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An intelligent system for monitoring and analyzing competencies in the learning process

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Abstract. The article proposes an intelligent system (a software-analytical complex) based on an artificial neural network for managing the educational process based on data received from corporate business units. Modelling business process improvement involves using the Deming cycle.

The paper presents a structure (model) of a software-analytical complex that makes it possible to identify and trace explicitly interconnected vertical and horizontal processes, which gives a formalized description of the system that meets the algorithm requirements. There is an ontological model of the program analytics complex structure built; it is linked to a set of solutions using databases and knowledge bases; it is divided into classes of objects and categories with hierarchical relationships between them. In order to share this knowledge, a specific description of this data must be provided to the SAC. This description must be formal enough to be understood by another system and written in the same language.

The novelty is in the consideration of a variant of solving the problem of integrating information systems associated with weakly structured subject-oriented information flows of an educational institution using the methods of set theory and category theory. The properties of relations between accounting objects are described at a high abstraction level; it becomes possible to significantly expand the scope of the proposed method for constructing a software-analytical complex based on an ontological model for various subject areas, taking into account the multi-level consideration of the subject area itself, the same consideration of finite and infinite ranges of values. At the same time, the necessary abstraction level is automatically determined to ensure the structural and parametric integrity of the system being formed and the interpretation of the emerging problems of data analysis represented by semantic models.

Keywords: *additional professional education, competencies, Deming cycle, artificial neural network, formal model, software analytical package.*

Knowledge in the modern world should not only correspond to the time, but also to constantly improve and accumulate for their effective application in the future. In various spheres of their activity, enterprises record and replenish knowledge in the knowledge bases of intelligent information systems. However, according to modern conditions, the issues of intellectual management in the educational spheres require developing the implementation of new IT technologies; today there is no intellectual approach to controlling and analysing received competencies in the learning process both for a university and an enterprise.

It is important to note that nowadays the process of introducing information (including intellectual) technologies in the framework of education is at an advanced stage. For example, in a scientific study [1], information technologies are considered as a teaching tool in a higher educational institution. In [2], it was revealed that information technologies in the higher education system increase the education effectiveness. The problem of using information and communication technologies in the educational process of a higher educational institution is considered in [3]. The work [4] considers information technologies in the context of their integration into the modern process of education in higher educational institutions and determines the prospects for their successful application in higher education. The research [5] aims to link information and communication technologies (ICT) in the processes of dissemination and use of knowledge in higher education institutions (HEIs). The study [6] analyzes the impact of information technologies on the education process in universities. The analysis of literary sources has revealed that the problem of intellectualization of information technologies (including for the analysis of acquired competencies in training in the higher education system) is not considered explicitly.

Thus, the task of developing an intelligent system (including a formal model) based on an artificial neural network for continuous analysis of acquired competencies in the process of studying at a university becomes relevant.

The article is further structured as follows:

– section 2 considers a model of continuous improvement of the additional professional education processes;

– section 3 considers the neural network node diagram of the software-analytical complex;

– section 4 discusses the work results.

The model of continuous improvement of additional professional education processes

The main goal of the development and implementation of *additional professional education* (APE) is to provide high-quality education for corporate staff in a continuous production process. In turn, to ensure continuous adaptation and improvement of the educational process at all *life cycle* (LC) stages of the APE, it is most expedient to use the model and the *software analytical complex* (PAC) itself, to control and analyze the acquired competencies in the APE learning process both from the side of the educational institutions, and from the bodies controlling the learning process (departments and ministries of the Russian Federation) and interested enterprises.

Such model will make it possible to determine the information rules for the interaction of business processes, to identify objects in the HSS, to reflect the sequence of business processes and performance benchmarks.

The formal model of continuous improvement of the APE business processes is presented in Figure 1.

In order to organize training in APE programs in the planning process ("*plan*"), regulatory bodies

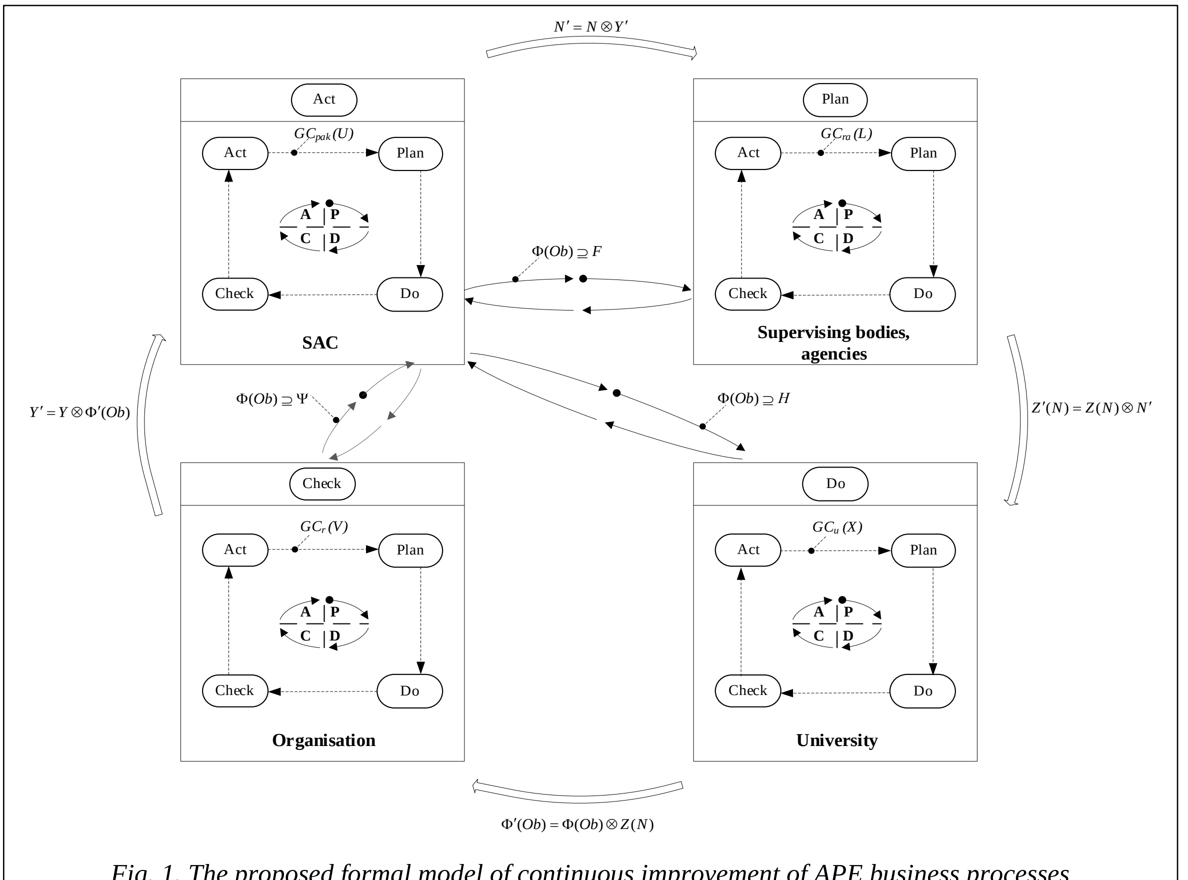

Fig. 1. The proposed formal model of continuous improvement of APE business processes

and departments in federal laws and regulations determine the basic requirements for the process of training students in APE and develop regulatory documents. There is a determined list of necessary software, equipment, laboratories, etc.; it is presented as a function $Z(N)$ reflecting the regulatory documentation for organizing the educational process (plans, work programs, practices, etc.). To eliminate disproportions in the labor market, reduce the employment time of qualified workers in the educational process and increase the level of professional preparedness of the population, a set of goals and objectives of learning processes is set $N = \{n_1, ..., n_d\}$ (where d is the number of goals and objectives) including vocational *retraining programs* (RP).

At each stage of the described business process, the professional competencies $\Phi(Ob)$ of the learner Ob can be evaluated by the function $F = \{f1, …, fi\} \in$ Q reflecting labor actions. Necessary skills in the form of competencies of AVE programs from the state (professional standards, a reference book of professional competencies, etc.) can also be represented by a set of functions $\Phi(Ob) \supseteq F$, where Q is a set of competencies that meet the requirements of the state and employers, i.e., a student's reference model.

The generalized labor functions and actions of the student in the APE programs are achieved by the value of $\Phi'(Ob)$ at the "*check*" stage in the form of a final certification. At the final stage – "action" ("*act*"), it becomes possible to analyze the fulfillment of requirements both by regulatory authorities and by employers; new and popular areas of APE programs are determined in accordance with the economy sectors and professional standards that ensure the competitiveness of the implementation of AVE programs.

At the execution stage ("*do*"), universities draw up curricula, regulations, and work programs for disciplines. During the educational process of APE programs, the object Ob learns new necessary knowledge and skills with new values of $\Phi'(Ob)$ and is reflected in the form of a multilinear function of certain category objects f: $\Phi(Ob) \times Z(N) \to \Phi'(Ob)$. Based on the multilinearity of the mapping and applying the First Isomorphism Theorem [7], we come to the commutativity of the diagram by the representable formula:

$$\begin{cases} f:\Phi(Ob)\times Z(N)\to\Phi_1'(Ob) \\ g:\Phi(Ob)\times Z(N)\to\Phi_2'(Ob) \end{cases} \Rightarrow \exists\, h:\Phi_1'(Ob)\to\Phi_2'(Ob).$$

Accordingly, the composition of morphisms along any directed path depends only on the beginning and end of the path; in our case, the Ob object can achieve the required value of new necessary knowledge and skills through different sequential chains, which opens up opportunities for optimizing the process itself. The universal object of this diagram is the tensor product of $\Phi(Ob)$ and $Z(N)$. That is, we have the formula:

$$\Phi'(Ob) = \Phi(Ob) \otimes Z(N), \quad (1)$$

where the sign $\otimes$ is a tensor product.

According to our construction, all objects of the subject area under consideration are represented by their parameter values. To form various alternative chains, we can use the ordering of objects according to their similarity using the clustering method that represents objects as vectors. The numerical parameters of such vectors are attributes of the corresponding objects and can be interpreted as a geometric location of an object in some space. Taking into account the fuzziness (or incompleteness) of data on the properties of objects, we come to blurring of the boundaries of clusters and fuzzy clustering.

The choice of any alternative chain will be reduced to the option of choosing the components to be taken into account; the best trajectory of the educational process will be chosen according to a set of complex fuzzy criteria [8].

In HSS, it is necessary to use continuous information support of the life cycle of processes. At the life cycle stages of the process under consideration, it is possible to single out the following subsets of criteria for assessing the quality of competencies from different points of view:

a) $GC_u(X)$ – from the university's point of view;

b) $GC_r(V)$ – from the organization's point of view;

c) $GC_{ra}(L)$ – from the point of view of regulatory agencies and authorities;

d) $GC_{pak}(U)$ – from the PAK administrator's point of view.

Strengthening control on the part of the state is reflected in the requirements for students – the subset $L = \{l_1, …, l_k\}$, as well as universities define the requirements in the form of a subset $X = \{x_1, …, x_n\}$, which is used in the main criteria. All requirements are analyzed and controlled in the subset $U = \{u_1, …, u_j\}$, which allows making timely changes and adjustments to the learning process.

In turn, organizations determine the requirements for labor activities, the necessary skills and knowledge of employees, which can be formalized as a subset $V = \{v_1, …, v_m\}$.

There can be following restrictions:

– on the one hand, the requirements for the level of necessary knowledge and skills trained from the professional standard by employers, which we will present in as a function $\Psi = \{\psi_1, ..., \psi_{i_2}\} \in M$;

– on the other hand, university's requirements to the level of students in the programs of further vocational education, which can be represented as a function $H = \{h_1, ..., h_{i_3}\} \in M$, where M is the set of requirements from the professional standard for a specialist, reflected in generalized functions.

The following formulas represent a system that allows achieving personal goals and objectives:

$$\begin{cases} \Phi(Ob) \supseteq \Psi, \\ \Phi(Ob) \supseteq H, \\ \Phi(Ob) \supseteq F. \end{cases} \quad (2)$$

The requirements of the professional standard that determine the experience gained can be represented as a function depending on the set of goals and objectives for implementing additional professional education $Y(N)$. When the requirements change, a set $Y'(N) = Y(N) \otimes \Phi(Ob)$ is formed, for which $Y'(N) \supseteq \Phi(Ob)$ is true. Based on these requirements, a set of refined goals and objectives N' can be formed, represented by the formula:

$$N' = N \otimes Y'(N). \quad (3)$$

In view of the foregoing, the following formula can represent the formation of new regulatory documents:

$$Z'(N) = Z(N) \otimes N'. \quad (4)$$

Thus, a formal model has been developed for the continuous improvement of the business processes of APE during the life cycle of systems, which makes it possible to form a single data repository of the HSS.

An ontological model was built to form the PAC structure. The formal model of the PAK ontology is represented by an ordered triple of the following form [8]: $PAK = \langle M, R, U \rangle$, where: M is the set of HSS modules; R is a set of relations between HSS modules; U is a set of functions performed by HSS modules.

Many scientists mention the effectiveness of using the ontological approach when designing systems using artificial intelligence [8, 9]. Thus, the list of HSS modules can be represented as a finite set of the form $M = \{M_1, …, M_n\}$. The elements of the set M are described by m features $P = \{p_1, …, p_m\}$. Thus, each element M has the form $M_i = \{p^i_1, p^i_2, …, p^i_k\}$, where k is the number of instances of the j-th attribute p of the element M_i.

The list of module functions can be represented as a finite set of the form $U = \{u_1, u_2, …, u_n\}$. The elements of the set U are described by a pair of the following form $u_i = \{name, source\}$, where name is the module *name*, *source* is the set of module functions, $I = 1, …, n$.

Thus, based on the above, the ontology model has the following form: $O^{PAK} = \{PAK, R, U\}$. Figure 2 shows a fragment of the ontology described by this structure. The ontology editor Protege using the OntoGraph plugin was chosen as a software tool for creating an ontology.

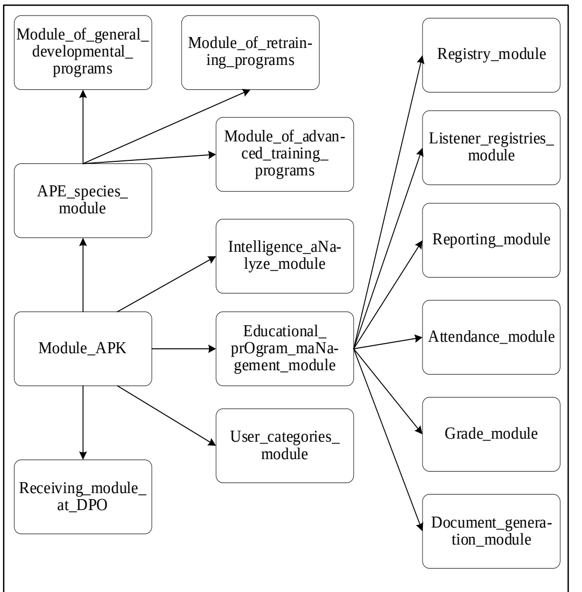

Fig. 2. Ontological model of the PAC structure

The ontological model of the HAC structure is associated with a set of solutions using databases and knowledge and is divided into classes of objects and categories with a hierarchy relationship between them. To share this knowledge, it is necessary to provide a specific description of these data in the PAK. Such description must be sufficiently formal for understanding by another system and also written in the same language.

A scheme of a pak neural network node

Intelligent systems based on artificial neural networks currently allow solving various problems such as pattern recognition, forecasting, optimization, control [10].

The development of a HSS for monitoring and analyzing the acquired competencies when learning under APE programs also provides for the presence of a neural network node, which is an artificial neuron scheme corresponding to a formal model of continuous improvement of business processes based on the PDCA cycle. Thus, the neural network node scheme consists of the following sections: plan, do, check, act (Fig. 3).

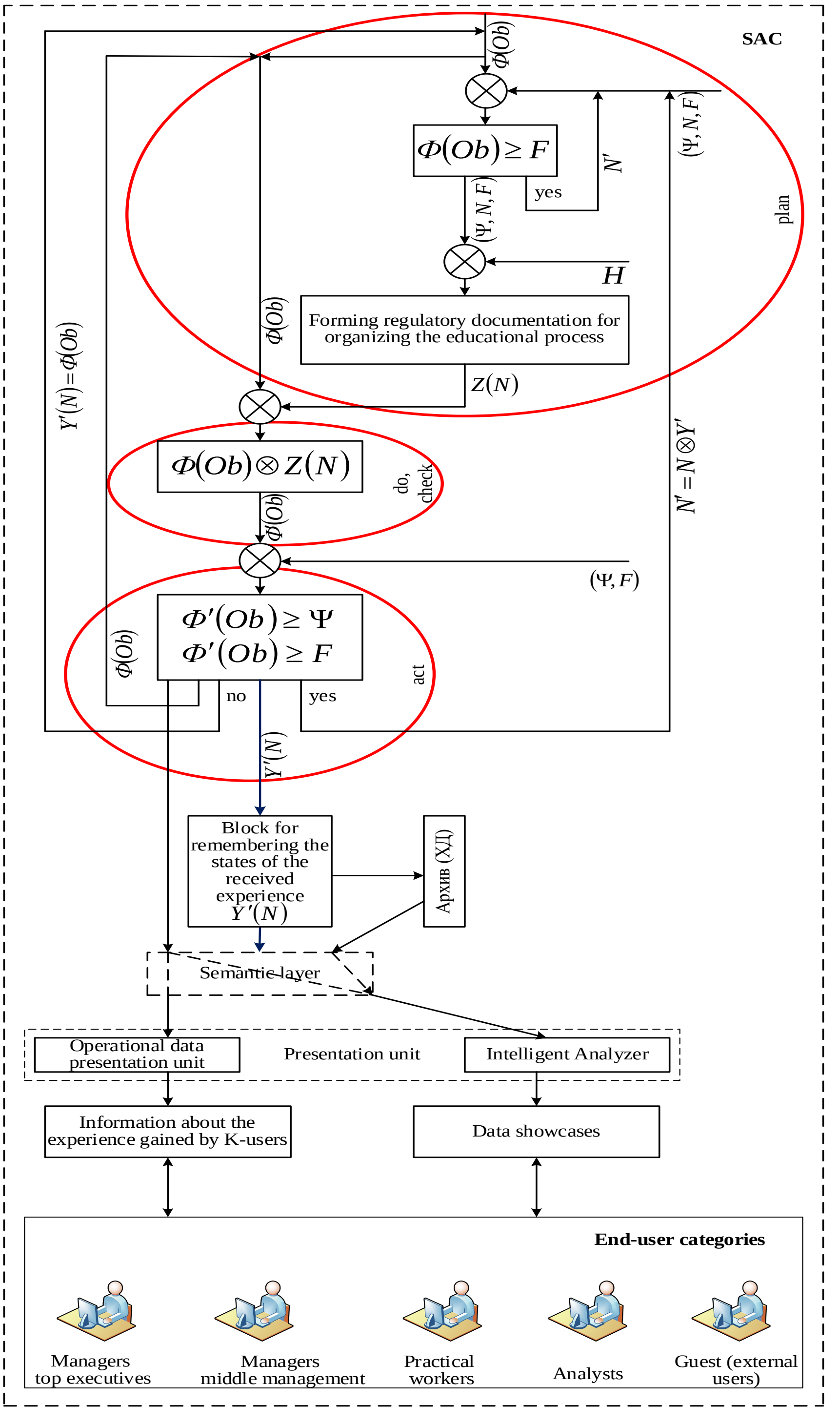

Fig. 3. A scheme of a neural network node (corresponding to the formal model of continuous improvement of business processes based on the PDCA cycle)

In the "plan" section, the input signal is the value corresponding to the trainee's competencies – Φ(*Ob*).

The weight, in turn, is a vector of three elements:

– many requirements for the level of trainees on the part of employers – Ψ;

– a set of goals and objectives of the learning process – *N*;

– a set of requirements for the competencies of trainees from the state (professional standards, a reference book of professional competencies, etc.) – *F*.

In the first block of the "*plan*" section adder, the trainee's competencies are compared with the state requirements for the considered competencies of trainees.

If student's competencies exceed the state requirements, then the weight vector is adjusted in the *PAK* in the section of the set of goals and objectives, which can be achieved, for example, by raising the level of qualifications, etc. If the requirements of the state exceed student's competence, then there will be a transition to the second block of the adder. Here, the vector of the three elements described above is the input, and the weight, in turn, is university's requirements for the level of students in the APE programs.

In the second block of the adder, regulatory documentation for organizing the educational process (plans, work programs, practices, etc.) is formed based on a set of goals and objectives – $Z(N)$.

The "*do, check*" section on the presented scheme of a neural network node involves the implementation of a learning process (training sessions are held according to a training schedule, including at the enterprise's material and technical base). In this case, the input is also a value corresponding to student's competencies – $\Phi(Ob)$, the weight is represented by the documentation for organizing an educational process – $Z(N)$. The adder block of the "*do, check*" section is aimed at replenishing competencies with new values.

The "*act*" section receives competencies as input supplemented with new values – $\Phi'(Ob)$, the weight is a vector of two elements:

1) requirements for the level of trainees from the part of employers – Ψ;

2) requirements for the competencies of trainees from the state (professional standards, a reference book of professional competencies, etc.) – F.

The adder of the "*act*" section is aimed at identifying the compliance of competencies supplemented with new values – $\Phi'(Ob)$ with the requirements for the level of trainees from the employers – Ψ, as well as the requirements for the competencies of trainees from the state – F.

In the case when the competencies replenished with new values – $\Phi'(Ob)$ exceed the requirements for the level of trainees from the employers – Ψ; as well as the requirements for the competencies of trainees from the state – F, in the PAC, the weight vector is adjusted in the section of the set of goals and objectives associated with the refinement of goals, which, similarly to the plan section, can be achieved, for example, by raising the level of qualifications, etc.

If the requirements for the level of trainees on the part of employers are Ψ; as well as the requirements for the competencies of trainees from the state – F are not achieved, then the learning process should be started from the beginning. However, it is necessary to adjust the values of the weight vector of the plan section aimed at lowering the requirements for learning outcomes.

The result of the final certification, which is the output from the adder, section "*act*", is entered into the block for storing the states of the experience gained $Y'(N)$.

Based on the above and the studies [11–13], the sets of objects of each section (Fig. 3) form categories with the vector relations between them that are defined by "adjacent" functors. This allows us to apply the same conclusions to each of the above sections and to consider any of them in detail and use the most important property of adjoint functors – their continuity.

The full functioning of the neural network node is due to paying special attention to such a property of the neural network as the ability to learn based on data coming from the external environment [14–16]. Currently, neural networks are taught by the following methods: supervised and unsupervised. The choice of a method depends on the training conditions of a neural network [17].

The presented diagram of a neural network node involves using a supervised learning algorithm when a training data set is an input, on the basis of which the neural network identifies dependencies and correctly responds to an incoming test data set.

Thus, the knowledge received from a teacher will be transferred to the network in full. After completing the training, a teacher can be turned off and the neural network will go into autonomous operation.

It should be noted that the presented abstract model of a neural network node can also be applied to automate other business processes in the field of education.

Conclusion

We propose the concept and architecture of building a PAC, a researched subject-oriented area in the field of education.

It is shown that it is expedient to use the developed models in implementing HSS in order to perform operational adjustments to the learning process.

The constructed neural network node provides an opportunity to implement a formal model of continuous improvement of business processes based on the PDCA cycle. The result of the work of the presented neuron is the possibility of making the necessary adjustments to the weight vector, to the requirements for the level of trainees on the part of employers, to the set of goals and objectives of the learning process or to the requirements for the competencies of trainees from the state. This approach makes it possible to train highly qualified specialists in priority areas of scientific and technological development of the Russian Federation in accordance with modern Russian and world standards.

Thus, it is advisable to use the proposed models within the framework of implementing a software analytical complex, which will fully ensure the efficiency of correcting the learning process and the quality of graduates.

Considering that all studies were carried out at a high level of abstraction with a description of the properties of relations between accounting objects as mathematically described objects, it became possible to significantly expand the scope of the proposed method for constructing a HSS based on an ontological model for various subject areas, taking into account the multilevel consideration of the subject area itself, the same consideration of finite and infinite ranges of values. At the same time, the necessary abstraction level is automatically determined to ensure the structural and parametric integrity of the system being formed and the interpretation of the emerging problems of data analysis represented by semantic models.

All this contributes to the replenishment of data collections and their preliminary processing with the identification of features, classification, systematization, enrichment, optimization and purification to increase information richness.

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Интеллектуальная система контроля и анализа компетенций в процессе обучения

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В статье предлагается интеллектуальная система (программно-аналитический комплекс) на основе искусственной нейронной сети для управления учебным процессом на данных, полученных от структурных подразделений организации. Для моделирования совершенствования бизнес-процессов используется цикл Деминга.

Представлена структура (модель) программно-аналитического комплекса, позволяющего выявить и проследить связанные друг с другом вертикальные и горизонтальные процессы, что дает формализованное описание системы, удовлетворяющее требованиям алгоритма. Построена онтологическая модель структуры комплекса программной аналитики, которая увязывается с набором решений с использованием баз данных и знаний и разбивается на классы объектов и категории с иерархическими отношениями между ними. Чтобы поделиться этими знаниями, в SAC необходимо предоставить их конкретное описание. Оно должно быть достаточно формальным, понятным для другой системы и написано на том же языке.

Новизна заключается в решении задачи интеграции информационных систем, связанных со слабоструктурированными предметно-ориентированными информационными потоками образовательного учреждения, с использованием методов теории множеств и теории категорий. Описание свойств отношений между объектами учета происходит на высоком уровне абстракции, появляется возможность существенно расширить сферу применения предлагаемого метода построения программно-аналитического комплекса на основе онтологической модели для различных предметных областей с учетом многоуровневого рассмотрения самой предметной области, а также конечных и бесконечных областей значений. При этом автоматически определяется необходимый уровень абстракции для обеспечения структурной и параметрической целостности формируемой системы и интерпретации возникающих задач анализа данных, представленных семантическими моделями.

Ключевые слова: дополнительное профессиональное образование, компетенции, цикл Деминга, искусственная нейронная сеть, формальная модель, программно-аналитический комплекс.

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