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Optimization of the graduates labour market: dynamic modeling, Russian and foreign experience

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Abstract: The article substantiates the relevance and importance of constructing a model for optimizing the structure of graduate training and output by universities to meet the labour market needs, and presents a review of the literature focused on this issue. In addition, the authors examine the two existing approaches to determining the tools for achieving balance in the labour market: econometric, whereby the main criterion for assessing the quality of equilibrium is the wage level, and dynamic models. The authors present their own approach to constructing an optimization deterministic dynamic model that does not require knowing the probability characteristics of the process under consideration.

The proposed solution is constructed using a deterministic approach in which the following vectors are formed: the phase vector, whose coordinates are the values of the parameters describing the training process in higher education institutions at a certain fixed point in time; the controlling action vector (control vector) that allows influencing (by means of funding, the school-leaving exam score required for admission and other parameters) the structure, volume and quality of university training on various degree courses (educational programs), as well as the corresponding deterministic restrictions. The construction of the optimisation model is realised in two stages. At the first stage, a discrete dynamic model is formed that describes the influence of the control vector on the parameters of the system parameters phase vector. At the second stage, restrictions are formed on the parameters of the mathematical model that take into account the labour market demand for university graduates, and the quality criteria (functionals) that allow evaluating the process under consideration at a set final point in time.

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1. INTRODUCTION

The aspiration to obtain a university degree is obvious and mainly connected with the opportunity to enhance material well-being. However, while higher education in the modern world has become more accessible than ever before, it ceases to be a "social elevator" for everyone, since the balance between the labour market needs and the structure of university graduate training is currently uneven.

First, this imbalance relates to the structure of specialisms provided. Thus, the share of graduates with university degrees increases, while the share of those holding secondary vocational degrees declines every year. In 1990 Russia had 4.8 times more graduates with secondary and basic vocational qualifications than those with university degrees, whereas in 2017 there were 1.6 times more of the latter than the former: the shift is mainly due to the growth in the number of university graduates with degrees in humanities, social sciences and economics.

Second, the imbalance is due to the quality of graduate training.

This context and the related issues are characteristic of most world economies. Elias and Purcell (2003) note the increase in the number of university graduates: 3 times for men and 2 times for women (Elias&Purcell, 2004); the researchers also point out that since 1960s a programme has been in place in the UK intended to facilitate access to higher education, which has proved to be rather controversial, as the share of unemployed among those with university degrees has been on the increase. The growth in the number of university graduates out of employment has also been registered in the European Union: since the start of the recent recession about 1/6 of young university graduates in Greece and Spain are unemployed (Kačerová Eliška, 2016), with the lowest unemployment rate among graduates registered in Germany in 2015 (8%). The main reasons for the imbalance between the labour market and the higher education system noted in most papers are the mismatch between the market demands

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and the specialisms provided by universities (Němec, 2013; (Hennemann&Liefner, 2010; O'Leary и Peter Sloane, 2016), excess of supply over demand: there are more graduates than the market needs (Research of Long-Term, 2007). According to some estimates, Europe's economy loses about 1% of GDP as a result of unemployment among young professionals (The Economist, 2013).

There have been quite a few studies focusing on identifying the university graduates' competences that influence their future career and pay (Hovorková, 2012; Kalousková & Vojtěch, 2008; Kačerová Eliška, 2016; Roshchin S., 2014 и др.). These factors include education (Becker, 1964; Schultz, 1961), relevant experience (Cranmer, 2006), learning ability (Spence, 1974), positive attitude (Hillage and Pollard, 1998) and indirectly perceivable qualities such as emotional stress and innate abilities (Albrecht, 1981).

However, research shows that there is a gap between the skills acquired at university and the skills demanded by employers (Cranmer, 2006; Davies, 2000; Finn, 2000; Lindsay, 2002). The issue of starting salary and set of competences is beyond the scope of this study and is not largely focused on in this article.

The authors are mostly interested in the tools for optimizing the structure of graduate training by universities with an orientation to labour market needs in order to reduce the unemployment rate. The Russian and foreign research literature features models for forecasting the economies' demand for qualified personnel with professional university degrees. However, most of the models do not take into account the specifics of higher education and do not address the issue of employment opportunities for professionals with university degrees.

2. APPROACHES AND MODELS RELATED TO CREATING BALANCE ON THE LABOUR MARKET

There are diverse models created by the Bureau for Labour Statistics within the US Department of Labor (BLS, 1997; Hecker, 2005), the Australian MONASH model (Sue&Yan, 2005; Dixon&Rimmer, 1998), the British MDM model (Junankar et al, 2007), the German INFORGE and Ifo models (Lutz et al, 2003).

All the methodologies for making staffing forecasts at national or regional level are based on econometric methods and the "required labour resources" approach; the input parameters used are macroeconomic forecasts for goods and services output by economy sectors. In foreign countries with developed market economies, such as the USA, Germany, Australia, and Great Britain, labour resources balances and macroeconomic models are being developed for medium-term forecasts for staffing component necessary for the stable development of national economies.

Among the few models designed to solve the problem focused on by the authors (optimizing the structure of graduate training by universities to meet the labour market needs), one can note the econometric model developed by Gottschalk and Hansen (2003), the main idea of which is the balance between sector 1, where professionals with university degrees are employed, and sector 2, which employs those with secondary vocational education; university graduates can be employed in both sectors.

The equilibrium condition depends on the sector-specific wage premium offered to graduates and the relative wage between sectors. Consequently, it will be optimal for some graduates to choose employment in the non-graduate sector. Any change in wages across sectors will then influence the allocation of graduates between the two sectors. For instance, if there is a skill-biased technological change in sector 1, then the efficiency parameter will increase as graduates become more productive in sector 1. This in turn increases the premium paid to graduates in sector 1, which encourages graduates in sector 2 to move there and so reduces the proportion of graduates in non-graduate occupations.

Gottschalk and Hansen's model is merely an adaptation aimed at finding the balance between professionals with degrees of different level; the main postulate of the wage equation was used in earlier models (Gerard J. van den Berg and Geert Ridder (1993), Albrecht and Axell (1984)).

Another type of models that can be used to optimize employment in the labour market of those with different levels of academic degrees, are dynamic models. However, in the existing models, like in the previous econometric model, wages are the main counterbalancing factor.

The most noteworthy in this respect are approaches and conclusions presented in the paper by Yuan Huiguang and Fan, Sikai (2011), who concluded that higher education expansion does not necessarily result in decreased educational return, the adjustment result is determined by the demand changes.

Another dynamic model for creating balance on the labour market is described by Lee Donghoon and Wolpin Kenneth I. (2010). They account for the pattern of changes in wage inequality, for the increased relative wage and employment of women, for the emergence of the college wage.

Another application of dynamic modeling closely related to assessing the unemployment rate is described by David Soler et al (2018). They present a stochastic dynamic mathematical model to study the evolution of unemployment rate and other relevant related variables in a country. This model is composed by three basic interrelated subsystems: demographic, economic and wellbeing. A key aspect of this model is that it considers three UN well-being variables simultaneously: Human Development Index, Gender Empowerment Index and Gender Differentiation Index. These variables involve key concepts for human development, such as Health, Education, Economy and Female Labor.

Modern models of the Russian labour market have also been developed, among which the most famous are A.G. Korovkin's model (1989), the methodology for determining the needs developed by "IBS Expertiza" in collaboration with the Russian Economic University named after Plekhanov (Kosorukov, 2012), and the methodology for macroeconomic forecasting of the economy's demand for personnel, developed by the Center for Budget Monitoring in

Petrozavodsk State University (Gutov et al, 2007; Macroeconomic, 2018).

When analysing research papers, the authors were interested by the models described below.

The model of Petrozavodsk State University (PetrSU) is based on dynamic modeling; the basic postulate of labour market equilibrium is simple - the difference between incoming and outgoing personnel flows in the labour market should be minimal; the model takes into account labour productivity (the ratio of gross added value by foreign economic activity to the average number of employees in foreign economic activity) which is used to determine the average number of employees.

In the model developed by A.B. Panyukov, the algorithm of interval analysis of time series is used; the essence of the model is that the difference between the number of graduates with degrees of different levels and the demand for these graduates should be minimized; the demand for graduates is determined quite simply: it is calculated based on the regression equation of labour productivity dependence on investment (Panyukov, 2011), the logic of the model construction is very similar to PetrSU's model.

N.N. Muravyova (2009) uses econometric methods to construct a model for regulating the output of graduates with higher professional education taking into account the regional economy's needs. The model was constructed using factor analysis to select the most significant parameters (6 out of 13 parameters were chosen) that have an impact on the resulting indicator – the number of higher education institutions' graduates in demand by regional economy (those who find employment within one year after graduation); regression analysis was also used to quantify the correlation between the number of university-educated professionals demanded by the regional economy and the region's socio-economic indicators, and construct a regression equation to determine the significance of each of the factors identified.

Below the authors present an adaptation of the dynamic model (Shorikov, 1997) for optimizing the structure of university graduate training to meet the labour market needs.

3. DETERMINING THE PHASE VECTOR AND THE CONTROL VECTOR

To determine the parameters of the model for the training process under consideration the authors had to do the following:

1. Determine the criteria for the quality of university training.
2. Define the criteria for the labour market demand for new professionals.
3. Form the phase vector of the process ("the object state vector"), construct its transformation matrix.
4. Form the control vector of the process, construct its transformation matrix.

Table 1 shows the indicators that form the phase vector and the control vector. The authors determined that the phase vector (the object state vector) describes two types of parameters: the demand for university graduates by field and by education level.

Table 1. List of indicators to form the phase vector and control vector matrices

PHASE VECTOR	
Demand for graduates (types of degree courses and specialities/specialisms)	
1	The number of full-time bachelor's degree graduates
2	Share of graduates who found employment within a year after graduation in the total number of graduates of the higher education institution
Demand for graduates (degree levels)	
3	Average score in the graduation certificates by field (institute)
4	Number of students per one teaching staff member
	Number of full-time undergraduates on bachelor's and specialist degree courses
	Number of full-time teaching staff positions
5	Share of students actively involved in educational and research activities
	Number of awards (medals, certificates, etc.) received in exhibitions and scientific research contests
	Number of scientific publications: * total number of publications co-authored by students; * number of students' independent publications, not co-authored by any university staff members
	Number of intellectual property copyright registration certificates that include students
CONTROLLING ACTION VECTOR	
6	Average USE (Unified State Exam, Russian school-leaving exam) score of undergraduates studying bachelor's and specialist degree courses
7	Share of state-financed places
8	Number of scholarship awardees

Since the study uses a deterministic approach that requires setting unambiguous targets, the authors formulated the following four objectives:

1) minimizing the number of unemployed graduates;

2) minimizing the discrepancy between the number of successful university applicants and the number of graduates;

3) maximizing the number of students' awards (certificates, diplomas, medals, etc.).

The next section describes the mathematical formalization of the optimization model of the structure of bachelor's, specialist and master's degree training with the orientation to the labour market needs.

4. A DYNAMIC MODEL FOR PROGRAM CONTROL OF THE TRAINING STRUCTURE

On an integer time interval $_{\mathrm{i}}$ $(T \in \mathbf{N})$; (hereinafter, $\mathbf{N}$ is the set of all natural numbers), a model of the dynamics of the process of program control of university training structure (PCUTS) is formed as a system of linear discrete-time recurrent vector equations:

$$x(t+1) = A(t)x(t) + B(t)u(T),$$
$$x(0) \in X_0, \quad t \in \overline{0, T-1}, \tag{1}$$

where $x(t) = \{x_1(t), x_2(t), \ldots, x_5(t)\} \in \mathbf{R}^5$ – is the phase vector of the system;

$u(t) = \{u_1(t), u_2(t), u_3(t)\} \in \mathbf{R}^3$ – is the control vector, available to player P (hereinafter, $\mathbf{R}^k$ – is a *k*- dimensional vector (Euclidean) space of column vectors, even if they are written into a row to save space.

To determine the main parameters characterizing the dynamics of the process under consideration, i.e. to form the elements of matrixes $A(t)$ and $B(t)$ are having dimensions (5×5) and (5×3) respectively, it is necessary to describe the information capabilities of the subject of control *P* in the process of program control (Shorikov, 2005; Shorikov, 1997) by the dynamic system.

It is assumed that in the course of PCUTS process and fixed natural number s>>T>0 implementation, at every moment in time $t \in \overline{1, T}$ the control subject has the following information capabilities corresponding to the realizations of the system phase vector, to the controlling action and to the risk vector on the integer time interval $\overline{-s, t}$, preceding the control process under consideration:

1) the history of the system phase vector realization is known
$$x_t(\cdot) = (x_1(\cdot)_t, x_2(\cdot)_t, \ldots, x_5(\cdot)_t = \{(x_1(\tau), x_2(\tau), \ldots, x_5(\tau))\}_{\tau \in \overline{-s,t}} = \{x(\tau)\}_{\tau \in \overline{-s,t}};$$

2) the history of the system controlling action realization is known

$$u_t(\cdot) = (u_1(\cdot)_t, u_2(\cdot)_t, u_3(\cdot)_t) = \{(u_1(\tau), u_2(\tau), u_3(\tau))\}_{\tau \in \overline{-s,t-1}} = \{u(\tau)\}_{\tau \in \overline{-s,t-1}}.$$

Since the variables of the phase vector and the control vector are independent on each other (they cannot be expressed by means of one another), to construct the system of recurrence equations (1), i.e. to form matrixes $A(t)$ and $B(t)$, the tools of regression-correlation analysis or an algorithm based on solving systems of linear algebraic equations that use the data of the process history can be applied. The database of the activities of Russian universities was created for this purpose.

Then, based on the available data, the ***problem of posteriori identification*** (Shorikov, 2005; Shorikov, 1997) of all the basic elements of the discrete-time dynamic system (1) was solved, i.e. the elements of matrixes $A(t)$ and $B(t)$ were formed.

As a result of solving this problem, matrices $A(t)$ and $B(t)$ have a specific form, and system (1) describes the dynamics of the PCUTS process under consideration.

Then, based on the available conditions of the dynamic system parameters realization (1), the following restrictions are formed, which determine the areas of their admissible values:

$$\forall t \in \overline{0, T}: \ x(t) \in X_1(t) \subset \mathbf{R}^5, \ X_1(0) = X_0,$$
$$X_1(t) = \{x(t) : x(t) = \{x_1(t), x_2(t), \ldots, x_5(t) \in \mathbf{R}^5, \ \forall i \in \overline{1, n}, \ x_i(t) \in \Delta x_i(t)\}, \tag{2}$$

where $\Delta x_i(t) \subset \mathbf{R}^1$ is a closed numerical interval; that is, at every moment in time $t \in \overline{0, T}$, the values of the phase vector of the dynamic system under examination are limited by the corresponding polyhedron in space $\mathbf{R}^5$;

$$\forall t \in \overline{0, T-1}: u(t) \in U_1(t) \subset \mathbf{R}^3,$$
$$U_1(t) = \{u(t): \ u(t) \in \{u^{(1)}(t), u^{(2)}(t), \ldots, u^{(N_t)}(t)\},$$
$$\forall i \in \overline{1, N_t}, u^{(i)}(t) = = \{u_2^{(i)}(t), u_2^{(i)}(t), u_3^{(i)}(t)\} \in U_1^{(i)}(t)\},$$
$$U_1^{(i)}(t) = \{u^{(i)}(t): \ u^{(i)}(t) = = \{u_1^{(i)}(t), u_2^{(i)}(t), u_3^{(i)}(t)\} \in \mathbf{R}^3,$$
$$\forall j \in \overline{1, p}, \ u_j^{(i)}(t) \in \Delta u_i(t)\}, \tag{3}$$

where $\Delta u_i(t) \subset \mathbf{R}^1$ is a finite set of numbers; $U_1(t)$, for each $t \in \overline{0, T-1}$, there is a finite set of vectors – different values of ***control intensity*** in the PCUTS process, namely, a finite set that consists of $(N_t \in \mathbf{N})$ vectors in $\mathbf{R}^3$.

The subject *(P)* of the PCUTS process is supposed to know the equation (1) and restrictions (2), (3).

The PCUTS process under consideration is assessed by the value of vector functional (quality criterion) $\Phi=(\Phi_1, \Phi_2, \ldots, \Phi_r)$ (where $i \in \overline{1, r}, \Phi_i: \ \mathbf{R}^5 \to \mathbf{R}^1$ is a scalar-valued functional) determined on possible realizations of the final state of the trajectory $x(T) = \bar{x}(T; \overline{0, T}, x(0), u(\cdot)) \in \mathbf{R}^5$ of the system (1) on the time interval $\overline{0, T}$, generated by collection (x(0),u(·)), satisfying the following conditions in accordance with restrictions (1) – (3)

$$\forall t \in \overline{0, T}:$$
$$x(t) = \bar{x}(t; \overline{0, T}, x(0), u(\cdot), v(\cdot)) \in X_1(t);$$
$$u(\cdot) = \{u(t)\}_{t \in \overline{0, T-1}}, \quad \forall t \in \overline{0, T-1}: u(t) \in U_1(t);$$

and the values of this vector functional, in accordance with the scalarization method for vector functional, are calculated by means of the following formulae:

$$\Phi(\bar{x}(T; \overline{0T}, x(0), u(\cdot))) = \Phi(x(T)) = \sum_{i=1}^{r} \lambda_i \Phi_i(x(T)), \tag{4}$$

$$\forall i \in \overline{1,r} : \lambda_i \geq 0, \sum_{i=1}^{r} \lambda_i = 1. \quad (5)$$

Then, for the system (1) – (5), the objective of the *program* PCUTS process from the point of view of the player *P* can be formulated as follows: on a set time interval $\overline{0,T}$, the player *P* is required to form such program control $u^{(e)}(\cdot) = \{u^{(e)}(t)\}_{t \in \overline{0,T-1}}$ ($\forall t \in \overline{0,T-1}: u^{(e)}(t) \in U_1(t)$), that the value of functional Φ is minimum (maximum), defined on the corresponding realization of trajectory $x^{(e)}(T) = \bar{x}(T; \overline{0,T}, x(0), u^{(e)}(\cdot)) \in \mathbf{R}^5$ of the system (1).

The general scheme for achieving the objective of optimization (PCUTS) for a given point in time (T) involves completing three main tasks.

1. Identifying the dynamics of the process under consideration, i.e. forming the parameters of a discrete dynamic system of type (1). To identify the dynamics of the system, an iterative algorithm is proposed, which combines the procedure for solving multidimensional systems of algebraic equations and the mean square interpolation of the source data.

2. Calculating the value of the functional (4) for fixed program control.

3. Forming optimal program control $u^{(e)} = \{u^{(e)}(t)\}_{t \in \overline{0,T-1}}$ for the optimization task under consideration (PCUTS).

5. CONCLUSION

The modeled parameters for optimizing the structure of university training should be the target indicators for regional development and reflect the processes involved in the modernization of the higher professional education system (transition to a two-level education system) and the labour market demand for qualified personnel. The parameters of the dynamic system (1) − (5), formed in accordance with the requirements to optimize the structure of training, which determine vector $x(t)$, are: the number of students taking higher professional education degree courses (specialities), the number of unemployed university graduates (by field/speciality/specialism).

The main parameters for managing the structure of university training (the parameters of the control vector $u(t)$) are the average wage (by field) in the region, the number of state-funded places, and the average USE score required for university admission (by field and speciality).

In conclusion, it should be noted that the construction of the optimization model for the examined process is realized within the framework of a deterministic approach based on the formation of a system that describes the dynamics of the process and contains a phase vector and a control vector. The construction of the mathematical model for the process as a whole is carried out in two stages. At the first stage, the influence of the control vector parameters on the phase vector parameters is determined, i.e. the equations describing the dynamics of the process are derived. At the second stage, restrictions on the control vector (management resource) are formed, taking into account the labour market demand for university graduates, and quality criteria (functionals) are defined that allow evaluating the graduates' quantitative and qualitative characteristics.

The proposed model allows estimating and calculating an optimized scenario of the university's output taking into account the regional market demand. The main result of our model is the reduction in the total number of unemployed graduates of the university and improved quality of student training. As a part of further work on the model development it is suggested to carry out a model optimization of the university's output scenarios taking into account the labour market demand for the increased range of graduates' specialisms.

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