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# Determining the Effectiveness of Scientific Research of Universities Staff

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**Abstract**

The problem of determining the effectiveness of scientific research carried out by teachers of universities is considered. In particular, the results of the publishing activity of teachers are investigated. For the comparative analysis of teachers' effectiveness, it is offered to formalize this problem in a class of problems of multicriteria optimization and to apply methods of a multiattribute choice of variants. Approaches to aggregating the effectiveness of teachers' team and justifying the advantage of choosing the most productive teams over less productive ones are also proposed. The problems of determining the most effective teacher and the most effective team of teachers are given.

**Keywords**

Scientific activity of universities, teacher effectiveness, multicriteria optimization, weight coefficients, teacher ranking, aggregation of teachers' team effectiveness, the most effective teacher.

## 1. Introduction

Higher education plays an important role in the development of domestic science. In all developed countries, university science is the main factor in the development of science and is gradually becoming a powerful innovative factor not only in higher education but also in the development of the entire education system in Ukraine.

It is known that science is the most effective area of investment. It is estimated that the return on investment in science can be 500 percent or more [1, 2]. The effectiveness of scientific work in universities is assessed by various criteria. There are publications, indexes of citations of scientific papers, the novelty of scientific developments, conformity of the teacher publications to the disciplines that he teaches, and so on. It should be noted that both scientific and teaching activities are obviously poorly structured subject areas. For research of such areas, it is expedient, in particular, to apply methods of expert estimation and the theory of decision-making.

We can conclude on many grounds, that in recent decades, science, including science in our country, is gradually moving to universities. The importance of intensifying research in universities and stimulating the development of science by university teachers is due to a number of factors [3, 4]:

- almost 70% of doctors of sciences and more than 70% of candidates of sciences work in the system of higher education in Ukraine;
- more than 80% of postdoctorate and PhD students carry out their training at universities;
- high quality of education, the formation of adequate content of academic disciplines, modernization of practical and laboratory work can be fully ensured only through the use of relevant scientific advances;
- PhD thesis and Doctor of Science dissertation of teachers should be based on new knowledge and be the result of scientific activity;

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- scientific research indirectly stimulates teachers to improve the quality of teaching and modernize the disciplines they teach;

- the creation of new high-quality textbooks and manuals, as a rule, is the result of the introduction and understanding of research in universities;

- the need to support at the appropriate level the scientific component of teachers and the tendency to increase the scientific potential of university teachers, the functioning of the system of graduate and doctoral studies is the main factors that dictate the need for scientific activities of university teachers;

- ensuring high quality of training of students, providing them with the basics of research activities require the teaching staff to support the scientific component of their activities at a high modern level. Of the indirect positive factors of scientific activity of teachers, which indirectly affect the teachers' team, it should be noted that:

- scientific research promotes additional interaction between teachers and university departments;

- the need for scientific activity naturally requires the creation of new temporary research teams;

- research teams in the universities can become the basis for innovative development of new technologies;

- the exchange of ideas in the mode of scientific interaction causes the appearance of synergetic effects and contributes to the improvement of both the scientific component of teaching and methodological aspects of this activity.

## 2. The purpose of the work

The purpose of the work is to develop a mathematical model of accounting for scientific results of teachers that ensures the relevance, completeness, and adequacy of the effectiveness of scientific activities of teachers and teachers' teams (departments, faculties and so on).

In addition, the purpose of this work is to develop a process of evaluation, accounting, and incentives for teachers, determining the effectiveness and coordination of research, which helps to increase the efficiency of scientific activities in domestic universities. The essential aspects of the study of the effectiveness of scientific activity are:

- control function, in particular, under the terms of the contracts concluded by the universities with teachers;

- motivation of teachers to improve the quality of methodological and research components of their activities;

- raising the rating of the universities in national and international rankings by increasing publication activity and timely updating of information on formal achievements of teachers;

- transparency of scientific activity of teachers, opportunity to demonstrate the scientific level to colleagues and to compare the effectiveness with other teachers;

- improvement of the corporate culture at departments and faculties.

To ensure the quality of this area should apply a qualimetric approach [5-7] to the development of technology for evaluating the effectiveness of the scientific work of teachers of universities. The elements of the technology of teacher evaluation should be:

- structuring information about the state and level of the scientific subsystem of universities;

- justification of effectiveness criteria of scientific activity of teachers of the universities;

- justification and implementation of approaches to the calculation of integrated characteristics of the scientific activity of teachers;

- development and justification of aggregate performance indicators of teachers' teams;

- introduction of modern reasonable approaches to adequate comparison of achievements of teachers and departments.

## 3. Objectives of research

To achieve the goal of the work it is expected to perform a set of the following tasks:

- to carry out the theoretical analysis of a problem of creation of a system for an estimation and quality control of teachers scientific activity;

- consider and explore the role of the subjective component in the decision support system for the quality of research;

- develop approaches to measuring qualimetric effectiveness indicators of research;
- to determine the main criteria for assessing the quality and effectiveness of scientific activities;
- develop and apply assessment methods using expert technologies;
- to offer and justify the interpretation of the integral effectiveness of scientific activity of teachers;
- to offer approaches to determining the ratings of teachers, taking into account the need for their motivation to improve the quality of teaching and stimulate research.

## 4. Review of recent research

Some aspects of determining the effectiveness of scientific research have been studied by various scientists: Belov O.V. [4], Bilukha M.T., Hnatiuk N.O., Kushnarenko N.M. [1], Surmin Yu.P. [9], Sheiko V.M. [1] and others.

The specificity of the study of scientific activity of teachers is that the activities of high school teachers are multifaceted. Scientific activity, in principle, is not subject to adequate regulation, and in cases where research is carried out on the background of teaching, the task is significantly complicated. After all, publishing activity is only one of the many aspects of teachers' work. Therefore, the requirements for the effectiveness of scientific activities of teachers have many features and nuances. The complexity of studying this issue is supplemented by the fact that the scientific activity of high school teachers is only one of the areas of their work, and not always the highest priority.

At the same time, it should be noted that in the most common international and national rankings, the most important coefficients are assigned for high research indexes:

– Times Higher Education World University Ranking;
– QS World University Ranking;
– Academic Ranking of World Universities.

The national system of rating evaluation of the activity of universities is also formed taking into account scientific indicators. Such indicators are, in particular:

- quality index of research, scientific and technical activity: "Rating of universities of Ukraine";
- indicator of international scientometric and web-metric data: "Top-200 Ukraine";
- reputation of the universities in the field of scientific research;
- the volume of the research budget of the universities per each teacher;
- teacher citation indices;
- formal indicators of scientific activity of teachers, which are reflected in the international scientometric databases Scopus, Web of Science, etc .;
- the number of publications in the most prestigious scientific journals;
- share of foreign scientists and joint publications with foreign scientists.

It should be noted that in the study of information related to research and in its analysis at the present stage, the methods of mathematical statistics are most often used.

According to the authors, to increase the level of research, appropriate mathematical models should be developed and methods of decision theory, methods of solving multicriteria optimization problems, expert technologies, "soft" calculations, etc. should be used in this field. This paper is devoted to the development of this direction.

## 5. Research methods

In the authors' view, to achieve the above purpose of the work and the formulated objectives, the following scientific directions may be useful:

- multicriteria optimization problems;
- processing of expert information;
- determination of weight coefficients of criteria;
- methods of aggregation of multi-attribute data;
- methods of group choice.

In determining the effectiveness of scientific activities of teachers of the universities can also be used regulations, data from Internet resources, information about the characteristics of scientific work of teachers, modern methods of systems analysis and information technology.

It should be noted that there are usually different approaches to modeling decision-making problems: multipurpose, multiattribute, and multicriteria. Multiattribute decision-making is carried out for the problems of choosing from a set of alternatives, which are characterized by numerical attributes, often in the presence of a single goal. Multicriteria decision-making is decision-making with many attributes and the presence of several, usually opposite goals (criteria) [10-14].

We will assume that the parameters of the effectiveness of teachers' research are points in a multi-attribute space. Therefore, it is logical to consider the problems of determining the effectiveness of scientific activities of teachers as problems of multiattribute choice and formalize them in the class of problems of multicriteria optimization.

In addition, it is known that building a structure of preferences in a formalized form is a difficult problem for a person: specialists in subject areas do not always have a clear idea of the structure of preferences on the set of alternatives. In most cases, a person can not adequately determine the weight coefficients, as well as explicitly formulate the heuristics that are used by him in the decision-making situation [15, 16].

When solving problems of multicriteria optimization, the problem of determining the area of effective solutions is strictly objective and is solved without the use of any heuristics. Narrowing the area of effective alternatives requires the use of additional information from experts, as effective sets of parameters cannot be formally compared with each other. To determine a single solution to a multicriteria problem, as a rule, three heuristics are used [10]:

- to translate all the values of the parameters of the alternatives to the dimensionless form in a given range of values, one of the allowable transformations is used;
- the vector of the relative importance of criteria is defined;
- it is assumed that the solution of a multicriteria problem is the point of intersection of the ray of the normalized weight coefficients of the relative importance of the criteria and the area of effective alternatives to the problem.

We formulate heuristics that should be used to solve the problem of multicriteria optimization.

Heuristics H1. The type of monotone function for converting the values of the parameters of alternatives to the dimensionless form is carried out according to formulas that must meet the following requirements:

- take into account the need to minimize deviations from the optimal values for each parameter;
- have a common starting point and the same order of change of values on the whole set of alternatives;
- maintain the preference ratio on the set of alternatives being compared, according to the set of parameters, and thus not change the set of effective alternatives.

Heuristics H2. The best alternative in solving the problem of multicriteria optimization should be considered an alternative for which deviations from the best values of the parameters for each estimate are minimal.

To achieve the goal of the research formulated in this paper, we will also use expert technologies that are widely used in various fields of human life and are actively developing in recent decades.

One of the key concepts of expert technology is heuristics, which can be axioms, postulates, assumptions, presumptions, paradigms, hypotheses, additions, propositions, and so on. Heuristics are empirical methodological rules that can help to find solutions and help to define incorrect problems.

## 6. Mathematical model of scientific effectiveness

The peculiarity of the scientific activity of teachers is that such activity, as a rule, is not exclusive or autonomous. The teacher of universities should carry out research on the background of his other professional activities. Therefore, the research of the teacher, on the one hand, can not be separated from the general flow of its activities, on the other hand, research, directly and indirectly, has a great influence on the other areas of activity of the teacher.

Let us build a table that characterizes and illustrates the criterion base for evaluating the effectiveness of scientific activities of teachers of universities.

**Table 1**
Effectiveness of scientific activities of teachers of universities

| Scientific and practical activity | Educational and pedagogical activity | Social and organizational activity | Certification training and raising the personal scientific level | Interaction with leadership and colleagues |
|---|---|---|---|---|
| Preparation of publications.<br>Participation in scientific seminars.<br>Participation in conferences.<br>Organization of conferences, symposia, etc. | Execution of academic workload: lectures, seminars, practical classes, laboratory work, etc.<br>Ensuring the educational process and research area: management of diplomas, term papers, etc.<br>Development of curricula, work programs of academic disciplines. | Supervision in student groups.<br>Preparation of student competitions.<br>Organization and holding of competitions of student scientific works.<br>Organization of hackathons, etc. | Certification training courses.<br>Acquaintance with the latest scientific achievements. | Execution of standing assignments.<br>Participation in the meetings of the department, etc. |

Let the number of teachers whose activities should be compared be equal to $n$, and let the set of their indices be denoted by $J = \{1,...,n\}$.

To prepare a mathematical model for determining the effectiveness of scientific activities of teachers, let us consider some attributes of scientific and practical activities of teachers of universities $v^i = (v_1^i, v_2^i, v_3^i, v_4^i, v_5^i, v_6^i, v_7^i, v_8^i, v_9^i), i \in J$, which can be used to determine the effectiveness of their research and used to compare the effectiveness of different teachers, different departments, as well as to calculate the dynamics of this indicator in different periods:

$v_1^i$ – the total number of publications of teachers, $i \in J$;

$v_2^i$ – the number of publications of teachers in a given period, $i \in J$;

$v_3^i$ – the total number of publications of teachers in international scientometric databases (Scopus, Web of Science, etc.), $i \in J$;

$v_4^i$ – the number of publications of teachers in international scientometric databases (Scopus, Web of Science, etc.) in a given period, $i \in J$;

$v_5^i$ – index of citations of scientific works of teachers (total number of citations of all scientific works of the teacher, department, faculty or university in scientometric bases), $i \in J$;

$v_6^i$ – index of citations of scientific works of teachers in a given period (total number of citations for the period of all the above scientific papers), $i \in J$;

$v_7^i$ – average index of citations of scientific works of teachers (average number of citations per one scientific work of a teacher, department, faculty or university in scientometric databases), $i \in J$;

$v_8^i$ – average index of citations of scientific works of teachers in a given period (average number of citations for the period per one scientific work of a teacher, department, faculty or university in scientometric databases), $i \in J$;

$v_9^i$ – Hirsch index (h-index) of teachers and other indices used in scientometric databases, $i \in J$ .

The problems of determining the most effective teacher (from the point of view of scientific activity), the most effective department in the scientific activity, or the most productive faculty in the scientific direction will be formalized in the class of multicriteria optimization problems. In this case, taking into account the need to use heuristics in such cases, we will pay considerable attention to the subjective component of multicriteria problems.

Note that today there are three main approaches to describing the problems of introspective (internal, in-depth) analysis: using binary relations, the choice function, and the criterion approach. The latter approach involves the assumption that each alternative can be evaluated by a specific number, which is the value of the criterion, so the comparison of alternatives is reduced to comparing the corresponding numbers. It is clear that in many practical situations, multicriteria is a way to increase the adequacy of goal description.

The problem of multicriteria optimization is formalized in the following formulation:

$$\begin{aligned} & f_i(v) \to \max, \quad i \in I_1, \\ & f_i(v) \to \min, \quad i \in I_2, \\ & v \in A, \quad A \subseteq E^k, \end{aligned} \tag{1}$$

where $A-$ set of alternatives (in our case – indicators of scientific activity of teachers), which are characterized by $k$ parameters, which belong to space $E^k$;

$y(v) = (f_1(v),..., f_k(v))$ – vector of evaluations of alternatives or criteria, which is specified by the mapping $f : A \to E^k$;

$I = \{1,..., k\} -$ set of indexes of criteria;

$I_1 = \{1,..., k_1\}, \ I_2 = \{k_1 + 1,..., k\} -$ sets of indices of criterion functions, which, respectively, are maximized and minimized, $I_1 \cup I_2 = I.$

Thus, when solving the problem of determining the best teacher, the following approach can be proposed. First, the integrated indicators of each teacher are determined by some aspects (for example, popularity among students, publishing activity, social and organizational activities, and so on). Moreover, the application of this indicator may be preceded by stratification, namely the distribution of voting participants to bachelors, graduates, only those who attended classes more often, and so on. At the next stage, an aggregate indicator of publishing activity is determined among teachers or teachers' teams. Other aggregate indicators are also calculated. The winner is then determined by solving the multicriteria optimization problem.

That is, in most cases, the solution of problems related to the analysis of teachers' activities is a compromise. Note that for the solution adequate finding and justification should provide the calculation of the weight coefficients of the criteria.

## 7. Determination of weight coefficients of criteria

It is possible at the initial stage to determine the weight coefficients by experts, although it is known that a person can not reliably assign weight. Therefore, it is necessary to comprehensively approach and determine by indirect methods the importance of parameters that characterize the effectiveness of scientific activities of teachers.

Research on expert evaluation problems and the practice of building decision support systems show that experts and decision-makers do not always have a clear idea of the structure of preferences on the set of alternatives [16]. In most cases, a person can not adequately determine the weight coefficients, as well as to allocate in the explicit case of heuristics, which are used by him in the decision-making situation.

There are several common ways to represent the values of the weight coefficients $n$ of the criteria of the problem of type (1):

- arbitrary real or natural numbers $-\infty < \rho_i < \infty, \ i \in I;$

- real numbers, taking into account restrictions (one-sided or two-sided), for example, $\rho_i > 0, \ i \in I;$ $-5 \le \rho_i \le 5, \ i \in I; \ 0 < \rho_i < 1, \ i \in I;$

- real or natural numbers, taking into account the condition of centering: $\sum_{i \in I} \rho_i = 0, \ -\infty < \rho_i < \infty, \ i \in I;$

- real numbers taking into account the condition of normalization: $\sum_{i \in I} \rho_i = 1, \ \rho_i > 0, \ i \in I$;

- real numbers taking into account the idealization condition: $\max_{i \in I} \rho_i = 1, \ \rho_i > 0, \ i \in I$.

A common form of representation of normalized weight coefficients is the interval form $\rho \in \left[\rho_i^H, \rho_i^B\right], i \in I, \ 0 < \rho_i^H \le \rho_i^B < 1, \ i \in I.$

The method of determining the function of belonging of the weight coefficients values to the fuzzy set (0,1) is also used. Approaches to the definition of membership functions and algorithms for constructing membership functions based on the analysis of the frequency of the values are that each weight coefficient as a result of the procedure of accounting for the frequency of values will be characterized by its membership function to fuzzy set [17]. This approach significantly expands the possibilities of modeling subject areas and solving problems of multicriteria optimization [18].

## 8. Aggregation of effectiveness of scientific activity of teachers

Decision-making is based on individual or group introspective analysis of the problem and the choice of the way how to solve it. The introspective analysis consists in the observation of the researcher's own feelings, thoughts, images, experiences, acts of thinking without the use of any tools or standards and is not accompanied by significant loss of information. The study of introspective analysis and processing of the subjective component in the application of expert technologies in poorly structured complex systems is an important and relevant direction for improving decision support processes.

The problems of analysis of the scientific activity of teachers can be adequately formalized in the class of problems of ranking alternatives that is ordering the set of alternatives according to the degree of manifestation of some properties. An important and widespread tool for the application of expert technologies, which is now a classic, is the task of collective determination of the ranking of alternatives, which by some criteria is "closest" to all rankings built by analyzing parameters. The most reasonable method of finding the resulting ranking of alternatives is to calculate the median of the given rankings.

It should be noted that the aggregation of the effectiveness of scientific activities of teachers can be carried out using different measurement scales: absolute, ratio, interval, ordinal, or nominal. One of the important heuristics in the problems of introspective analysis of the subjective component of decision-making is to determine the average that should be applied. This is due to the fact that an important place among all methods of data analysis is occupied by data averaging algorithms. Today, there are several common averages used to analyze subjective information.

It is known [19] that for nominal features, namely measured in the scale of names, the only mode is an acceptable average. For data measured on an ordinal scale, the median is acceptable. When examining the information measured in the interval scale, it is possible to use only the arithmetic mean. And for the analysis of the data set in the scale of relations, degree averages and geometric averages are used.

## 9. Metrics for measuring the distances between the indicators of scientific activity of teachers

When comparing the effectiveness of scientific activities of teachers of universities, each teacher corresponds to a point in the parametric space

$$v^i = \left(v_1^i, ..., v_k^i\right) \in V, \ i \in J = \{1, ..., n\}, I = \{1, ..., k\}, \quad (2)$$

where $n$ – the number of teachers, $k$ – the number of assessment parameters.

When organizing the achievements of teachers, the absolute values of their scientific achievements can be used or the achievements of teachers can be compared on an ordinal (rank) scale. That is, teachers can compare with each other on different values of parameters in the cardinal and ordinal scales. If the parameters of type (2) cannot be measured objectively, then expert estimates are used. Ordering teachers' achievements according to the values of parameters that cannot be measured in quantitative scales can be formalized in the class of collective ranking problems.

## 9.1. Formalization of the problem of ranking teachers' achievements in assessment in ordinary measurement scales

In practical situations, problems when the parameters of teachers cannot or should not be measured in absolute terms often arise. Therefore, it is advisable to consider only the relationship between performance indicators of teachers that is to set the ranking of teachers' achievements on those parameters that are considered important for comparison or important for some current research.

Since teachers are compared by a group of parameters, the problem to determine the resulting ranking of teachers arises (taking into account the whole set of parameters). The most common method of finding a compromise ranking in group selection problems is to calculate the median of the given rankings. This group of methods used to summarize expert information is the most reliable and mathematically sound.

### 9.1.1. Statement of the problem of determining the resulting ordering of teachers by a group of parameters specified in the ordinal scales

Suppose that $k$ parameters are given, for each of which it is possible to evaluate teachers, that is to build such a ranking of teachers for each parameter, which indicates the degree of manifestation of this parameter in the teacher's activity. The smaller the value of the selected parameter has the teacher, the lower will be his rank in a given ranking

$$R^i = \{a_{i_1} \succcurlyeq \ldots \succcurlyeq a_{i_n}\},\ i_j \in J = \{1,\ldots,n\},\ j \in J\ ,\ i \in I. \tag{3}$$

It is necessary to find some group (resultant, aggregate, collective, consensus, integrative) ranking of $n$ teachers $R^* = \{a_{i_1} \succcurlyeq \ldots \succcurlyeq a_{i_n}\},\ i_j \in J\ ,\ j \in J$, which will be the closest in some sense to the rankings of teachers of type (3), built taking into account each parameter.

In this paper, the symbol $\succcurlyeq$ denotes the relation of non-strict advantage, namely, when $\succcurlyeq \in \{\ \succ,\ \approx\ \}$. Thus, the problem is logically formalized in the class of problems of non-strict collective ranking [20] (definition of perfect quasi-orders [21], ordering [22], quasi-series [23], ranking with connections [24], quasi-orders, clustered rankings [25]).

### 9.1.2. Statement of the problem of determining the resulting ordering of teachers by a group of parameters specified in the ordinal scales with incomplete rankings

In practice, there are often situations when not every teacher can be evaluated on all the parameters selected for evaluation. Requiring a mandatory assessment of all teachers means deliberately creating inaccurate initial data. Therefore, it is necessary to forecast situations when for each parameter it is possible to establish a partial order on the subset of teachers $A_i, i \in I$, the whole set of teachers $A,\ A_i \subset A,\ i \in I,$ for whom this is possible. It should be noted that the problems associated with incomplete data have been studied by many scientists, in particular, in [26, 27].

We introduce the definition of the incomplete ranking of teachers $R_i^H,\ i \in I$, of the set $A$: it is a binary relation given on a subset of teachers $A', A' \subset A$, which satisfies the properties of completeness, reflexivity, antisymmetry, transitivity: but only on the subset $A', A' \subset A$, and not on the whole set $A$.

Let be given partial orders by $k$ parameters

$$R^{Hi} = \{a_{i_1} \succcurlyeq ... \succcurlyeq a_{i_n}\}, \ i_j \in J = \{1,...,n\}, \ j \in J, \ n_i < n, \ i \in I, \tag{4}$$

on the selected subsets of teachers $A_i \subset A, i \in I$. It is necessary to find some resulting ordering of $n$ teachers $R^* = \{a_{i_1} \succcurlyeq ... \succcurlyeq a_{i_n}\}, \ i_j \in J, \ j \in J$, which is built on the basis of given incomplete orders of the form (4).

The initial stage of solving the problem described in this paper is to unite all the teachers, whose achievements are arranged according to different parameters, into a single set $a_i \in A, i = 1,...,n,$ to determine the resulting ranking $R^*$. That is, by the subsets $A_i \subset A, i \in I,$ the full set of teachers $A = \bigcup_{i=1}^{k} A_i$ is determined.

It is clear that different variants of relations between subsets are allowed: $A_{i_1} \cup A_{i_2} = \varnothing,$ $A_{i_1} \cup A_{i_2} \neq \varnothing, \ A_{i_1} = A_{i_2}, \ i_1, i_2 \in I.$

The set of all possible teacher rankings by parameters is an area of acceptable solutions for determining the resulting ranking of teachers $R^*$, built on incomplete rankings of the form (4).

## 9.2. Metrics for measuring the distances between the indicators of scientific activity of teachers

When applying the algebraic approach, metrics are introduced to measure distances.

1) Cook metric of mismatch of ranks (places, positions) of teachers in rankings by each of the parameters

$$d(R^j, R^l) = \sum_{i \in I} \left| r_i^j - r_i^l \right|, \tag{5}$$

where $r_i^l$ - the rank of the $i$ -th teacher in the ranking by the $l$ -th parameter of assessment $R^l, l \in L, \ 1 \le r_i^l \le n.$

Note that the values of the ranks of teachers may not be integers, as the problem is formalized in the class of group finding a non-strict ranking.

2) Hamming metric presupposes a transition to another space. To move from the space of ranks to the space of pairwise comparisons of teachers, individual preferences for each of the parameters are presented in the form of a matrix of pairwise comparisons

$$B^l = \left(b_{ij}^l\right), j \in I, \ l \in L, \tag{6}$$

where $b_{ij}^l = 1, \ i, j \in I, \ l \in L$, if and only if the *i*-th teacher dominates the *j*-th teacher by the *l*-th parameter. Moreover, $b_{ij}^l = -b_{ji}^l, \ i, j \in I, l \in L.$ If the values of the parameters specified in the ordinal scale are equivalent for two teachers, then $b_{ij}^l = b_{ji}^l = 0, \ i, j \in I, l \in L$.

Hamming metric is used to determine the distances between teachers' relationships

$$d^H(B^j, B^l) = 0{,}5 \sum_{i \in I} \sum_{s \in I} \left| b_{is}^j - b_{is}^l \right|, \ j, l \in I, \ i, s \in J \ .$$

3) The quadratic metric looks like this

$$d^k(B^j, B^l) = \left( \sum_{i \in I} \sum_{s \in I} \left( b_{is}^j - b_{is}^l \right)^2 \right)^{1/2}, \ j, l \in I, \ i, s \in J \ .$$

4) The metric of dominance are also used:

$$d^d(B^j, B^l) = \max_{i, s \in I} \left| b_{is}^j - b_{is}^l \right|, \ j, l \in I, \ i, s \in J \ .$$

5) You can also use the distance, which is based on the vectors of preference $\pi^l = (\pi_1^l, ..., \pi_n^l)$, $l \in I$, where $\pi_i^l$ – the number of indicators of teachers, which precede the indicators of the $i$ – th teacher in the $l$ – th ranking of the form (4). B.G. Litvak [28] proposed for the vectors of preferences $\pi^1$ and $\pi^2$, formed on the basis of rankings $R^1$ and $R^2$, to determine the distance by the formula:

$$d^{\pi}(R^1, R^2) = \sum_{i \in I} \left| \pi_i^1 - \pi_i^2 \right|.$$

## 9.3. Criteria for determining the generalized ranking of teachers' achievements on the basis of rankings set by individual parameters

For the Cook metric (5) using the utilitarian criterion, the Cook-Sayford median is calculated:

$$R^{CS} \in \Omega^{CS} = Arg \min_{R \in \Omega^R} \sum_{l \in L} d^K\left(R, R^l\right).$$

When using the egalitarian criterion $GV$-median (compromise) is calculated:

$$R^{GV} \in \Omega^{GV} = Arg \min_{R \in \Omega^R} \max_{l \in L} d^K\left(R, R^l\right).$$

For the Hamming metric (6) using the utilitarian criterion, the Kemeni-Snell median is calculated:

$$R^{KC} \in \Omega^{KC} = Arg \min_{B \in \Omega^B} \sum_{l \in L} d^H\left(B, B^l\right).$$

When using the egalitarian criterion $VG$-median (compromise) is calculated:

$$R^{VG} \in \Omega^{VG} = Arg \min_{B \in \Omega^B} \max_{l \in L} d^H\left(B, B^l\right).$$

Similar criteria that determine the medians of given rankings are used for quadratic metric, dominance metric, and preference vector.

## 9.4. Peculiarities of taking into account incomplete rankings of teachers, determined by parameters in ordinal scales, when calculating the generalized ranking of teachers’ achievements

Taking into account the peculiarities of incomplete rankings of teachers by the parameters that characterize their activities, requires the introduction of additional heuristics.

Heuristics H3. The distance from any ranking $R^*$ to each ranking, determined by comparing the results of scientific activities of teachers, $R^{iH}, i \in I,$ is equal to the sum of the probabilistic and definite part.

Heuristics H4. The absence of assessments of individual teachers by some parameters creates an unknown relations between all other assessments of teachers and does not participate in the ranking that is this assessment of the teacher is not represented in the incomplete ranking. Thus, when specifying incomplete rankings for assessments for each parameter, we have the following number of teachers’ assessments:

$n_i$ – given by the parameter $i \in I$ in the incomplete ranking $R^{iH}, i \in I,$ which will be a definite part of the distances;

$(n - n_i) = \nu_i$ – not specified by the parameter $i \in I$ in the incomplete ranking $R^{iH}, i = 1, ..., k,$ which will be a probabilistic part of the distances.

Individual incomplete advantages given by each parameter on subsets of teachers' assessments $R^{lH}, l \in I,$ can also be represented as an incomplete matrix of pairwise comparisons (MPC)

$$B^{lH} = \left(b_{ij}^{lH}\right), j \in I, \ l \in L.$$

Hamming metric is used to determine the distances between the relations of this matrix.

Heuristics E5. The mathematical expectation of indefinite distances between teachers' assessments in the ranking is equal to 8/9. That is, the distance between the elements of the MPC, at least one of which is not defined, must be equal to 8/9 (based on the assumption that the equality of its values "-1", "0" or "1" are equally likely). And the distances between the elements have respectively the following distributions: (0,1,2), (1,0,1), (2,1,0). The probabilistic part from ranking $R^{iH}, i \in I$, given by $i-$th ($i \in I$) parameter to any other ranking for Hamming metric is always equal $9 \cdot v_i \cdot (v_i - 1)/16, i \in I$.

## 10. Aggregation of data in the calculation of objective indicators of scientific activity of teachers, defined in the cardinal scales

The accumulated experience of expert evaluation in various areas of human activity convincingly shows that any statistical operations become more useful and reasonable when reducing the number of features used for analysis. Therefore, the problem of aggregating the features that characterize the activities of teachers to a smaller number of constructed "factors" (aspects, etc.) occupies a significant place in the problems of determining the effectiveness of scientific activities of teachers. The analysis of the set of teachers' assessments by a group of parameters is to determine the level of general consistency of teachers' assessments and to select, if necessary, a group of "homogeneous" subgroups that combine the parameters of teachers with agreed assessments. The formulation of these problems is dictated by the fact that the transition to the aggregation of estimates by different parameters is possible only after identifying the structure of preferences. For example, if the overall consistency of estimates by parameters is low and the group of parameters is divided into several subgroups, within which the consistency of estimates is high, then aggregation should be performed for these subgroups by estimates of parameters.

In the analysis of assessments of scientific activity of teachers and in determining the relative importance of publications, there are problems of presenting these assessments in a systematic way and there are problems of comparison and aggregation of assessments. The use of mathematical methods in the analysis of expert assessments allows to adequately summarize the judgments of specialists and identify the information that they have in a latent form.

If there are objective parameters that characterize the activities of teachers, different approaches can be proposed. We introduce the notation for the parameters of scientific activity of each teacher $j$, $j \in J$, as follows:

$v_1^j$ – the number of articles in editions that are included in the scientometric databases of Scopus or WoS by the $j-$th teacher;

$v_2^j$ – the number of articles in conference proceedings, which are included in the scientometric databases of Scopus or WoS by the $j-$th teacher;

$v_3^j$ – the number of articles in Ukrainian periodicals by the $j-$th teacher;

$v_4^j$ – the number of abstracts at international and Ukrainian conferences by the $j-$th teacher;

$v_5^j$ – the number of training manual and textbooks by the $j-$th teacher;

$v_6^j$ – the number of monographs by the $j-$th teacher;

$v_7^j$ – the number of prize-winning students of All-Ukrainian Olympiads and All-Ukrainian competitions of scientific works (2nd round), the supervisor of which is a $j-$th teacher;

$k_s$ – the number of co-authors in the relevant scientific work (the author is one of the co-authors).

To determine the integrated (aggregated) effectiveness of the scientific activity of the $j-$th teacher on the basis of objective indicators, it is proposed to use the following empirically derived formula:

$$Q_j^{(1)} = \left( 6\sum_{s=1}^{v_1^j}(1/k_s) + 3\sum_{s=1}^{v_2^j}(1/k_s) + \sum_{s=1}^{v_3^j}(1/k_s) + \left( \sum_{s=1}^{v_4^j}(1/k_s) \right)/5 + 4\sum_{s=1}^{v_5^j}1/k_s + 8\sum_{s=1}^{v_6^j}1/k_s + 5v_7^j \right) /$$
$$\max_{i \in J}\left( 6\sum_{s=1}^{v_1^i}(1/k_s) + 3\sum_{s=1}^{v_2^i}(1/k_s) + \sum_{s=1}^{v_3^i}(1/k_s) + \left( \sum_{s=1}^{v_4^i}(1/k_s) \right)/5 + 4\sum_{s=1}^{v_5^i}1/k_s + 8\sum_{s=1}^{v_6^i}1/k_s + 5v_7^i \right), j \in J.$$

We will also introduce indicators related to the survey of students to determine the best teacher:

$v_8^j$ – the number of students who voted for the $j$ – th teacher;

$v_9^j$ – the number of students who took part in the voting;

$v_{10}^j$ – the number of students studying at the department where the $j$ – th teacher works.

$Q_j^{(2)} = \left( v_8^j / v_9^j + v_8^j / v_{10}^j \right) / \max_{i \in I} \left( v_8^i / v_9^i + v_8^i / v_{10}^i \right)$

The integral value of the teacher's rating will be determined by the formula:

$$Q_j^{(3)} = Q_j^{(1)} / 2 + Q_j^{(2)} / 2, \quad j \in J.$$

## 12. Conclusions

In this work, the approaches to research of productivity of scientific activity of teachers of universities, comparison of scientific activity of departments, faculties, and universities as a whole are investigated. The result of scientific research is a publication that confirms the fact of scientific accomplishment, with which the scientist will be able to familiarize not only his colleagues but also the world community. The scientific work is not completed until it is published and indexed in a scientometric database. In the modern scientific world, publishing activity is becoming increasingly important for every scientist and teacher of universities, regardless of the direction of his research. The following main scientific results are obtained:

- the statement of problems of definition of scientific researches productivity of teachers is offered;
- a theoretical analysis of the problem of creating a system of evaluation and quality control of scientific activities of teachers is carried through;
- the role of the subjective component in the decision support system regarding the quality of scientific research is considered and researched;
- approaches to measuring qualimetric performance indicators of scientific research is developed;
- criteria for assessing the quality and effectiveness of scientific activities are defined;
- approaches to determining the ratings of teachers are proposed, taking into account the need for their motivation;
- the interpretation of the integral efficiency of scientific activity of teachers is offered and substantiated.

In the future, based on the analysis of the obtained solutions to the problem of determining the results of scientific research of teachers, approaches to determining the coefficients of the relative performance of teachers in the form of membership function to a fuzzy set can be proposed.

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