Formation of a soft model of regional attractiveness of the university

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Abstract. A new fuzzy-multiple technique is presented and tested in the article, which makes it possible to assess the level of attractiveness of a university in the eyes of applicants based on a list of university performance indicators available on the website of the Ministry of Education and Science, and also to compare the attractiveness of universities selected by the applicant’s criteria. The methodology is supposed to be implemented in software focused on applicants to universities.

1 Introduction

Currently, there are a lot of methods for evaluating the attractiveness of higher education institutions based on data from monitoring the effectiveness of educational organizations on the website of the Russian Ministry of education and science [1]. The performance indicators of a university and its attractiveness for students are closely interrelated, as it is noted in many studies [2-5]. Many authors note that the formation of attractiveness (image, reputation) of a university, in accordance with the results of sociological research, is primarily influenced by such factors as the quality of educational activities of the university, the results of its scientific activities, and the scientific activity of the university. In accordance with the results of the statistical study presented in [2], the main factors that form the reputation of the university we present in Table 1.

The study [3] shows that factors affecting the reputation of a university can be ranked as follows: 1) the volume of state budgetary financing of the university; 2) the amount of extra budgetary funds received by the university; 3) the cost of study at the university; 4) the funds of the university for development of material and technical base of the university; 5) the percentage of candidates and doctors of science of the university; 6) the academic performance of students of the university; 7) the effectiveness of the university in relation to graduate employment; 8) the number of students of the university; 9) the number of monographs published by the teachers of the university; 10) the amount of research works of the university; 11) the number of postgraduate students of full-time and part-time forms of education; 12) the number of issued by the teachers of the university articles in journals.

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included in the VAK list. We also present a model [3, 6] for calculating the significance of factors that characterize the financial activity of a university and affect the formation of the reputation of a higher education institution.

Table 1. Factors forming the university reputation

| Factor                                                                 | Rank | Specific weight, % |
|------------------------------------------------------------------------|------|--------------------|
| Interaction of the university with employers and employment of graduates| 1    | 21,8               |
| Qualification of university teaching staff                            | 2    | 21,5               |
| Quality of educational activity of the educational institution         | 3    | 12,0               |
| Key performance indicators of the university at the national level     | 4    | 10,3               |
| Reputation of the university's rector and management staff             | 5    | 8,9                |
| Indicators of economic activity of the educational institution         | 6    | 8,6                |
| Results of scientific activity of the university                      | 7    | 8,5                |
| Educational and methodical activity of the educational institution     | 8    | 8,4                |

The need to create a new methodology for assessing the attractiveness of the university is connected to the current lack of satisfactory mathematical models that allow us to bring together indicators that reflect the success of the university in various areas: educational, scientific, human resources, international, infrastructure, financial and economic. As a rule, the analysis is reduced to the study of statistical data in various areas of activity, followed by a comparison of individual indicators. There are no methods that allow you to combine the entire set of indicators for a particular university, form a numerical assessment based on it, and, as a result, rank the studied universities based on the rating marks.

The problem is primarily related to the heterogeneity of the studied indicators, the presence of both absolute and relative values among them, as well as the presentation of statistical information in the form of time rows. These problems can be solved with the help of fuzzy logic conclusions apparatus that allow us to form a comprehensive assessment of the object's state based on a set of heterogeneous indicators.

The main purpose of the research presented in this article is to develop a fuzzy-multiple methodology that allows you to assess the level of attractiveness of the university for applicants based on the list of performance indicators of the university available on the website of the Ministry of education and science, as well as to compare the attractiveness of universities selected according to certain criteria. The methodology should be the basis of software that helps the applicants choose a university based on their own system of preferences.

The proposed method allows to form a comprehensive numerical assessment of the performance of universities based on the aggregation of six groups: 1) education; 2) research; 3) HR capacity; 4) international activity; 5) infrastructure; 6) financial and economic activities. Based on the formed estimates, a rating of universities in the region under consideration can be compiled. The mathematical model used by the proposed method is based on a system of fuzzy logic conclusions called a fuzzy five-level [0,1] - classifier [7-9]. The methodology is based on existing joint developments in assessing the state of systems based on fuzzy logic conclusions [8-10].

2 Material and methods

Experimental material: the data on monitoring the effectiveness of educational
organizations listed on the website of the Ministry of education and science of the Russian Federation [1], including archival data. The proposed method includes the following steps.

Step 1. Forming a list of universities selected according to the criteria defined by the applicant (training areas, territorial distribution, etc.). For this study we selected three universities, grouped by territorial feature (region) and the maximum contingent for a given branch of science. It is important that the list of universities can be formed based on the organization's position on the main indicators in comparison with the thresholds given on the same website (for example, all indicators should not be lower than the thresholds). When developing software that implements the methodology, it is necessary to organize an interface that assumes that the applicants can choose the required number of universities in accordance with their own preferences.

Step 2. Creating a list of important indicators for the applicant. In this study, the indicators are formed by 6 groups that most fully and objectively reflect the effectiveness of the university:

1) educational activity (5 indicators): the average score of the unified state exam of students enrolled in bachelor and specialist programs in all forms of education; the share of students in master's degree programs in the total number of students of bachelor’s, specialist’s and master's programs; the total number of listeners of programs of additional professional education; the number of enterprises which have signed contracts on training of specialists; the number of enterprises, which are the bases of practice with contractual arrangements;

2) scientific activity (5 indicators): the total amount of funds received (for the reporting year) from scientific research performed in-house; the total number of publications of the organization per 100 researchers; the total number of postgraduate students (adjuncts), interns, resident physicians, assistant interns; the share of postgraduate students (adjuncts), interns, resident physicians, assistant interns studying full-time; the number of dissertation councils;

3) human capacities (6 indicators): proportion of academicians with degrees; the proportion of research workers with degrees; the proportion of academicians younger than 65 years; the proportion of academicians younger than 40 years; average salary of teachers (without external part-time teachers and working on civil contracts); the average salary of scientific workers (without external part-time and working on civil contracts);

4) international activity (3 indicators): the share of foreign students in the total number of students enrolled in bachelor's, specialty, master's programs; the total number of foreign postgraduates (adjuncts), interns, resident physicians, assistant interns; the number of articles prepared jointly with foreign organizations;

5) infrastructure (3 indicators): percentage of students who are not provided with the own dormitory among students who need it; the number of personal computers; percentage of personal computers with Internet access;

6) economic and financial activities (5 indicators): proportion of university income from extra-budgetary sources; the share of university income from educational activities in the total income of the university; the share of university income from research and development in total revenues of the university; the share of extra budgetary funds income from educational activities; the share of extra budgetary funds income from research and development.

Thus, we considered 27 indicators. When developing software, it is necessary to take into account the possibility of excluding the applicant from the list of indicators that do not have a subjective significance for him. The authors did not include many absolute indicators from the website that reflect the scale of the educational institution (often due to the "historical heritage" – for example, study areas), as well as reflecting state support (which may also not reflect the actual degree of effectiveness of the university).
Step 3. The ranking of importance of indicators, calculation of weight coefficients of direction (obligatory condition $\sum_{i=1}^{27} k_i = 1$). Here, the principle of shared distribution is used to calculate the coefficients. It is assumed that all 6 groups have equal weight and it is equal to $1/6$; within the group, the indicators are equilibrium ($1/6$ is divided by the number of indicators within the group). At the same time, when developing software, it is necessary to take into account the possibility of ranking indicators in accordance with the applicant’s preferences (for example, calculating weight coefficients according to the Fishburne rule).

Step 4. Calculation of normalized values of indicators. For each indicator (for all years and for all selected universities), its maximum value is determined, and then all available statistical values of the indicator are divided by it.

Step 5. Aggregation of time series for the selected number of years. For example, the calculation of a given indicator for three years (2017, 2018, and 2019) for each of the universities is performed using the formula:

$$x_i = \frac{1}{6} \cdot X(2017) + \frac{1}{3} \cdot X(2018) + \frac{1}{2} \cdot X(2019)$$  \hspace{1cm} (1)

It is evident that the condition is met: $0 \leq x_i \leq 1$, $i=1,...,27$.

Step 6. Definitions of linguistic variables.

Each indicator is associated with a linguistic variable $B_{i\ell}$, whose term set is $B_i = \{B_{i1}, B_{i2}, B_{i3}, B_{i4}, B_{i5}\}$, $i = 1,2,...,27$, consists of the following terms: $B_{i1}$ – “very low level of indicator”; $B_{i2}$ – “low level of indicator”; $B_{i3}$ – “average level of indicator”; $B_{i4}$ – “high level of indicator”; $B_{i5}$ – “very high level of indicator”. Standard term membership functions are used for fuzzy five-level [0,1] classifier [6-7].

A linguistic variable was introduced: $g$ = “evaluation of the effectiveness of the university”. The universal set for a linguistic variable is the numeric segment [0,1]. The term set consists of five terms $G = \{G_1, G_2, G_3, G_4, G_5\}$ that evaluate the state of the system: $G_1$ – “very bad”; $G_2$ – “bad”; $G_3$ – “satisfactory”; $G_4$ – “good”; $G_5$ – “excellent”. Membership functions are standard trapezoidal, defined in Table 2.

In addition, six additional linguistic variables have been introduced that correspond to estimates for individual areas of university activity: $g_1$ = “assessment of the university in educational activities”; $g_2$ = “assessment of the university in scientific activities”; $g_3$ = “assessment of the university in the field of human resources”; $g_4$ = “assessment of the university in international activities”; $g_5$ = “assessment of the university in educational activities”; $g_6$ = “assessment of the University in financial and economic activities”. Universal sets, term sets and membership functions are introduced in the same way as for the final evaluation.

The values of the membership functions of the terms of the linguistic variable "indicator level" for each of the indicators are calculated using the formulas given in Table 2.

Расчет весов термов лингвистических переменных $g_i= «оценка эффективности деятельности вуза по i-й группе», i = 1,2,...,6, на основе формулы:

Step 7. Calculation of the weights of the terms of linguistic variables $g_i= “evaluation of the effectiveness of the university in group I”, based on the formula:

$$p_l = \sum_{i=1}^{N} k_i \cdot \mu_{g_i}(x_i) \cdot \mu_{g_i}(x_i), l = 1,...,5.$$  \hspace{1cm} (2)
N is number of parameters in the group (the weight vector of the group is multiplied by a scalar to vector values of the membership function of the corresponding term).

Step 8. Calculation of numerical values of linguistic variables $g_i$ = “assessment of the effectiveness of the university in group $i$”, based on the formula:

$$g = \sum_{i=1}^{5} p_i \cdot \bar{g}_i$$ (3)

where $\bar{g}_i$ – the middle of the intervals, which are the carriers of terms,

$\bar{g}_1 = 0.125$, $\bar{g}_2 = 0.3$, $\bar{g}_3 = 0.5$, $\bar{g}_4 = 0.7$, $\bar{g}_5 = 0.885$.

Step 9. Preparation of final calculation tables for each university, Tables 6,7,8, which include assessments of activities by groups. Aggregation of values into the final grade $g$ = “assessment of the attractiveness of the university” according to the above algorithm.

Step 10. Drawing up a rating of universities based on the data obtained. Application.

3 Results

Calculations were made for three selected universities (named University-1, University-2,). The calculation process for each of the six groups of indicators is in Table 2 (for University-3).

The calculation of the final score is shown in Table-3. As follows from the final calculations, the final score is $g$(University-3)=0.4407,

$\mu(0.4407) = \mu_2(0.4407) = 0.1$, $\mu(0.4407) = \mu_3(0.4407) = 0.9$,

(more "satisfactory" than "bad").

Similarly, we got the evaluations for the other two universities from the list:

$g$(University-1)=0.7278, $\mu(0.7278) = \mu_4(0.7278) = 1$ («good»);

$g$(University-2)=0.5418, $\mu(0.5418) = \mu_5(0.5418) = 1$ («satisfactory»).

The final analysis of the selected three universities is presented in Table 4. As it follows from the calculations, the preference rating is headed by the University-1, which is characterized by fairly high ratings for all six groups of indicators. Then there is the University-2, which has relatively low grades in scientific, international, and financial and economic activities. The last in the list is University-3, lagging behind the first two universities in all positions and is characterized by extremely low ratings for international and educational activities [11-15].

4 Conclusions

A practical method for evaluating the attractiveness and ranking of universities for applicants based on a list of indicators selected from a given list based on their own preferences has been developed [16-17]. The data for evaluation can be taken from the public website of the Ministry of education and science of Russia. The presented method is new, versatile, and variable. It can be used to create software aimed at applicants (Table 2, 3, 4).

Table 2. Calculation table University-3

| № | Indicators | Weight | Indicator value | Terms |
|---|------------|--------|-----------------|-------|
|   |            |        |                 |       |
|   | Description                                                                 | Weight | $B_0$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ |
|---|-----------------------------------------------------------------------------|--------|-------|-------|-------|-------|-------|-------|
| 1 | Average score of unified state exam of students enrolled for bachelor's and  | 1/30   | 0,96  | 0     | 0     | 0     | 0     | 1     |
|   | specialist's programs in all forms of education                              |        |       |       |       |       |       |       |
| 2 | The share of students enrolled in master's programs in the total number of  | 1/30   | 0     | 1     | 0     | 0     | 0     | 0     |
|   | students enrolled in bachelor's, specialty, and master's programs             |        |       |       |       |       |       |       |
| 3 | Total number of students in additional professional education programs       | 1/30   | 0,25  | 0     | 1     | 0     | 0     | 0     |
| 4 | Number of companies that have contracts for training specialists             | 1/30   | 0,03  | 1     | 0     | 0     | 0     | 0     |
| 5 | Number of enterprises that are bases of practice with contractual relations  | 1/30   | 0,15  | 1     | 0     | 0     | 0     | 0     |

**Assessment g1. Term weights *6**

|   | Equation | $B_0$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ |
|---|----------|-------|-------|-------|-------|-------|-------|
| 6 | $g_1=0,312 \cdot 0,6 + 0,2 \cdot 0 + 0 \cdot 0,2$ |        |       |       |       |       |       |
| 7 | Total amount of funds received (for the reporting year) from scientific      | 1/30   | 0,10  | 1     | 0     | 0     | 0     | 0     |
|   | research performed in-house                                                   |        |       |       |       |       |       |       |
| 8 | Total number of publications of the organization per 100 science workers     | 1/30   | 0,74  | 0     | 0     | 0     | 1     | 0     |
| 9 | Total number of postgraduate students (adjuncts), interns, residents, and    | 1/30   | 0,16  | 0     | 0     | 0     | 0     | 0     |
|   | trainee assistants                                                             |        |       |       |       |       |       |       |
| 10| Percentage of full-time postgraduate students (adjuncts), interns, residents,| 1/30   | 0,82  | 0     | 0     | 0     | 0,3   | 0,7   |
|   | and trainee assistants studying full-time                                     |        |       |       |       |       |       |       |

**Assessment g2. Term weights *6**

|   | Equation | $B_0$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ |
|---|----------|-------|-------|-------|-------|-------|-------|
| 11| $g_2=0,419 \cdot 0,3 + 0,28 \cdot 0,2 + 0 \cdot 0,2 \cdot 0,14$ |        |       |       |       |       |       |
| 12| Percentage of teaching staff with academic degrees                           | 1/36   | 0,93  | 0     | 0     | 0     | 0     | 1     |
| 13| Percentage of research workers with academic degrees                         | 1/36   | 0,46  | 0     | 0     | 1     | 0     | 0     |
| 14| Percentage of teaching staff in the age group under 65                       | 1/36   | 0,95  | 0     | 0     | 0     | 0     | 1     |
| 15| Percentage of teaching staff in the age group under 40                       | 1/36   | 0,72  | 0     | 0     | 1     | 0     | 0     |
| 16| Average salary of teaching staff (without external part-timers and working   | 1/36   | 0,92  | 0     | 0     | 0     | 0     | 1     |
|   | under civil contracts)                                                        |        |       |       |       |       |       |       |
| 17| The average salary of scientific workers (without external part-time)        | 1/36   | 0,85  | 0     | 0     | 0     | 0     | 1     |
| №  | Indicators                                                                 | Weight | Indicator value | Terms |
|----|---------------------------------------------------------------------------|--------|-----------------|-------|
|   |                                                                           |        | $B_{i1}$        | $B_{i2}$ | $B_{i3}$ | $B_{i4}$ | $B_{i5}$ |
| 17 | Share of international students in the total number of students enrolled in bachelor's, specialist's, and master's programs | 1/18   | 0,43            | 0       | 0,2     | 0,8     | 0       | 0       |
| 18 | Total number of international post-graduate students( adjuncts), interns, residents, and trainee assistants | 1/18   | 0,07            | 1       | 0       | 0       | 0       | 0       |
| 19 | Number of articles prepared jointly with foreign organizations            | 1/18   | 0,04            | 1       | 0       | 0       | 0       | 0       |
| 20 | Percentage of students who are provided with a hostel, in the number of students who need a hostel | 1/18   | 1               | 0       | 0       | 0       | 0       | 1       |
| 21 | Number of personal computers                                              | 1/18   | 0,33            | 0       | 1       | 0       | 0       | 0       |
| 22 | Percentage of personal computers with Internet access                      | 1/18   | 0,50            | 0       | 0       | 1       | 0       | 0       |
| 23 | Share of university revenues from extra-budgetary sources                  | 1/30   | 0,37            | 0       | 0,8     | 0,2     | 0       | 0       |
| 24 | Share of the university's income from educational activities in the total income of the university | 1/30   | 0,96            | 0       | 0       | 0       | 0       | 1       |
| 25 | Share of the University's income from research and development in the total income of the university | 1/30   | 0,45            | 0       | 0       | 1       | 0       | 0       |
| 26 | Share of extra-budgetary funds in income from educational activities       | 1/30   | 0,29            | 0       | 1       | 0       | 0       | 0       |
| 27 | Share of extra-budgetary funds in income from research and development     | 1/30   | 0               | 1       | 0       | 0       | 0       | 0       |

Assessment g3. Term weights *6

$g3=0,788$

| Term | Value |
|------|-------|
| 1    | 0     |
| 2    | 0     |
| 3    | 0,1   |
| 4    | 0,7   |
| 5    | 0,1   |
| 6    | 0,66  |

Assessment g4. Term weights *6

$g4=0,234$

| Term | Value |
|------|-------|
| 1    | 0     |
| 2    | 0,6   |
| 3    | 0,0   |
| 4    | 0,2   |
| 5    | 0     |
| 6    | 0     |

Assessment g5. Term weights *6

$g5=0,405$

| Term | Value |
|------|-------|
| 1    | 0     |
| 2    | 0,3   |
| 3    | 0,3   |
| 4    | 0     |
| 5    | 0,16  |

Assessment g6. Term weights *6

$g6=0,43$

| Term | Value |
|------|-------|
| 1    | 0,2   |
| 2    | 0,3   |
| 3    | 0,2   |
| 4    | 0     |
| 5    | 0,2   |

Table 3. The final calculated table, University-3
| №  | Indicators                              | Weight | Value  | Terms of linguistic variable «Indicator level» | B_1 | B_2 | B_3 | B_4 | B_5 |
|----|----------------------------------------|--------|--------|-----------------------------------------------|-----|-----|-----|-----|-----|
| 1  | Assessment g1. Educational activity     | 1/6    | 0.3120 |                                               | 0   | 1   | 0   | 0   | 0   |
| 2  | Assessment g2. Scientific activity     | 1/6    | 0.4194 |                                               | 0   | 0.3 | 0.7 | 0   | 0   |
| 3  | Assessment g3. Staff potential         | 1/6    | 0.7881 |                                               | 0   | 0   | 0   | 0.6 | 0.4 |
| 4  | Assessment g4. International activity  | 1/6    | 0.2348 |                                               | 0.2 | 0.8 | 0   | 0   | 0   |
| 5  | Assessment g5. Infrastructure           | 1/6    | 0.4056 |                                               | 0   | 0.4 | 0.6 | 0   | 0   |
| 6  | Assessment g6. Financial and economic activity | 1/6 | 0.4300 |                                               | 0   | 0.2 | 0.8 | 0   | 0   |
|    | Weights of terms                        |        | 0.03   |                                               | 0.45| 0.34| 0.1 | 0.07|      |

Table 4. Total assessment of the attractiveness of selected universities.

| №  | Indicators                              | University -1 | University -2 | University -3 |
|----|----------------------------------------|---------------|---------------|---------------|
| 1  | Assessment g1. Educational activity     | 0.6550        | 0.7555        | 0.3120        |
| 2  | Assessment g2. Scientific activity     | 0.7599        | 0.3765        | 0.4194        |
| 3  | Assessment g3. Staff potential         | 0.8015        | 0.8443        | 0.7881        |
| 4  | Assessment g4. International activity  | 0.7320        | 0.3148        | 0.2348        |
| 5  | Assessment g5. Infrastructure           | 0.7320        | 0.5931        | 0.4056        |
| 6  | Assessment g6. Financial and economic activity | 0.774 | 0.4225 | 0.4300        |
|    | Total assessment                        | **0.7278**    | **0.5418**    | **0.4407**    |

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