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USE OF THE LINK RANKING METHOD TO EVALUATE SCIENTIFIC ACTIVITIES OF SCIENTIFIC SPACE SUBJECTS

Abstract: A modification of the PageRank method based on link ranking is proposed to evaluate the research results of subjects of the scientific space, taking into account self-citation. The method of reducing the influence of self-citation on the final evaluation of the results of research activity of subjects of the scientific space is described. The evaluation of the results of research is calculated using the modified PR-q method, taking into account self-citation as a solution of a system of linear algebraic equations, matrix of which consists of coefficients determined by the number of citations of publications of one scientist in the publications of another scientist. The described method can be used for the task of evaluating the activity of the components of the scientific space: scientists, higher education institutions and their structural units.

For the task of evaluating the research activity of subjects of the scientific space, a method based on link ranking (PageRank method for web pages) and taking into account the self-citation of scientists is proposed. The latter allows for an adequate assessment, taking into account the abuses associated with the authors' excessive self-citation.

The essence of the constructed method lies in the construction of a system of linear algebraic equations, whose coefficients of the matrix reflect the citations of some scientists by others in the citation network of scientific publications. The value of the coefficients of the matrix of such a system of linear algebraic equations is subject to certain restrictions, which allow to reduce the influence of the factor of excessive self-citation of the author on his overall assessment of research activity.

The described method can be used to calculate the complex evaluation of the components of the scientific space: the scientist, the institution of higher education and its separate structural units. Evaluating research results provides an opportunity to verify the relevance of the research process to the goals identified at the planning stage and, if necessary, to adjust the progress of those studies. Also, the calculation of research evaluations of the components (objects and entities) of the scientific space is a powerful tool for managing research projects.

Keywords: PageRank algorithm, scientometrics, citation graph, self-citation.

1. Introduction

Important changes in the geography of science and scientific cooperation have taken place in recent decades. Scientific or scientific cooperation networks, which previously operated locally within universities and research institutes, and spread to one or more countries and were more static, now cover virtually the entire world. The rapid creation of new scientific information and the use of networking tools for scientists contribute to the dynamic development and diversification of scientific networks.

A scientific network is an association of subjects of scientific activity, that is, scientists who are united by certain rules for the creation and functioning of members within the network, in addition, the homogeneity of subjects of scientific activity does not exclude the presence of specific identifiers in them, it allows them to be studied separately.

Scientific networks can be combined to form a hierarchy. In addition, scientific networks as objects can be considered as part of some scientific space. The scientific space includes many structurally ordered scientific objects and subjects and their identifiers: scientists, higher education institutions and their individual structural units.

The interdisciplinary nature of research creates scientific networks and spaces that have no boundaries. Scientific networks can be seen as complex dynamic systems that self-organize and intensify knowledge-seeking activities [1].

The urgent task of researching scientific spaces is to evaluate the research activities of the subjects of space. Evaluating research results provides an opportunity to verify the relevance of the research process to the goals identified at the planning stage and, if necessary, to adjust the progress of those studies. Criteria for evaluating the results of the research work of scientists, as a rule, are scalar indicators of citation of publications that have been published by these scientists. There are several advantages to building such quantities, but there are also disadvantages. These disadvantages include the loss of some input and the existence of such marginal cases where the parameter does not change its value as the number of citations and publications increases. In addition, it is important that the constructed assessment take into account the cross-citation and self-citation of scientists [2]. That is why it is important to develop new or modify existing methods of evaluating the results of research activities of scientists who do not have these shortcomings.

2. Analysis of literary data and problem statement

It is generally accepted that the intensification of scientific cooperation is an effective tool for obtaining high-quality scientific results and, as a consequence, leads to an increase in the citation of publications based on these results. In [3], the hypothesis that a greater number of co-authors is a sign of higher quality of scientific publication was investigated. Scientific networks in the field of medicine were explored. The result is confirmation of this hypothesis (Fig. 1).

Research of scientific spaces is a complex task that must take into account the dynamics of the development of their components, as well as account for the numerous changes that result from the increase in the speed of information production and its dissemination. As scientific information is disseminated through the publication of scientific papers, data on citations of

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scientific publications, analysis of common keywords of publications and etc. can be used to form and evaluate the development of interaction between components of scientific spaces. Appropriate mathematical and algorithmic apparatus that allows you to explore scientific activities in different dimensions is included in a new direction – the analysis of scientific networks. One of the tasks of analyzing scientific networks is to build citation networks, on the basis of which it is possible to calculate evaluation of scientific activity as a network as a whole, its components, and each scientist separately.

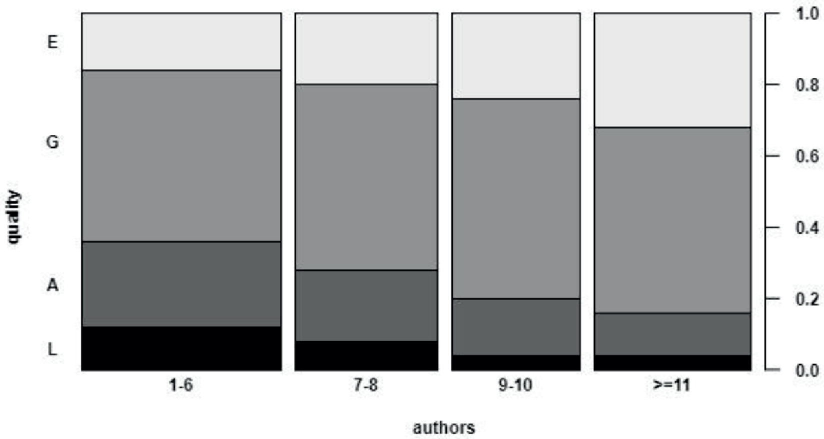

Fig. 1. The dependence of the number of authors on the quality of scientific publications in the field of medicine [3]. Quality: E-excellent, G-good, A-acceptable, L-limited.

The citation network includes nodes that are scientific publications and links between them that reflect citations from one scientific publication to another. In [4], the definition of a citation network was formulated as follows: when a d_i document refer d_j document it can be displayed with an arc connecting the node d_i with the node d_j. The display of all document citations will thus be rendered into a citation network or citation graph.

Known properties of the citation network:

1. The citation network is represented by an acyclic directed graph.
2. All citation arcs in the graph are directed back in time, that is, the citation can only occur in publications that have already been published in the past.
3. The weight of citation between co-authors in a scientific collaboration network may increase if the authors continue their scientific cooperation in the future.
4. Nodes and arcs that are added to the network remain in it and cannot be further removed.
5. Network changes occur mostly in the front of the network. The network which has already been formed as a whole is static.

Citation network analysis is needed first and foremost to identify scientific communities, which is one of the main tasks of network citation [5]. Also, the citation network is a powerful tool for scientifically evaluating the scientific activity of certain subjects of the scientific space [2].

The results of the research activities of scientists are usually evaluated on the basis of the citation of publications published by these scientists. The most common bibliometric index is the Hirsch Index. The principles of its construction are described in [6, 7]. The worse index is calculated as follows: a scholar obtains an index h if at least h articles have been published by a scientist, each cited at least h times. In [8] it is proposed to use the so-called g-index. This index represents the largest number g that corresponds to the number of articles that have been cited at least g2 times. In [9], the disadvantages of h- and g-indexes are indicated, which are the loss of information on citation of the most popular publications of the author, and the use of the e-index is proposed to eliminate these deficiencies. Several modifications of the h-index calculation are proposed in [10], including self-citation. In [11], the correlation of the Hirsch index with the g-index is considered, taking into account different samples of scientists and scientific collections, where the results of research activities were published. In [12], the authors describe the use of a generalized integral for calculating some bibliometric indices and propose ways to establish a functional relationship between the number of publications and the number of citations. The development of methods for evaluating scientific activity is described in [13].

For the task of evaluating the search results of information on the Internet, a so-called PR index is used based on the method of link ranking [14]. [15] described the application of the Monte Carlo method to accelerate the finding of the PR index. A modification of the Monte Carlo method to find a PR index in a dynamic network structure of which is constantly changing is considered in [16]. Since the PR index allows to take into account all citations between publications, in the opinion of the authors it is advisable to use it for the task of evaluating the scientific activity of subjects of the scientific space. In [2], a method for evaluating scientific activity based on link ranking was developed. However, it did not take into account self-citation, which can significantly affect the resulting assessment.

Calculation of scientific activity assessments is a powerful tool for managing scientific projects. [17] outlines ways to integrate project management and support decision making using a matrix model based on key portfolio events that can be used in the field of scientific project management, taking into account the results of evaluating research activities. Prospective directions in the development of technologies for evaluating the performance of subjects of scientific communities are the construction of complex assessments, which are described in [18-21]. The task of managing research activities is being actively researched. In particular, the application of the design approach is considered in [22, 23].

3. The purpose and objectives of the research

The goal of the research is to build a method for evaluating the results of research activities of scientists based on the analysis of citations of their publications of different types.

To achieve the goal, the task is to construct a method of evaluating the results of research activities of scientists on the basis of self-citation ranking of links.

4. A method for evaluating the research activity of subjects of the scientific space on the basis of self-citation ranking of links

Consideration of the self-citation factor, as it turned out, is an important aspect of the calculation of the correct evaluation of the research activity of the components of the scientific space. Based on the Supplementary Data Tables database for «A standardized citation metrics author database annotated for the scientific field» (PLoS Biology 2019) [24], the percentage of self-citation of scientific publications of scientists with different affiliations published in the PLoS Biology collection for the period from 2017 to 2018 Fig. 2. depicts the dependence of the number of PLoS Biology authors from different countries and the percentage of their self-citation during the specified period. The dashed line indicates the median self-citation. From Fig. 2. It is seen that the greatest self-citation is observed in authors from Armenia, Brunei, Cameroon, Ukraine and Russia.

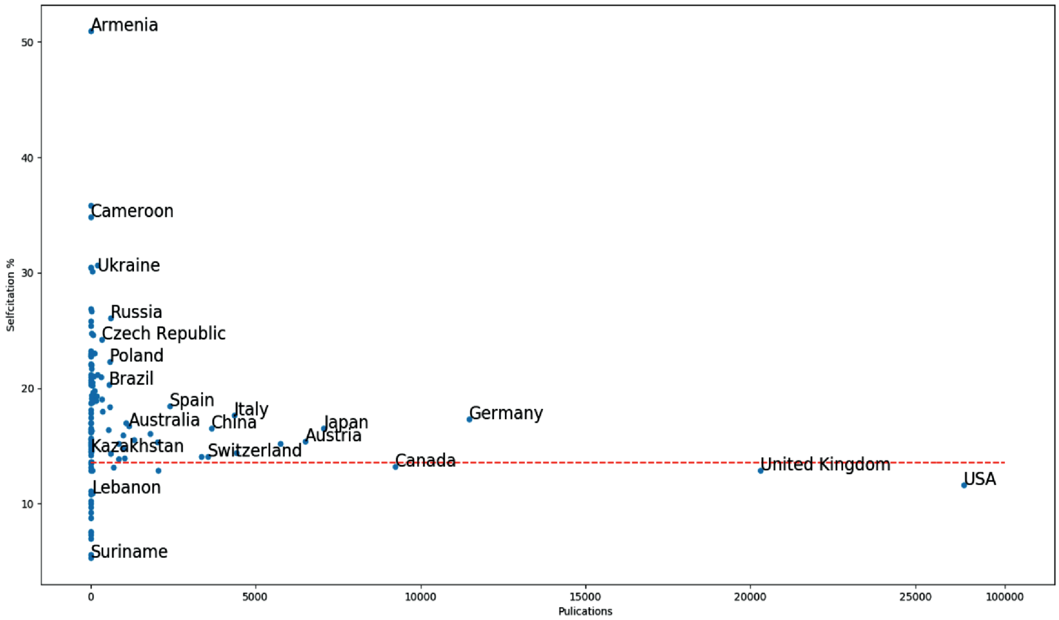

Fig. 2. Dependence of the number of PLoS Biology authors from different countries and the percentage of their self-citation for the period 2017-2018.

In paper [2] the scalar evaluation of the results of a scientist's research activity is considered as some functional mapping:

$$Q : A \to \mathbf{R} \tag{1}$$

where $\mathbf{R}$ is real numbers set, $A = \{a_1, a_2, \ldots, a_n\}$ is scientists set, n is the number of scientists. The results of research scientists examined through a set of publications of scientists $P = \{p_1, p_2, \ldots, p_m\}$, where m is the number of publications. To describe the results of research, two sets are introduced to consideration: a set that defines authorship between scientists and their publications $U \subset A \times P$ and a set specifies the ratio of citations to publications $C \subset P \times P$.

The task of evaluating the results of research activities of scientists is formed in terms of finding for each scientist a_i, $i = \overline{1,n}$, based on the given information on the citation of his publications, some assessment q_i that may be represented in the form of functionality:

$$q_i = Q\big(P(a_i), C(a_i)\big), \; i = \overline{1,n} \tag{2}$$

wh,ere $P(a_i) = \{p_j \in P \mid (a_i, p_j) \in U\}$, $j = \overline{1,m}$, $j = \overline{1,m}$ is set of the scientist publications, $C(a_i) = \{p_j \in P \mid (p_j, p_y) \in C, p_y \in P(a_i), y = \overline{1,m}\}$, $i = \overline{1,n}$, $j = \overline{1,m}$ is the set of all publications in which the publications of the scientist are cited, q_i are scalar evaluations of the results of the research activity of the scientists.

The authors summarized the idea of calculating online evaluates using the PR method [14] with link ranking and modified it to evaluate the research activity of scientists based on citations of their scientific publications. A scalar evaluation of the results of a research activity of a scientist a_i, $i = \overline{1,n}$, according to this method (PR-q) is calculated by the formula [2]:

$$q_i = \sum_{z=1}^{n} \beta_{iz} \xi_z q_z, \; i = \overline{1,n}, \tag{3}$$

where q_i is evaluation of the scientist research activity a_i, β_{iz} is the coefficient that is determined by the number of citations of a scientist's a_i publications in scientist's $a_z$publications, ξ_z is the coefficient that ensures the existence of a non-trivial solution of a system of linear algebraic equations (3), q_z is evaluation of research activity of the scientist a_z.

As a result of applying formula (3), a homogeneous system of linear algebraic equations of the form is constructed:

$$Bq = 0, \tag{4}$$

where B is the matrix of coefficients of this system of appearance:

$$B = \begin{pmatrix} 1-\beta_{11}\xi_1 & -\beta_{12}\xi_2 & -\beta_{13}\xi_3 & \cdots & -\beta_{1n}\xi_n \\ -\beta_{21}\xi_1 & 1-\beta_{22}\xi_2 & -\beta_{23}\xi_3 & \cdots & -\beta_{2n}\xi_n \\ -\beta_{31}\xi_1 & -\beta_{32}\xi_2 & 1-\beta_{33}\xi_3 & \cdots & -\beta_{3n}\xi_n \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ -\beta_{n1}\xi_1 & -\beta_{n2}\xi_2 & -\beta_{n3}\xi_3 & \cdots & 1-\beta_{nn}\xi_n \end{pmatrix}. \tag{5}$$

For a non-trivial (identically non-zero) solution of system (5) to exist, the matrix B must be degenerate, that is $|B| = 0$. The authors propose two methods for determining the coefficients so that a non-trivial solution exists. We also propose a method of rationing to determine a single solution of a system of linear equations, because if there is a non-trivial solution of system (4), then there are many solutions proportional to this.

Although the method makes it possible to evaluate the results of the research activities of the authors, taking into account all citations of their publications, it has some disadvantages, namely:

Self-citation can influence the evaluation of research results. Misuse of self-citation can lead to distortions of authors' evaluation results. A study [25] shows that the percentage of self-citation has a clear trend for growth since the 1970s. At the same time, there has been an exponential increase in the percentage of self-citation in the last decade. So, if in 1970 the average percentage of self-citation was 10%, in 2010 – 18%, in 2018 – almost 40%. It should also be noted that Ukraine and Russia are world leaders in self-citation among researchers.

The PR-q method assumes that the system of scientists being evaluated is closed. That is, all citations are made only between publications known to the system. In practical implementation of the method it is not always possible to process all scientific publications. Usually scientometric databases contain information about some subset of $P' \subset P$ publication for some subset of scientists $A' \subset A$. Usually scientometric databases contain information about a certain subset of publications for a certain subset of scientists. Therefore, there is a need to evaluate the results of research activities in open systems.

It is proposed a modification of the PR-q method to eliminate the disadvantages noted. Consider a method of reducing the impact of self-citation on the final evaluation of research results. Consider some nondecreasing function $f(\beta)$ for which the conditions $0 \le f(\beta) \le \beta$ for any valid values β.

When evaluating the results of a research activity, self-citation affects only the coefficients β_{ii}. We apply the function $f(\beta)$ considered to each of them. It allows to reduce the influence of self-citation on determination of the resultant evaluations by the method of PR-q. Let

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$\tilde{\beta}_{ii} = f(\beta_{ii}), \tilde{\beta}_{ij} = \beta_{ij}, i \neq j$, then to maintain the stability of the method, $\tilde{\xi}_{ij}$ must be laid in such a way as to ensure that the condition $|B| = 0$ is met. Then, evaluating the results of research on the PR-q method, taking into account self-citation, is found by solving a system of linear algebraic equations of the form:

$$\tilde{B}q = 0 \tag{6}$$

where

$$\tilde{B} = \begin{pmatrix} 1-\tilde{\beta}_{11}\tilde{\xi}_{11} & -\beta_{12}\tilde{\xi}_{12} & -\beta_{13}\tilde{\xi}_{13} & \cdots & -\beta_{1n}\tilde{\xi}_{1n} \\ -\beta_{21}\tilde{\xi}_{21} & 1-\tilde{\beta}_{22}\tilde{\xi}_{22} & -\beta_{23}\tilde{\xi}_{23} & \cdots & -\beta_{2n}\tilde{\xi}_{2n} \\ -\beta_{31}\tilde{\xi}_{31} & -\beta_{32}\tilde{\xi}_{32} & 1-\tilde{\beta}_{33}\tilde{\xi}_{33} & \cdots & -\beta_{3n}\tilde{\xi}_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ -\beta_{n1}\tilde{\xi}_{n1} & -\beta_{n2}\tilde{\xi}_{n2} & -\beta_{n3}\tilde{\xi}_{n3} & \cdots & 1-\tilde{\beta}_{nn}\tilde{\xi}_{nn} \end{pmatrix} \tag{7}$$

Consider the implementation of the proposed modification of the method. Let $f(\beta) = \frac{\beta}{2}$ that is, the importance of self-citation is reduced by half compared to citations by other authors.

Then $\tilde{\beta}_{ij} = \left\| C(a_i) \cap C(a_j) \right\|$, $i \neq j$ and $\tilde{\beta}_{ii} = \frac{1}{2}\left\| C(a_i) \cap \tilde{C}(a_i) \right\|$. We put $\tilde{\xi}_{ii} = \frac{1}{\left\|\tilde{C}(a_i)\right\|}$ and $\tilde{\xi}_{ij} = \frac{1}{\left\|\tilde{C}(a_j)\right\|} + \frac{\tilde{\beta}_{ii}}{(n-1)\tilde{\beta}_{ij}\left\|\tilde{C}(a_i)\right\|}$. The rows of the matrix will be linearly dependent, and hence the system of linear algebraic equations (6) will have countably infinite number of non-trivial solutions.

Consider the method of eliminating the second disadvantage of the PR-q method. Let P' is a closed system of publications of scientists A', that mean we know all publications and all citations $C' = P' \times P'$ between them. Let the tuple $\langle A', P', C' \rangle$ call a core. The core is a closed system.

The results of the research activities of the core scientists should be evaluated by the method of PR-q. Given that there are citations that do not belong to the core of the system, it is impossible to evaluate the results of scientific research by this method.

Suppose that the results of the research activities of all non-core scientists are equivalent. Then, without limiting the generality we can put the evaluation of their research activity equal to 1. Then the evaluation of the research activity of the scientist $a_i \in A'$ can be calculated by formula:

$$q_i = \sum_{z=1}^{n'} \beta_{iz}\xi_z q_z + \sum_{z=n'}^{n} \beta_{iz}\xi_z, \quad i = \overline{1,n'} \tag{8}$$

where q_i is evaluation of the results of the research activity of the scientist a_i, n' is the number of scientists in the core, β_{iz} is coefficient that is determined by the number of citations of a scientist's a_i publications in a scientist's a_z publications, ξ_z is coefficient that ensures the existence of a solution of a system of linear algebraic equations (8), q_z is evaluation of the results of the research activity of the scientist a_z.

5. Conclusions. The issue of abuse of authors' self-citation in scientific publications is analyzed. Authors' self-citation has been found to be a significant factor in the impact of the evaluation of research activity. To solve this problem, a method based on link ranking (PageRank method for web pages) and taking into account the self-citation of scientists allow them to carry out their correct evaluation. The method is intended to calculate the evaluation of research activities, taking into account the abuses associated with the authors' excessive self-citation.

The essence of the constructed method lies in the construction of a system of linear algebraic equations, matrix coefficients of which reflect the citation of some scientists by others over the citation network of scientific publications. Certain restrictions are imposed on the value of the matrix coefficients of such a system of linear algebraic equations, which make it possible to reduce the influence of the factor of excessive self-citation of the author on his overall assessment of scientific research activity.

The described method can be used to calculate the complex evaluation of the components of the scientific space: the scientist, the institution of higher education and its separate structural units.

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