Mathematical support for automated candidate selection using a documentary approach to assessing their competence⋆

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Abstract

This paper proposes an approach to formalizing the profile of higher education programs by constructing a matrix of links between disciplines and program learning outcomes. The concept of quantitative measurement of the contribution of each discipline to the achievement of program outcomes through the use of ECTS credits is introduced. Such a model allows for increasing the transparency of the structure of educational programs, ensuring their adaptability to changing labor market conditions, and identifying possible gaps in the educational process. The formulation of the task and the mathematical model of automated candidate selection using a documentary approach, which is used to assess their competence, are also considered. The stages of candidate selection and the tools for determining the similarity between job requirement profiles and candidate documentary profiles are presented. The purpose of the work, the formulation of the task, and the mathematical model of automated candidate selection are described. The educational trajectory is also considered as an indirect justification for the use of a documentary approach in personnel selection and in the tasks of assessing the competence of experts.

Keywords

candidate selection, expert competence, documentary approach, similarity measure, model, formalization, individual educational trajectory

1. Introduction

Ensuring automated ranking of candidates for positions based on a documentary approach is a pressing issue, the resolution of which will contribute to the objectification of many personnel selection problems, in which the human factor always plays a necessary role.

In the context of rapid technological development and constant changes in the labor market, ensuring prompt and adequate personnel assessment is a pressing issue. The reason for the constant attention to objective and reasonable assessment is the need to take into account the subjective aspects of decision-making in all procedures related, in particular, to the selection of candidates for various selection and decision-making tasks.

2. Review of research in this scientific field

The development of higher education programs requires ensuring that their structure meets the current requirements of the labor market, professional standards, and student needs. One of the key tasks is to ensure the transparency and adaptability of these programs [1, 2]. Formalizing an educational program through its profile allows for establishing clear links between competencies,

program outcomes, and educational components. The diversity of educational programs creates difficulties when transferring students between programs, especially in the context of minimizing the loss of existing competencies and program outcomes [3, 4].

The purpose of this work is to describe approaches to automating the assessment of candidates' suitability for vacant positions, as well as to describe and develop a formalized model of an educational program profile that ensures flexibility and adaptability in the organization of the educational process and the transfer of academic credits to higher education applicants. Based on the above formalization, the application of a documentary approach is considered when selecting candidates for expert groups or for certain positions that allow for such a formal comparison. At a minimum, this technology can be applied in the early stages of candidate selection.

Such approaches minimize the influence of subjectivity in the selection and recruitment of personnel. An automated approach can be useful in decision-making situations characterized by the following factors:

- A large number of candidates.

- The possibility of reliable self-presentation.

- The task involves a very significant subjective factor, etc.

The subjective aspect of decision-making regarding personnel assessment, in turn, depends significantly on the adequacy of the tasks facing the expert group and on the assessment tools used. The arsenal of expert assessment methods is quite broad, but the choice of the most attractive methods from among the available tools plays an extremely important role and significantly influences the final results [5, 6]. The human factor becomes a strategic aspect in the development of an enterprise in today's unstable market conditions [7, 8].

3. Problem setting and mathematical model of automated candidate selection using a documentary approach

Let us assume that in a decision-making situation related to human resource management, there is a requirement for the level of education of candidates and the possibility and necessity to formalize the requirements for the work experience required from the candidate. We will assume that this requirement is characterized by a vector consisting of two elements
An Example of equation

$$x = (x1, x2). \tag{1}$$

In vector (1), element $x1$ corresponds to the field or fields of knowledge in which the candidate received their education and, in turn, consists of three elements:
An Example of equation

$$x1 = (x11, x12, x13), \tag{2}$$

x2 – work experience, which in turn is also a vector and consists of two elements:

$$x2 = (x21, x22), \tag{3}$$

x21 – candidate's field of activity;
x22 – length of service in the relevant position in years or number of expert assessments officially carried out by the candidate.

Thus, developing a profile of the ideal candidate means, first and foremost, formalizing a set of skills, assessing competencies, and determining the level of experience.

The methods for setting requirements for the documentary level of candidates have the same format as the requirements for the position or the profile of the ideal candidate of type (1)-(3). That is, depending on the practical situation, the recruiter or the candidates themselves provide feedback in the form of vectors of type

$$qi = (qi1, qi2), i \epsilon I = \{1, \dots, n\}, \tag{4}$$

where qi1, in turn, is also a vector consisting of three elements

$$qi1 = (qi1, qi12, qi13), i\epsilon I. \tag{5}$$

The values of the elements in formula (5) correspond to the specialties in diplomas, respectively, of levels 1, 2, and 3 of education obtained by the candidate. If the candidate does not have a diploma of the corresponding level, the value of the element corresponding to this level of education is set to zero in this case.

The second element of vector (4), in turn, is also a vector consisting of two elements:

$$qi2 = (qi21, qi22), i\epsilon I. \tag{6}$$

Work experience in expression (6) is selected from a menu that formalizes the candidates' fields of activity.

Note 1. In all values of vectors (1)-(6) and their elements, it is permissible to use logical expressions with the disjunction & and conjunction V signs.

Based on the analysis of vectors (1)-(3) and (4)-(6), it is necessary to determine the degree of proximity between the requirements of the employer or selection organizer and the profiles of candidates [9]. Subsequently, after calculating these proximity measures, a rating is compiled and a selection is made.

Heuristic H1. The quality of the educational trajectory is sufficient to assert that the holder of a higher education document has sufficiently mastered the declared program outcomes and acquired the relevant competencies.

The rationale for heuristic H1 is described to some extent in this paper below in the section "Educational trajectory as a rationale for using a documentary approach."

The quality of the educational trajectory can also be determined based on testing candidates [10]. Depending on the educational trajectory, it is possible to predict the mathematical expectation of competence acquisition.

Heuristic H2. The distances between programs adequately reflect the correlation between the knowledge, skills, and competencies of holders of diplomas or other documents certifying different levels of higher education: bachelor's, master's, or doctor of philosophy.

Based on heuristics H1 and H2 and the mathematical model described by formulas (1)-(6), metrics can be applied to measure the distances between job profiles (1)-(3) and candidate profiles (4)-(6). Let us introduce a metric based on which we will determine the distances from the profile of the ideal candidate, i.e., the "standard" given by formulas (1)-(3), to the profile of each of the candidates of type (4)-(6)

$$di = d(x, qi), i\epsilon I. \tag{1}$$

To do this, we first create an expert-based similarity matrix of specialties Ms and a similarity matrix of fields Mg. We also introduce additional heuristics that reflect various relationships between different specialties and different fields of knowledge.

At the next stage of selection, based on the results of technical interviews and assessments of the candidates' experience and its duration, the values obtained in (4)-(6) are refined, depending on the level of the position. In doing so, emphasis may be placed on creativity, diversity of interests, depth of specialized knowledge, breadth of views on future activities, etc.

An important element in determining the ranking of candidates for vacant positions in an organization is the use of a comprehensive approach to candidate assessment. In particular, a decision on the level of a candidate's suitability for the proposed position can be made based on the results of a technical interview and assessments of the relevance and duration of their experience.

4. Stages of decision-making regarding the selection and recruitment of candidates for positions

Let us describe the structure of the personnel selection and recruitment processes.

Staff selection or recruitment is a multifaceted process that includes searching, attracting, selecting, interviewing, and hiring. In turn, staff selection is the evaluation and selection of those who are already involved in the recruitment process. In general, it should be noted that it is only possible to verify the reality of candidates' competencies based on the results of a probationary period, and even such verification is often largely probabilistic in nature.

Personnel selection is one of the stages of recruitment that focuses on assessing the professional and psychological qualities of candidates. Candidate selection involves evaluating resumes, analyzing competencies, determining the level of professionalism, conducting interviews, and testing [9, 10].

The assessment of candidates usually consists of conducting interviews, testing their knowledge and skills, and evaluating their suitability for the corporate culture [11, 12].

Determining the degree of suitability of candidates for vacant positions can be interpreted as the distance to the ideal. Therefore, selection procedures should be preceded by the development of a profile of the ideal candidate, which may include a set of skills, competencies, experience, etc. [13, 14].

Among the most popular approaches to personnel assessment at the selection stage are:

- determining the suitability of the candidate's profile to the job profile
- testing candidates
- establishing selection rules and preliminary classification of candidates
- documentary approach, etc.

Moreover, each of these approaches is multifaceted, diverse, and ambiguous in its application. Possible areas of application for automated rapid analysis of candidates, which can be used in practice in various decision-making situations:

- selection of experts to form an expert group in various fields of activity and in various subject areas
- selection of reviewers for student research competitions
- selection of reviewers and opponents when forming ad hoc academic councils for the defense of doctoral dissertations
- initial selection of members of specialized academic councils for the defense of doctoral dissertations
- selection of candidates for a certain vacant position
- preliminary assessment of candidates in various competitions using sequential analysis and screening out options that are unlikely to be successful in advance [15, 16]
- formation of program committees for international conferences [17]
- formation of editorial boards of scientific journals [18], etc.

5. Features of collective expert evaluation

An important element in the selection of candidates for vacant positions in any organization is the consideration of various aspects of collective decision-making in expert evaluation, in particular, the consistency of assessments.

The concept of consistency is applied in four aspects:

● if a relation is given on a set of candidates and a certain resulting relation is selected, consistent with the given

● when analyzing the consistency of experts or selection methods based on the relations they specify on a set of candidates without determining the resulting relation

● for metrized preference relations, the concept of cardinal consistency in strength of preference or supertransitivity is introduced

● in some decision-making situations, consistency is understood as the task of determining the ranking of candidates for vacant positions according to a metrized or qualitative matrix of pairwise comparisons that corresponds to a non-transitive relation.

The accumulated experience of expert assessment in various fields of human activity convincingly demonstrates that any statistical operations become more useful and justified when the number of characteristics used for analysis is reduced. Therefore, the problem of aggregating candidate characteristics into a smaller number of constructed factors, aspects, etc. occupies a significant place in personnel selection tasks. The analysis of the set of expert assessments of the entire group of experts or the selection methods used consists in determining the level of overall consistency of expert assessments and, if necessary, identifying homogeneous subgroups within the group that bring together experts with consistent assessments. These tasks are dictated by the fact that the transition to the aggregation of expert judgments is possible only after the structure of expert judgments has been identified. For example, if the overall consistency of expert assessments is low and the expert group is divided into several subgroups within which the consistency of expert assessments is high, then the expert judgments for these subgroups should be aggregated. Kenneth Joseph Arrow [19] formulated five axioms that correspond to the intuitive idea of fair group choice:

● axiom of universality

● the axiom of connection between group ordering and individual ordering – the condition of monotonicity

● Axiom of independence of disconnected objects

● Axiom of sovereignty of group members

● the axiom of the absence of a dictator.

Kenneth Arrow proved that when there are more than two objects, there is no rule for the consistency of individual preferences that would satisfy all of the above conditions (Arrow's paradox). The problems and main results in the field of group choice are discussed in detail by Herve Moulin in [20]. He also provides a classification, description of methods, algorithms, and procedures that are widely used in the global practice of collective expert assessment.

6. Personnel selection tools in the context of personnel assessment approaches

When assessing personnel, in particular when determining the level of relative competence of experts, the following groups of assessment tools are the most common, popular, and effective [21, 22]:

- Documentary approach
- Self-assessment
- Peer assessment
- Combined methods
- Testing
- Objective approaches: Effectiveness of participation in previous assessments; Based on the results of a control assessment; Research on participation in a specific assessment.

The above-mentioned tools for assessing candidates for vacant positions in an organization are presented in more detail in Table 1.

Table 1
Tools for assessing candidates for vacant positions in the organization

Approach number	Approach name	Comments
1	Documentary	It causes distrust due to the methods of formalization and consideration of objective data about experts, as well as the tendency characteristic of modern times to devalue official documents and the uncritical nature of some institutional decisions
2	Self-assessment	When conducting the expert self-assessment procedure, information is often obtained about the expert's level of self-confidence rather than their actual competence.
3	Peer assessment	In some tasks, confrontation may arise within the expert commission and among its members, which sometimes distorts the actual individual competence of experts.
4	Combined methods	Instead of a synergistic effect, processing unreliable data obtained by different methods in some cases leads to the accumulation of cumulative error
5	Testing	A psychodiagnostic method, which is a process of assessing the competencies, knowledge, skills, and personal qualities of candidates to determine their professional suitability for the position, compatibility with the corporate culture, and development potential
6	Objective approaches	Relatively reliable methods for determining the level of competence of experts, the adequacy of which can be assessed and justified to a sufficient degree

7. Mathematical model of alignment between competencies, program outcomes, and educational components

The higher education system in Ukraine is undergoing profound reforms related to the transition to a competency-based approach and the updating of state standards. According to Order No. 441 of the Ministry of Education and Science of Ukraine dated April 3, 2024, the new standards no longer define program outcomes, but only outline integral competencies and a list of general and professional competencies. The formulation of program learning outcomes is entrusted directly to the developers of educational programs, which, on the one hand, increases the autonomy of educational institutions, and on the other, creates the challenge of ensuring transparent and reasonable correspondence between program learning outcomes and the competencies defined by the standards.

In such conditions, the content of educational components (disciplines) becomes crucial. Disciplines are carriers of knowledge and skills that, through the formation of program learning outcomes, ensure the achievement of graduate competencies. Gaps or duplications in course topics or imbalances in their structure directly affect the quality of training, even if the program formally covers all the necessary program learning outcomes and competencies. In this regard, it is important to find formal tools that can assess the quality of educational content not only at the level of an individual course, but also in the context of the entire educational program.

Formal models that can not only describe the structure of educational content, but also provide a quantitative assessment of its consistency with program outcomes and competencies. To find such models, let us turn to contemporary research that applies mathematical, ontological, and categorical approaches to structuring educational content.

7.1. The educational trajectory as an indirect justification for the possibility of using a documentary approach

The structure of higher education standards by specialty provides for general and specific competencies that are ensured by program outcomes. Based on higher education standards, higher education institutions develop their own educational programs, which differ in the set of educational components and the distribution of ECTS credits allocated to these educational components. In addition, higher education institutions independently determine how disciplines ensure the formation of program outcomes.

Based on the documents submitted by candidates for vacant positions in the organization, it is possible to reflect the quality of their educational trajectory.

The mathematical model of the selection process is based on the KFS (Knowledge Flow Structure) model. The relationship between competencies, program outcomes, and educational components can be represented as a KFS model (Fig. 1).

For each educational program, a matrix can be created in the following format

$$(M) = (m_{ij})_{k \times n}, \tag{8}$$
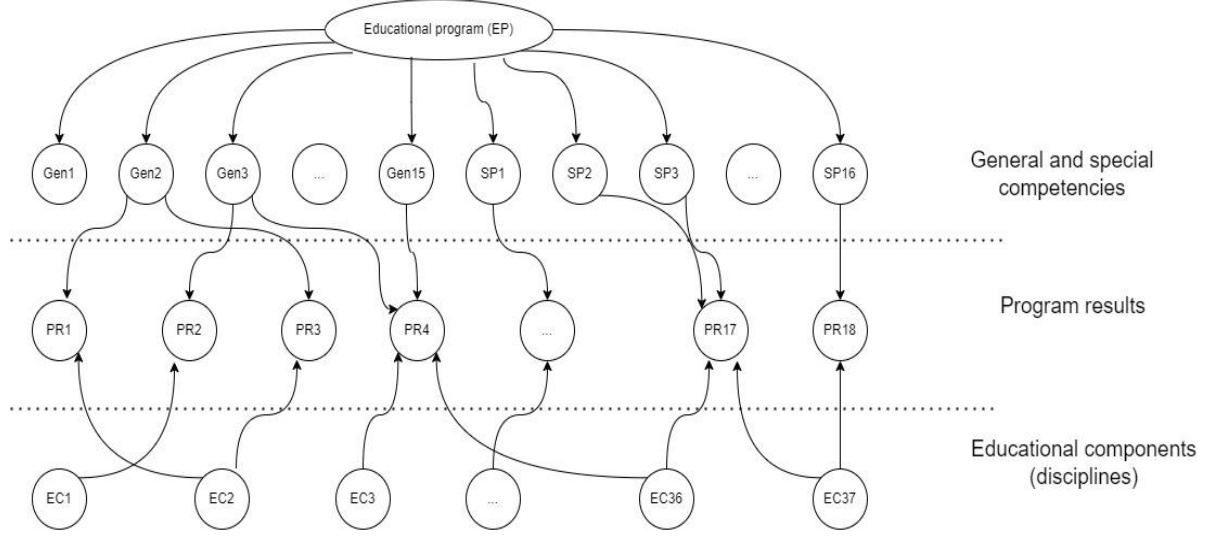
where: i – number of the educational component;
j – program outcome number.

The elements of the matrix of type (8) reflect the number of credits of the European Credit Transfer and Accumulation System aimed at achieving the j-th program outcome through the i-th educational component.

Based on matrix (8), the overall profile of the educational program is calculated as a vector
An Example of equation

$$V = (vj), j = 1, \dots, n, \tag{9}$$

where *vj=Sum(mij, i=1,…,k), j=1,…,n.*

Figure1 : Example of a KFS model of hypothetical relationships between competencies, program outcomes, and educational components.

The formalization of the educational program profile of type (9) can be represented as a vector of ECTS credit distribution by program outcomes:
An Example of equation

$$P = (pl), l = 1, \dots, s, \tag{10}$$

where *s is* the number of credits for the l-th program outcome.

The credit distribution vector of type (10) can be an important tool for modeling and studying interactions when modeling educational program profiles.

Both cardinal and ordinal measurement scales can be used to develop the described model. In particular, experts can set weighting coefficients for the importance of all model components—competencies, program outcomes, educational components, etc. The relative importance of these model components can be measured using alternative ranking, pairwise or multiple comparisons, as well as various methods of clustering results.

Thanks to the described model, it is possible to determine the degree of similarity between educational components, analyze the characteristics of program outcomes and other components of the model proposed by the authors.

The proposed model for formalizing educational programs is universal and can be applied to various specialties and different levels of education. It is particularly relevant for fields associated with rapid technological change, such as information technology.

7.2. Quality of educational trajectory

The quality of the educational trajectory can be reflected on the basis of the documents submitted by candidates for a vacant position.

Heuristic H3. The educational trajectory of a candidate for a vacant position in an organization adequately reflects the knowledge acquired and competencies mastered by the applicant as a result of studying at higher education institutions.

The quality of the educational trajectory can also be thoroughly and comprehensively examined and confirmed based on testing candidates for a vacant position in the organization.

8. Conclusions

In this paper, the authors consider the current problems of automated candidate selection using a documentary approach to assessing their competence. The problem statement and mathematical model of automated candidate selection using a documentary approach are presented, and the formalization of this problem is described.

To supplement the information when constructing a mathematical model and studying the relevant issues, additional heuristics are introduced, on the basis of which the logic of the study on assessing the quality of the educational trajectory is provided.

The structure and sequential representation of the stages of decision-making regarding the recruitment and selection of candidates for positions are considered. The most popular approaches to personnel assessment at the selection stage are also presented – assessment, testing, and ensuring a sound procedure for formalized ranking.

The paper describes the formalization of educational trajectory as the main formalism in modeling the task of selecting candidates and reasonably determining their ratings.

All approaches to modeling recruitment processes during personnel selection described in this work are relevant, justified, and promising. The authors plan to continue the research described in this work and apply new analysis tools.

Declaration on Generative AI

The author has not employed any Generative AI tools.

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