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THE INTEGRATED APPLICATION OF THE AHP AND THE DEA METHODS IN EVALUATING THE PERFORMANCES OF HIGHER EDUCATION INSTITUTIONS IN THE REPUBLIC OF SERBIA

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The measurement and evaluation of performance are critical for the efficient and effective functioning of the economic system, because this allows for the analysis of the extent to which the defined objectives are achieved. Organizational performance is measured by different methods, both quantitative and qualitative. Many of the known methods for the evaluation and measurement of organizational performance take into account only financial indicators, while ignoring the non-financial ones. The integration of both indicators, through the combined application of multiple methods and the comparison of their results, should provide a more complete and objective picture of organizational performance. The Analytic Hierarchy Process (AHP) is a formal framework for solving complex decision-making problems, as well as a systemic procedure for the hierarchical presentation of the problem elements. The Data Envelopment Analysis (DEA) is a non-parametric approach based on linear programming, which allows for the calculation of the efficiency of decision-making units within a group of organizations. The work is an illustration of the method and framework of the combined use of the multi-criteria analysis methods for the measurement and evaluation of the performance of higher education institutions in the Republic of Serbia. The advantages of this approach are reflected in overcoming the shortcomings of a partial application of the AHP and the DEA methods by utilizing a new, hybrid, DEAHP (Data Envelopment Analytic Hierarchy Process) method. Performance evaluation through an integrated application of the AHP and the DEA methods provides more objective results and more reliable solutions to the observed problem, thus creating a valuable information base for high-quality strategic decision making in higher education institutions, both at the national level and at the level of individual institutions.

Keywords: multi-criteria analysis, analytic hierarchy process, data envelopment analysis, organizational performance, higher education

JEL Classification: C44, C61, D81, I23

INTRODUCTION

The evaluation of organizational performance is one of the most important activities for all managers and stakeholders. As a tool allowing them to assess organizational strengths and weaknesses, as well as a competitive advantage over the competition, the evaluation of organizational performance creates conditions for defining the guidelines and selecting the measures that must be taken in order to overcome the existing problems.

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Organizational performance is, in general, multidimensional and influenced by a number of factors, such as financial factors, as the indicators of the financial position of the organization, strategic qualitative factors, which determine the internal activities of the organization and their relationship with the market and economic factors, including the business environment, etc. The aggregation of all these factors into a composite, overall performance measure is a subjective and complex process depending on the value and preference systems of decision makers in the decision-making process. Creating a performance measurement system is, therefore, a complex task, and what is to be considered as an optimal performance measurement system will vary from one case to another (Tangen, 2005). In this regard, it is important to understand how performance measurement systems are developed and integrated into organizations' management models. These findings are fully consistent with the basic multi-criteria decision-making paradigm, which has resulted in numerous studies of the possibilities of the application of multi-criteria decision making in the process of measuring and evaluating organizational performance (Aruldoss, Lakhsmi & Venkatesan, 2013).

As a result of the Bologna Process, internationalization and the introduction of private colleges and universities, higher education institutions are exposed to greater competition. There is a continuing need for comparing different educational institutions, so that those wanting to enroll in the faculty could opt for the best one under the observed criteria. The aim of the ranking is to establish transparency and make information about universities useful for multiple target groups, such as high-school graduates, their parents, university professors, university managers, ministries and employers. Numerous studies show that university ranking influences the selection of faculties/universities on the part of students who finish school. G. Saad (2001) notes that performance analysis allows for an efficient and effective allocation of available resources. It also allows higher education planners to identify universities with the highest level of performance.

The subject of the research is measuring the performance of higher education institutions in the Republic of Serbia (RS). Although awaited for a long time, the evaluation and ranking of the universities and faculties in RS have not been formally conducted, nor have criteria and the manner in which the ranking will be carried out been determined. In this regard, based on the case of the twelve faculties within the four state universities in the Republic of Serbia (Belgrade, Novi Sad, Nis, and Kragujevac), a new approach to their evaluation and ranking for the academic year 2013/2014 is proposed here, which eliminates arbitrariness and partiality.

The objective of the paper is to improve the performance evaluation process in higher education institutions in the Republic of Serbia based on the combined and integrated use of multi-criteria decision-making methods.

In accordance with the set objective and the subject of research, the starting hypothesis has been formulated:

H: The application of the hybrid Data Envelopment Analytic Hierarchy Process (DEAHP) method, through the synergistic effect of the combined use of the Analytic Hierarchy Process (AHP) and the Data Envelopment Analysis (DEA) methods, results in a formal, scientifically based framework for the evaluation of the performance of higher education institutions, thus creating assumptions for their objective and efficient ranking.

To this end, the work is structured as follows: first, a brief theoretical overview of the issue and the most important aspects of organizational performance measurement are provided. Then, the literature review points to the most important references dealing with the implementation of the AHP and the DEA methods in higher education institutions, after which the methods used in this work are briefly explained - the AHP, the DEA and the DEAHP. Based on the measurement of t he efficiency and ranking of the twelve selected faculties in the Republic of Serbia, the last part of the paper shows that the combined use of these methods results in a comprehensive and objective evaluation of the performance of the faculties observed.

THE LITERATURE REVIEW

In practice, multi-criteria analysis has proven to be a suitable theoretical and methodological instrument for covering and solving numerous decision-making problems, both in companies and non-profit organizations. The diverse nature of the factors influencing the decision-making process, the complexity of the business and the economic environments, and the subjective nature of a number of decisions are just some of the characteristics of financial decisions enabling the implementation of a multi-criteria methodological framework. The need for the simultaneous observation of multiple criteria, including decision makers' personal preferences, is an important management component. The application of multi-criteria decision making allows the decision maker (the manager) to actively participate in the decision-making process and helps them understand and deal with complexity and uncertainty as the characteristics of the business environment. This means that their role is not reduced to the passive implementation of an optimal solution (if any) resulting from the multi-criteria model applied, but rather that they actively participate in the process of problem structuring and modelling, as well as in the analysis, interpretation and implementation of the results obtained. Multi-criteria decision making can be said to provide a wide array of techniques for the synthesis of the multiple criteria used in performance measurement, with the aim of selecting, ranking, classifying and describing a set of alternative options, as numerous scientific and professional studies have proven.

Multi-criteria decision-making techniques, such as the Analytic Hierarchy Process, the Analytic Network Process, TOPSIS and others, have been extensively used in the measurement of organizational performance, both independently and in combination with other multi-criteria or traditional approaches.

The Analytic Hierarchy Process has been applied in a number of studies related to performance measurement in higher education institutions: V. M. R. Tummala and P. P. Sanchez (1988) successfully applied the AHP in measuring faculty performance; I. C. Ehie and D. Karahtanos, (1994) measured faculty business performance by applying the AHP; in recent years, J. R. Grandzol (2005) has applied the AHP in the process of selecting the optimal faculty to study at; D. N. Ghosh (2011) combined the AHP and the TOPSIS methods in the process of measuring the performance of four engineering faculties etc.

J. Johnes (1996, 2006) gave an overview of the methods that can be used in the measurement and evaluation of the performance of higher education institutions and, through the comparative performance measurement of universities in Great Britain, concluded that the DEA method had the advantage over the other methods. The DEA method was applied in the evaluation of organizational performance in a number of empirical studies relating to the measurement and evaluation of performance in higher education institutions: D. A. Antreas and S. Estelle (1997) used the DEA in the comparative analysis of the efficiency of higher education institutions in Great Britain; C. Ng. Ying and S. K. Li (2000) examined the research performance of higher education institutions in China; M Abbott and C. Doucouliagos (2003), also used the DEA method to evaluate the efficiency of the state universities in Australia; W. H. Kong and T. T. Fu (2012) constructed a student-based performance measurement model of business schools in Taiwan, combining the AHP and the DEA methods; C. Kao and H. T. Hung (2008) used the DEA to assess the effectiveness of the academic departments, as well as J. Nazarko and J. Šaparauskas (2014); Q. H. Do and J-F. Chen (2014) combined the Fuzzy AHP and DEA in measuring the efficiency of universities; B. D. Royendegh and S. Erol (2009) combined the DEA (Data Envelopment Analysis) and the ANP (Analytic Network Process) in measuring university performance etc.

THE METHODOLOGY

R. Ramanathan (2006) proposes a hybrid, DEAHP method, as a way to overcome the shortcomings of the partial application of the DEA and the AHP methods.

The Analytic Hierarchy Process (AHP) (Saaty, 1980) is an intuitive method for formulating and analyzing decisions, based on hierarchical problem structuring and making a pairwise comparison, based on the 1-9 comparison scale (Table 1). As a method that can successfully be used to measure the relative impact of a number of relevant factors on possible outcomes, as well as for prediction, i.e. the distribution of the relative probability of outcomes, it has been used in solving a number of complex decision-making problems. A good overview of the AHP application was given by O. S. Vaidya and S. Kumar (2006), S. Sipahi and M. Timor (2010), A. Ishizaka and A. Labib (2011), N. Subramanian and R. Ramanathan, (2012).

Data Envelopment Analysis (DEA) is a mathematical, non-parametric approach for the calculation of efficiency, based on linear programming, not requiring a specific functional form. It is used to measure the performance of decision-making units (DMU) by reducing multiple inputs to a single „virtual" input, and multiple outputs to a single „virtual" output, using weight coefficients, whereby for each organizational unit a corresponding linear programming model is formed and solved. The DEA method has proven to be successful, especially when evaluating the performance of non-profit organizations operating outside the market, because in their case, the financial performance indicators, such as the revenue and the profit, do not measure efficiency in a satisfactory manner. All data on inputs and outputs for each decision-making unit are entered into a certain linear program, which is actually one of the DEA models. In this way, the performance of the observed decision-making units is evaluated, which represents the ratio of the weighted output sum and the weighted input sum. Data Envelopment Analysis points to a relative efficiency, because decision-making units are observed and measured in relation to the others. Efficiency ranges from 0 to 1, and any deviation from 1 is attributed to an excess of inputs or a lack of outputs.

In the DEAHP problem model, the DEA method is used for deriving local decision-making priorities from the comparison matrix in respect of the observed elements in the AHP model. Tables 2 and 3 show the comparison matrices characteristic of the AHP method and the DEAHP method, respectively. As R. Ramanathan suggests, the elements aij, a_{ij}, $a_{ij} > 0$, $a_{ij} = 1/a_{ji}$, $a_{ii} = 1$ for each i in the AHP comparison matrix

Table 1 The 1-9 comparison scale

Intensity of relative importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one relative to the other	Experience and judgment slightly favor one activity over another.
5	Essential or strong importance	Experience and judgment strongly favor one activity over another.
7	Demonstrated importance	One activity is strongly favored, and its dominance is demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	Mean values between two close judgments	When compromise is needed.
Reciprocity of the above non-zero numbers		If one activity has one of the above numbers (for example, 3), compared to the other activity, then the second activity has the reciprocal value (i.e. 1/3), when compared with the other.

Source: Saaty & Kearns, 1985, 27

Table 2 The traditional AHP pairwise comparison matrix

	Element 1	Element 2	....	Element n
Element 1	1	a_{12}	...	a_{1N}
Element 2	$1/a_{12}$	1		a_{2N}
....	...	...	....	...
Element N	$1/a_{1N}$	$1/a_{2N}$	...	1

Source: Ramanathan, 2006, 1296

become the elements of the DEAHP comparison matrix in Table 3, adjusted for the application of the DEA method, in order to calculate local priorities. Each row of the matrix is viewed as a typical DMU, and each column as an output. In addition, the matrix contains the column with the so-called dummy, i.e. fictitious input, which takes the value of 1 for each DMU, to implement the DEA method.

R. Ramanathan proves that the application of the DEA method with the AHP comparison matrices provides the objectified values of decision-making priority elements, thus reducing the subjectivity of the assessment with the AHP method, and eliminating the rank inversion, which occurs by either adding or excluding an irrelevant alternative, which is a typical problem with the application of the AHP. The calculated DEA efficiencies can be interpreted as local priorities of decision-making units. Finally, the DEA is used for the aggregation of the finite decision-making priority elements. When the DEA approach is used in this sense, the alternatives are seen as the decision-making units, DMUs, and their local priorities, calculated in relation to each criterion, as the outputs,

Table 3 The DEAHP pairwise comparison matrix and the assessment of their effectiveness

	Output 1	Output 2	...	Output n	Fictitious input
DMU_1	1	a_2	...	a_{1N}	1
DMU_2	$1/a_{12}$	1	...	a_{2N}	1
...	...	...	...	...	...
DMU_N	$1/a_{1N}$	$1/a_{2N}$	...	1	1

Source: Ramanathan, 2006, 1296

Table 4 The AHP comparison matrix of the alternatives and the criteria

	Kriterijum 1	Kriterijum 2	....	Kriterijum J
Alternativa 1	y_{11}	y_{12}	...	y_{1J}
Alternativa 2	y_{21}	y_{22}		y2J
....	...	...	....	...
Alternativa N	y_{N1}	y_{N2}	...	y_{NJ}

Source: Ramanathan, 2006, 1298

using the dummy inputs column (Tables 4 and 5). On the other hand, unlike the classic DEA approach that only measures relative efficiency, the DEAHP method implicitly including the ability of the AHP to include both quantitative and qualitative decision-making factors results in a more complete performance assessment of the observed decision-making units.

THE DESCRIPTION OF THE PROBLEM AND THE STRUCTURING OF THE DEAHP MODEL FOR THE EVALUATION AND RANKING OF THE FACULTIES IN THE REPUBLIC OF SERBIA

In the present case, the evaluation and ranking of the faculties through the application of the AHP method will be performed by observing 12 faculties within the four state universities (Belgrade, Novi Sad, Nis, and Kragujevac) in the Republic of Serbia, according to five non-financial criteria (Figure 1). The criteria are regarded as the inputs (I_1, I_2, I_3) and the outputs (O_1,

Table 5 The DEA approach to evaluating the efficiency of alternatives in relation to the defined criteria

	Kriterijum 1	Kriterijum 2	....	Kriterijum J	Fiktivni ulaz
DMU 1	y_{11}	y_{12}	...	y_{1J}	1
DMU 2	y_{21}	y_{22}		y2J	1
....	...	...	....	...	1
DMU N	y_{N1}	y_{N2}	...	y_{NJ}	1

Source: Ramanathan, 2006, 1298

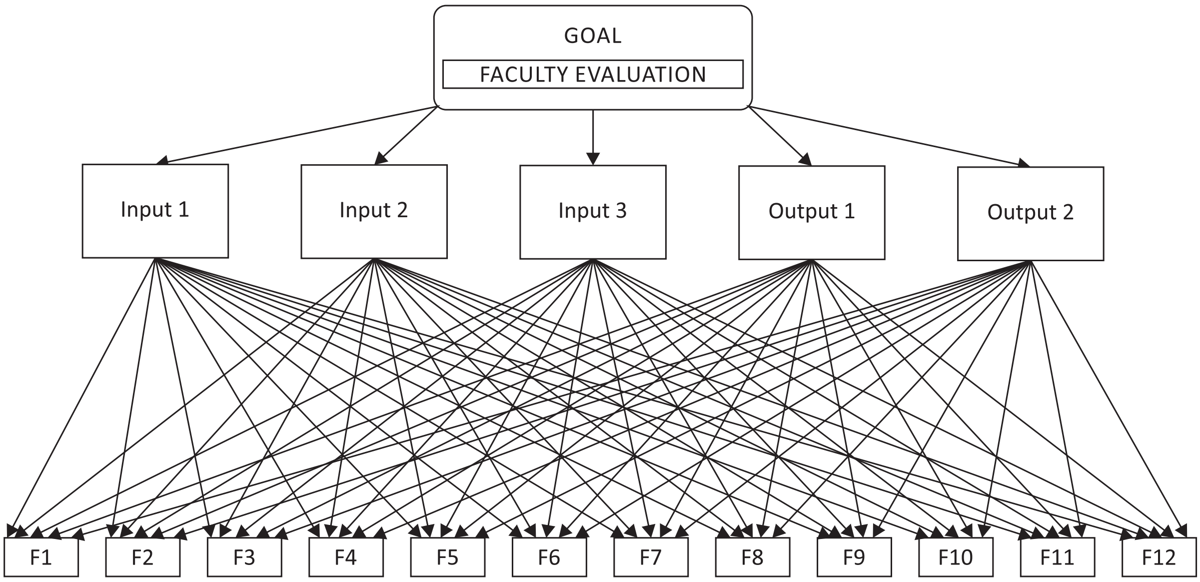

Figure 1 The AHP hierarchical structure of the problem of the evaluation and ranking of the faculties (the criteria are all the identified inputs and outputs).

Source: Authors

O_2), due to the fact that the same will be used in the DEA model. The key inputs are the number of the teachers (I_1), the number of the associates (I_2) at the faculty, and the number of the enrolled students (I_3). The main outputs are the number of the graduates (O_1) and the number of the doctoral dissertations (O_2). The faculties have been chosen from the field of natural, technical, and social sciences and humanities, whereas the criteria (for the application of the AHP method), i.e. the inputs and the outputs (for the application of the DEA method) were selected in accordance with the available data for the 2013/2014 academic year.

Based on the given hierarchical structure, the criterion comparison matrix within the AHP model of the evaluation and ranking of the observed faculties was formed, and together with the comparison based on the 1-9 scale, is shown in Table 6.

Structuring the DEA model for evaluating the efficiency of the faculties in the Republic of Serbia

The number of the DMUs to be compared depends on the objective of the study and the number of the homogeneous units whose performance in practice should be compared. It is recommended that the number of the DMUs should be larger than the product of the number of the inputs and the outputs, in order to effectively distinguish between an efficient and an inefficient DMU. In the present case, for the purpose of evaluating the efficiency of the faculties in the Republic of Serbia, 12 faculties, i.e. decision-making

Table 6 The criterion comparison matrix within the AHP model of the faculty ranking and evaluation

Criteria	Output 1	Output 2	Input 1	Input 2	Input 3
Output 1	1	2	1/4	1/3	1
Output 2	1/2	1	1/3	1/2	1/4
Input 1	4	3	1	2	2
Input 2	3	2	1	1	1/2
Input 3	1	4	1/2	2	1

Source: Authors

units, were selected, as well as 3 inputs (the number of the teachers, the number of the associates, and the number of the enrolled students) and 2 outputs (the number of the graduates and the number of the doctoral dissertations). The criteria for the selection of these inputs and outputs are quite subjective. There is no specific rule in determining the procedures for the selection of inputs and outputs. A set of inputs and outputs for measuring performance in the education sector is often criticized for its being inadequate and unsuitable for an efficiency analysis. Thus, the set is subject to change in accordance with research requirements. One of the reasons for this selection of the inputs and the outputs lies in a lack of up-to-date data and a lack of access to certain data on the inputs and the outputs in respect of the observed faculties.

Table 7 provides an overview of the structured DEA model for evaluating the efficiency of the faculties in the Republic of Serbia.

When applying a data envelopment analysis, the output-oriented CRS DEA model, which seeks to maximize the output at the given input level, where an inefficient unit becomes an efficient one through an increase in its outputs, was used.

Table 7 Structuring DEA model for evaluating the efficiency of the faculties

Faculty	Input 1	Input 3	Input 2	Output 1	Output 2
F_1	52	510	32	424	34
F_2	100	1350	36	1060	71
F_3	64	305	49	287	45
F_4	71	543	12	210	32
F_5	43	739	18	321	18
F_6	35	445	24	172	24
F_7	79	306	40	176	88
F_8	40	306	25	374	24
F_9	57	272	41	98	42
F_{10}	26	204	20	140	6
F_{11}	35	94	11	35	5
F_{12}	98	591	71	600	81

Source: Information brochures on the work of the faculty for the academic year 2013/2014.

The mathematical form of this model is as follows:

$$max\ h_k = \sum_{r=1}^{s} u_r \times y_{ro}$$

$$\sum_{r=1}^{s} u_r \times y_{rj} - \sum_{i=1}^{m} v_i \times x_{ij} \leq 0,\ j = 1,\dots ,n$$

$$\sum_{i=1}^{m} v_i \times x_{io} = 1$$

$u_r \geq 0,\ v_i \geq 0$

where:

y_{rj} - the output value,

x_{ij} - the input value,

u_r - the weight coefficient of the output y_{rj},

v_j - the weight coefficient of the input x_{ij},

$r = 1, 2, \dots, s$ - the number of the recorded products,

$i = 1, 2, \dots, m$ - the number of the used resources,

$j = 1, 2, \dots, n$ - the number of the DMUs.

Namely, in the observed problem for the faculty F1, the corresponding CRS DEA linear model is as follows:

$max\ h_k = 424\, y_1 + 34\, y_2$

With the system of limitations:

$52\, x_1 + 32\, x_2 + 510\, x_3 = 1$

$424\, y_1 + 34\, y_2 - (52\, x_1 + 32\, x_2 + 510\, x_3) \leq 0$

$1060\, y_1 + 71\, y_2 - (100\, x_1 + 36\, x_2 + 1350\, x_3 \leq 0$

$287\, y_1 + 45\, y_2 - (64\, x_1 + 49\, x_2 + 305\, x_3) \leq 0$

$210\, y_1 + 32\, y_2 - (71\, x_1 + 12\, x_2 + 543\, x_3) \leq 0$

$321\, y_1 + 18\, y_2 - (43\, x_1 + 18\, x_2 + 739\, x_3) \leq 0$

$172\, y_1 + 24\, y_2 - (35\, x_1 + 24\, x_2 + 445\, x_3) \leq 0$

$176\, y_1 + 88\, y_2 - (79\, x_1 + 40\, x_2 + 306\, x_3) \leq 0$

$374\, y_1 + 24\, y_2 - (40\, x_1 + 25\, x_2 + 306\, x_3) \leq 0$

$98\, y_1 + 42\, y_2 - (57\, x_1 + 41\, x_2 + 272\, x_3) \leq 0$

$140\,y_1 + 6\,y_2 - (26\,x_1 + 20\,x_2 + 204\,x_3) \leq 0$

$35\,y_1 + 5\,y_2 - (35\,x_1 + 11\,x_2 + 94\,x_3) \leq 0$

$600\,y_1 + 81\,y_2 - (98\,x_1 + 71\,x_2 + 591\,x_3) \leq 0$

$y_1, y_2 \geq 0$

$x_1, x_2, x_3 \geq 0$

Appropriate models are formed in the same way as for other decision-making units, i.e. the faculties.

THE RESULTS OF THE APPLICATION OF THE AHP, DEA, AND DEAHP METHODS

The results of the AHP method

The Superdecision software package was used to calculate the weight coefficients of the criteria, and, on the basis of them, the final alternative priorities. Table 8 shows that the highest priority and rank 1 is given to the criterion Number of teachers (0.368173), and the lowest rank to the criterion Number of doctoral dissertations (0.078690).

The final ranking of the alternatives within the AHP model for the evaluation and ranking of the faculties by using the Superdecision software package is accounted for in Table 9. The results obtained show that Faculty 12 is ranked the best, only to be followed by Faculty 2, ranked the second.

Table 8 The weight coefficients and the rank within the AHP model for the evaluation and ranking of the faculties, calculated by using the Superdecision software package

Criterion	Weight coefficients	Rank
Output 1	0.126346	4
Output 2	0.078690	5
Input 1	0.368173	1
Input 2	0.193262	3
Input 3	0.233529	2

Consistency ratio: *CR* = 0,0742

Source: Authors

Table 9 The priorities and the final ranking of the alternatives within the AHP model for the evaluation and ranking of the faculties

Alternative	Total	Normalized	Idealized	Rank
Faculty 1	0.0394	0.0788	0.3519	5
Faculty 2	**0.1107**	**0.2214**	**0.9886**	**2**
Faculty 3	0.0414	0.0829	0.3699	4
Faculty 4	0.0360	0.0721	0.3219	6
Faculty 5	0.0352	0.0704	0.3144	7
Faculty 6	0.0185	0.0370	0.1654	9
Faculty 7	0.0445	0.0890	0.3972	3
Faculty 8	0.0170	0.0340	0.1518	10
Faculty 9	0.0295	0.0590	0.2633	8
Faculty 10	0.0087	0.0174	0.0775	11
Faculty 11	0.0070	0.0140	0.0626	12
Faculty 12	**0.1120**	**0.2240**	**1.0000**	**1**

Source: Authors

In the event that the process of evaluation and comparison involves several experts, i.e. decision-makers, it is possible to use the geometric mean as a way to combine and objectify the assessment (Saaty & Peniwati, 2008):

$$w_i = \sqrt[K]{\pi_{k=1}^{k=K} w_{ik}} \qquad \forall\, i$$

where w_i is the final weight of the *i*-th factor, and the relative weight of the *i*-th element, calculated on the basis of the assessment of the *k*-th evaluator.

The results of the DEA method

For the evaluation of the efficiency of the faculties in the Republic of Serbia, the input-oriented CCR model was used, with a constant return to scale (CRS). The results presented in Table 10 were obtained from the three inputs (the number of the teachers, the number of the associates, the number of the enrolled students) and the two outputs (the number of the graduates, the number of the doctoral dissertations). Given the fact that the literature abounds in dilemmas about the relationship between the DMU and the number

Table 10 The efficiency and optimal values of the weight coefficients of the inputs and the outputs within the output-oriented CRS DEA model

DMU No.	DMU Name	Efficiency	Input 1	Input 2	Input 3	Output 1	Output 2
1	F1	0.90949	0.01453	0.00000	0.00048	0.00115	0.01241
2	F2	1.00000	0.00000	0.00725	0.00055	0.00069	0.00383
3	F3	0.95397	0.00000	0.00000	0.00328	0.00224	0.00692
4	F4	1.00000	0.00000	0.05362	0.00066	0.00101	0.02464
5	F5	0.70426	0.02326	0.00000	0.00000	0.00219	0.00000
6	F6	0.75553	0.02857	0.00000	0.00000	0.00113	0.02339
7	F7	1.00000	0.00000	0.00000	0.00327	0.00000	0.01136
8	F8	1.00000	0.00000	0.00000	0.00327	0.00223	0.00690
9	F9	0.67119	0.01754	0.00000	0.00000	0.00069	0.01436
10	F10	0.57332	0.03160	0.00000	0.00088	0.00410	0.00000
11	F11	0.36652	0.00000	0.00000	0.01064	0.00726	0.02247
12	F12	0.99293	0.00851	0.00000	0.00028	0.00067	0.00727

Source: Authors

of input and output values, it is proposed that the number of DMUs is at least two times larger than the sum of input and output values (2 + 1). Bearing in mind the fact that the proposed model has a total of five variables (3 inputs and 2 outputs), the minimum number of decision-making units is 10. In this model, 12 DMUs, i.e. 12 faculties in the Republic of Serbia, were used. The efficiency was determined by using the DEAFrontier software package.

The results demonstrated in Table 11 point to the conclusion that the faculties F2, F4, F7, and F8 are relatively efficient, i.e. the 4 decision-making units form an efficient envelope. Their efficiency is 1, which means that they do not have „surpluses" in the input or „deficits" in the output variables. The other faculties may be regarded as relatively inefficient.

The results of the DEAHP method

In accordance with R. Ramanathan's suggestions (2005), the DEA method can be used for deriving the objectified local decision-making priority elements. As B. R. Royendegh and S. Erol (2009) have also shown, it is possible to establish and implement an effective model for ranking decision-making units with multiple outputs and inputs, using the DEA method combined with the AHP/ANP methods. Table

Table 11 The efficiency and ranking of the faculties, calculated by using the output-oriented CRS DEA model

Faculty	Efficiency	Rank
F1	0.90949	7
F2	**1.00000**	**1**
F3	0.95397	6
F4	**1.00000**	**1**
F5	0.70426	9
F6	0.75553	8
F7	**1.00000**	**1**
F8	**1.00000**	**1**
F9	0.67119	10
F10	0.57332	11
F11	0.36652	12
F12	0.99293	5

Source: Authors

12 shows the criterion comparison matrix, where the evaluation input values result from the AHP criterion comparison based on the 1-9 scale. These values can be further used, as suggested by Ramanthan, as the output values in the corresponding DEA model (Table 13), which the column of the fictitious input values is also added to, as a condition for the establishment and application of the DEA model. The application of the DEA method in such a structured problem results in the relative efficiency of inputs and outputs, i.e. the selected criteria, which, however, are not of importance for the further implementation of the DEAHP method, given the fact it is not necessary that either they or their relative importance should be taken into account when forming the DEAHP comparison matrix and calculating the DEAHP relative efficiency of alternatives. Table 14 shows the DEAHP criterion comparison matrix, while Table 15 presents the comparison matrix of the decision-making units, the alternatives, in relation to Output 1. The input values are evaluations resulting from comparing pairs of alternatives, the faculties, in the AHP model. The table usually includes a column with the fictitious input value, as well as output columns, in order to apply the DEAHP model. Table 16 presents the calculated DEAHP relative efficiencies of the decision-making units, i.e. their local priorities, in relation to Output 1.

The relative efficiencies of the alternatives, the faculties, observed in relation to Output 1, are shown in Table 16. The alternative comparison matrices in relation to Output 2, as well as the other inputs, can be formed in the same manner, followed by the application of the DEA method to determine local priorities, i.e. the relative efficiencies of the decision-making units observed.

Table 12 The criterion comparison matrix within the AHP model for the evaluation and ranking of the faculties

Criteria	Output 1	Output 2	Input 1	Input 2	Input 3
Output 1	1	2	1/4	1/3	1
Output 2	1/2	1	1/3	1/2	1/4
Input 1	4	3	1	2	2
Input 2	3	2	1	1	1/2
Input 3	1	4	1/2	2	1

Source: Authors

Table 13 The DEAHP comparison matrix for the evaluation of the efficiency of the criteria

DMU	I1	O1	O2	O3	O4	O5
I1	1	1	2	0.250	0.333	1
I2	1	0.5	1	0.333	0.5	0.25
O1	1	4	3	1	2	2
O2	1	3	2	1	1	0.5
O3	1	1	4	0.5	2	1

Source: Authors

Table 14 The efficiency of the criteria calculated by using the DEAHP method

DMU No.	DMU name	Efikasnost
1	I1	0.60000
2	I2	0.70000
3	O1	1.00000
4	O2	1.00000
5	O3	1.00000

Source: Authors

Since the local alternative priorities are calculated in relation to all individual inputs and outputs, the next step is the formation of the DEAHP alternative comparison matrix (Table 17) in relation to all the criteria simultaneously, whereby the input values of the matrix are represented by the local alternative priorities, calculated in relation to individual criteria, where the table usually includes the column of the fictitious input value to implement the DEA method. The final priorities of the alternatives, i.e. their DEAHP relative efficiencies, are given in Table 18, from which it is clear that the faculties F1, F2, F3, F5, F7, F9, and F12 are relatively efficient, while the others are relatively inefficient, with the faculty F11 being ranked the lowest. Finally, Table 19 presents a comparative overview of the alternative priorities, i.e. their relative efficiencies[1], calculated by using all the three methods.

Table 15 The DEAHP alternative comparison matrix in relation to Output 1

DMU	I1	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12
F1	1	1	0.5	4.000	5	3	5	5	3	7	5	7	0.333
F2	1	2	1	6	7	5	8	8	5	8	7	9	4
F3	1	0.2	0.167	1	3	0.5	4	4	0.25	4	3	6	0.2
F4	1	0.2	0.143	0.333	1	0.333	4	4	0.333	4	3	5	0.2
F5	1	0.333	0.2	2	3	1	3	3	0.333	5	4	7	0.2
F6	1	0.2	0.125	0.25	0.25	0.333	1	0.5	0.2	3	2	4	0.143
F7	1	0.2	0.125	0.25	0.25	0.333	2	1	0.25	4	3	6	0.143
F8	1	0.333	0.2	4	3	3	5	4	1	7	6	8	0.25
F9	1	0.143	0.125	0.25	0.25	0.2	0.333	0.25	0.143	1	0.5	4	0.125
F10	1	0.2	0.143	0.333	0.333	0.25	0.5	0.333	0.167	2	1	4	0.125
F11	1	0.143	0.111	0.167	0.2	0.143	0.25	0.167	0.125	0.25	0.25	1	0.111
F12	1	3	0.25	5	5	5	7	7	4	8	8	9	1

Consistency ratio: *CR* = 0,09886

Source: Authors

Table 16 DEAHP relative efficiency of alternatives in relation to Output 1

DMU No.	DMU name	Efficiency
1	F1	0.87500
2	F2	1.00000
3	F3	0.66667
4	F4	0.55556
5	F5	0.77778
6	F6	0.44444
7	F7	0.66667
8	F8	0.88889
9	F9	0.44444
10	F10	0.44444
11	F11	0.11111
12	F12	1.00000

Source: Authors

Table 17 The local alternative priorities in relation to the criteria (outputs and inputs)

DMU	I1	C1	C2	C3	C4	C5
F1	1	0.55556	0.66667	0.833	0.875	1
F2	1	1	0.66667	1	1	1
F3	1	0.77778	1	0.44444	0.66667	0.66667
F4	1	0.77778	0.11111	0.88889	0.55556	0.5
F5	1	0.44444	0.33333	1	0.77778	0.22979
F6	1	0.33333	0.44444	0.75	0.44444	0.26047
F7	1	0.875	0.66667	0.5	0.66667	1
F8	1	0.44444	0.44444	0.11111	0.88889	0.33617
F9	1	0.57143	0.66667	0.55556	0.44444	1
F10	1	0.11111	0.33333	0.44444	0.44444	0.12077
F11	1	0.22222	0.11111	0.25	0.11111	0.12077
F12	1	1	1	0.88889	1	1

Source: Authors

Table 18 The final priorities of the alternatives calculated by applying the DEAHP method

DMU No.	DMU name	Efficiency
1	F1	1.00000
2	F2	1.00000
3	F3	1.00000
4	F4	0.88889
5	F5	1.00000
6	F6	0.75000
7	F7	1.00000
8	F8	0.88889
9	F9	1.00000
10	F10	0.45454
11	F11	0.25000
12	F12	1.00000

Source: Authors

Table 19 The comparative analysis of the priorities of the alternatives, obtained by using the AHP, the DEA, and the DEAHP methods

	AHP efficiencies	DEA priorities (efficiencies)	DEAHP priorities
F_1	0.3519	0.90949	**1.00000**
F_2	0.9886	**1.00000**	**1.00000**
F_3	0.3699	0.95397	**1.00000**
F_4	0.3219	**1.00000**	0.88889
F_5	0.3144	0.70426	**1.00000**
F_6	0.1654	0.75553	0.75000
F_7	0.3972	**1.00000**	**1.00000**
F_8	0.1518	**1.00000**	0.88889
F_9	0.2633	0.67119	**1.00000**
F_{10}	0.0775	0.57332	0.45454
F_{11}	0.0626	0.36652	0.25000
F_{12}	**1.0000**	0.99293	**1.00000**

Source: Authors

It is noticeable that the faculties F2 and F12 have the matching priority values, calculated by using all the three methods, which only confirms the fact that these are the best performing faculties.

CONCLUSION

This paper has presented a hybrid DEAHP method for measuring and evaluating the performance of the 12 state faculties in the Republic of Serbia. The idea was to take on a new, comprehensive approach and, through the integrated and combined use of the DEA and the AHP methods, obtain a more complete and objective evaluation of faculty performance and perform their ranking. The ultimate goal of this study was to improve the evaluation process of higher education institutions in Serbia, using the multi-criteria analysis methods.

The proposed approach of combining the Analytic Hierarchy Process, as a method for decision-making support in terms of complexity and uncertainty, and robust non-parametric methods, such as the Data Envelopment Analysis, provides a flexible, systematic, and objective framework for a comprehensive (absolute and relative) efficiency measurement and performance evaluation, and, implicitly, stands for a reliable basis for making high-quality strategic decisions in higher education institutions. Through the simultaneous use of the non-financial indicators and the possibility of including not only the quantitative but also the qualitative factors and their combination (through the AHP), the proposed approach significantly reduces the subjectivity and bias frequently present in the measurement and evaluation of organizational performance. In theoretical and methodological terms, some dilemmas remain, relating to the functioning of the DEAHP method in the case of inconsistent evaluation matrices (Ramanathan, 2006), which can, however, be verified or denied in future empirical research. It would be useful to perform a solution sensitivity analysis and check whether and how changes in the relative importance of the selected criteria in the AHP method affect the ranking of the alternatives, and what consequences this may have for the integrated application with the DEA method, both generally and in specific cases.

Based on the results obtained, it can be concluded that there are potentially wide possibilities of the application of the scientifically based multi-criteria analysis methods and models, especially in the field of higher education, which creates better conditions for making high-quality management decisions with long-term effects on society. If viewed in a broader social context, the results of the conducted research can contribute to the improvement of the management and governance systems within higher education institutions, and can be a significant indicator of the further development of higher education institutions and the Serbian society as a whole. Furthermore, the results can form the basis for future studies, in combination and by comparison with the results obtained by other multi-criteria decision-making methods in order to find the best combination of methods for the evaluation and ranking of not only higher education institutions in the context of the continuous higher education reform process, but also of other non-profit organizations in the Republic of Serbia.

In fact, the conducted process of efficiency evaluation and performance measurement of the observed faculties has had certain limitations, the most important ones being related to the fact that the analysis included a relatively small number of the model inputs and outputs, and omitted those relating to scientific research and the financial component, as extremely important dimensions for the functioning of the observed higher education institutions. By including these factors into the analysis, a more realistic, multidimensional evaluation of faculty performance would be obtained, which makes room for a new interpretation of the results obtained, a correlation analysis, a solution sensitivity analysis, and further research in this direction. In addition, due to a lack of up-to-date and transparent data, and despite the obligation of publishing annual information brochures on the work of the faculties, there is no possibility of forming sufficiently long data time series that would enable various econometric analyses and a comparison of actual faculty performance by periods.

ENDNOTE

1 It is known that the priorities of the AHP model can be interpreted in various ways, depending on the context of the problem. In this case, they have the meaning of efficiency. The efficiencies of the alternatives, calculated by using the AHP method, are taken from the column of the idealized values, obtained by dividing all the individual priority values by the highest value in the column of the normalized values.

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