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2 RATING OF EDUCATIONAL INSTITUTIONS USING MATHEMATICAL INSTRUMENTS TAKING INTO ACCOUNT INNOVATIVE AND SCIENTIFIC CAPITAL INVESTMENT

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ABSTRACT

As the analysis of the methods of determining the rating of educational institutions, conducted in Section 1 of this study, showed, there is currently no single and universal approach. It is the lack of such a technique that has been identified as a major drawback at the present stage. This section solves this problem, and with the help of a mathematical model it is proposed to determine the rating of the best educational institutions in the region. Relevant clusters of educational institutions of the region have been established and systematized, taking into account their sectoral significance, form of ownership, efficiency of state funding and the amount of own revenues. It has been determined, that educational institutions that effectively use their innovative and scientific potential receive planned allocations and a bonus for the appropriate rating, taking into account innovative and scientific investments. Educational institutions that do not meet the requirements of the task in the model are doomed to liquidation.

KEYWORDS

Educational institutions, mathematical model, rating, general and special funds, budget allocations, fixed assets.

2.1 RATING – A PREREQUISITE FOR EDUCATIONAL INSTITUTIONS AND THEIR FURTHER DEVELOPMENT

A modern educational institution in world-class higher education provides for a real and tangible stay of a correspondent research, production and educational institution in the global space. Therefore, successful internationalization is a necessary prerequisite for joining the elite club of leaders of modern education and science. And if until recently the level of internationalization was measured by the percentage of foreign teachers and students, then over the last decade a new mode of internationalization, a system of international university rankings that simultaneously act as a «judge and mediator», has emerged and been actively formed. Indeed, the instrumental mission of rankings is to compare the teaching and research potential of educational institutions and thus identify ways to reform and further develop them. More importantly, in the process of this comparison, the ratings state the substantive field of the «ideal type» of a modern educational institution as an educational, research and innovation center of the knowledge society [1, 2].

2.2 THE RATING METHODOLOGY OF EDUCATIONAL INSTITUTIONS WITH THE HELP OF MATHEMATICAL TOOLS TAKING INTO ACCOUNT INNOVATION AND RESEARCH INVESTMENTS AND ITS SOLUTIONS

Ukraine has not yet reached the required level of quality and accessibility of education in the system of higher education institutions. To solve the problems of ratings of educational institutions in a particular area of the region, we propose to use modern computer technology and the existing mathematical tools of applied mathematics, which is based on the use of mathematical models [3].

Let's move on to the monitoring of indicators that should be included in the mathematical model of analysis to improve the formation of financial resources in the rating system of educational institutions.

The effectiveness of the institution's use of its budgetary resources can be assessed by relative indicators. The process of building a mathematical model for improving the rating system of a budget educational institution should begin with the analysis of statistical information. This statistical information should include a small number of general indicators that inform about the state of funding of the budgetary educational institution, etc. [4, 5]. In particular, it is necessary to establish the amount of fixed assets, the total expenditures and revenues of the general and special funds of the budgetary institution. Knowing the amount of budget allocations and the factors, influencing their planning, you can determine the amount of expenditures of the general fund of the budgetary institution.

In the future, for each budgetary *educational* institution «p» of the region, its planned (unscheduled) accumulation RP_p can be defined as the ratio of revenues PP_p of the special fund to the amount of expenditures of the budgetary institution PA_p:

$$PN_p = \frac{Dsf_p}{V_p}. \tag{2.1}$$

Based on the indicators of planned (unscheduled) accumulation, we will group educational institutions in the region into E categories of funding efficiency, each of which will be characterized by its average level of funding efficiency SE_e:

$$SE_e = \frac{\sum_{p \in GE(e)} RP_p}{|GE(e)|}, \tag{2.2}$$

where $GE(e)$ – set of educational institutions in the region that belong to the category of funding efficiency e.

It is clear, that the efficiency of financing an educational budgetary institution is also influenced by the peculiarity of the relevant state, communal, or private property. Therefore, we will conduct an appropriate classification of educational institutions by appropriate status and ownership. Let the g-th property include educational institutions p, which form the set $G(g)$. By means of expert assessments we assign to the g-th property the corresponding categories of planned (unscheduled) accumulation KRG_g.

Assignment of categories of efficiency of the g-th property is carried out in such a way that the values of these categories increase with the growth of the favorableness of the respective property in relation to the efficiency of providing educational services. Educational budget institutions with the lowest average efficiency of providing educational services and budget financing are assigned category 1. Thus, educational institutions of the region can be grouped by categories of financing efficiency and g-th property (municipal, public, private). For each of these groups, we will differentiate educational institutions according to their property class.

This grouping is carried out by analyzing statistical information in the region, highlighting the property categories of small, medium and large educational budget institutions $(m = 1,2,3)$. Let the m-th category in relation to property be formed by educational institutions p, which form the set $M(m)$. The power of this finite set $|M(m)|$ is determined by the number of its elements. That is, the number of educational institutions in the region, classified by the anount of property to category m, is determined by the mentioned capacity. Let's set the average amount of property of educational institutions of category m:

$$SM_m = \frac{\sum\limits_{p \in M(m)} PA_p}{|M(m)|}, \quad (2.3)$$

where PA_p – amount of property of a particular educational institution p.

We will cluster educational institutions in the region. One cluster $CR(e,g,m)$ includes those educational institutions that have a category of financing efficiency e, their ownership and subordination belongs to category g, and property status – to class m.

We use the conducted clustering to build proposals for reforming budget policy in the field of education in the region. The purpose of such changes is to reduce (sequestration) and optimize budget expenditures, a fairer redistribution of budget allocations (budget expenditures) of the general fund of a budget institution, which does not lead to a significant increase in social tension.

In order to stimulate the subjects of educational budget institutions that provide educational services, we propose to introduce a surcharge for the rating of an educational institution. The *rating surcharge* should be applied, depending on the category of g-th property, to which the institution belongs, taking into account scientific and innovative investment projects in fixed assets of the institution for the current period. Because scientific and innovative investment projects (the amount of innovative acquired property) in the fixed assets of this institution for the current period is much easier to assess than the amount of intellectual property of the subject. However, there is a threat of liquidation of inefficient educational budget institutions, whose own revenues will not cover the surcharge for the rating of an educational budget institution.

Elimination of inefficient educational budget institutions is a necessary attribute of an efficient market economy and hopelessly inefficient educational budget institutions must experience it. However, there are numerous material and moral losses for society. In case of underfunding by the state and self-sufficiency of an educational budget institution, its rating decreases, and, consequently, the base of the rating allowance decreases, or the corresponding allowance is canceled altogether. In addition, the number of unemployed, spending on social programs and social tensions are growing. With the reduction of research and innovation efficiency and investment, inefficient educational budget institutions are faced with the need to increase efficiency and many of them can take this opportunity. To manage the process of scientific and innovative efficiency and investment of educational institutions in the region, it is proposed to choose rating allowances, which are calculated and implemented using the following optimization model.

We will adhere to the condition that the budget request is provided with the necessary funds for both general and special funds of an educational budget institution. In addition, it is necessary to minimize the expected losses from the reduction of investment income due to the elimination of inefficient educational budget institutions.

Consider the assessment of the expected funding of an educational budgetary institution. Assume that the rating allowance SPM_g is determined by the category of planned (unscheduled) accumulation of property category g, which includes the educational budgetary institution p:

$$SPM_g = \alpha + (KRG_g - 1) \cdot \Delta\alpha, \tag{2.4}$$

where α – base rating allowance rate; $\Delta\alpha$ – additional accumulation of a property category; KRG_g – category of property accumulation.

Let's set the expected income OP for an institution from the cluster $CR(e,g,m)$. According to the accepted calculations, the average amount of allowances of an institution of this cluster is SM_m. Multiplying the amount of property of the institution by the average efficiency of the cluster institution SE_e, by analogy with formula (2.1), (2.2), we obtain an estimate of the income of the educational budgetary institution:

$$OP_{e,g,m} = SM_m \cdot SE_e. \tag{2.5}$$

Let the planned accumulation of an institution have a value β. Then the expected amount of revenue SP for an institution from the cluster $CR(e,g,m)$ is:

$$SP_{e,g,m} = SM_m \cdot (\alpha + (KRG_g - 1) \cdot \Delta\alpha) + SM_m \cdot SE_e \cdot \beta. \tag{2.6}$$

If the amount of allowances and accumulations for an institution exceeds the amount of its income, the educational budgetary institution faces the threat of liquidation:

$$SM_m \cdot (\alpha + (KRG_g - 1) \cdot \Delta\alpha) + SM_m \cdot SE_e \cdot \beta \geq SM_m \cdot SE_e. \tag{2.7}$$

Given that $SM_m > 0$, we can reduce this ratio by SM_m, resulting in:

$$(\alpha + (KRG_g - 1) \cdot \Delta\alpha) + SE_e \cdot \beta \geq SE_e. \tag{2.8}$$

Since there is an inefficient use of budget allocations of an educational budget institution, if condition (2.8) is met, liquidation does not occur. In this case, the institution will be forced to spend part of its own revenues of the special fund of the budgetary institution to pay the rating allowance. Let us introduce for consideration the liquidation coefficient *KL*, which is equal to the ratio of budget allocations of the general fund to the own revenues of a budgetary institution:

$$KL = \frac{BA - VN}{VN} = \frac{BA}{VN} - 1, \tag{2.9}$$

where *BA* – budget allocations; *VN* – own revenues, declared by an educational budgetary institution.

It is natural to assume, that an educational budget institution with high efficiency, established according to official statistics, effectively redistributes the income of the special fund of the budget institution, and, consequently, have a lower liquidation rate. This dependence can be represented by the relation:

$$KL_e = MKL \cdot \left(1 - \frac{SE_e}{MRP}\right), \tag{2.10}$$

where *MKL* – maximum liquidation coefficient; SE_e – average efficiency of an institution, which belongs to the *e*-th category of efficiency; $MRP = \max_p \{RP_p\}$ – maximum of the recorded planned accumulations of the region.

Estimating the average liquidation coefficient, we can predict the actual own revenues of a budgetary institution:

$$PF_{e,g,m} = (1 + KL_e) \cdot OP_{e,g,m}. \tag{2.11}$$

Given the amount of actual income of the special fund of a budgetary institution, adjust the condition of liquidation of the institution (2.12):

$$\alpha + SE_e \cdot \beta \geq (1 + KL_e) \cdot SE_e - (KRG_g - 1) \cdot \Delta\alpha. \tag{2.12}$$

Fulfillment of condition (2.12) means the full use of the projected actual own revenues of a budgetary institution and is estimated by us as a condition of real liquidation.

Next, we take into account the factor of transfer of fixed assets at the liquidation of an institution using the renewal coefficient *KZ*:

$$KZ = \frac{PK - ZL}{DK}, \tag{2.13}$$

where *DK* – amount of fixed assets of a liquidated institution; *PK* – amount of the same fixed assets after its transfer to other owners, or return to the owner; *ZL* – costs of liquidation of an educational budgetary institution.

Determining the average value of the liquidation ratio for the region, we can estimate the revenue losses from the liquidation of an educational budget institution of the cluster $CR(e,g,m)$:

$$VL_{e,g,m}(\alpha,\beta) = (1 - KL)\cdot(SM_m \cdot (\alpha + (KRG_g - 1)\cdot \Delta\alpha) + SM_m \cdot SE_e \cdot \beta). \tag{2.14}$$

We will divide clusters of educational budgetary institutions of the region into two sets. The first set of effective educational institutions of *EP* includes those educational institutions of the region, for which liquidation condition (2.12) is not fulfilled. The second set of inefficient educational institutions *NEP* includes such educational budgetary institutions, for which condition (2.12) is fulfilled, ie, which fall into the category of liquidated, even taking into account the effect of subsidies from the state fund.

Based on the conducted estimates, we can derive a formula for calculating the total revenues of *SD* to the special fund of a budgetary institution, taking into account the depreciation of the capital of inefficient educational institutions:

$$\begin{aligned} SD(\alpha,\beta) = & \sum_{(e,g,m)\in EP} (SM_m \cdot (\alpha + (KRG_g - 1)\cdot \Delta\alpha) + SM_m \cdot SE_e \cdot \beta) + \\ & + KZ \cdot \sum_{(e,g,m)\in NEP} (SM_m \cdot (\alpha + (KRG_g - 1)\cdot \Delta\alpha) + SM_m \cdot SE_e \cdot \beta). \end{aligned} \tag{2.15}$$

To implement a fair redistribution of revenues (budget allocations, subventions) between efficient and inefficient educational budgetary institutions, we will also introduce to consider the coefficient of the expected load *NM* on the fixed assets of a budgetary educational institution:

$$NM_{e,g,m}(\alpha,\beta) = \frac{SM_m \cdot (\alpha + (KRG_g - 1)\cdot \Delta\alpha) + SM_m \cdot SE_e \cdot \beta}{SM_m}, \tag{2.16}$$

which is a share of the division of the total own revenues of the educational budget institution by its property (fixed assets).

Now we will form an optimization problem to estimate the base rate of the rating allowance α and planned (unscheduled) accumulation β. The criterion of optimality can be chosen as the amount of minimum total losses from the liquidation of educational budget institutions. However, this criterion leads to many solutions to many important problems. Therefore, another value was chosen as the criterion of optimality, which also gives positive social consequences. Namely, it is the minimization of the maximum coefficient of *MNM* allowances and load on the clusters of the model:

$$MNM(\alpha,\beta) = \max_{e,g,m}\left\{NM_{e,g,m}(\alpha,\beta)\right\}. \tag{2.17}$$

In addition, we make it a condition that the specified coefficients for each educational institution take values not less than some minimum base value *BNM*:

$$NM_{e,g,m}(\alpha,\beta) \geq BNM. \tag{2.18}$$

The value BNM can be established on the basis of the analysis of current values of coefficients of load on property in the region. In the future, one of the possible methods for selecting the specified value will be shown.

We will also impose constraints on the planned accumulation of a budgetary institution. We will assume that it must be greater than the allowance for the rating by an amount not less than $\Delta\beta$.

Given the introduced notation, the optimization model of our problem can be written in the form:

$$MNM(\alpha,\beta) \to \min, \tag{2.19}$$

$$SD(\alpha,\beta) \geq NOD, \tag{2.20}$$

$$NM_{e,g,m}(\alpha,\beta) \geq BNM, \tag{2.21}$$

$$\beta \geq \alpha + \Delta\beta, \tag{2.22}$$

$$0 \leq \alpha \leq 1, \quad 0 \leq \beta \leq 1, \tag{2.23}$$

where NOD indicate the necessary revenues to the special fund of an educational budgetary institution.

The solution to this optimization problem will be the parameters of education and budget policy in the region.

Let us analyze the formulation of the optimization problem (2.19)–(2.23). First of all, let us simplify the representation of the objective function. To do this, in formula (2.16) we reduce the numerator and denominator by the common factor PA_m. As a result, we get:

$$NM_{e,g,m}(\alpha,\beta) = \alpha + SE_e \cdot \beta + (KRG_g - 1) \cdot \Delta\alpha. \tag{2.24}$$

Based on the obtained ratio, the representation of the maximum coefficient of planned accumulation of an educational institution is simplified.

$$MNM = \max_{e,g,m}\{NM_{e,g,m}(\alpha,\beta)\} = \alpha + \max_{e,g}\{SE_e \cdot \beta + (KRG_g - 1) \cdot \Delta\alpha\}. \tag{2.25}$$

It is natural to assume, that in important cases the problem model contains a cluster of institutions, which are characterized by maximum gradations in efficiency E and in the planned accumulation of industry G. In this case, the previous formula is simplified to the next:

$$MNM = \alpha + SE_E \cdot \beta + (KRG_G - 1) \cdot \Delta\alpha. \tag{2.26}$$

To simplify constraint (2.20) for each cluster of educational institutions, we introduce our own coefficient of conditional depreciation of fixed assets of an institution:

$$UKZ_{e,g} = \begin{cases} KZ & \text{at } \alpha + SE_e \cdot \beta > (1 + KT_e) \cdot SM_m \cdot SE_e - (KRG_g - 1) \cdot \Delta\alpha; \\ 1 & \text{at } \alpha + SE_e \cdot \beta \leq (1 + KT_e) \cdot SM_m \cdot SE_e - (KRG_g - 1) \cdot \Delta\alpha, \end{cases} \tag{2.27}$$

which is equal to the usual depreciation coefficient when liquidation condition (2.12) is met and equal to one in the opposite case. Using the introduced coefficient and formula (2.15), we present constraint (2.20):

$$\sum_{(e,g,m)} UKZ_{e,g} \cdot (SM_m \cdot (\alpha + (KRG_g - 1) \cdot \Delta\alpha) + SM_m \cdot SE_e \cdot \beta) \geq NOD. \quad (2.28)$$

After simple transformations we get:

$$\alpha \cdot \sum_{(e,g,m)} UKZ_{e,g} \cdot SM_m + \beta \cdot \sum_{(e,g,m)} UKZ_{e,g} \cdot SM_m \cdot SE_e \geq$$

$$\geq NOD - \sum_{(e,r,g)} UKZ_{e,g} \cdot SM_m \cdot (KRG_g - 1) \cdot \Delta\alpha. \quad (2.29)$$

Now analyze constraint (2.21). Given relation (2.24), it can be written as follows:

$$\alpha + SE_e \cdot \beta \geq BNM - (KRG_g - 1) \cdot \Delta\alpha. \quad (2.30)$$

It is clear from the inequality record, that when it is performed for clusters of educational budget institutions with efficiency «*e*» and the lowest category of planned accumulation ($KRG_g = 1$), it is performed for other clusters of the same efficiency and higher categories of planned accumulation ($KRG_g > 1$). Therefore, this inequality can be simplified to the form:

$$\alpha + SE_e \cdot \beta \geq BNM. \quad (2.31)$$

Since all the values on the left side of the inequality are non-negative, when it is performed for clusters with minimal efficiency e_0, it will also be performed for more efficient clusters. Thus, we come to the following constraint on the minimum efficiency of clusters:

$$\alpha + SE_{e_0} \cdot \beta \geq BNM. \quad (2.32)$$

Summarizing the transformations and eliminating the term in the objective function, which does not depend on the optimized parameters α and β, we can write the following simplified formulation of the optimization problem:

$$\alpha + SE_E \cdot \beta \to \min, \quad (2.33)$$

$$\alpha \cdot \sum_{(e,g,m)} UKZ_{e,g} \cdot SM_m + \beta \cdot \sum_{(e,g,m)} UKZ_{e,g} \cdot SM_m \cdot SE_e \geq$$

$$\geq NOD - \sum_{(e,r,g)} UKZ_{e,g} \cdot SM_m \cdot (KRG_g - 1) \cdot \Delta\alpha, \quad (2.34)$$

$$\alpha + SE_{e_0} \cdot \beta \geq BNM, \tag{2.35}$$

$$\beta - \alpha \geq \Delta\beta, \tag{2.36}$$

$$0 \leq \alpha \leq 1,\ 0 \leq \beta \leq 1. \tag{2.37}$$

We perform numerical implementation of the proposed model using the Excel application package.

Given the above and simplified formulation of the optimization problem, it is possible to make a numerical implementation of the proposed model using econometric tools. All this made it possible to analyze the results of the model on specific statistics of the region, to assess the methods of use and effectiveness of the proposed methodology. Thanks to the mathematical model, it is possible to determine the ranking of the best higher education institutions in the region that effectively use the innovation and research potential. The main provisions of the section are covered in [6].

If the problem of ranking educational institutions in this section is solved, then the problem of determining the region or regions in terms of funding remains open. This can be interpreted as a major constraint under Section 2. Therefore, a study on the vector for identifying regions to ensure their funding will be conducted in Section 3.

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