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A DYNAMIC MODEL FOR EVALUATION OF THE ECONOMIC CLUSTER DEVELOPMENT STRATEGY REGARDING TRANSPORT COMPONENT

Abstract. The article presents an approach to evaluating the strategy of economic development of the cluster, which includes a dynamic economic-mathematical model and tools of adaptive modeling, in particular the formation of generalized model coefficients based on neuro-fuzzy model. The mechanism of obtaining estimates of generalized coefficients of the dynamic model, which influences the choice of the scenario of development of the studied clusters and the forecasted limits of possible changes of economic indicators is shown. Computer experiments of choosing the strategy of economic development of clusters (on the example of Kyiv region and Kyiv, Dnipropetrovsk and Odessa regions) and analysis of alternative scenarios of their development.

According to the results of the study, the combination of a nonlinear dynamic model with a neuro-fuzzy model makes it possible to find such scenarios of economic development of the cluster that will provide a constant and balanced growth of the studied cluster. This, in turn, will provide a targeted increase in economic growth at the micro or macro levels and timely prevention of economic downturn.

***Keywords*:** dynamic economic system, cluster, fuzzy set theory, computer simulation, alternative development scenarios.

JEL Classification C10, C13, C45, C89, C91, E20, O00, R11

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ДИНАМІЧНА МОДЕЛЬ ОЦІНЮВАННЯ СТРАТЕГІЇ РОЗВИТКУ ЕКОНОМІЧНОГО КЛАСТЕРА З УРАХУВАННЯМ ТРАНСПОРТНОЇ СКЛАДОВОЇ

Анотація. Представлено підхід до оцінювання стратегії економічного розвитку кластера, що включає динамічну економіко-математичну модель та інструментарій адаптивного моделювання, зокрема формування узагальнених коефіцієнтів моделі на базі нейронечіткої моделі. Це механізм отримання оцінок узагальнених коефіцієнтів динамічної моделі, який впливає на вибір сценарію розвитку досліджуваних кластерів і спрогнозовані межі можливих змін економічних показників. Проведено комп'ютерні експерименти вибору стратегії економічного розвитку кластерів (на прикладі Київської області та м. Києва, Дніпропетровської та Одеської областей) і здійснений аналіз альтернативних сценаріїв їхнього розвитку. Дослідження ґрунтується на застосуванні методів системного аналізу, а також апарату математичної статистики й економіко-математичного, адаптивного, зокрема імітаційного та нейронечіткого моделювання тощо.

За результатами дослідження виявлено, що поєднання нелінійної динамічної моделі з нейронечіткою моделлю дає змогу знайти такі сценарії економічного розвитку кластера, що забезпечить постійне і збалансоване зростання показників досліджуваного кластера, забезпечить цілеспрямоване підвищення рішення економічного зростання на мікро- або макрорівні та своєчасне попередження економічного спаду.

***Ключові слова*:** динамічна економічна система, кластер, теорія нечітких множин, комп'ютерне моделювання; альтернативні сценарії розвитку.

Формул: 2; рис.: 8; табл.: 2; бібл.: 17.

Introduction. The key to sustainable development of any country is the creation of economic clusters and ensuring their stable and effective development, taking into account transport and economic ties. The study of the current state of such an economic system and the search for possible directions of its development show that it is a complex, multi-element, open dynamic system with intricate (mostly uncertain, or partially determined) internal and external connections. The economic ties that occur in this process determine the ability to adapt and develop any territorial socio-economic and transport systems. The interaction of these connections, are non-linear, allows for a normal reproductive process. Such circumstances prove the essential importance of choosing a strategy for the development of the economic (including transport) system for the formation of recommendations for the dynamic stability and stability of the functioning of the corresponding cluster.

The study aimed to determine a strategy for the economic development of a cluster, taking into account its key factors, based on a nonlinear dynamic model in combination with a neuro-fuzzy model to improve the performance and development of the economic system.

Analysis of recent research and problem definition. Most often, for systems of a socio-economic nature, this dependence defies a strict formal description. Therefore, only on the basis of system analysis is it possible to structure the economic system of the cluster in any aspect, due to the specific focus of the study and the availability of the necessary information about the system. The structuring of an economic cluster depends on the adopted variant of differentiation of criteria, «accents» of planning a strategy for the development of an economic cluster/object, whether it is a territory, industry, production or a set of enterprises.. The structure of the system acts as a way of organizing it, only then as some kind of abstraction created by the researcher. However, the decomposition (structuring) of the system into elements and the connections between them is determined not by the whim of the researcher, but by the objective internal properties of the system itself.

Proceeding from this, studies of the development of an economic cluster (for example, a territorial unit) should be considered as the study and forecasting of the nonlinear behavior of a complex dynamic system as a subsystem of the national or world economic system [12, p. 293—299; 13, p. 345—352; 15, p. 187—188]. Various economists identify and evaluate different sets of components of the structure of the economic system of a cluster (region) [2; 6; 7]. Models using the theory of fuzzy sets are analyzed in works [1; 3; 4 ; 8, p. 137—147; 9, p. 894—913; 10, p. 44—58; 16, p. 338—353].

Methodology and research methods. As a result of the analysis of the existing interpretations of the structure of the economic system of the cluster, according to the authors [11, p. 107—121; 14, p. 96—101], it is necessary to use such an appropriate system of basic macro-indicators, the use of which would allow to: promptly and adequately respond to the variability of the external and internal economic environment; identify and implement the appropriate choice of development strategy, that is, anticipate events, developing alternative scenarios for their development; make adequate management decisions based on the analysis results.

Therefore, let's single out three components of the structure of the economic system that affect the development of the cluster progressively or degrading: labor, which is reflected in the dynamics of the population and labor force; financial — growth of equity capital (financial savings and production capacity); credit — attracting loans.

It is proposed to use, in particular, such a system of differential equations (adapted by the authors of the model [5, p. 454—464]):

$$\begin{cases} \dfrac{dY_1}{dt} = \alpha Y_2 Y_3 - \gamma Y_1; \\ \dfrac{dY_2}{dt} = \mu(Y_2 + Y_3) - \beta Y_1 Y_3; \\ \dfrac{dY_3}{dt} = \delta Y_2 - \lambda Y_3, \end{cases} \quad (1)$$

dependent variables of which correspond to the selected components, namely: $Y_1 = Y_1(t)$, which describes the share of the employed population of its total volume (%) during time t (labor resource); $Y_2 = Y_2(t)$ — the share of the gross product of the cluster from its total volume (%) during the time t (GRP); $Y_3 = Y_3(t)$ — the share of loans provided by the cluster from its total volume (%) during time t (attracted loans); t — the independent variable.

The nonlinear differential system (1) describes the behavior of the economic system in the coordinates «labor resource — gross regional product — attracted loans» over time t, that is, mathematically reproduced economic development over time, starting from the moment t_0.

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Scalar quantities α, γ, μ, β, δ, λ (generalized coefficients) are included in this system as constant (control) parameters. Note that in the formation of generalized coefficients of the model (1) it is necessary to take into account both quantitative and qualitative factors, so it is logical to use an apparatus based on the theory of fuzzy sets.

To solve system (1), it is necessary to form generalized coefficients of the model α, γ, μ, β, δ, λ. To include the factors included in the corresponding *l*-th generalized coefficient of the model (1), according to the recommendations of experts, a certain set of subgroups of factors $\{X_i^l\}$ and a set of factors (indicators) $\{X_{ij}^l\}$ are selected that can affect this generalized coefficient. These sets are put in correspondence, using fuzzy logical inference, sets of possible states, characterizing the possible states $\{G^l\}$ of the corresponding factors. An important component of this process is the procedure for obtaining knowledge from experts for constructing on its basis fuzzy sets of terms of variables from the set $\{X_i^l\}$. The structure of the neural network for determining the *l*-th generalized coefficient, for example, the dynamic model (1) is shown in (*Fig. 1*) in the form of a logical inference tree. Note that the structure of the neural network for all other coefficients (β, γ, μ, δ, λ) will have a similar form.

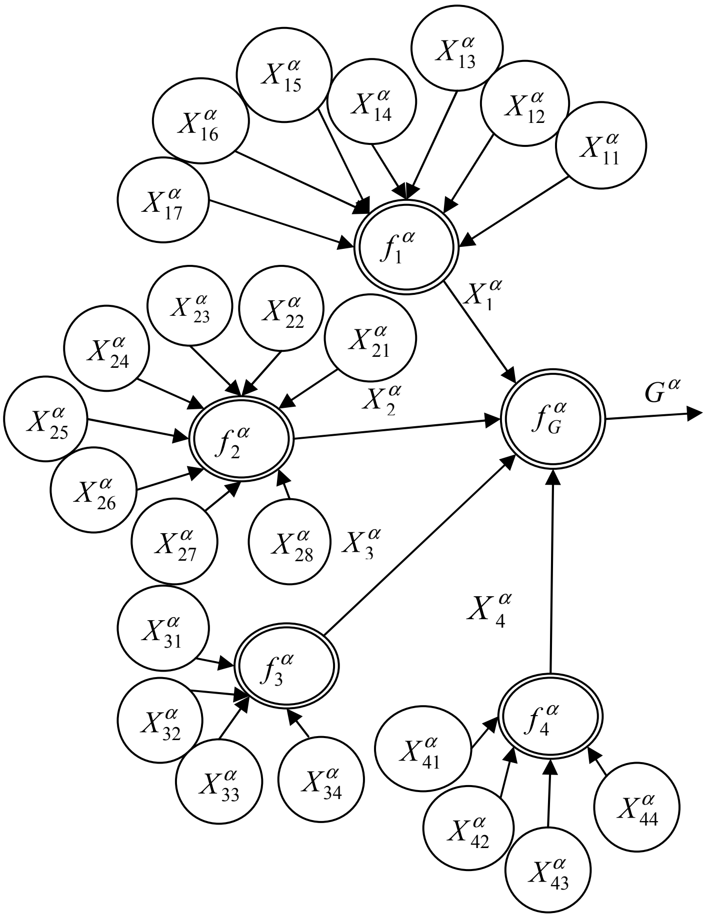

Fig. 1. **Block diagram of a neuro-fuzzy model for determining a generalized coefficient α, a dynamic model (1)**

Source developed by the authors.

The analytical form of recording the decision rule for finding the *l*-th generalized coefficient of dynamic model (1) (the effective indicator G^l acquires the meaning of the term d_j^l where the membership function is maximum) using weights and membership functions of all variables has the form:

$$G^l = \arg \max_{\{d_1^l,\ldots,d_j^l\}\, p=\overline{1,k_j},\, j=\overline{1,m}} \left\{ w_p^{d_j^l} \prod_{i=1}^{n} \mu^{a_i^{jp}} \left(X_i^l \right) \right\}, \qquad (2)$$

where $w_p^{d_j^l}$ — the weight of the p-th rule ($p=\overline{1,k_j}$) for the term d_j^l of the output variable G^l (the less significant a factor is from the point of view of experts, the less weight is assigned to it).

Estimation of scalar quantities α, γ, μ, β, δ, λ of nonlinear dynamic model (1) allowed to determine the range of their variation. The numerical values of the *l*-th generalized coefficient vary within the numerical values (0, 10], that is, there is such a value for which the value of the membership function of the output variable G^l (2) will be the largest among all in the rule base for the set values of the input variables X_i^l, $i=\overline{1, N}$ (*Table 1*).

Table 1

Defuzzification results

Output variable	Linguistic meaning	Numeric equivalent
G^l	very low (VL)	0,01–1
	low (L)	1,01–2
	below average (BA)	2,01–3
	average (A)	3,01–5
	above average (AA)	5,01–7
	high (H)	7,01–9
	very high (VH)	9,01–10

Source: developed by the authors

The results of the research. For a comprehensive analysis of economic development at the macro and micro levels, based on the dynamic model (1) and the proposed scheme for determining the generalized coefficients of the nonlinear model (1), three economic clusters were selected, which reflect the general economic dynamics of the economic development of regions throughout the territory Ukraine, namely: Kyiv region and Kyiv, Dnipropetrovsk and Odesa regions (*Table 2 and Fig. 2*).

Table 2

Share in the total volume in the Kyiv region and Kyiv, Dnipropetrovsk and Odesa regions (%)

Kyiv region and Kyiv	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Gross Regional Product	21,65	22,67	22,32	21,73	23,67	25,05	27,53	27,95	28,83	28,70	28,96	29,13
Loans granted	53,31	55,29	54,85	55,72	54,32	54,55	59,69	60,30	59,75	57,39	56,43	51,67
Employed population by region	10,57	10,58	10,59	10,61	10,60	10,64	11,58	12,76	12,91	12,98	12,98	12,98
Dnipropetrovsk region	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Gross regional product	11,04	10,22	10,73	10,75	10,14	10,04	11,12	10,82	10,25	10,52	10,38	10,27
Loans granted	11,61	13,24	16,14	18,51	19,82	20,49	19,34	21,54	23,35	25,08	24,50	27,87
Employed population by region	7,53	7,61	7,61	7,53	7,51	7,50	8,15	9,00	8,76	8,61	8,57	8,53
Odesa region	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Gross regional product	4,96	5,33	4,98	4,72	4,44	4,58	4,72	5,02	5,02	5,01	4,87	4,95
Loans granted	4,03	3,76	4,10	3,81	4,25	4,36	4,35	3,02	2,48	2,58	2,63	2,84
Employed population by region	5,09	5,15	5,15	5,16	5,21	5,22	5,59	6,18	6,15	6,11	6,12	6,15

Source: developed by the authors based on data from www.ukrstat.gov.ua, www.bank.gov.ua, www.me.gov.

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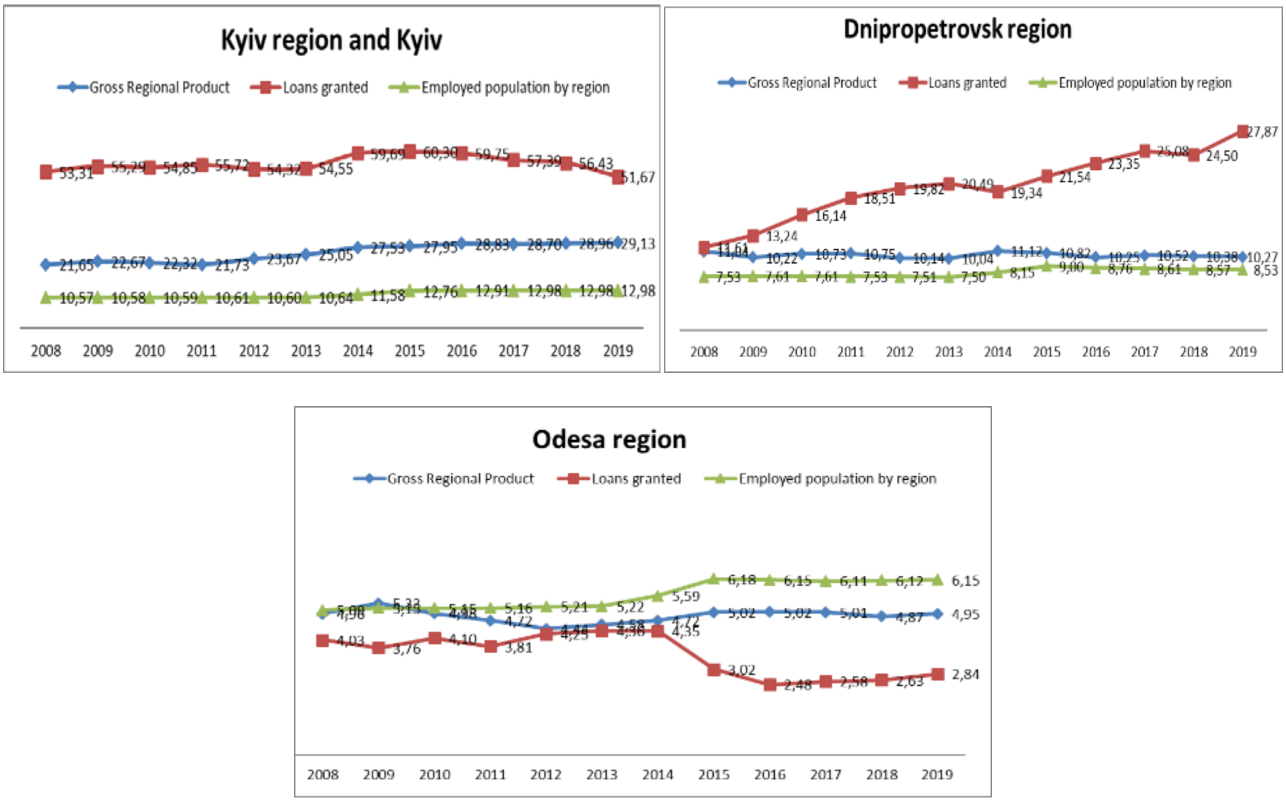
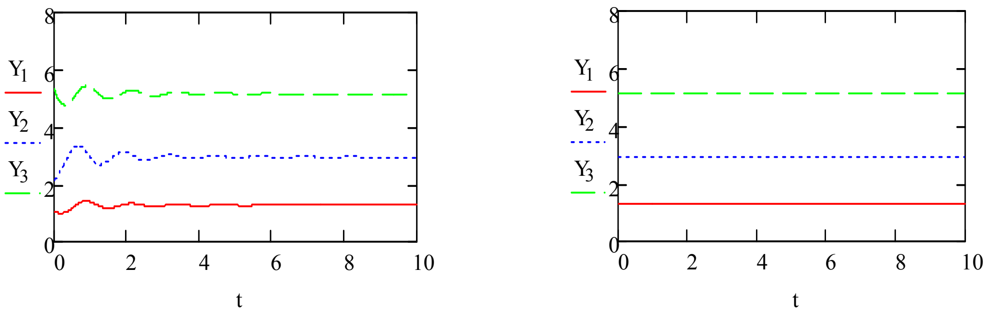


Fig. 2. **Dynamics of the main indicators of development for 2008—2019 in the Kyiv region and Kyiv, Dnipropetrovsk and Odesa regions**

Source: own calculations based on data from www.ukrstat.gov.ua, www.bank.gov.ua, www.me.gov.

Computer modeling of alternative scenarios of the regional development strategy was carried out in the Mathcad environment. Applying the dynamic model (1) on the basis of statistical data of the main indicators of regional economic development in 2008—2019 and in accordance with forecast calculations for the inertial scenario of development, the following results were obtained for the Kyiv region and Kyiv (*Fig. 3*).



a b

Fig. 3. **Dynamics of economic development of the Kiev region and Kiev based on MM (1) at** $\alpha = 0{,}5$; $\mu = 1{,}7$; $\gamma = 6$; $\beta = 2{,}1$; $\delta = 4{,}4$; **for** $t[0{,}12]$ **(for 2008—2019)** $Y[1{,}057; 2{,}165; 5{,}331]$ **(a) and for** $t\ [0{,}10]$ **(forecast years) at** $Y\ [1{,}298; 2{,}913; 5{,}167]$ **(b) — inertial scenario**

Source: developed by the authors.

In a similar way, the results were obtained for Dnipropetrovsk (*Fig. 4*) and Odesa regions (*Fig. 5*).

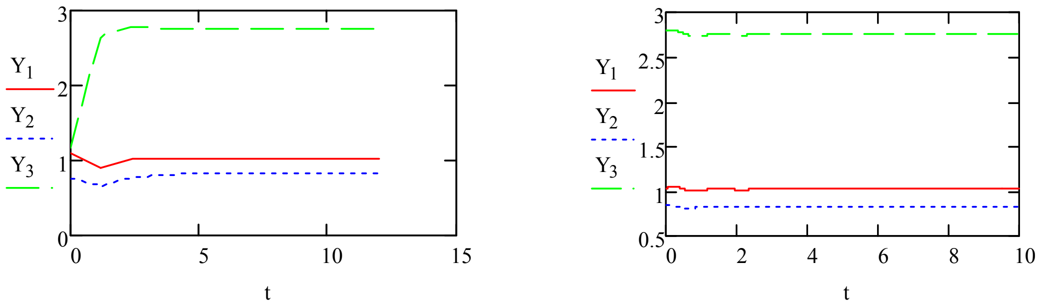


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Fig. 4. **Dynamics of economic development of Dnepropetrovsk region based on MM (1) at $\alpha = 2{,}7$; $\mu = 1{,}1$; $\gamma = 6$; $\beta = 1{,}4$; $\delta = 7$; $\lambda = 2{,}1$ for $t[0,12]$ (for 2008—2019) at $Y[1{,}104; 0{,}753; 1{,}161]$ (a) and for $t[0,10]$ (forecast years) at $Y[1{,}027; 0{,}853; 2{,}787]$ (b) — inertial scenario**

Source: developed by the authors.

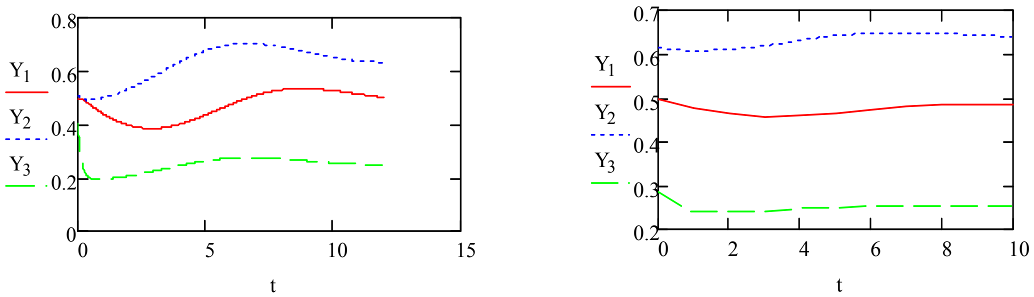

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Fig. 5. **Dynamics of economic development of the Odesa region based on MM (1) at $\alpha = 1{,}2$; $\mu = 0{,}27$; $\gamma = 0{,}4$; $\beta = 2$; $\delta = 2{,}9$; $\lambda = 7{,}4$ for $t[0,12]$ (for 2008—2019) at $Y[0{,}496; 0{,}509; 0{,}403]$ (a) and for $t[0,10]$ (forecast years) at $Y[0{,}495; 0{,}284; 0{,}615]$ (b) — inertial scenario**

Source: developed by the authors.

As the calculation results show (see *Fig. 3—5*), when applying the inertial scenario (see *Fig. 3—5b*) of the economic development of the regions under study, there is a constant trend in their development, does not provide an opportunity to improve or change the situation.

Further model experiments were carried out to search for such a scenario of economic development in order to improve the situation in the regions under study and to give appropriate recommendations for assessing the groups of factors using the models under study.

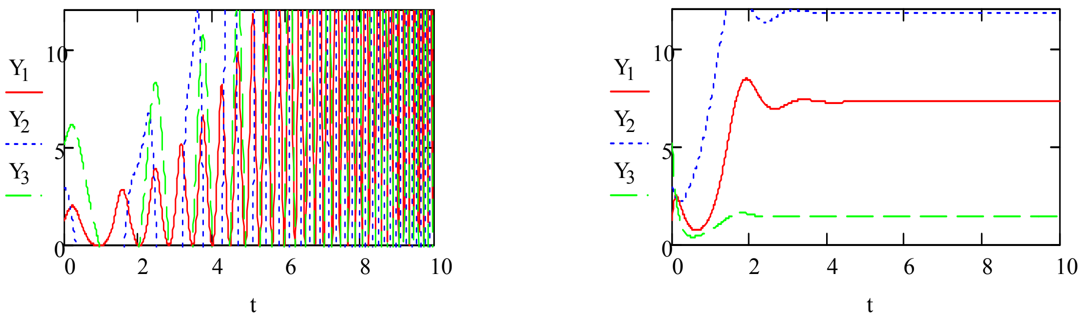

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Fig. 6. **Dynamics of economic development of the Kyiv region and Kyiv at $\alpha = 0{,}5$; $\mu = 1{,}7$; $\gamma = 2$; $\beta = 2{,}1$; $\delta = 4{,}4$; $\lambda = 1$ for $t[0,10]$ (forecast years) at $Y[1{,}027; 0{,}853; 2{,}787]$ (a) — crisis scenario and for $\alpha = 2{,}5$; $\delta = 1$; $\gamma = 6$; $\lambda = 8$ (b) — modernization scenario**

Source: developed by the authors.

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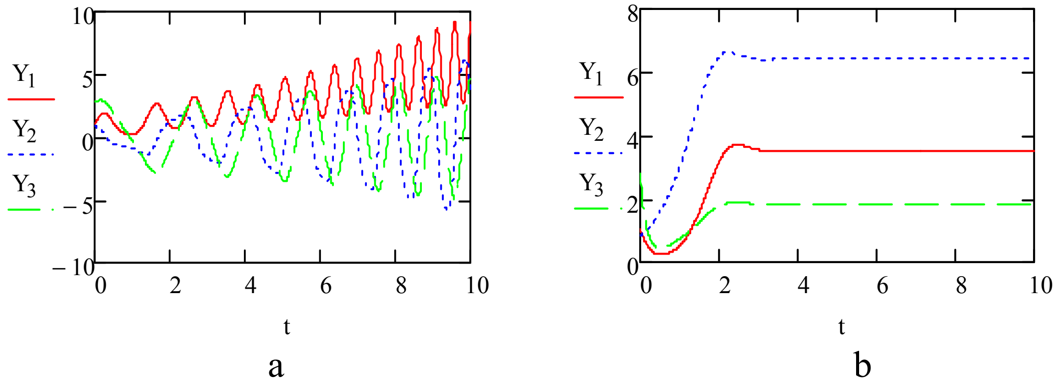

Fig. 7. **Dynamics of economic development of the Dnipropetrovsk region at** $\alpha = 2{,}7$**;** $\mu = 1{,}1$**;** $\gamma =$**;** $\beta = 1{,}4$**;** $\delta = 5$**;** $\lambda = 1$ **for** $t[0{,}10]$ **(forecast years) at** $Y[1{,}027; 0{,}853; 2{,}787]$ **(a) — crisis scenario and for** $\delta = 2$**;** $\gamma = 9$**;** $\lambda = 7$ **(b) — modernization scenario**

Source: developed by the authors.

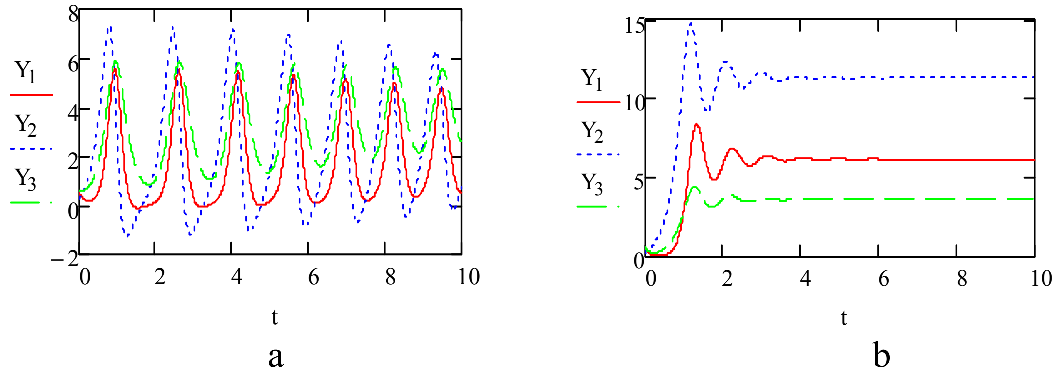

Fig. 8. **Dynamics of economic development of the Odesa region at** $\alpha = 1{,}2$**;** $\mu = 0{,}27$**;** $\gamma = 0{,}4$**;** $\beta = 2$**;** $\delta = 2{,}9$**;** $\lambda = 7{,}4$ **for** $t[0{,}10]$ **(forecast years) at** $Y[0{,}495; 0{,}284; 0{,}615]$ **(a) — crisis scenario and for** $\mu = 3$**;** $\gamma = 8$**;** $\lambda = 9$ **(b) — modernization scenario**

Source: developed by the authors.

Fig. 6a — 8a show a crisis scenario of the development of events over time t (the first unit of time t, transient processes occur for each variable). All variables are in a stable periodic fluctuation. (*Fig. 6b — 8b*) show a modernization scenario of development, where: in the first unit of time t, there is a failure in the economy of the studied regions, in fact, for the crisis period, but later on there is a stabilization of the situation, which leads to the growth and development of the regional economy and, accordingly, improving the country's economy as a whole.

According to the decision maker, if the basic generalizing coefficients are correctly found, it is able to reach a rational decision, in which it will be possible to modernize the economy of the region, on the effective use of the resources available in the region on the basis of an intensive type of economic growth: increased employment, growth of gross regional product, reduction of credit burden through the use of new innovative technologies, attracting investment, increasing exports and the like.

Conclusions. The article describes a nonlinear mathematical model of economic development of a cluster and the conceptology of its construction, based on a synergetic approach to studying the dynamics of economic development of any economic object (at the micro or macro level — an organization, region, cranes, etc.).

The analysis made it possible to obtain information on the main indicators and generalized coefficients of the models, which affects the choice of the appropriate scenario for the economic development of the clusters under study over time and to determine the cause-and-effect relationships between them.

Analysis of the economic development of economic clusters shows that their economic growth is observed under the modernization scenario (*Fig. 6b — 8b*). In the presence of an inertial (*Fig. 6b — 8b*) or crisis (*Fig. 6a — 8a*) scenario of the development of events — there is an invariability or instability of economic development, leading to impoverishment. With the results of computer modeling of options (*Fig. 6 — 8a* and *8b*) it was found that scalars are important indicators: λ, γ and δ for the Dnipropetrovsk region; μ, γ and δ for the Odesa region; α, λ, γ and δ for the Kyiv region and Kyiv in which the economic system is brought to a stable state.

Thus, it can be argued that the presented nonlinear dynamic model (1), in combination with a neuro-fuzzy model, makes it possible to form such scenarios of the economic development of the cluster, which will ensure a constant and balanced growth of indicators characterizing the effectiveness of the functioning processes and allows to purposefully increase the level of economic growth by micro- or at the macro level.

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