Uniform Assessment of the Company's Employee's Competence Using Natural Language Processing Methods for Their Further Use in Corporate Knowledge Management Systems

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Abstract—**Introduction. The article determines the relevance of research in the field of creating uniform forms and methods for describing the knowledge, experience, and competencies of employees for their further accounting in corporate knowledge management systems; a comparative analysis of approaches to describing intellectual capital and employee competencies is presented.**

Approaches and methods. As a methodological basis, the functional subdivision of employee competencies is used according to the sources of its occurrence. The research is conducted based on an ontological approach and Natural Language Processing. The prospects of using the proposed set of methods for describing competencies are demonstrated.

The results of the study. The paper shows that the most effective method of describing corporate knowledge, the carriers of which are the company's employees, is an educational-competence approach that divides such knowledge into four components: competencies acquired in the process of education, work experience, co-author activity, as well as Background knowledge. Moreover, the competencies themselves can be uniformly determined using comparative methods of linguistic analysis using frequency analysis of texts of documents related to the employee. Examples of solving specific problems by using Natural Language Processing methods in solving the tasks of assessing the competencies of employees are given.

Discussion and conclusions. The work conducted has shown the possibility of creating a unified effective methodology for describing the professional competencies of the company's employees, which is an integral part of the general complex of corporate knowledge. The components of the methodology are already widely used in production practice.

Keywords: knowledge management, educational competencies, Natural Language Processing, ontological approach, tacit knowledge.

I. Introduction

To date, one of the most promising areas of full-scale implementation of artificial intelligence systems in all areas of modern industry is the rapid development of industrial knowledge management systems. This leads to the fact that the creation of a corporate knowledge management system based on the competencies of employees becomes one of the modern priorities for the development of the modern economy [1].

It should be noted that the idea of directly considering the experience and knowledge of employees in building business management systems began to be developed quite a long time ago. Already in the fifties of the last century, models were developed to link the knowledge and experience of company employees with the growth rate of production of innovative products, which includes a significant part of their formalized knowledge. Thus, in the work [2] R. Solow described a model of economic development based on knowledge and competencies.

One of the first steps towards building a system of quantitative accounting of production and organizational and technical improvements created in the process of creating innovative products was the K. Arrow model, which describes innovative progress as the main way to increase labor productivity associated with the accumulation of some additional experienced by employees of the company associated with the performance of their direct production duties at the workplace [3].

The next step in clarifying the description of the impact of human capital on improving business efficiency was the model proposed by R. Lucas [1], which took into account the assessment of the comparability of the impact of human and material capital on the innovative production process based on the assumption that in addition to tangible assets, the intellectual contribution of employees is essential in the capital of the enterprise, in essence representing the reification of human knowledge, existing in all intermediate products used for the release of this final product.

In the future, this concept was reflected in the methodology for assessing technological progress through the number of types of intermediate products, called the "Barro and Sala-and-Martin models" [3], which described the process of accumulation of human capital in a commodity product through the function of producing the final product by considering previous technological changes.

In the development of these ideas, G. Becker proposed [4] to present the human capital of the company in the form of two main parts: the knowledge and skills accumulated by its

employees in the process of education and work at all stages of the production of the final product.

However, the resulting analytical models of human capital, although they made it possible to quantify the impact of employees' knowledge and experience on the final cost of the product, still did not allow the creation of a general descriptive model that allowed the company to manage based on assessments of the effectiveness of innovations, since these models in no way described the impact of innovations directly on management processes.

The use of Natural Language Processing methods for semantic analysis of texts created and used by an employee in his/her activity allowed to bring the work on the formal description of competencies to a higher level.

II. Approaches and methods

In the early nineties of the last centuries, K. Wiig published an article [5], which marked the beginning of research in the field of knowledge management. At the same time, according to the European Guide to Good Practice in Knowledge Management, knowledge is understood as a combination of data and information, to which the opinion, competencies, and experience of the subject are added, which as a result gives an asset that can be used to assist in decision-making. Thus, the objects considered by computer science (data, information, model, knowledge, competencies) became the main unit containing quantifiable innovations [6].

The opportunity to start creating systems that determine the systematic management of enterprise development and the pace of creation of its innovations based on the study of computer science categories turned out to be quite a product idea and by the end of the last century, three principal areas of work on the creation of corporate knowledge management systems were formed:

- technologies and methods of extraction and formalization of corporate knowledge [7],
- management of administrative and managerial processes of the company through the influence of knowledge on the business processes of the enterprise [5],
- quantitative assessment of the impact of corporate knowledge manifested in one way or another on the company's financial assets [8]].

In the future, based on the three approaches to the study of corporate knowledge outlined below, a substantial number of corporate title management methodologies have developed, which have allowed solving a large number of corporate governance automation tasks.

So, the methodology of the "knowledge network" (KnowNet) [9] presented a solution to the corporate knowledge management system in the form of a process for managing the strategic values of the company. The CommonKADs corporate knowledge management methodology [10] is an approach to the development of knowledge management systems based on the creation of standard descriptive models structuring the processes of solving problems of converting qualitative knowledge described by experts into a form suitable for quantitative accounting. The methodology of corporate knowledge management processes DECOR [11] is a description of the process of conducting projects for the creation of knowledge management systems, which is created based on combining the CommonKADs methodology and the IDEF5 systems research standard, which allows for an ontological description of complex systems using dictionaries of rules and terms, which makes it possible to draw conclusions about the development of a knowledge management system and optimize it. The On-To-Knowledge methodology developed at the University of Karlsruhe [12], based on the development of methodologies based on the development of CommonKADs and DECOR methodologies, can be used to create corporate knowledge management systems for large companies based on project methods.

The further process of development and implementation of knowledge management systems based on the technologies and concepts listed above has led to the fact that almost all the world's leading industrial leaders have switched to the use of such systems, which are based on the principle of the dualism of knowledge management, which includes a complex of specialized software and organizational management business processes specially built for these company [13].

A distinctive feature of such systems is not only high efficiency but also serious financial costs that the company requires for its full implementation. And if industrial giants can quite afford such investments in knowledge management, counting on a fairly quick return, then smaller companies most interested in the integrated implementation of knowledge management systems are forced to build less comprehensive, but cheaper and no less workable systems based on the fact that the three areas of study listed at the beginning of this article are corporate knowledge allows you to build independent and less costly solutions based on, that the company's KM system can be represented as a controlled process with feedback [14].

At the same time, it should be borne in mind that the entire scheme of the corporate knowledge management process can be effectively used only when a universal carrier of knowledge units is found, used both in the processes of extracting new knowledge, in the processes of corporate governance, and in the processes of evaluating intellectual capital, which is part of the assets of the enterprise.

Such an elementary fragment of corporate knowledge is the competence of an employee, which is the ability to practically use his knowledge in a particular elementary area. A phenomenally successful example of the qualitative definition of employee competencies for their use in corporate knowledge management systems was implemented by Davenport and Prusak [15], who described competencies as a constantly replenishing combination of personal educational and practical experience, as well as surrounding contextual information and intuition. In the future, this personal knowledge, presented in the form of competencies, were subdivided into two large segments [16]:

- educational and competence-based knowledge previously

acquired by employees in previous periods through training and performance of their work duties [17],
- background knowledge, which is knowledge of the subjective features of the world order, which is information known to all members of a certain community [18].

These works laid the foundations of a competence-based educational approach to the description of corporate knowledge, the further development of which is devoted to this work. The use of NLP methods for generalizing corporate documents in order to recognize named entities in them that characterize the competencies of employees has significantly expanded the information base necessary for carrying out work.

III. The results of the study

This article provides a solution to the urgent task of creating a set of techniques that allow step-by-step integration of disparate information systems used by companies into a single knowledge management environment, in terms of a uniform description of competencies, knowledge, and experience of employees of the enterprise.

Let us first draw attention to the fact that the entire body of knowledge used by the enterprise in its activities KK can be divided into two components:

$$KK = KD + K \tag{1}$$

where KK is the total amount of corporate knowledge that is the object of management of the corporate knowledge management system,

KD is the total amount of explicit corporate knowledge that is owned by the enterprise and formalized explicitly in the corporate documentation used and used in the technological and business processes of the enterprise,

K is the total amount of knowledge that the company's employees possess and use in their work; it should be borne in mind that it is the amount of employee knowledge that is most used in creating corporate innovations that are not formally owned by the company but is only attracted for the duration of the employee's employment.

Based on this, any enterprise involved in the active creation of innovations is especially interested in taking into account the knowledge, experience, and competencies of employees by constantly fixing the increment of their knowledge in the form of formalized documents that become the property of the company, and by creating formal methods of comparing competencies that allow replacing one employee with another fairly quickly [19].

The greatest value for the company is the knowledge of employees obtained through their preliminary training. Therefore, a considerable number of works using ontological approaches have recently been devoted to the study and structuring of such knowledge [9].

In 2021, the author of the article conducted work on the transformation of the family of ontologies of ITMO University curricula into subject ontologies of finite competencies using dictionaries of rules and terms implemented based on combining the CommonKADs methodology and some ways of applying the IDEF5 standard .

Thus, taking the ontological approach as the basis for the structural construction of a unified description of the model of educational competencies of a specialist, the generalized ontology of competencies of a specialist in the i-th training program can be presented in the form of a so-called "light ontology" (without taking into account, in the first approximation, a set of rules describing the principles of the existence of concepts) [20]:

$$O_i = \{C, R\} \tag{2}$$

where O_i is the considered ontology of competencies of the i-th educational program, C – a set of concepts describing educational competence, R - a set of hierarchical relationships between concepts.

At the same time, the attribution of the ontology of educational competencies to the class of "light ontologies" in the first approximation allows us to significantly simplify further operations necessary for further manipulation with such structures. This will significantly facilitate the procedures for obtaining summary descriptions of educational competencies, since the operation of combining Light-weighted ontologies can be reduced to merging them. In this case, the ontologies of the educational competencies of the curriculum O_1 and O_2 merge to form the resulting ontology $O_{(1+2)}$ it can be implemented as follows:

$$O_{1+2} = O_1 \vee O_2 \text{ where } O_1 \vee O_2 = (C_1 \vee C_2, R_1 \vee R_2) \tag{3}$$

Consistently using equation 3 for all educational programs successfully mastered by the student, is enough to simply get his total educational competencies for the entire previous period in a formalized and universal form.

This suggests that the task of describing and classifying the knowledge acquired by each employee of the enterprise through training is currently solved in general terms and is reduced to the transformation of standard educational curricula (most of which are formalized in detail by educational institutions) in the ontology of the final competencies of graduates. And now when a trained specialist comes to the company, it is these competencies that become part of the corporate knowledge associated with the company's workforce.

At the same time, a significant role in the total competencies of employees is also the professional experience gained by them because of their practical detail, as well as the knowledge gained by MIM in the process of communicating with colleagues. The influence of these components on general corporate knowledge is especially noticeable in research centers and innovative enterprises, where the qualification of an employee increases significantly during the period of his research activity [21].

In this regard, the next step in the development of a formalized description of corporate knowledge was the proposal formulated in [22] not only to consider the total competence

knowledge of innovation employees in the form of a cumulative set of basic competencies in the equation 1,

$$K = \sum_{i=1}^{N} \sum_{j=1}^{M} K_{ij} \quad (4)$$

where N is the total number of employees of the company, M is the number of concepts of educational competencies accepted for consideration, K_{ij} is a quantitative description of the j–th competence of the i-th actor.

But also consider the individual competencies of each of the company's employees as a composite quantity 5:

$$K = K_0 + K_1 + K_2 + KB \quad (5)$$

where K0 is the educational competencies of an employee of the company determined by the operation of merging his educational ontologies, K_1 – additional competencies of a specialist obtained during the period of production activity, K_2 – "social/co-author" competencies, which are the research competencies of the specialist's environment, KB – background competencies of a specialist, representing information that is certainly known to all members of the community.

The proposal to consider the individual competencies of an employee in the form of a superposition of specialist competencies related to his education, work experience, and non-production-related social communications and certainly known to all members of the community because they represent complementary qualities of the performer of work. However, all these competencies, having various sources of occurrence for each employee, manifest themselves differently in human production activities, which means they require specialized methods of their assessment and should be presented in the form of components that differ from each other. Table 1 shows a comparative assessment of the parts that make up the employee's competence, determined by the equation 5.

TABLE I. COMPARATIVE ASSESSMENT OF THE COMPONENTS OF AN EMPLOYEE'S PERSONAL COMPETENCE

Parameter	**Competencies related to education**	**Competencies related to work experience**	**Competencies related to co-authorship**	**Competencies related to background knowledge**
Notation in equation 5	K_0	K_1	K_2	KB
The type of knowledge	Implicit knowledge	Implicit knowledge	Tacit knowledge	Tacit knowledge
Method of definition	Studies based on frequency analysis of texts	Studies based on frequency analysis of texts	Studies based on frequency analysis of texts	Studies based on frequency analysis of texts
Sources of occurrence	Educational programs and curricula of courses previously mastered by the employee	"Incoming" and "outgoing" production documentation concerning the employee	Texts of the work of the co-authors of the employee on his scientific articles	Texts obtained because of the procedures for extracting background knowledge
Divisions of the company interested in information	HR Department	HR Department, Production Department, Planning Department	HR Department, Production Department, Planning Department	HR Department, Customer Service Department

At the same time, if it is easy enough to obtain the educational competencies of an employee of the company by conducting a consistent analysis of all the training programs he has completed, then to determine the components of the competencies K_1, K_2, and KB, it is necessary to develop slightly different methods of identification. This is because, unlike educational procedures, the employee's production activities, especially those taking place in the innovation production environment, are quite difficult to formalize and structure in advance.

IV. THE RESULTS OF THE STUDY

Based on the purpose set and the availability of developed and tested methods of analysis, work was conducted to create unified mechanisms that allow, based on the analysis of formal sources, to determine the competence of a specialist.

First, we will determine the additional competencies of the specialist that he received during his production activity (the term K_1 in equation 5). Moreover, this process will be conducted based not on the analysis of the features of the activities conducted by him but based on their result.

At the same time, we will be based on three statements stating the following:

- the new competencies of the employee received during the period of activity are the development of his previously accumulated competencies and can be added to his previously accumulated competencies by enriching the earlier ontology of competencies [23],
- all newly revealed knowledge is verbal, and can be expressed in terms of existing knowledge, representing some concepts of educational ontology [24],
- thirdly, if concepts (terms) and contextually related concepts often appear in incoming and outgoing documents related to the employee under study, then it can be assumed that he is competent in the field described by these concepts.
- Thus, the task of determining the additional scope of competencies (term K_1) obtained by a particular employee can be reduced to a sequence of the following actions:
- definition of new concepts that it encounters in his work in "incoming" and "outgoing" documents,
- enrichment with newly identified concepts of the initial competence ontology of the specialist.

At the same time, the task of "enriching" a certain "unsteady ontology" of competencies is being solved by analyzing a collection of texts related to the current activity of a specialist, followed by the inclusion of newly identified concepts in the updated ontology.

Thus, we have a certain initial ontology of competencies $O\{\}$, describing concepts (terms), and employee competencies, and there is a certain corpus of new KDocs documents containing "incoming" and "outgoing" texts that the employee worked with during the period under study, containing a set of terms not previously encountered in his educational competence.

Then the task of modifying the educational ontology of the OModif employee's competencies with newly identified

concepts can be quite simply illustrated by the scheme on Fig. 1.

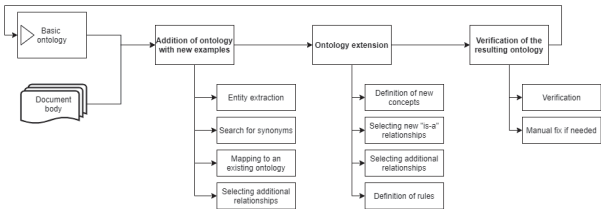

Fig. 1. The workflow of the process of enriching the ontology of the employee's competencies with new concepts identified in the corpus of texts (incoming and outgoing) with which he worked during the period under consideration

At the same time, the enrichment of the ontology of employee competencies with new concepts can be conducted by consistently solving the following tasks:

- extraction of entities with signs of newly identified concepts (terms) for this employee throughout the body of texts under consideration [25],
- definition of concepts semantically related to the newly identified term [26],
- construction of relations and rules linking newly identified concepts based on methods of semantic relations extraction,
- the expansion of the ontology of the employee's competencies should be carried out taking into account the small volumes of the corpus of the studied texts [25].

When implementing the algorithm presented in Fig. 1, to solve the problem of eliminating the possibility of excessive entities appearing in the created formal ontologies, the problem of eliminating the ambiguity of terms must be solved without fail.

A similar problem can be solved using the skip-gram machine learning model, which is used to search for related xi words for a given text of length n. The use of Adaptive extensions of the standard Skip-gram model makes it possible to solve the problem of word ambiguity by introducing a hidden variable z_i.

$$p(y, z|x) = \prod_{i=1}^{N} p(z_i) \prod_{j \in c(t)} p(y_{ij}|z_i, x_i) \qquad (6)$$

where x_i - the $i-th$ word in the text of length N, y_i - the context of the word x_i, z_i - the number of the meaning of the word x_i.

At the same time, the process of finding new concepts in the author's texts that characterize his acquired competencies can be carried out either by conducting a frequency analysis of the author's texts [27], or (for serious simplification) using the keywords of his texts and in their absence in the text – by the method of thematic modeling of the text of the article [28].

Having completed all the above actions, as a result, we will receive an updated ontology of the competencies of the employee in question, the difference between which and the initial educational competence will be, according to the assumptions we have made, the additional competencies of the employee K_1, obtained based on the analysis of those incoming and outgoing documents with which he worked.

The applied values of such an analysis can be data received by the information systems of HR departments related to the processes of staff development and issues of intra-corporate functional migration [29].

At the same time, when analyzing the contribution of a researcher carried out exclusively according to the outgoing texts of his published scientific articles, the identification of the K_1 term by the above algorithm makes it possible to fully assess his specific scientific productivity both in the direction of research conducted in the organization and the work that the employee performs on an initiative basis. In this case, the mechanisms of internal corporate HR regulation can receive the necessary information about the expansion or modernization of the organization's research plans.

The next step is to consider the process of identifying the component of employee competencies K_2 (see equation 5) describing his "social/co-author" competencies. This part of the competencies is most characteristic of researchers and researchers and represents the research competencies of the scientist's environment. Their presence and the possibility of accounting for the total competencies of an employee of a research enterprise is explained by the fact that a significant part of the time is spent by the researcher in formal and informal contact with his scientific environment, including completely unrelated to the company in which the scientist whose competencies are being considered works [30].

Because measuring the activities of research organizations based on the analysis of the co-authorship of its employees is a well-established practice [31], [32], it makes sense to use its approaches when determining the total individual competencies of a particular researcher.

For a particular researcher (let us call him Emmett), the "social/co-author environment" (often unrelated to production duties) from a formal point of view are the co-authors of his published scientific texts. At the same time, if we conduct a complete analysis of all the scientific texts of Emmett's co-authors, according to a workflow similar to the one shown in Figure 1, it is possible to simply single out a set of additional K2 competencies designed in the form of an ontology, which Emmett himself does not possess, but which the co-authors of his works possess. At the same time, it can be assumed that such competencies are easily available to the company where Emmett works, either at the level of consultations or in the form of involvement in work as part of a temporary labor collective [33]. The set of additional competencies of each K_2 employee should be considered with a certain reduction coefficient, considering the probability of connecting or not connecting co-authors to new Emmett research.

In conclusion, we will describe approaches to identifying the component of an employee's competencies related to his background knowledge (term KB of equation 5), which is

information known to all members of a certain community and not always documented in one way or another, and, therefore, mostly related to implicit knowledge.

Currently, the creation of methods for formalizing implicit background knowledge for use in corporate knowledge management systems is still in the initial stages of development. However, applying the assumptions formulated above about their verbality and the possibility of being explicitly embedded in the educational competencies of employees to background knowledge, it seems possible to use methods of formalizing implicit background knowledge by analogy with background knowledge research conducted in the linguistic theory of translation that is currently sufficiently developed [34], [35]. At the same time, as operational methods for extracting background knowledge by studying the thesaurus of "everyday oral texts" of the subject, involving the analysis of everyday use of the language "in live communication", various types of specialized testing of oral and written storytelling of the subject on a given set of topics, as well as more complex practices can be used [36].

The efficiency of the methods proposed in this article for assessing the qualifications of employees of enterprises has been tested in practice by the work of the department engaged in recruiting personnel of a pharmaceutical company [37]. At the same time, three types of tasks were solved to determine the degree of compliance with the requirements of the vacancy of the qualification of a specialist hired to perform standard work:

- an employee of mass professions performing simple standard operations,
- a qualified specialist trained according to the described educational standards (followed by the definition of a roadmap for retraining in the workplace),
- a scientist carrying out research in an innovative field of knowledge, involved in the production of similar (but not identical) works in the research department of the company.

Because when solving this problem, a comparison of a limited number of concepts of competence ontologies was required, its solution could be carried out using a limited set of texts. Therefore, it was carried out by the method of direct semantic comparison of the texts of the formalized vacancy requirement and the applicant's resume by keywords using POS-tagging, recognition of named entities, and comparison of synonyms of key concepts.

Solving the tasks of the second category required comparing a much larger number of employee parameters characterizing his educational level and the qualification requirements of the employer. Therefore, to assess compliance, not only formal requirements for the vacancy and the applicant's resume were used, but also sets of documents describing the applicant's detailed qualifications (according to the training programs he completed) and documents describing in more detail his job responsibilities at his future workplace. Using the methods of analyzing these texts listed above, it was possible to create a methodology for determining the compliance of a qualified applicant with the requirements of a vacancy, but also to build a roadmap for his further training in the workplace [37].

The need to solve problems of the third type arises when the K1 obtained by an employee in the course of his scientific activity (according to the expression 5) is decisive and independently acquired by a researcher in a "developing field of knowledge" with an unsteady structure of concepts. Tasks of this kind have to be solved when it is necessary to evaluate the possibility of quickly including a researcher in a research team of a similar, but not the same research direction.

This requires the creation of special procedures for assessing specific knowledge in the innovation field. Such a task can be solved based on determining the degree of semantic correspondence of the researcher's scientific texts and the formal requirements determined by scientific texts generated in the direction of research of his possible vacancy.

At the same time, the degree of semantic correspondence of texts can be determined by directly comparing vector representations of texts generated by a neural network model of the language trained on the applicant's scientific publications and texts of scientific materials with which he will work at his future workplace. To do this, a pre-trained GloVe (Global Vectors) language model was used in the results of a worthless study [38]. At the same time, the vector proximity of the required and available competencies will be determined by calculating the cosine of the angle between the directions of the vectors p and s, built based on the collections P and S (representing the studied arrays of texts of the scientist and his new working group, respectively):

$$sim(p,s) = \frac{ps}{||p||||s||} = \frac{\sum_{i=1}^{n} p_i s_i}{\sqrt{\sum_{i=1}^{n} p_i^2}\sqrt{\sum_{i=1}^{n} s_i^2}} \qquad (7)$$

where p is the resulting vector of the collection P obtained by processing a previously trained with GloVe model of the collection of texts of scientific publications of the author, s is the resulting vector of the collection S obtained by processing with GloVe a previously trained model collection of scientific texts describing the research areas of the working group he wants to join.

The degree of proximity of $sim(p,s)$ to the unit will indicate the compliance of the researcher's knowledge with the requirements of the scientific vacancy.

As for the set of explicit corporate knowledge KD (see equation 1), because of them are presented in the form of various text documents, they are also by semantic analysis of texts to identify semantic units in them that are similar in meaning to the concepts that make up the educational ontology of the enterprise describing competencies company personnel.

However, because the systematization of the concepts underlying the explicit knowledge recorded in corporate documents occurs, as a rule, based on an object-industry approach expressing the features of that main area of activity of the enterprise, the description of knowledge based on them will not significantly coincide with the structures of the competencies of employees based on initial educational competencies

(see equation 5). In this regard, to share an explicit corporate knowledge of KD and the competencies of K employees (see equation 1) as part of a single corporate knowledge management environment, they should be brought to a single comparable form. For this purpose, it is necessary to conduct procedures for identifying correspondences between the ontology built in the concepts of object-branch ontology and the competence ontology of employees based on educational ontologies. This is a complex task that requires additional consideration beyond the scope of this work, and its solution will be considered in the future.

V. Discussion and conclusions

As a result of the conducted research, the following conclusions can be drawn that are important for the further development of practical methods and methods for evaluating and evaluating employee competencies in corporate knowledge management systems of companies.

Firstly, the most effective method of describing corporate knowledge as a constantly replenishing combination of personal educational experience, surrounding contextual information, individual values, and intuition is an educational competence approach that divides such knowledge into four components: competencies acquired in the process of professional education, work experience, co-author activity, as well as Background knowledge.

Secondly, all the four components of employee competencies listed above can be described in a uniform way through the concepts of initial educational competencies, which may indicate the construction of a single formal methodology designed to describe the total competencies of an employee.

Thirdly, when creating methods for identifying employee competencies, comparative methods of linguistic research based on the frequency analysis of texts or documents related to an employee are most applicable.

Fourth, the methods described in this paper for describing individual competencies of employees have proven themselves well in solving several practical tasks related to the recruitment of qualified personnel.

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