PROFESSIONAL EDUCATION

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MATHEMATICAL MODEL OF AN EDUCATIONAL PROGRAM QUALITY ASSESSMENT

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Abstract

The purpose *of this article is to substantiate the methods, principles and approaches to building a mathematical model for quantitative assessment of the educational program quality functioning, regardless of the subject area and specialty for which it has been developed.* ***Methods:*** *The article analyzes sixty-five educational programs developed in accordance with thirty-five specialties within fourteen subject areas. These programs operate in forty-nine higher education institutions in different regions of Ukraine. An interval scale has been developed, which allowed translating the qualitative characteristics (criteria) of the educational program into quantitative ones. Using the regression analysis method and software product PRIAM (planning, regression and model analysis) a mathematical model has been built, that allows not only to assess the quality of the educational program in more accurate and reliable way, but also to determine the level and duration of its accreditation.* ***Results:*** *to quantify the educational program quality, a mathematical model has been developed and its statistical characteristics have been analyzed. Informativeness, adequacy, accuracy and stability have been determined, and the diagrams of criteria (regressors) mutual influence on the educational program quality have been built.* ***Discussion:*** *a linear regression model based on a qualimetric approach and TQM principles has been proposed. The use of regression analysis methods allowed to identify the criteria (regressors) mutual influence, determine their priority and quantify the educational program quality as a whole. This approach allows to reasonably choose the optimal number of criteria, their mutual influence and priority. This further allows to more reliably and accurately determine the level of educational program accreditation, which is relevant for each higher education institution.*

Keywords: educational program, evaluation methods, higher education institutions, mathematical model, quality criteria, regression analysis.

1. Introduction

In today's economic environment, any higher education institution (HEI) is competitive and effective if it has priority educational programs (PEP) that respond immediately to the fleeting demands of the labor market.

The authors' analysis of the "List of subject areas and specialties in which higher education students are trained" showed that there are 29 subject areas in Ukraine, covering 121 specialties. Within these subject areas and specialties there is a large number of educational programs. However, to determine their priority and demand from stakeholders, it is necessary to have effective mechanisms and tools that would allow constant monitoring and evaluation of the existing programs quality. Based on the

obtained data, it is possible to predict the ways of their further modernization and development.

One of such promising mechanisms is the use of mathematical models based on qualimetric approaches and principles of total quality management (TQM). This allows not only a qualitative but also a quantitative assessment of the educational programs (EP) criteria and characteristics approved in the Regulation [1].

In the future, this approach makes it possible to determine the level and duration of an educational program accreditation. Today, in our opinion, this problem is not fully resolved. This is due to the fact that the existing methods, principles and approaches to the EP quality assessment do not allow to

accurately and reliably determine the level of its accreditation on which the certificate validity depends.

Therefore, the research related to the mathematical model of quantitative assessment of EP functioning quality is relevant and timely.

2. Analysis of recent research and publications, problem statement

The effectiveness of using the mathematical models of any objects (processes, services, products, etc.) depends on the correct choice of its construction method. This is confirmed in [2 - 5]. At the same time, special attention should be paid to formalization procedures, which involve translating the purpose of research into a mathematical form [6,7]. Today, there are a large number of publications related to the use of regression analysis methods for building mathematical models. Unfortunately, in all publications, technological processes act as a modeling object. For example, processing of high-strength steels [8], management processes, performance indicators of enterprises [9], forecasting the state of hard aerodrome pavements [10], printing services [11, 12], modes of electrocontact bonding (choosing coatings and the optimization technology) [13], modeling of parameters of thermal sprayed coatings processes [14].

The analysis of scientific publications conducted by the authors showed that mathematical modeling, in particular the construction of regression models, is almost not used to assess the quality of the educational processes functioning and HEI activities. Mathematical methods are usually used in publications as a tool for obtaining competencies in subjects taught in Bachelor's and Master's training [15, 16].

Therefore, the scientific problem associated with the construction of a mathematical model of an educational program quality assessment needs to be developed. This is due to the current legal framework for training specialists at all educational levels.

3. The purpose and objectives of the research

The purpose of the research is to choose and substantiate the methods, principles and approaches to building a mathematical model that allows you to quantify the educational program quality of any subject area and speciality.

To achieve this goal the following tasks have

been completed:
- the research method has been chosen and substantiated;
- the expert opinions of the branch expert council (BEC) of 65 educational programs have been analyzed;
- the interval scale for transforming qualitative characteristics (criteria) into quantitative ones has been developed;
- based on the results of experimental research, a data matrix has been formed to build a mathematical model;
- a mathematical model has been built and its statistical characteristics (informativeness, adequacy, accuracy and stability).

4. Materials and methods of research

The research used the information provided in [17] regarding the accreditation results of 65 educational programs of the second (master's) higher education level. The studied educational programs cover 14 areas of knowledge. Accreditation of these programs has been carried out in accordance with the requirements [1, 18].

To build a mathematical model, a passive experiment, qualimetric approach, TQM principles, and regression analysis have been used. The results have been processed using the PRIAM software product [19].

5. The results and discussion

Building a model is a solution to a complex formalized task, using existing mathematical methods and tools. However, it should be noted that the mistakes made in the process of formalization are almost impossible to correct during the processing of research results. This is due to the fact that formalization involves the transformation of the research purpose into a mathematical form and the statistical methods of analysis application. Therefore, to build a mathematical model, a special scheme has been developed (Fig. 1). It consisted of 4 stages. Each of the stages is responsible for the particular component of the model and allows identifying its "weaknesses" and "strengths".

At **the first stage** (Fig. 1) the tasks to be solved during the research were identified:

1. Analyze the conclusions of the BEC upon the possible EP accreditation in concordance with the established scale (A, B, E and F) according to [1]. To perform this task, the qualitative characteristics of 65 educational programs of the second (master's) higher education level have been analyzed [17].

2. Develop basic and additional interval scales (to

transform qualitative characteristics into quantitative and to determine the intervals of the accreditation level).

3. Form an initial matrix for quantitative evaluation of EP quality criteria to build a mathematical model.

4. Choose the method and structure of the mathematical model.

5. Build a mathematical model and determine its statistical characteristics using the PRIAM software product.
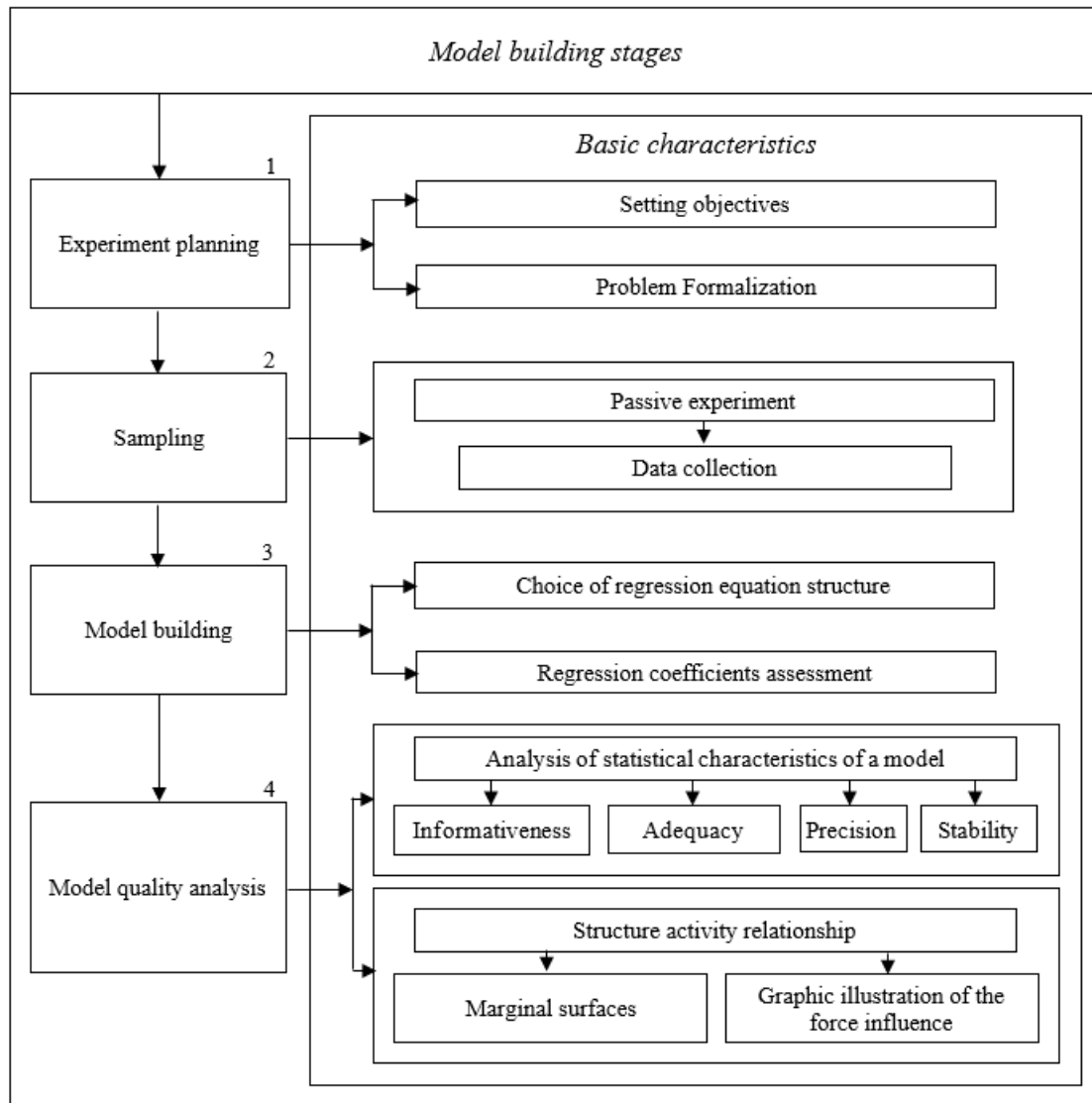

Fig. 1. The scheme of the mathematical model of EP quality assessment

6. Analyze the statistical characteristics of the model and build the dependence of the regressors (criteria) impact power on the educational program quality.

In **the second stage** during the passive experiment, to form the data matrix the results of BEC expert evaluation of 65 educational programs have been taken. These programs had different levels of accreditation (exemplary, granted, conditioned (deferred) and denied accreditation). In particular, 4 educational programs had the exemplary accreditation level, 31 programs –

granted, 23 programs – conditioned (deferred), 7 programs – denied accreditation. It should be noted that in the studied EP data each criterion had only a qualitative assessment. This is due to the fact that the assessment was carried out according to a four-level scale (A, B, E and F).

The authors have developed a basic and additional interval scale to transform the qualitative assessment into a quantitative one and to determine the level of accreditation (Tables 1, 2). This approach allowed more precisely evaluating each criterion and obtaining its quantitative assessment.

Table 1

Interval scale for quantitative assessment of EP quality criteria (basic)

Qualitative assessment (according to [1])	Quantitative assessment in points	Definition	Explanation
A	3,76 – 5	high level of compliance	full compliance, with an innovative character
B	2,51 – 3,75	sufficient level of compliance	partial noncompliance, shortcomings are insignificant
E	1,26 – 2,5	low level of compliance	noncompliance, possible elimination within a year
F	0 – 1,25	noncompliance	noncompliance, elimination is impossible

The use of an additional scale is stipulated by the regression analysis requirements. This is due to the fact that when calculating the regression it is necessary to enter the input interval Y.

Table 2

Interval scale for determining the accreditation level (additional)

Y	Exemplary accreditation	Granted accreditation	Conditioned (deferred) accreditation	Denied accreditation
	5	3,75	2,5	1,25

Using the basic and additional scales for all 65 educational programs, qualitative assessments of criteria (literal) and accreditation levels (verbal) were translated into quantitative ones.

At the same time, each EP was evaluated according to 9 criteria. These are: "Design and goals of EP" - DG; "Structure and content of EP" - SC; "Access to EP and determination of learning outcomes" - ADLO; "Training and teaching according to EP" - TT; "Control measures, HEI students evaluation and academic integrity" - CMAI; "Human resources" - HR; "Educational environment and material resources" - EEMR; "Internal quality assurance of EP" - IQA; "Transparency and publicity" - TP. This is due to the fact that these criteria are standardized in Regulation [1, 18] and form the educational program quality. In addition, these criteria are further used to build a mathematical model, ie are its regressors. Detailed procedures for the criteria estimation are given in [20].

The results of experimental studies in the form of the main working matrix have been summarized in the table. A fragment of the working matrix for building the model is shown in table 3.

In our case, the construction of a mathematical model was carried out as part of a passive experiment. For this purpose, according to the main working matrix, training and control matrices has been formed. Considering that the initial data is an observation matrix (passive experiment), it has been divided into training (with the best possible properties for building a model) and control (for unbiased verification of the model).

This approach is based on the fact that the training matrix completely covers the entire area of definition and has the minimum possible correlation between regressors (criteria). This ensures a model with satisfactory quality characteristics (adequacy, informativeness and sustainability). According to the results of the calculation, the educational matrix has included 25 educational programs. A model was built on this matrix. The other 40 EPs moved to the control matrix. Further, the control matrix was used to verify the constructed mathematical model. In **the third stage**, the linear structure of the regression equation was first selected on the basis of the developed matrices with the help of PRIAM software product in the automatic mode. Then the regression coefficients were estimated and the model (1) was constructed:

$$Y=3{,}21685+ 0{,}865646x_2 + 0{,}647632x_4 + 0{,}00501515x_5 + 0{,}0536686x_7 - 0{,}0113172x_8 + 0{,}348952x_9 + 0{,}396513x_1x_3 - 0{,}568461x_1x_4 - 1{,}62092x_6x_9 \quad (1)$$

where $x_1 = 0{,}523013*(X_1 – 3{,}212)$;
$x_2 = 0{,}673129*(X_2 – 2{,}7456)$;
$x_3 = 0{,}85034*(X_3 – 3.824)$;
$x_4 = 0{,}436224*(X_4 – 3{,}5924)$;
$x_5 = 0{,}43163*(X_5 – 3{,}7168)$;
$x_6 = 0{,}516742*(X_6 – 3{,}5352)$;
$x_7 = 0{,}882768*(X_7 – 3{,}8672)$;
$x_8 = 0{,}393329*(X_8 – 3{,}8024)$;
$x_9 = 0{,}429923*(X_9 – 3{,}676)$.

At **the fourth stage**, the analysis of statistical characteristics was carried out.

Summarized results of the analysis are shown in table 4.

Table 3

Fragment of the working matrix to build a mathematical model

Educational programs	Factors									Y	Decision of the National Agency
	Natural definition of regressors										
	DG	SC	ADLO	TT	CM	HR	EEMR	IQA	TP		
	Formalized regressors notation and their numerical values										
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9		
EP1	3,5	3	5	3,2	5	3,5	3,2	3,5	5	3,75	exemplary
EP2	3	2	3,4	1,6	3,5	2,8	3	3,2	3	2,5	conditioned (deferred) accreditation
EP3	3,4	3,7	3,4	3,6	3,5	3,2	5	3,4	3,5	3,75	granted
EP4	2,8	2	3,5	3,5	3,2	3	3,4	3,5	3,2	2,5	conditioned (deferred) accreditation
…	…	…	…	…	…	…	…	…	…	…	…
EP16	5	3,7	5	3,6	5	3,65	5	5	3,65	5	exemplary
EP17	5	3,65	4,8	5	5	5	3,72	3,55	3,45	5	exemplary
EP18	1,7	1,45	3,2	1,35	1,35	1,43	3,5	3,4	3,45	1,25	denied accreditation
…	…	…	…	…	…	…	…	…	…	…	…
EP62	3,65	3,7	3,75	5	3,6	5	3,6	5	5	3,75	granted
…	…	…	…	…	…	…	…	…	…	…	…
EP65	1,3	1,3	3,2	3,35	3,68	3,6	3,4	3,7	3,6	2,5	conditioned (deferred) accreditation

Table 4

Statistical characteristics of the model quality

Characteristic	Name	Legend	Value
Informativeness	Multiple correlation coefficient	R	0,952437
	Estimated value of Fisher criterion to verify the significance of R	F_R	16,2806
	The critical value of the Fisher criterion to verify the significance of R	$F_{cr\,R}$	2,58763
	Degrees of freedom	ν_1	9
		ν_2	15
	The scattering fraction explained by the model	R^2	0,907136
	Box-Wetz criterion	γ	2
	Hypothesis about the multiple correlation coefficient significance	-	accepted
	Informativeness level	-	good
Adequacy	Residual variance	$S^2_{res\,var}$	0,1109554
	Reproducibility variance	$S^2_{rep\,var}$	0,1575
	Estimated value of Fisher criterion to test adequacy	F_{ad}	7,18204
	Critical value of Fisher criterion to test adequacy	$F_{cr\,val}$	2,58763
	Degrees of freedom (ν_1, ν_2)	ν_1	9
		ν_2	15
	Hypothesis of the adequacy	-	accepted
Accuracy	Average accuracy of data description in percent deviation	%	14,9821
	Average absolute approximation error	Δ	0,344729
Stability	COND (conditionality number)		4,73105
	conclusion	-	satisfactory
	Part of the explanation by dubious regressors	%	9,69
	conclusion	-	satisfactory
Level of significance	α	-	0,05

Thus, as shown by Table 4, the model is informative, adequate and stable, both in structure and in calculations. To determine the most influential criteria (regressors) with the help of the PRIAM software product, the marginal surfaces of their combined influence on the educational program quality has been constructed (see Fig. 2-5).
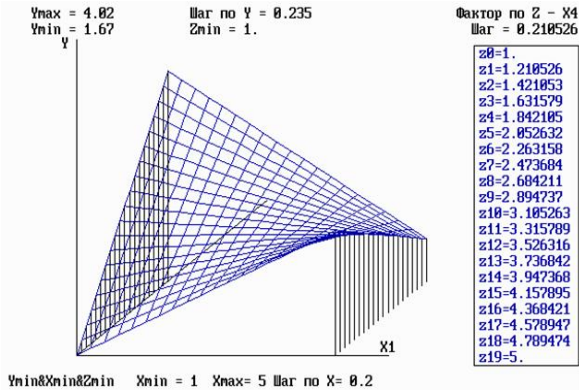

Fig. 2. Marginal surface of the combined effect of X_1 and X_4 regressors on the EP quality (Y)
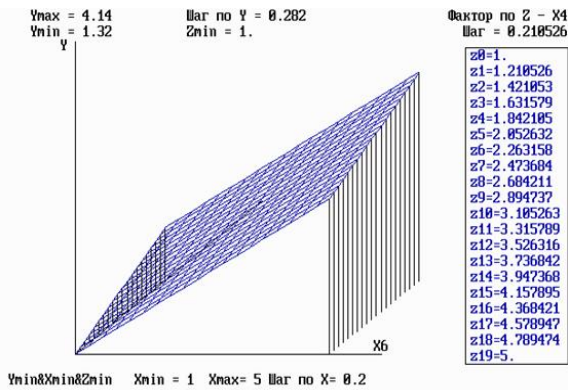(other factors recorded at 3.00)

Fig. 3. Marginal surface of the combined effect of X_6 and X_4 regressors on the EP quality (Y)
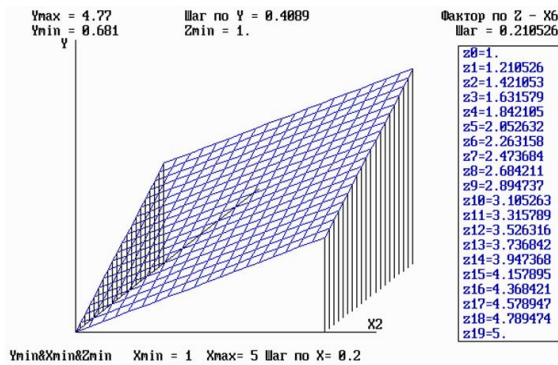(other factors recorded at 3.00)

Fig. 4. Marginal surface of the combined effect of X_2 and X_6 regressors on the EP quality (Y)
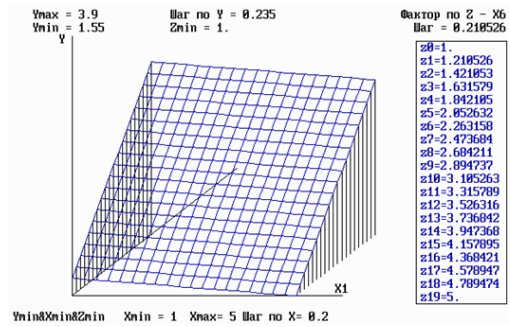(other factors recorded at 3.00)

Fig. 5. Marginal surface of the combined effect of X_1 and X_6 regressors on the EP quality (Y)
(other factors recorded at 3.00)

The diagram result analysis of the surfaces showed that the combined effect of the criteria can both significantly increase and decrease the EP performance quality as a whole.

Thus, this approach allows identifying "weaknesses" and "strengths" for each EP. Further, in accordance with the TQM principles to improve the EP performance quality it is recommended to develop and implement corrective and preventive organizational and technical measures, such as those given in [21].

According to the results of statistical analysis, the dependence of the regressors (criteria) impact share on the EP quality has been constructed (Fig. 6).
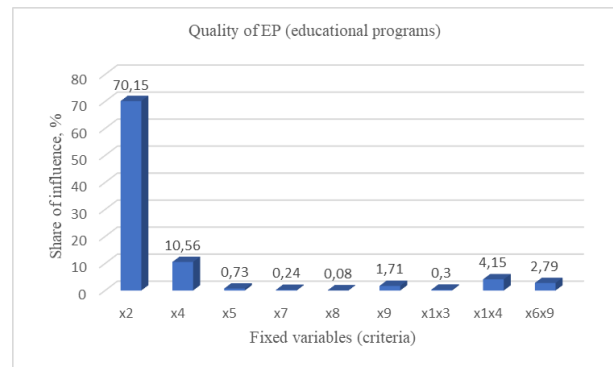

Fig. 6. Distribution of the regressors' impact power on the Y response (EP quality) for the model

As it can be seen from the figure, the most influential criteria are the following two: "Structure and content of EP" - SC (X_2) and "Training and teaching according to EP" - TT (X_4). Their impact share on the EP performance quality is 70.15% and 10.56%, respectively. Therefore, when developing EP, special attention should be paid to these components. It should be noted that the EP quality also depends on the combined impact of the criteria. For example, the combined impact of the "Design

and goals of EP" - DG (X_1) and "Training and teaching according to EP" - TT (X_4) criteria is 4.15%, and "Human resources" - HR (X_6) and "Transparency and publicity"- TP (X_9) is 2.79%. This is due to the fact that these criteria are fundamental to the educational program quality and are present in "explicit" or "implicit" form in all its components. Also, this result is directly confirmed by the monitoring analysis of educational programs conducted by higher education institutions.

6. Conclusions

The results of 65 EPs accreditation represented by 35 specialties in 14 subject areas have been analyzed.

It has been proved that qualitative assessment has a high level of subjectivity and therefore does not always correctly reproduce the quality of the EP and the level of its accreditation.

The basic and additional interval scale has been developed, which allows to more accurately quantifying each criterion of EP quality and the level of its accreditation. In the future, the data obtained in accordance with this scale are used to build a mathematical model.

A mathematical model that describes the quality of EP performance, regardless of the subject area and specialty has been built. The model is adequate, informative and stable.

The developed model allows quantifying the EP quality and more accurately and reliably determine its accreditation level and certificate validity.

According to the results of the mathematical model analysis, it has been found that the most influential criterion is the "Structure and content of EP" (its share is 70.15%).

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Метою даної статті є обґрунтування методів, принципів і підходів до побудови математичної моделі для кількісного оцінювання якості функціонування освітньої програми незалежно від галузі знань та спеціальності за якою вона розроблена. Методи: у статті проаналізовано шістдесят п'ять освітніх програм, які розроблені за тридцятьма п'ятьма спеціальностями в рамках чотирнадцяти галузей знань. Дані програми функціонують в сорока дев'яти закладах вищої освіти, які розташовані в різних регіонах України. Розроблено інтервальну шкалу, що дозволило перевести якісні характеристики (критерії) освітньої програми в кількісні. За допомогою методу регресійного аналізу та програмного продукту ПРІАМ (планування, регресія і аналіз моделей) побудовано математичну модель, яка дозволяє більш точно та достовірно не тільки оцінити якість функціонування освітньої програми, а й визначити рівень і термін її акредитації. Результати: для кількісного оцінювання якості функціонування освітньої програми розроблена математична модель та проведено аналіз її статистичних характеристик. Визначено інформативність, адекватність, точність і стійкість, та побудовано графіки взаємного впливу критеріїв (регресорів) на якість освітньої програми. Обговорювання: запропоновано лінійну регресійну модель, в основу якої покладено кваліметричний підхід і принципи TQM. Застосування методів регресійного аналізу дозволило виявити взаємний вплив критеріїв (регресорів), визначити їх пріоритетність та кількісно оцінити якість функціонування освітньої програми в цілому. Такий підхід дозволяє обґрунтовано вибрати оптимальну кількість критеріїв, їх взаємний вплив та пріоритетність. Це надалі дозволяє більш достовірно і точно визначити рівень акредитації освітньої програми, що є актуальним для кожного закладу вищої освіти.

Ключові слова: освітня програма, методи оцінювання, заклади вищої освіти, математична модель, критерії якості, регресійний аналіз

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Математическая модель оценивания качества образовательной программы

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Целью данной статьи является обоснование методов, принципов и подходов к построению математической модели для количественной оценки качества функционирования образовательной программы независимо от отрасли знаний и специальности, по которой она разработана. Методы: в статье проанализированы шестьдесят пять образовательных программ, которые разработаны по тридцати пяти специальностям в рамках четырнадцати отраслей знаний. Данные программы функционируют в сорока девяти высших учебных заведениях, которые расположены в разных регионах Украины. Разработана интервальная шкала, позволившая перевести качественные характеристики (критерии) образовательной программы в количественные. С помощью метода регрессионного анализа и программного продукта ПРИАМ (планирование, регрессия и анализ моделей) построена математическая модель, которая позволяет более точно и достоверно не только оценить качество функционирования образовательной программы, но и определить уровень и срок ее аккредитации. Результаты: для количественного оценивания качества функционирования образовательной программы разработана математическая модель и проведен анализ ее статистических характеристик. Определены, информативность, адекватность, точность и устойчивость, также построены графики взаимного влияния критериев (регрессоров) на качество образовательной программы. Обсуждения: предложена линейная регрессионная модель, в основу которой положен квалиметрический подход и принципы TQM. Применение методов регрессионного анализа позволило выявить взаимное влияние критериев (регрессоров), определить их приоритетность и количественно оценить качество функционирования образовательной программы в целом. Такой подход позволяет выявить оптимальное количество критериев, их взаимное влияние и приоритетность. В дальнейшем это позволяет более достоверно и точно определить уровень аккредитации образовательной программы, что актуально для каждого высшего учебного заведения.

Ключевые слова: образовательная программа, методы оценивания, высшие учебные заведения, математическая модель, критерии качества, регрессионный анализ.

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