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ARCHITECTONICS OF THE "ANTI-CRISIS" INFORMATION-ANALYTICAL SYSTEM [1]

This article presents a schematic diagram of the "Anticrisis" information analysis system, which aims at a comprehensive assessment of the parameters of the economic security of the Subjects of the Russian Federation while taking into account diverse risks, threats and the forecasting thereof. The schema reflects the interaction of the individual software modules that it comprises. It describes the integration of the modules with a unified database management system: access to the database, automatic backup and restore of databases in real-time and transmission of data over an open channel using modern encryption algorithms. The basic units of the system consist in: a unit for diagnosing the state of economic security; a unit for the welfare of the individual and residential area; a unit for extremism; a correlation unit; a modelling unit for the forecasting of the security of Subjects of the Russian Federation. As part of the simulation unit, a primary generalised mathematical model, based on a system of nonlinear differential equations, designed to take account of the correction factors, as well as taking into account all types of interaction indicators, is provided. The main types optimisation problems of interaction metrics are compiled using generalised models. Forecasts from 2016 to 2020 are generated on the basis of constructed optimisation propositions.

Keywords: "Anticrisis" information analysis system, nonlinear prediction, individual welfare and inhabited areas, socio-economic crises, threat probability, diagnosis of socio-economic status of the Ural Federal District

Implementation

When creating any software system, it is always necessary to isolate the main core (main part) in which any given object will be analysed. Thus, the core of the "Anticrisis" architectural and analytical complex is the well-being of the individual and area of residence. The welfare schematic diagram and indicators influencing it are considered in detail by the authors in [1, 2].

An evaluation of the well-being of individuals and areas of residence is broken down into 8 modules:

— assessment module of the state of well-being at the level of the person (spiritual, vital, social and well-being module (I));

— assessment of the state of well-being at the level of the area of residence (resource, economic and political, infrastructural and well-being module (II)).

The database consists of a collection of absolute values of the indicators and their normalised evaluation. Input data is presented in the form of a time series; their selection for the study being carried out over the years 1998–2015 across the respective territories and within the core modules of well-being. In the study [3] an individual and residential area welfare analysis of subjects of the Ural Federal District, assumed to be typical, is presented.

The main purpose of this complex is crisis detection and diagnosis, the probabilistic assessment of threats and risks, as well as forecasting the state of the region for the next 3–5 years.

Model

As mentioned above, 140 indicators are used in describing the welfare of each area. Since this dataset is too large to be used to describe a single area, the authors have attempted to describe [3] the well-being of typical representatives of UFD using a small set of parameters (key variables). For this purpose, a mathematical approach associated with correlation functions was used (correlation unit fig. 1, 2)

In the context of the present approach, all indicators are determined by the rate of change in the time series, the reciprocal correlation function of the shear parameters and the analogue impulse

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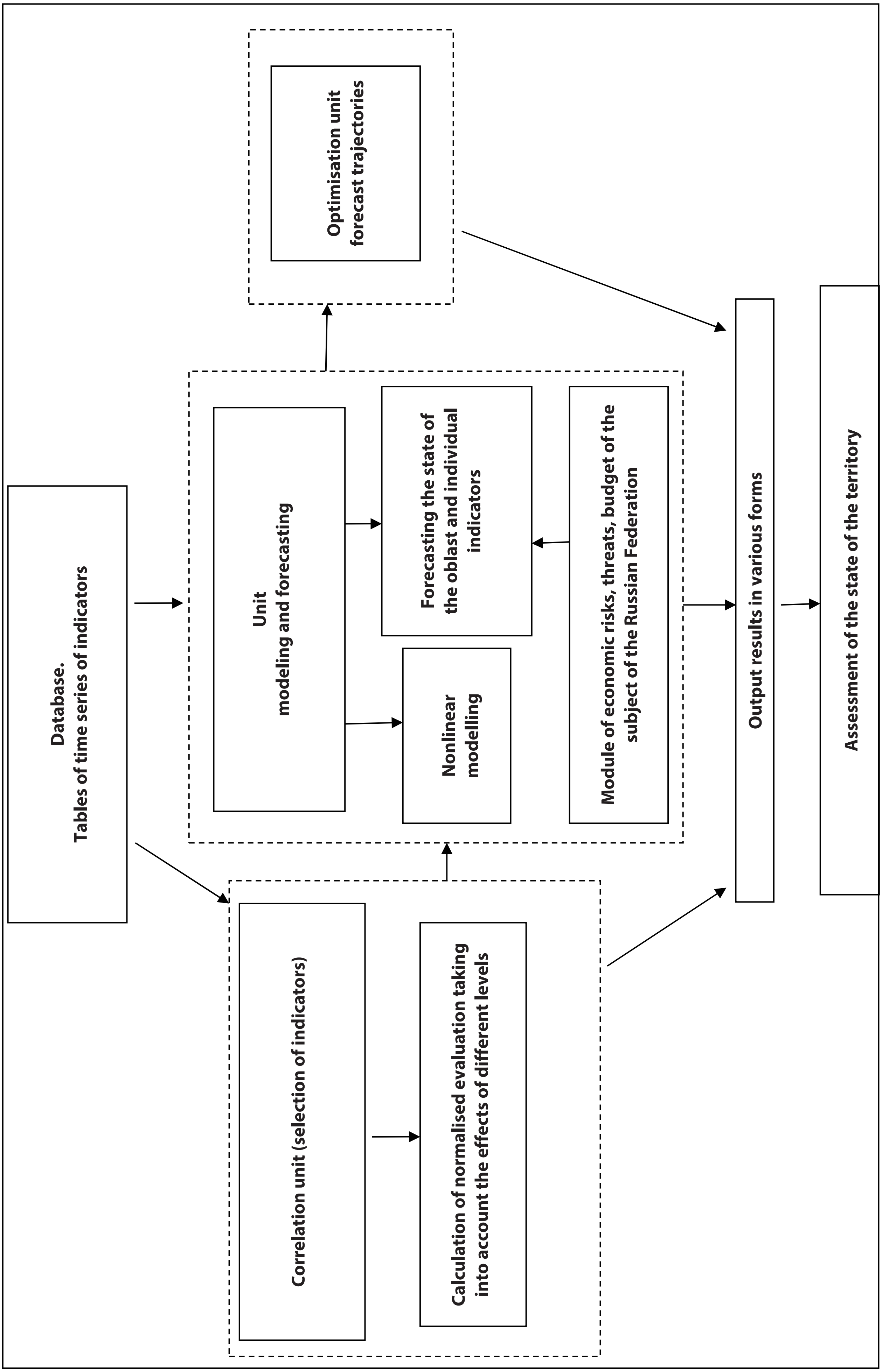

Fig. 1. *Block diagram of the analysis of the well-being of the individual and area of residence*

response of the indicators themselves. The analogue of the impulse response takes into account the sign of the change indicator.

The shear cross-correlation function is defined [3, 9]:

$$C(\tau)=\frac{\sum_{t=1}^{k-\tau}X(t)Y(t+\tau)}{\sum_{t=1}^{k-\tau}X(t)Y(\tau)}, \tag{1}$$

where t—time; $X(t)$, $Y(t)$—value of the indicator at time t; $Y(t+\tau)$—value of the indicator with a shift in time; τ—time shift; k—maximum value of t. Key indicators are selected on the basis of (1) the entire set of indicators and the main types of interaction and mutual influence (primary, secondary) indicators.

Function (1) differs from the expression for the correlation function [4, 5], in that it is more sensitive to small changes in the indicator, leading to better identification of crisis situations. From the behaviour of the function (1), the similarity of the two indicators can also be judged. Next, a normalised evaluation for the effects of different levels is determined, and, on this basis, tomographic maps of UFD areas constructed. Research related to the interdependence of indicators on each other's performance is described in more detail in the paper [3], and tested using indicators from the Sverdlovsk region.

Modelling and forecasting

Various types of interaction metrics with key indicators describe using a system of non-linear non-homogeneous first order differential equations (see Fig. 2, 3):

$$\begin{cases}\dfrac{dx_0}{dt}=\sum_{i=0}^{2}a_i x_i+\sum_{i,j=0}^{2}a_{ij}x_i x_j+D_0,\\ \dfrac{dx_1}{dt}=\sum_{i=0}^{2}b_i x_i+\sum_{i,j=0}^{2}b_{ij}x_i x_j+D_1,\\ \dfrac{dx_2}{dt}=\sum_{i=0}^{2}c_i x_i+\sum_{i,j=0}^{2}c_{ij}x_i x_j+D_2,\end{cases} \tag{2}$$

where x_0 is the primary indicator, x_1 and x_2 is the secondary indicators of impact on the main index; a_i, b_i, c_i ($i = 0, 1, 2$) are the coefficients of the linear velocity of the impact indicators of change; a_{ij}, b_{ij}, c_{ij} ($i = 0, 1, 2$; $j = 0, 1, 2$) are the coefficients of pairwise effects i indicator on j and on the rate of its variability, D_i—the constant influence on the rate of change of the indicator.

The system describes how to separate the impact of each indicator in terms of their rate of change (linear terms) and pairwise interaction by nonlinear terms [3, 6]. On the basis of this system, the main types of crises are obtained and analysed. These are characterised by the rapidity of entry into the crisis (high-speed or low-speed entry), the depth of the crisis (overcoming crisis levels—C1, C2, C3), the duration of the crisis, the initial entry point to the crisis.

Mathematical risk model

When forecasting, a normalised indicator taking risks into account is calculated (Fig. 3). This calculation is based on 5 basic indicators obtained by the authors during tomographic analysis.

Dynamics of change of five major indicators, describes the well-being of the individual and of the areas of residence according to two models.

I. Risk management model in a generalised normalised assessment of the region

1. The matrix of the interdependence of indicators is calculated on the basis of function of the triple (double) correlation and its averaging

2. The obtained matrix is used as the basis for assigning the weighted coefficients to the indicators and calculating the generalised, normalised indicator:

3. When calculating risks coefficients were used α_j^i where i indicates the region and j the level at which the region was in the year under review t.

4. The probabilities of occurrence of an adverse event are determined p_j^i.

5. A correction factor $\alpha_j^i p_j^i$, responsible for a decrease in the generalised, normalised evaluation $NE_f(t)$ at time t, is introduced:

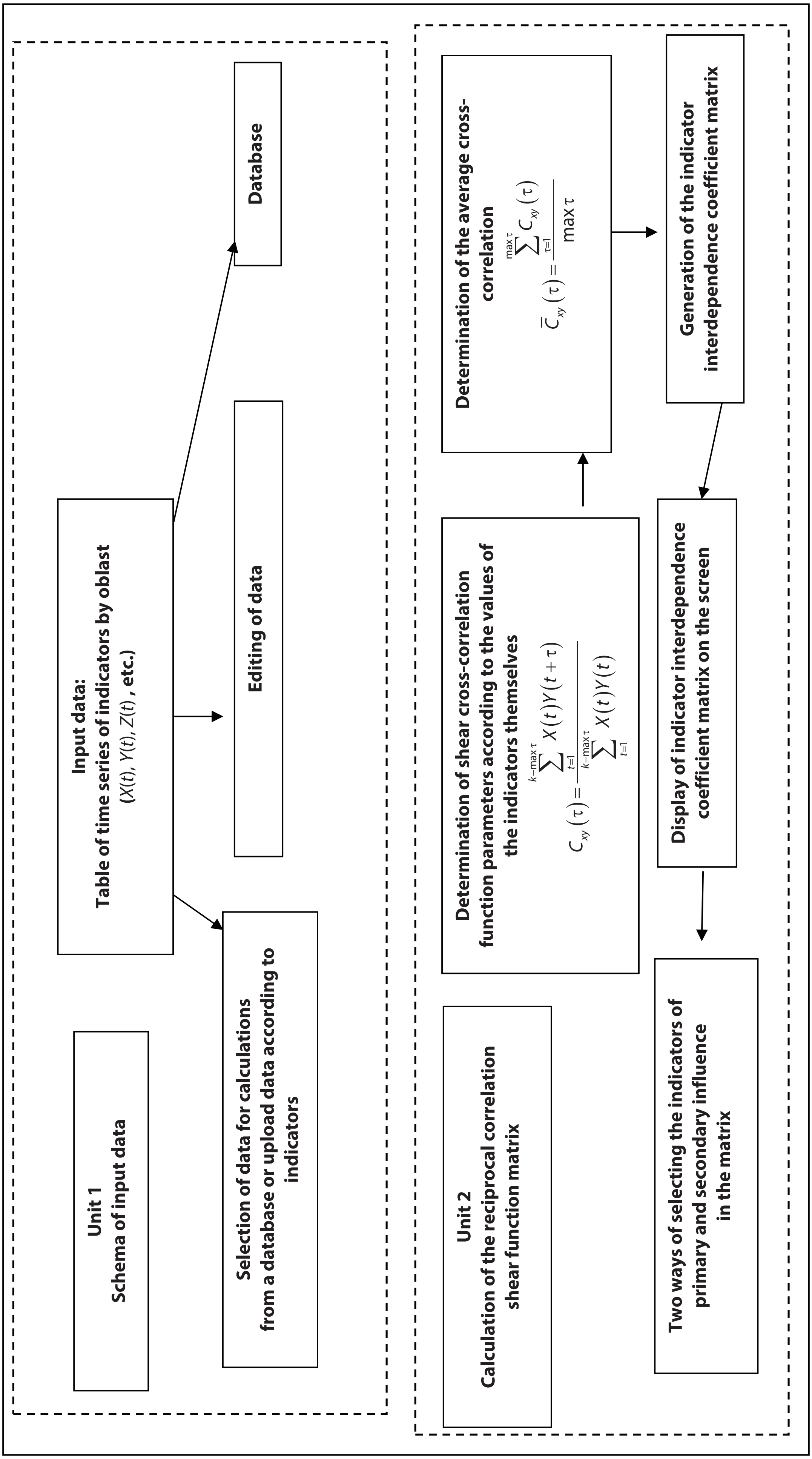

Fig. 2. *Expanded schematic diagram of the analysis of the well-being of the individual and area of residence (Units 1–2)*

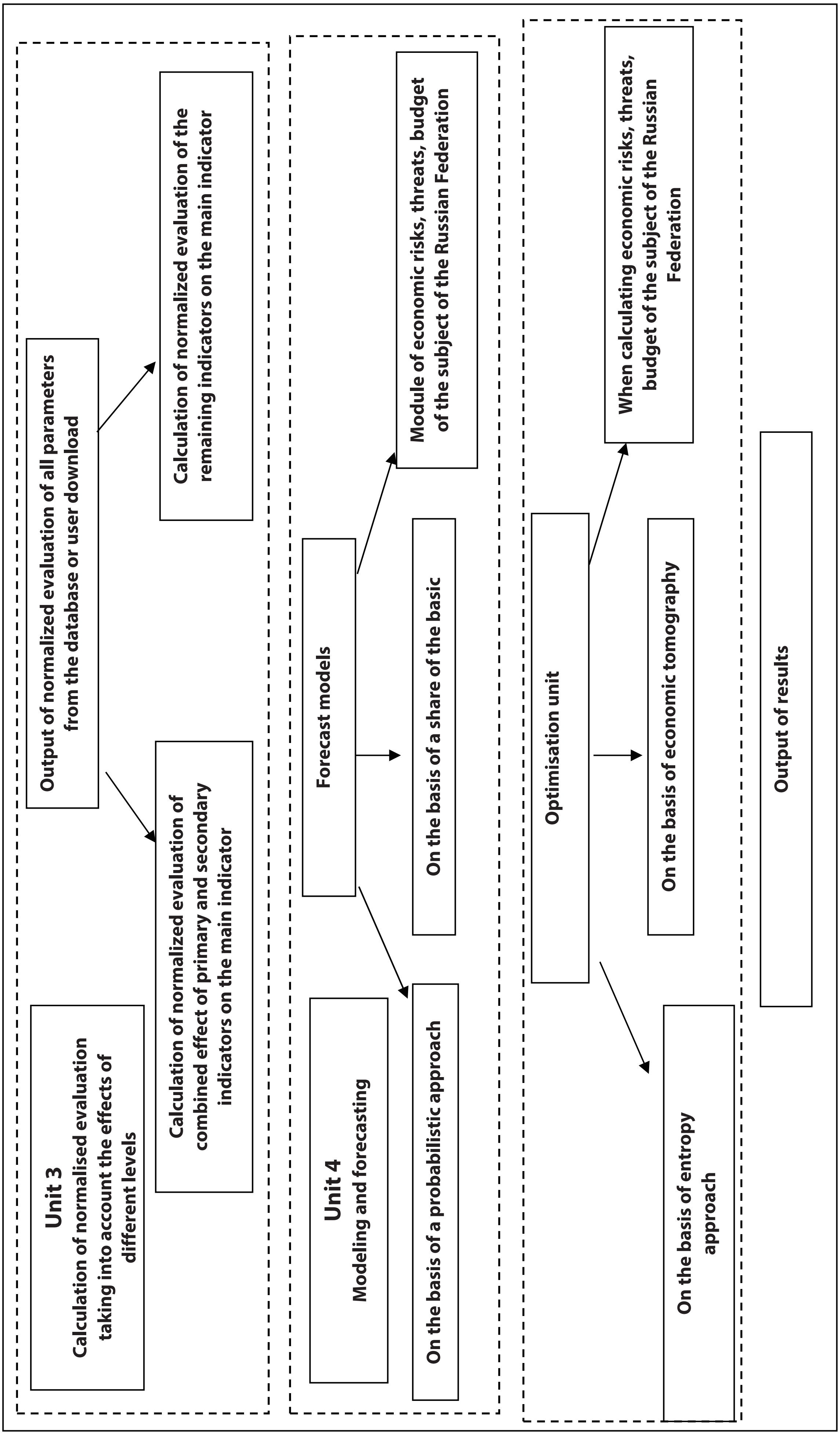

Fig. 3. *Expanded schematic diagram of the analysis of the well-being of the individual and area of residence (Units 3–4)*

$$NE_k(t) = NE_f(t) \cdot \left(1 - \sum_n \alpha_j^i p_j^i\right). \tag{3}$$

The summation in (3) is carried out on all types of adverse events.

We consider the dynamics of the generalised, normalised evaluation (*NE*) describing the well-being of the individual and area of residence. For the mathematical description, the following non-linear, heterogeneous differential equation is proposed in the general form:

$$\frac{d}{dt} NE_k = f(NE_k) + Q(NE_k, t). \tag{4}$$

where $f(NE_k)$ is the function that depends on the index NE_k, taking into account the occurrence of adverse events in the next year; $Q(NE_{k,t})$ is the function of external influences.

When forecasting, we use Euler's finite difference method, for example

$$\frac{dx_0}{dt} = \frac{(x_0)_{i+1} - (x_0)_i}{\Delta t},$$

where $(x_0)_{i+1}$ is the predicted value $i + 1$ year $(x_0)_i$ is the known value in the year i, Δt is annual stepwise increment. We write the forecast model (2) in the form of

$$NE_k(t+1) = NE_k(t) + \left(\sum_n \alpha_j^i p_j'^i\right) \cdot y(NE_k(t)) + Q(NE_k, t), \tag{5}$$

where $p_j'^i$ is the probability of occurrence of adverse events n to $t + 1$ year, $y(NE_k(t))$ is the non-linear function of the normalised valuation; in the simplest case, taking a linear form.

II. Mathematical model of interaction of five basic indicators, taking into account different types of risks

We consider the dynamics of change of five major economic indicators, describing the well-being of the individual and of the areas of residence. For a mathematical description of the interaction of the five indicators, we have proposed the following system of non-linear, heterogeneous differential equations in general terms:

$$\begin{cases} \dfrac{dx_0}{dt} = f_0(x_i) + Q_0(x_i, t), \\ \dfrac{dx_1}{dt} = f_1(x_i) + Q_1(x_i, t), \\ \dfrac{dx_2}{dt} = f_2(x_i) + Q_2(x_i, t), \\ \dfrac{dx_3}{dt} = f_3(x_i) + Q_3(x_i, t), \\ \dfrac{dx_4}{dt} = f_4(x_i) + Q_4(x_i, t), \end{cases} \tag{6}$$

where x_i represents the main indicators ($i = 0, 1, 2, 3, 4$), $f_i(x_i)$ represents the reciprocal indicator functions (which depend only on the indicators themselves), taking into account the occurrence of adverse events in the next year; $Q_i(x_i, t)$ is the function of external influences. This system not only takes into account the interaction of indicators taking risks into account, but also describes the influence of external impacts.

We assume that the reciprocal indicator functions $f_i(x_i)$ have a linear form, that is, the system of equations (6) is transformed into

$$\begin{cases} \dfrac{dx_0}{dt} = D_0 + \left(a_0x_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right) + Q_0\left(x_i, t\right), \\ \dfrac{dx_1}{dt} = D_1 + \left(b_0x_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right) + Q_1\left(x_i, t\right), \\ \dfrac{dx_2}{dt} = D_2 + \left(c_0x_0 + c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right) + Q_2\left(x_i, t\right), \\ \dfrac{dx_3}{dt} = D_3 + \left(d_0x_0 + d_1x_1 + d_2x_2 + d_3x_3 + d_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right) + Q_3\left(x_i, t\right), \\ \dfrac{dx_4}{dt} = D_4 + \left(e_0x_0 + e_1x_1 + e_2x_2 + e_3x_3 + e_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right) + Q_4\left(x_i, t\right), \end{cases} \quad (7)$$

where a_i, b_i, c_i, d_i, e_i ($i = 0, 1, 2, 3, 4$) are the constant coefficients of linear impact indicators on the rate of their changes D_i is the constant affecting the rapidity character of indicators, $p_j'^i$ is the probability of occurrence of adverse events n to $t + 1$ year.

Modelling of the development of indicators

On the basis of the system of equations (7), we formulate the following models of development indicators:

1. Rapid and slow flowing processes To the rapidly flowing processes we attribute the growth rate of gross regional product (GRP), the price index for consumer goods and the overall unemployment rate. As a result, system (7) can be rewritten in the form of

$$\begin{cases} \dfrac{dx_0}{dt} = D_0 + \left(a_0x_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right) + Q_0\left(x_i, t\right), \\ 0 = D_1 + \left(b_0x_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right) + Q_1\left(x_i, t\right), \\ \dfrac{dx_2}{dt} = D_2 + \left(c_0x_0 + c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right) + Q_2\left(x_i, t\right), \\ \dfrac{dx_3}{dt} = D_3 + \left(d_0x_0 + d_1x_1 + d_2x_2 + d_3x_3 + d_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right) + Q_3\left(x_i, t\right), \\ 0 = D_4 + \left(e_0x_0 + e_1x_1 + e_2x_2 + e_3x_3 + e_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right) + Q_4\left(x_i, t\right). \end{cases} \quad (8)$$

The system is reduced to 3 non-linear differential equations with constant coefficients. This system is solved numerically with the assignment of initial conditions and functions of external influences.

2. One of the indicators is principal and the others are secondary. Consequently, the function of external influence remains singular.

$$\begin{cases} \dfrac{dx_0}{dt} = D_0 + \left(a_0x_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right) + Q_0\left(x_i, t\right), \\ 0 = D_1 + \left(b_0x_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right), \\ 0 = D_2 + \left(c_0x_0 + c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right), \\ 0 = D_3 + \left(d_0x_0 + d_1x_1 + d_2x_2 + d_3x_3 + d_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right), \\ 0 = D_4 + \left(e_0x_0 + e_1x_1 + e_2x_2 + e_3x_3 + e_4x_4\right)\left(\sum_n \alpha_j^i p_j'^i\right). \end{cases} \quad (9)$$

When forecasting, we use Euler's finite difference method, for example

$$\frac{dx_0}{dt}=\frac{\left(x_0\right)_{i+1}-\left(x_0\right)_i}{\Delta t},$$

where $(x_0)_{i+1}$ is the predicted value for $i + 1$ year, $(x_0)_i$ is the known value for the year i, Δt is the annual stepwise increment [7]. Consequently, the extension of solutions of the obtained system of equations in the future time interval is carried out $t \in [T; T + T_p]$, where T_p is the forecasting interval in question, and the result is a prediction of the development of the situation over time, based on the selected scenario of management changes in certain parameters of the system [8].

The authors have carried out a complete tomographic analysis of the well-being of the person and areas of residence for individual subjects of the UFD. Internal interactions were identified of primary and secondary indicators at different levels of well-being, as well as the well-being of the subject of the UFD as a whole. For example, the "GRP growth rate" indicator for 2007 is located in a zone with respect to the normal level in 2008; the crisis zone 3, in 2009—in crisis zone 2; the interaction of other indicators in 2009 can be observed to have a significantly smaller effect the remaining indicators (crisis 1). That is to say, the system that characterises the socio-economic condition of the region can holistically withstand the destructive influence of a complex crisis.

For other subjects of the UFD, an analogous tomographic analysis produced for the period 2000–2015 across 9 main indicators. The tomographic representation captures the one-year crisis of 2008–2009: Kurgan, Sverdlovsk Region and Yamalo-Nenets District were in crisis 1; Chelyabinsk in crisis 2; KhMAO in pre-crisis 3; however, Tyumen (without autonomous districts) in 2009 had moved from crisis 1 to pre-crisis 3. By 2015, all observed areas had deteriorated: Kurgan, Tyumen Region and Yamalo-Nenets District were already in crisis 1; KhMAO was in pre-crisis 3 (borderline significance PC3-C1) and the Sverdlovsk and Chelyabinsk regions were in pre-crisis 2.

Optimisation unit

In the unit (Fig. 3), the entropy-based Shannon approach was used in relation to the welfare of the individual and areas of residence. The entropy function is calculated on the basis of a nonlinear probability density to obtain an optimisation of the spatial and planar map interaction parameters. In contrast to the well-known models based on normal distribution characteristics, a special feature of this method is the ability to obtain the nonlinear characteristics of entropy distribution indicators.

An analysis of entropy functions is carried out with regard to the five key indicators (rate of natural population growth, the consumer price index for food products, the rate of GRP growth, the overall unemployment rate, the proportion of the population with incomes below the subsistence minimum relative to the total population). Additionally, the projection onto the plane of the entropy function of interacting parameters is restored.

Information entropy:

$$H\left(\vec{x},t\right)=\int p\left(\vec{x},t\right)\ln\left(p\left(\vec{x},t\right)\right)d\vec{x},$$

where $p\left(\vec{x},t\right)$ is the probability density function and $\vec{x}$ is the vector of indicators. $p\left(\vec{x},t\right)$. The function is determined on the basis of the Fokker–Planck–Kolmogorov non-linear differential equation.

The Fokker–Planck–Kolmogorov equation and its steady-state solution

The probability distribution for the statistical data can be determined in a standard way, breaking all the variables in the same period of the segments, and then determining how many of the indicator values fall into this range. Along with the basic method, it is also possible to take advantage of the Fokker–Planck–Kolmogorov equation:

$$\frac{dp\left(\vec{x},t\right)}{dt}=-\vec{\nabla}\cdot\left(\vec{A}\left(\vec{x},t\right)p\left(\vec{x},t\right)\right)+\vec{\nabla}^2\left(D\left(\vec{x},t\right)p\left(\vec{x},t\right)\right), \tag{10}$$

where $p\left(\vec{x},t\right)$ is the probability density function; $\vec{A}\left(\vec{x},t\right)$ is the drift function corresponding to the variation of indicators; $D\left(\vec{x},t\right)$ is the diffusion function; x_i ($i = 1, \ldots, n$) is the system indicators. This equation is supplemented with initial and boundary conditions, as well as the normalisation condition.

Right-hand side can be transformed through the flow probability $\vec{j}\left(\vec{x},t\right)$ to the view

$$-\vec{\nabla}\left(\vec{A}\left(\vec{x},t\right)p\left(\vec{x},t\right)\right)+\vec{\nabla}^2\left(D\left(\vec{x},t\right)p\left(\vec{x},t\right)\right)=\vec{\nabla}\left(D\left(\vec{x},t\right)p\left(\vec{x},t\right)\vec{\nabla}\left(U\left(\vec{x},t\right)+\ln\left(D\left(\vec{x},t\right)p\left(\vec{x},t\right)\right)\right)\right)=-\vec{\nabla}\left(\vec{j}\left(\vec{x},t\right)\right).$$

When converting it was taken into account that the drift function $\vec{A}(\vec{x},t)$ is defined by a potential field $\vec{\nabla}U(\vec{x},t) \equiv -\vec{A}(\vec{x},t)/D(\vec{x},t)$.. As a result, (10) can be written in a more compact form

$$\frac{dp(\vec{x},t)}{dt} = -\vec{\nabla}\cdot\left(\vec{j}(\vec{x},t)\right). \tag{11}$$

Equation (11) describes an economic system without external influences (field). Let us first consider the stationary problem (stationary probability density), i. e. $dp(\vec{x},t)/dt = 0$. As a result, we obtain

$$\vec{j}(\vec{x}) = \vec{j}_0 \text{ or } D(\vec{x})p(\vec{x})\vec{\nabla}\left(U(\vec{x}) + \ln\left(D(\vec{x})p(\vec{x})\right)\right) = \vec{j}_0, \tag{12}$$

where $\vec{j}_0$ is the constant vector of integration of the stationary equation (11). Continuous integration vector $\vec{j}_0 = 0$ due to the fact that the probability density at infinity is zero and thus there is no stream available. Taking the above solution of the differential vector equation into account, (12) will take the form of

$$p_0(\vec{x}) = \frac{C}{D(\vec{x})}e^{-U(\vec{x})}, \tag{13}$$

Where C is the normalisation constant. Stationary distribution of the density indicators (4) is obtained by the separation of variables in (12). We introduce the full potential of the system in the form of $F(\vec{x}) = U(\vec{x}) + \ln|D(\vec{x})| - \ln|C|$, allowing the expression (13) to be written in a compact form:

$$p_0(\vec{x}) = e^{-F(\vec{x})}. \tag{14}$$

This stationary probability density must satisfy the normalisation condition.

Results of the numerical calculation

As a result of numerical calculations using various methods, several types of predictive trajectories were obtained (Fig. 4). Probabilistic trajectories (upper and lower limits) are obtained on the basis of the stationary probability density function (14), i.e., a value is selected for normalised estimates corresponding to 5 % of the "tails" of the distribution (Fig. 5). The inertial forecast is obtained on the basis of lack of external influence, leading to a gradual decrease in the normalised valuation. All of the data from the normalised evaluation are shown in the table.

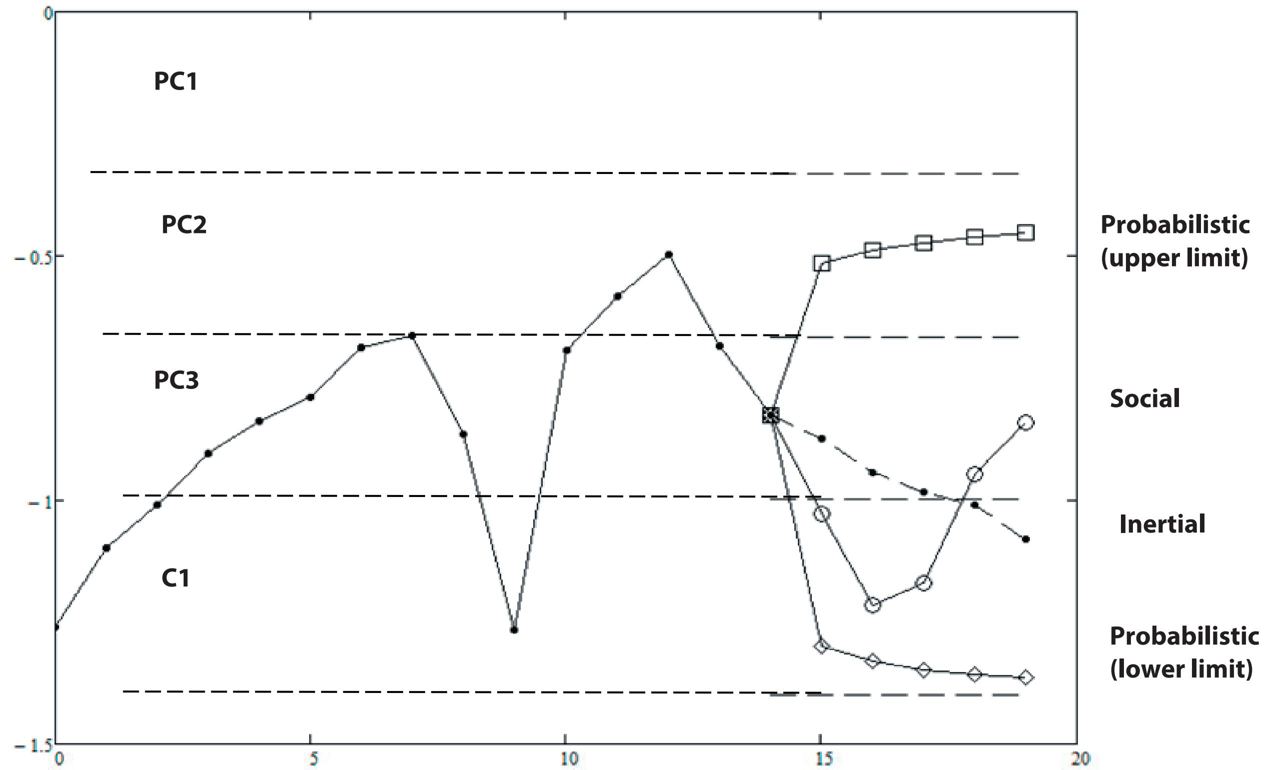

Fig. 4. *Generalised normalised score on all indicators for the Sverdlovsk region and the projected trajectory. Levels: PC1 (0.001–0.332), PC2 (0.333–0.665), PC3 (0.666–0.999), C1 (1–1.399)*

Table

Generalised normalised score for the Sverdlovsk Region and forecasting curves 2014–2019

Forecasting view	Year										
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Inertial	1.261 (C1)	1.1 (C1)	1,01 (C1)	0.905 (PC3)	0.838 (PC3)	0.792 (PC3)	0.689 (PC3)	0.665 (PC2)	0.865 (PC3)	1.268 (C1)	0.694 (PC3)
Probabilistic (lower limit)	1.261 (C1)	1.1 (C1)	1,01 (C1)	0.905 (PC3)	0.838 (PC3)	0.792 (PC3)	0.689 (PC3)	0.665 (PC2)	0.865 (PC3)	1.268 (C1)	0.694 (PC3)
Probabilistic (upper limit)	1.261 (C1)	1.1 (C1)	1,01 (C1)	0.905 (PC3)	0.838 (PC3)	0.792 (PC3)	0.689 (PC3)	0.665 (PC2)	0.865 (PC3)	1.268 (C1)	0.694 (PC3)
Social	1.261 (C1)	1.1 (C1)	1,01 (C1)	0.905 (PC3)	0.838 (PC3)	0.792 (PC3)	0.689 (PC3)	0.665 (PC2)	0.865 (PC3)	1.268 (C1)	0.694 (PC3)

the ending table

Forecasting view	Year								
	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Inertial	0.582 (PC2)	0.498 (PC2)	0.686 (PC3)	0.827 (PC3)	0.874 (PC3)	0.945 (PC3)	0.983 (PC3)	1,01 (C1)	1.081 (C1)
Probabilistic (lower limit)	0.582 (PC2)	0.498 (PC2)	0.686 (PC3)	0.827 (PC3)	1.301 (C1)	1.332 (C1)	1.349 (C1)	1.359 (C1)	1.363 (C1)
Probabilistic (upper limit)	0.582 (PC2)	0.498 (PC2)	0.686 (PC3)	0.827 (PC3)	0.516 (PC2)	0.490 (PC2)	0.474 (PC2)	0.462 (PC2)	0.452 (PC2)
Social	0.582 (PC2)	0.498 (PC2)	0.686 (PC3)	0.827 (PC3)	1.0285 (C1)	1.2165 (C1)	1.1705 (C1)	0.9465 (PC3)	0.8435 (PC3)

Figure 5 presents the estimates of the probability density distribution of the generalised normalised valuation for Sverdlovsk oblast in the period from 2000 to 2015 and its approximation formula (14), where the full potential is a six-degree polynomial:

$$F(x) = 483{,}637x^6 - 2566{,}33x^5 + 5504{,}77x^4 - 6104{,}93x^3 + 3699{,}06x^2 - 1167{,}31x + 152{,}62.$$

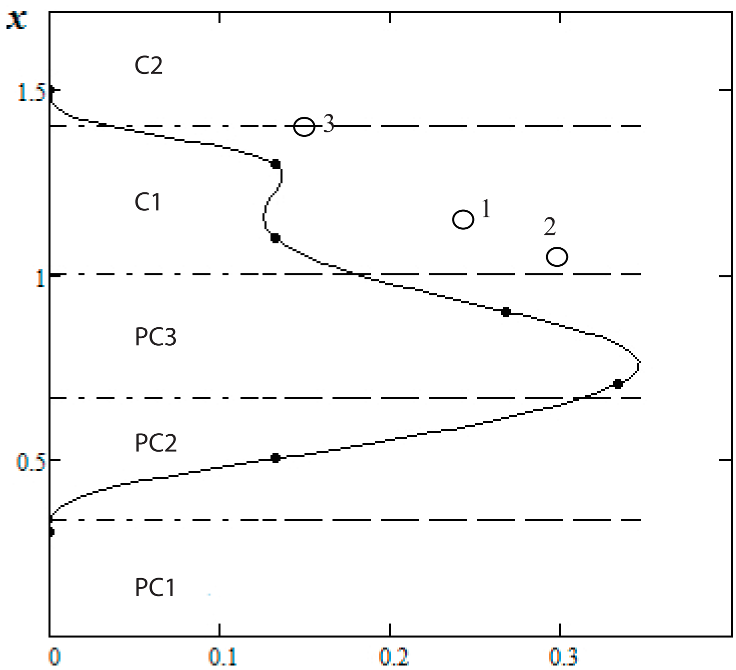

Fig. 5. *Approximation of the stationary probability density function of the distribution of the normalised generalised evaluation of the Sverdlovsk region in the period from 2000 to 2015 according to the formula (14)*

As can be seen, the probability density is very different from a normal distribution, having a maximum of 2 (global — point 2; local — point 3 in Figure 5): pre-crisis region 3 with a probability of realisation of 34.5 %; crisis region 1 with a probability of realisation of 13.7 %. Point 1 on the graph corresponds to the value of the probability density in 2015.

Conclusion

The study allowed us to obtain a diagnostic picture of the well-being of the individual and area of residence in the Ural Federal District according to the individual indicators as well as across the whole region. The authors conclude that it is possible to accurately diagnose crises, assess threats and gain more confidence in times of crisis. This approach allows us to study in detail the interaction of individual indicators and their groups to diagnose the state of the region as a whole, as well as to predict the development of the region for 3–5 years in advance.

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