy;

– to develop methods for assessing the compliance of competence-based results of educational activities with the needs of the regional economy.

To fulfill the mentioned tasks the present paper focuses on considering specific models, methods and algorithms for assessing the compliance of the competence content of education with the requirements of professional standards and the current needs of the real economic sector as well.

2. METHODOLOGY

The educational standards of the competence approach are aimed at forming a system of competencies including basic knowledge and study skills as well as raising individual personal qualities needed for hard work and a high level of activity. The competence approach in professional standards reflects professional competencies and job responsibilities in accordance with the qualification level.

Note, that the educational and professional standards have not been united in one mutually dependent and interdependent system yet. Modern requirements for educational standards appeal to the connection of the educational process with the future professional development [2-4, 7, 11]. This connection plays a vital role in the conditions of digitalization. There have already been made the attempts to create a certain system for evaluating the quality of education [5, 6, 8, 10], taking into account the professional component.

There is a growing interest in the formalized tools developed to assess the degree of goal achievement, quality, performance and effectiveness of education. These tools allow us to quantify and/or qualitatively assess the level of formation of target competencies. In this study, we will propose two algorithms. The first algorithm makes it possible to give a general assessment of educational results with regard to the corresponding educational standard and a hierarchical model based on the curriculum of the institution. Moreover, this algorithm makes career-oriented adjustment of the hierarchical model and the educational process. It is based on the mechanism of complex estimation based on dichotomous convolution trees. The second algorithm is able to analyze the information about educational standards at the regional area as well as the level of formation of digital competencies within these standards and to identify the impact of the obtained results on the main performance indicators of the region in the digital economy. This algorithm allows building a neural network model for predicting the result indicators.

3. THE FIRST ALGORITHM

The process of mastering the required competencies, in particular those shown in educational standards, can be represented as a hierarchical tree of goals (a hierarchical model), according to which some competencies of the lower level of the hierarchy are grouped into higher level competencies, e.g. pairs, classes or groups. The most complex competence is on the top level of the hierarchical model. This comprehensive competence reflects the integrated level of forming and developing all elementary competencies of the lower levels of the hierarchy. We will use dichotomous trees with a branching restriction, according to which each node of a higher-level tree can be divided only into two branches. The mechanism of integrated assessment is supposed to be used to assess the level of integrated competence. Having known the estimates of elements of the lower level of the hierarchy on the certain scale, the mechanism of integrated assessment of dichotomous convolution trees allows us to get the estimates of elements of the next levels of the hierarchy on that scale. In this case we move from bottom to top. The convolution procedure is performed with the use of special convolution functions (matrices) defined on the direct product X×X, where X is the rating scale. The scheme of convolution procedure is shown in figure 1.

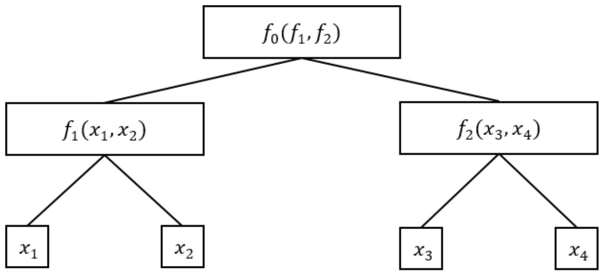

Figure 1 Fragment of the convolution procedure

In the case of an ordinal rating scale, the convolution functions can be represented as convolution matrices. Figure 2 shows a fragment of the matrix representation of the complex estimation mechanism.

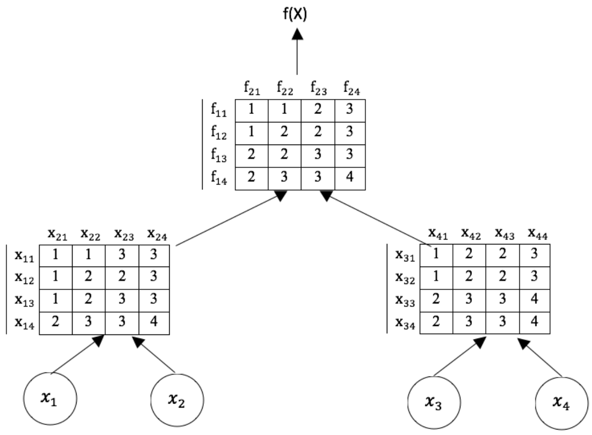

Figure 2 Fragment of the matrix representation of the complex estimation mechanism

This example uses an ordinal scale that has 4 gradations of the level of competence formation: 1 – low, 2 – satisfactory, 3 – medium, 4 – high. The interpretation of ordinal scale gradations is unique for each competence at any level of the hierarchical model. The convolution matrix element at the intersection of the *i*-th row and the *j*-th column characterizes the level of convolution competence formation when the *i*-th level of competence on the left and the *j*-th level of competence on the right are convoluted.

Let us consider an example of a dichotomous tree for forming a comprehensive assessment of competence (fig.3). The tree has been built on the basis of the curriculum of Master's degree course «Information Business Analytics».

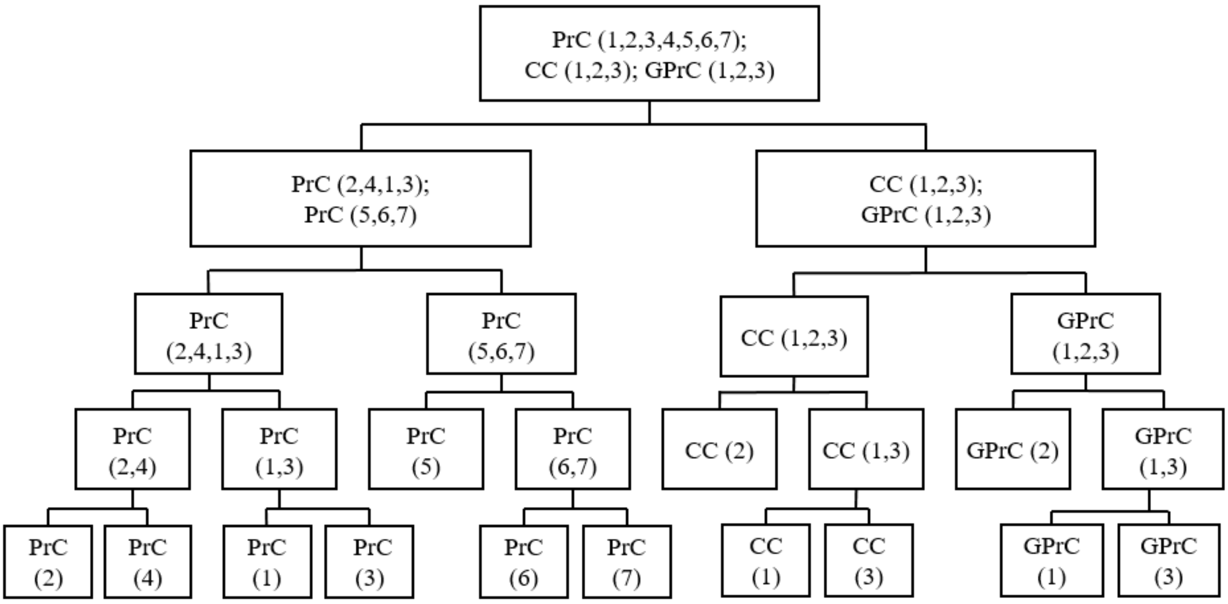

Figure 3 An example of a dichotomous tree

Each position of this tree corresponds to some professional competence (PrC), some general professional competence (GPrC) or cultural competence (CC). For example, PrC (6) refers to the ability to manage design innovation and research teams, GPrC (3) refers to the ability to adapt to the conditions of the tasks and offer innovative solutions, CC (2) refers to the ability to make decisions in unusual situations, as well as to accept the ethical and social responsibility for their actions.

The estimates of the competence formation at the lower level of the hierarchical tree can also be calculated based on the hierarchical models of competence formation within the curriculum (fig. 4).

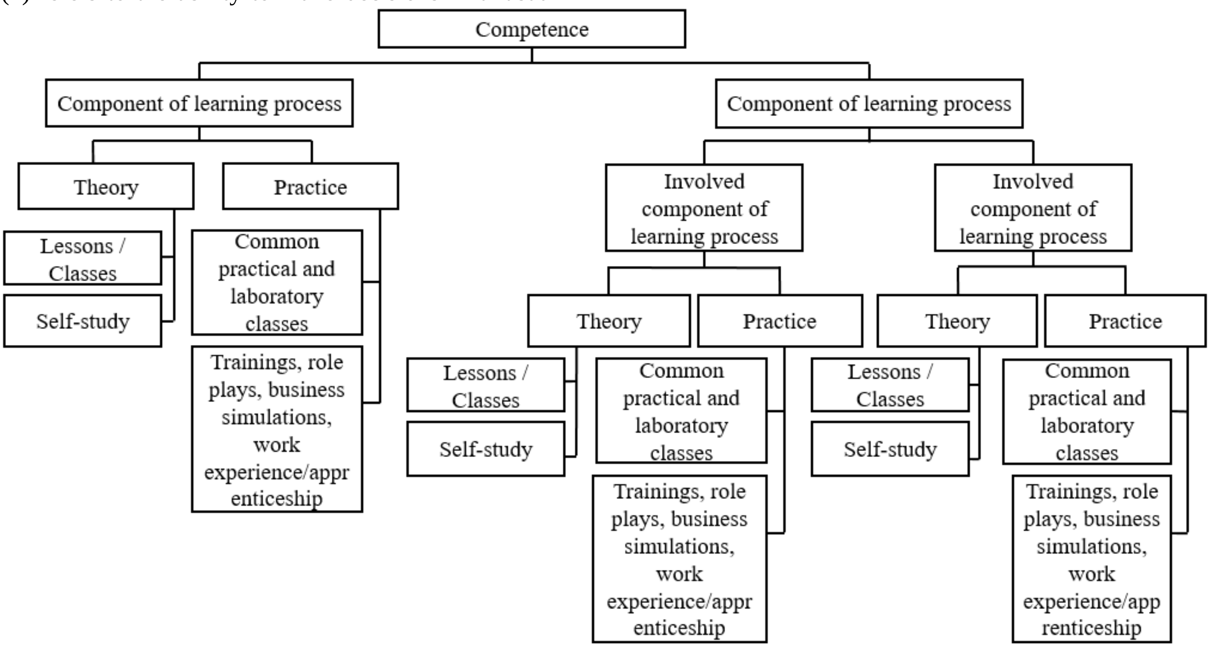

Figure 4 Hierarchical assessment model of competence formation at the lower level of the hierarchical competence model

The most important procedure of the complex estimation mechanism, making a great impact on the estimating results, is the procedure for filling in the convolution matrices. There must be a sufficiently correct and well-adopted procedure that would allow you to carry out an assessment of interpretation in the subject area and adjust the parameters of competence development to achieve certain strategic and tactical goals. In this study, we propose an approach to filling in convolution matrices based on the distribution of credit units of time needed to acquire the competencies. It is assumed that the more credits are allocated for the development of competence, the more this competence is prior and significant. To formalize the preference relationship among the competencies some fuzzy linguistic information processing technologies are used [1]. When filling in the convolution matrices of the competencies of the lowest level of the hierarchy, a number of credit units of time allocated for the development of the competence on the left and a number of credit units of time allocated for the development of the competence on the right is calculated. There has been introduced the linguistic relation of preference of a competence with a large or equal number of credit units of time over a competence with a smaller or equal number of credit units of time. The linguistic preference relation is set by the triple $< S, T, U >$, where S is the name of the linguistic variable, $T = \{T_1, T_2, T_3, T_4\}$ (where T_1 is equivalent, T_2 is somewhat preferable, T_3 is significantly preferable, and T_4 is absolutely preferable). The basic scale is $U = [1, \infty)$, its values reflect the ratio of the number of credit units of time covering the dominant competence to the number of credit units of time covering the less dominant competence. Figure 5 shows the term membership functions.

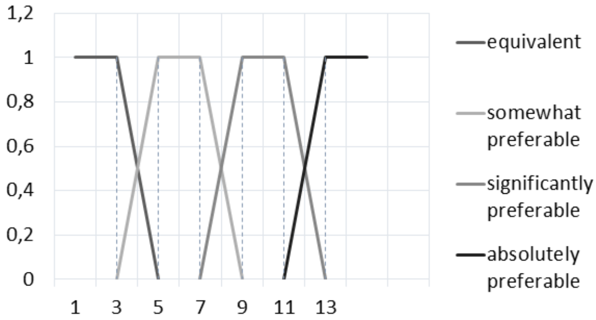

Figure 5 Term membership functions of the linguistic preference relation of the competence model elements

When the two specific competencies are combined, the corresponding element of the basic scale is calculated and the term is selected, the measure of which the considered element of the basic scale belongs to is the highest. Each term corresponds to a special convolution matrix. In this study, it is supposed to use the convolution matrices shown in table 1.

Table 1. Convolution matrices corresponding to the terms T_1, T_2, T_3, T_4

T_1					T_2					T_3					T_4				
	1	2	3	4		1	2	3	4		1	2	3	4		1	2	3	4
1	1	1	2	2	1	1	1	2	2	1	1	1	1	2	1	1	1	1	1
2	1	2	3	3	2	2	2	2	3	2	2	2	2	3	2	2	2	2	2
3	2	3	3	4	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3
4	3	3	4	4	4	3	3	4	4	4	3	3	4	4	4	4	4	4	4

It is assumed that the sum of the credit units of time of the competence on the left is greater than the sum of the credit units of time of the competence on the right. If this condition is not met, the competencies are reversed.

For convolution competencies of higher levels the total number of credit units of time is calculated for the competencies of the convolution. The further procedure for determining the preference term and the corresponding convolution matrix is similar to the procedure described above. As a result of the convolution procedure of the hierarchical competence model, the degree of comprehensive development of all competencies located at the lower level of the hierarchy is calculated, taking into account the priorities implemented in the learning process.

The extent, to which the assessment meets the needs of the real sector of the economy and whether the priorities for the development of competencies are correctly set, can only be assessed when they are included in the activity. Employers from the most popular segments of the labor market for this educational programme can give an assessment from the perspective of the real sector of the economy. The priority of labor market segments can be estimated, for example, by analyzing hierarchies (fig. 6).

However, the practice shows that the academic assessment obtained in this way does not always correspond to the assessment of the competence of young employees from the employers' point of view.

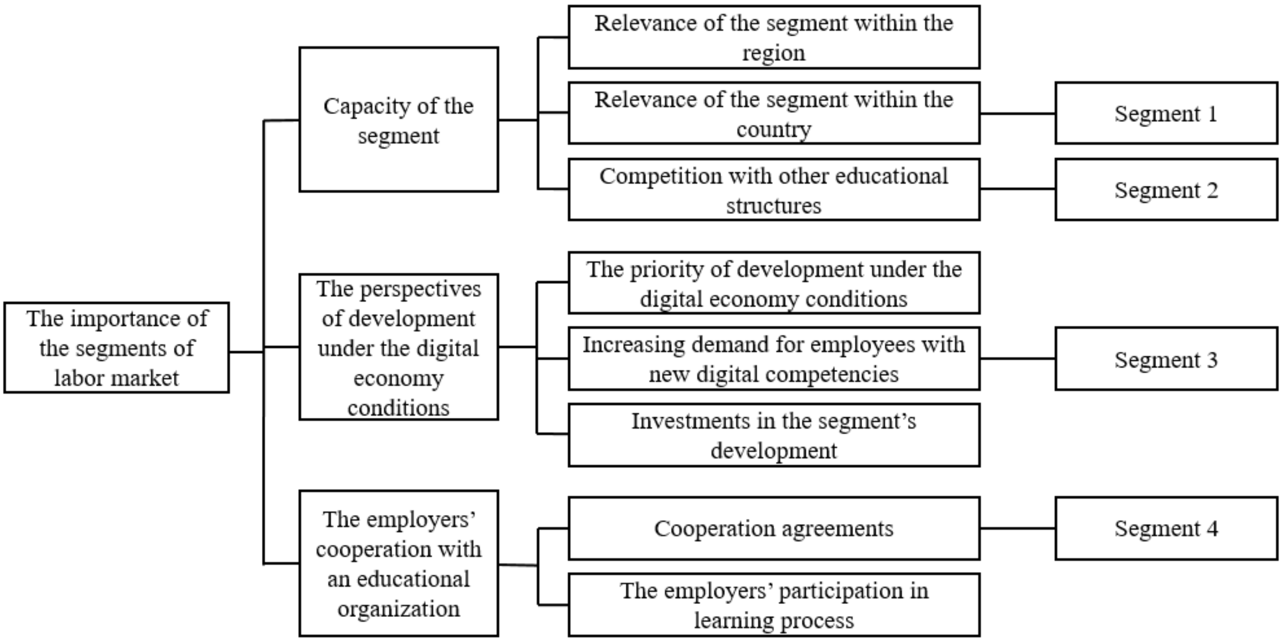

Figure 6 Hierarchy for assessing the importance of labor market segments

If the assessment of competence when included in activities from the perspective of employers from highly important segments of the labor market does not coincide with the comprehensive assessment obtained by the hierarchical competence model, this indicates the need to adjust the parameters of the hierarchical model, and, consequently, the redistribution of credit units of time among the competencies and elements of the educational process. This will allow you to properly intensify efforts to develop competencies.

This study provides a special mechanism that allows a formalized adjustment of the convolution matrices in the integrated assessment mechanism, taking into account the discrepancy between the integrated assessment and the employer's estimates from the most important segments of the labor market.

In order to implement the adjustment a statistical database is used, which for each respondent contains the following items: assessment of competence development of lower level of competence model; integrated assessment of higher level of competence model; integrated assessment of competence starting involved in activities from the point of view of the employer; the importance of the segment of the labor market where the assessment has been done.

The degree of divergence of a comprehensive assessment for a competence model and an integrated assessment of competence starting involved in activities from the point of view of the employer is evaluated by the criterion:

$$\frac{\sum_A (\lambda(A))(\omega(A) - \sigma(A))^2}{\sum_A \lambda(A)}, \qquad (1)$$

where $\omega(A)$ is an assessment of a competence model; $\sigma(A)$ is an integrated assessment of competence done by the employer and $\lambda(A)$ is the importance of the segment of the labor market.

The decision to adjust the parameters of the competence model is made in a situation when the criterion value is greater than a certain threshold value. The adjustment is aimed at minimizing the compliance criterion under consideration.

The adjustment is expected to meet the following requirements:

– the elements of the new convolution matrix cannot deviate by more than 1 from the elements of the original matrix;

– the non-decreasing condition is executed in each column and each row of the matrix;

– the minimum possible number of matrix elements is changed. the minimum possible number of matrix elements is changed.

The adjustment of convolution of matrices is a process of training the convolution matrices using the elements of the statistical database. To make correction we propose to use a method based on constructing a tree of probable states.

To start the adjustment, the order of matrix convolution is determined. After that, the tree of probable states is built. The tree of probable states, in contrast to the dichotomous competence model, allows branching into more than two branches. At the first stage, we have only one node – the root node, which contains the values of all the lower-level competencies. According to the order of convolution, the possible values that can be obtained for the root node during convolution are determined. All the values between the two collapsible values are considered and those that do not meet the adjustment requirements are deleted. For example, for a pair of criteria 1 and 3 the potential values may be 1, 2 and 3. However, the value 3 does not meet the deviation condition by 1 (according to the matrix, the value 1 is obtained). For each of the potential values, the sum of adjustments is calculated. It is obtained from the deviation value obtained during the matrix adjustment and the sum of adjustments fixed at the previous stage.

At the last stage, the optimal path is chosen. With the lowest value of the total adjustments this path gives the closest possible value of the general competence the graduate has to the employer's assessment.

Figure 7 shows a demo example of a tree of probable states. Two collapsible criteria are shown in bold, and the total adjustment is shown in italics.

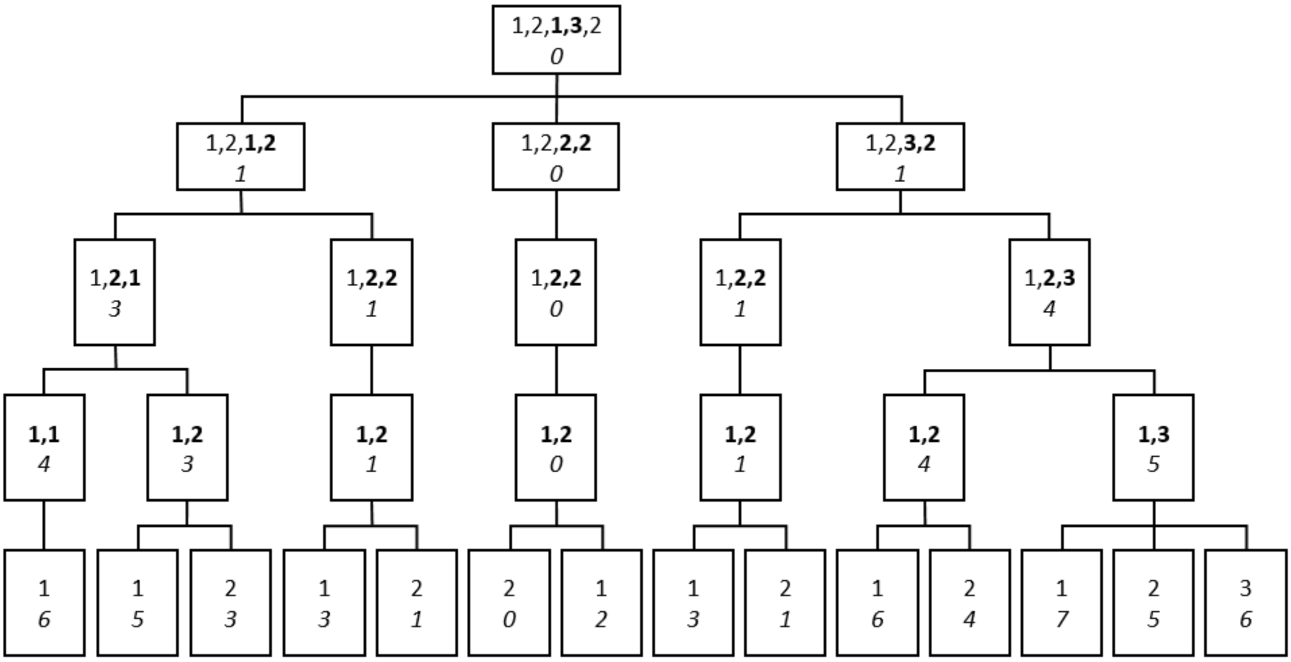

Figure 7 The tree of probable states

For the training process the statistical database is divided into two subsets, training and testing. Training is performed on the training subset, and testing of the competence model is performed on the testing subset. The certain threshold value is introduced for the criterion of compliance of assessments based on the competence model and employers' assessments, at which training is considered being successful.

After the adjustment we get new convolution matrices. By a certain metric it is possible to determine which of the typical convolution matrices they are closer to and replace the obtained convolution matrices with the standard ones. At the same time a certain degree of dominance among the competencies appear and, accordingly, the model of distribution of credit units of time for competence formation becomes more certain.

4. THE SECOND ALGORITHM

Let us describe the second algorithm developed for forming an assessment of the impact of developing digital economy competencies on the development of the region in the digital economy.

The region's success in the digital economy largely depends on how effectively educational institutions train personnel with the digital competencies. It is assumed that the quality and effectiveness of education affects all the main indicators of the region's performance in the digital economy such as:

– accepted norms and administrative indicators;
– personnel and training programmes;
– research competencies and technological achievements;
– information infrastructure;
– information security;
– economic indicators;
– social effects.

Digital competencies are supposed to be demonstrated in the educational standards of various educational areas. Each educational direction forms digital competencies at a certain level, measured on a certain ordinal scale. The level of competence formation depends on the above mentioned indicators of education digitalization and the number of credit units of time allocated for the development of digital competencies. In this study, a neural network algorithm is proposed to identify the dependence of the resulting indicators of the digital regional economy on the degree of formation of digital competencies in the educational process.

Let us take a look at the steps of the algorithm.

Step 1. A list of key digital competencies is made.

Step 2. A list of all educational standards of higher, secondary professional and further education that are implemented by educational institutions at the regional level is made.

Step 3. A list of digital competencies included in the educational standards defined in the second step is made.

Step 4. The digital competencies obtained in step 3 are being structured for each type of education (secondary professional, higher, further). Structuring includes:

– recognition of the equivalence of two competencies that have different names in different standards;

– recognition of the equivalence of two competencies that implement the same labor function;

– construction of a hierarchical model of convolution of educational standard competencies that are aimed at forming a single digital competence.

Step 5. The level of formation of a certain digital competence as a result of mastering a certain educational programme is evaluated. The level of competence formation is evaluated on a linguistic scale: $< H, T, U >$, where H is the name of the linguistic variable, $T = \{T_1, T_2, T_3, T_4\}$ (where T_1 is a low level, T_2 is satisfactory, T_3 is middle and T_4 is a high level). The basic scale is $U = [1, \infty)$, its values reflect the number of credit units of time covering the dominant competence to the number of credit units of time covering the competence under consideration. The term set of this linguistic variable is demonstrated in figure 8.

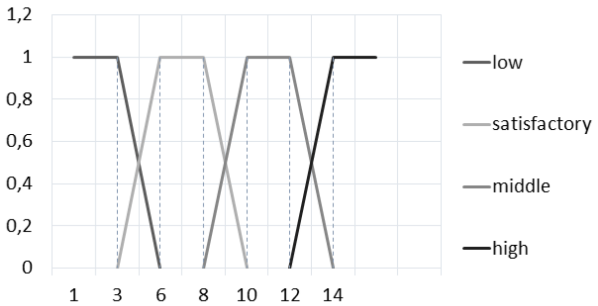

Figure 8 Terms of the linguistic variable named «The level of competence development»

If the competence is elementary, then the number of credit units of time on the basic scale is indicated from the curriculum, but if the competence is obtained as a result of convolution of competencies, then the number of credit units of time covering it is the total number of credit units of time defined for developing these competencies. The term with the highest membership measure is selected for each competence in accordance with the term membership measure.

Step 6. A special distribution bar graph is produced for each digital competence for each type of education. The horizontal axis of the bar graph shows the possible values of the level of competence development (the terms of the linguistic variable), and the bars show the number of educated people with the level of competence development for an academic year (fig. 9).

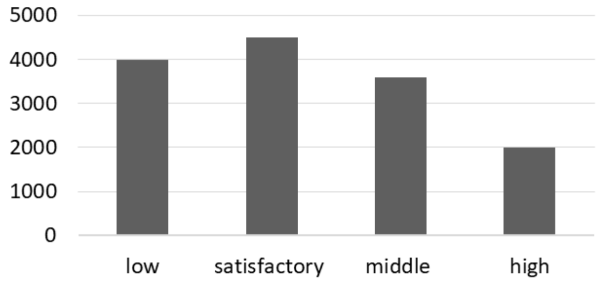

Figure 9 A bar graph of the distribution of the level of competence development

Step 7. The special indices of digitization of secondary professional, higher and further education are introduced. These indices are calculated for each educational institution. The indices are also measured in the linguistic scale described in step 6. One of the methods for constructing linguistic indices is given in [9]. The index is calculated with the use of a hierarchical model, whose main indicators are: the production process (the number of purchases for the provision of services in an electronic form, kept in one information system); technological process (a number of online courses posted on open portals, availability of a platform with an electronic schedule of classes, a number of audiobooks); quality control (a number of subscribers on portals); logistics (a number of online courses in foreign languages); information infrastructure (digital services); information security and human capital. The digitalization index is calculated as the geometric average of the normalized values of individual indicators. A linguistic variable for the digitalization index is introduced, its term set contains such values as losers, followers and leaders.

Step 8. A special distribution bar graph at the regional level is produced based on the linguistic indices of digitalization of educational structures of various types built in step 7. The horizontal axis of the bar graph shows the terms of the linguistic digitalization index and the bars show the number of educational structures in the region that belong to the corresponding category.

Step 9. Training and test sets consisting of vectors of regional indicators are made up for training the neural network algorithm. For each region the following data is specified:

– bar graphs of the distribution of educational structures of each type in dynamics over 5 years;

– bar graphs of the distribution of digitalization of various educational structures at the regional level in dynamics over 5 years;

– sub-indices of the region's performance efficiency in the digital economy listed before the algorithm description.

All indicators are available in open sources. The results of the rating of digitalization of Russian regions can be used as one of the performance indicators of the region.

Step 10. A neural network algorithm is designed to determine the dependence of sub-indices of the region's performance efficiency in the digital economy on the indicators of education digitalization in dynamics listed in step 9 and indicators of digital competencies development in the dynamics. The structure of the neural network algorithm is shown in figure 10.

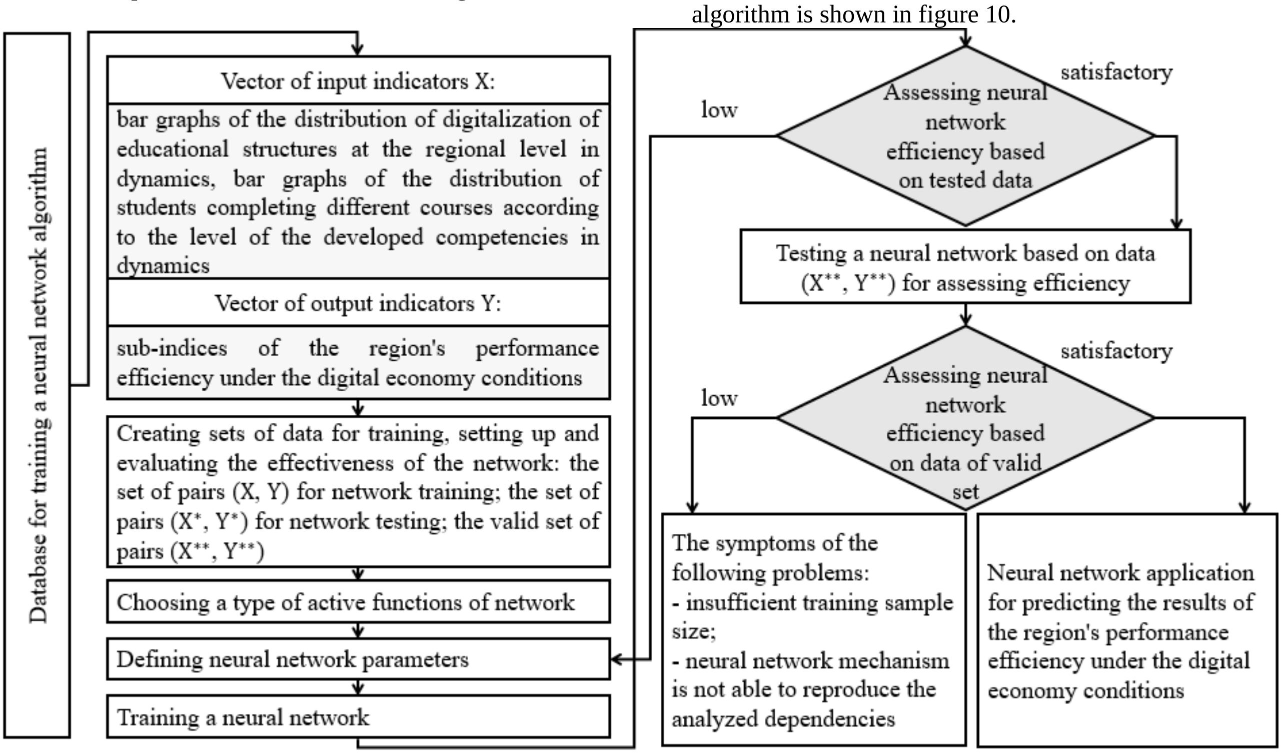

Figure 10 Structure of the neural network algorithm

Step 11. The neural network algorithm is analyzed. The analysis should reveal the dependence of the region's performance indicators in the digital economy on the indicators of digitalization of education and the development of digital competencies. The tools for defining and analyzing the sensitivity of the neural network algorithm allow you to determine the significance of each element of the input parameters. This will make it possible to develop proposals for a promotional strategy towards regional development of education in the era of digital economy.

5. CONCLUSION

This paper examines models and algorithms devised for assessing the competence content of various levels of education and its compliance with the needs of the real sector of the economy. The proposed algorithms make it possible not only to get generalized assessments of competence content, but to work out effective strategies for achieving good results in educational process satisfying the needs of the economy and society in the conditions of dynamic mass introduction of new digital technologies in the industrial and social spheres. The proposed algorithms have been brought to software implementation. They have been tested and are ready for practical implementation.

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