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METHODOLOGY FOR DETERMINING THE LIMIT VALUES OF NATIONAL SECURITY INDICATORS USING ARTIFICIAL INTELLIGENCE METHODS

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Abstract. Applying artificial intelligence methods, the paper frames the algorithm structure and software for the formalized determination of the type of distribution (automatic classification) of the probability density function and the vector of limit values by justifying theoretically security gradations and determining quantitatively security indicators. The methodological basis of the research is the applied systems theory, statistical analysis, and methods of artificial intelligence (cluster analysis). The study of the approaches applied showed the absence of a theoretical basis for determining security gradations and the absence of their theoretical quantitative justification. The theoretical basis for determining security gradations is the concept of an extended "homeostatic plateau", which connects three levels of security in both directions: optimal, crisis, and critical with spheres of positive, neutral and negative feedback. To determine the bifurcation points (vector of limit values), the “t-criterion” method is used, which consists in constructing the probability density function of a “benchmark” sample, determining whether it belongs to the type of distribution with the calculation of statistical characteristics (mathematical expectation, mean square deviation, and asymmetry coefficient) and formalized calculation of the vector of limit values for characteristic types of distribution (normal, lognormal, exponential). To solve the problem of recognising (automatic classifying) the type of distribution of probability density functions of security indicators, artificial intelligence methods are used, namely, a discriminant method from the class of cluster analysis methods using quantitative and qualitative metrics: Euclidean distance, Manhattan metric and recognition by characteristic features. To digitize the determination of the vector of safety indicators limit values, an algorithm structure and software in the C++ programming language (version 6) have been developed, which ensures full automation of all stages of the algorithm and the adequacy of recognising graphic digital data with a predetermined number of clusters (types of distribution). A distinctive feature of the proposed method of formalized determination of the security indicators limit values is a complete absence of subjectivity and complete mathematical formalization, which significantly increases the speed, quality and reliability of the results obtained when evaluating the level of sustainable development, economic security, national security or national stability, regardless of the level of a researcher's qualification.

Keywords: national security, homeostatic plateau, safety indicators, limit values, distribution types, automatic classification, artificial intelligence

JEL Classification: C00, C02, C18, C50, C61, F50, F52, H56, Q01

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1. Introduction

Limit values of indicators of the state of various components of national security and sustainable development are the most important tool for analysis, forecasting and strategic planning of security development. In a more general case, the theory of security assumes knowledge and interrelationship of safe conditions for the functioning of various security objects: space, technical, economic, social and ecosystems, without knowledge of which it is impossible to protect the vital interests of security objects. "The understanding of these dependencies led to the advancement of the anthropic principle in science and philosophy - one of the principles of modern cosmology, which claims that the world's physical constants are optimally appropriate for the emergence of the biosphere and the beginning of sociogenesis” (Kachinskyi, 2013). An interesting paradoxical explanation of the anthropic principle is given by Kazyutinsky and Balashchev (1989) "The presence of life, of which we are a representative, imposes a number of very strong restrictions on the properties of the universe." or "The universe cannot be other than it is, since we exist", which should be understood not as the possibility of human intelligence to influence the universe, but as the impossibility of the emergence and existence in the universe of intelligence, whose properties would be different.

The emergence of a new paradigm of social development – sustainable development – prompted an active search for national approaches to its management, which resulted in conceiving a number of projects on conceptions of sustainable development (Butlin, 1987; Daly & Townsend, 1993; Johannesburg Declaration on Sustainable Development, 2002; UNDP, 2012). On the one hand, thanks to the latest technologies and innovations, the production process becomes more efficient, thus enhancing the countries' competitiveness and reducing their vulnerability due to market fluctuations. On the other hand, economic growth entails an increase in the number of resources, materials and fossil fuels used, which leads to environmental pollution and degradation, especially in low-income countries.

Therefore, if countries do not take steps in all three directions - to support economic growth, promote social development and strive for environmental sustainability – and to reach compromise solutions among them, then it is unlikely that such countries will advance far on the path to sustainable industrial development, regardless its current level. Such a conception is directly consistent with the interpretation of security development. In addition, knowledge of the safe conditions for the existence of the ecosystem provides a number of more important functions – monitoring the state of the studied system in comparison with the limit values allows evaluating adequately the current state, setting goals, strategizing and determining objectively the effectiveness of the actions of governments and authorities.

Determining the boundaries of safe existence is the most important stage of determining the level of security. A systematic study of the problem of sustainable development in the security dimension is impossible without determining the limits of the safe conditions for the system's vital functions, without knowing which it is impossible to protect the vital interests of security objects. Therefore, determining the limit values of safety indicators is very closely related to the concept of dynamic stability of the economic system and its individual components or to the mechanism of homeostasis. Many studies are limited to calculating the integral index of the security object without comparison with the vector of limit values, which does not make any sense and only determines their increase/decrease in separate periods and can lead to a false conclusion regarding the maximization of the integral index.

The interpretation of homeostasis as the system's ability to dynamic equilibrium for technical systems is somewhat different from economic systems. If the purpose is to ensure that the integral index of development is within threshold or optimal values, then this is accompanied by a violation of the equilibrium and the emergence of new production relations that permanently change the previous state of equilibrium. At the same time, the economic system moves into a new state endowed with better qualitative characteristics. That is, in the process of development, not only the structure of the system (composition of elements and connections) changes but also the relationships between the elements of the system and the mechanism of its functioning. Therefore, homeostasis in the economic system determines not only the ability to dynamic stability for the existing mode of operation but also the ability to manage – the transition to a new state of economic equilibrium, that is, the controllability of the economic system. Therefrom goes the importance of scientifically based determination of limit values of safety indicators for safety management. The most common practice of their determination is an analogue approach and various expert and point estimates, target and legally established normative values, as well as recommendations and resolutions of authoritative international and European organizations (van Kampen, et al., 2014; Reiman & Pietikäinen, 2010; Araujo et al., 2009). So, it can be stated that there are no formalized approaches to scientifically based determination of limit values of safety indicators yet.

The determination of limit values during integral evaluation varied from their complete disregard (State Statistics Service of Ukraine, 2003) to scalar (no more or no less) and vector (Ministry of Economic Development and Trade of Ukraine, 2013) with five ranges below the optimal values, i.e., exceeding the optimal values up to the upper threshold and critical values is not taken into account at all. Moreover, all limit values are determined by experts, and the ranges are equal (0.2 each), which is unlikely in reality.

In general, the following approaches to determining the limit values of safety indicators can be defined (Kachinskyi, 2013):

1. Heuristic methods: snowball method, analogy method, calibration method.
2. Stochastic methods: diagnostic method (cluster analysis, fuzzy set theory method, t-test method, logistic regression method).
3. Analytical methods: the Ahiezer-Holtz method, methods of information theory, and the method of the "golden section" rule.
4. Methods of nonlinear dynamics (wavelet analysis).

Heuristic methods are mainly based on expert, subjective estimates, which undoubtedly reduces the practical and scientific value. Therefore, they can be used in the case when statistical information is unreliable, absent or available in limited quantities; part of the information is of a qualitative nature; the complexity of the task and resource limitations do not allow experts to independently collect and summarize all the necessary information; other methods cannot be used for some reason.

Analytical methods and methods of nonlinear dynamics are too general and need to be improved in each practical case, besides, it is not about determining the vector of limit values. The main disadvantages of the used approaches are: a lack of a theoretical basis for determining security gradations; a lack of their theoretical quantitative justification.

In the authors' opinion, stochastic methods (diagnosis) have a good theoretical basis and practical significance in processing statistical data, the prospect of further development and are most suitable for formalization and universal application.

In view of this, the purpose of the article is to develop a methodology and software for scientific substantiation of the vector of limit values of national security indicators using artificial intelligence methods.

2. Materials and Methods

The concept of gradations of security should be connected with the concept of "homeostatic plateau", which was first proposed by Gigch (1978) in the applied theory of systems and included the plateau itself and the destruction of the system from both sides. The concept of "extended homeostatic plateau", which was proposed in (Kharazishvili et al., 2020), additionally contains ranges of threshold and critical values with a region of neutral and positive feedback, staying in which is dangerous for the system. Moreover, the change in the type of feedback does not occur immediately upon crossing the sphere, but at first the existing type of communication decreases exponentially, and then another type of communication grows, also exponentially (Figure 1).

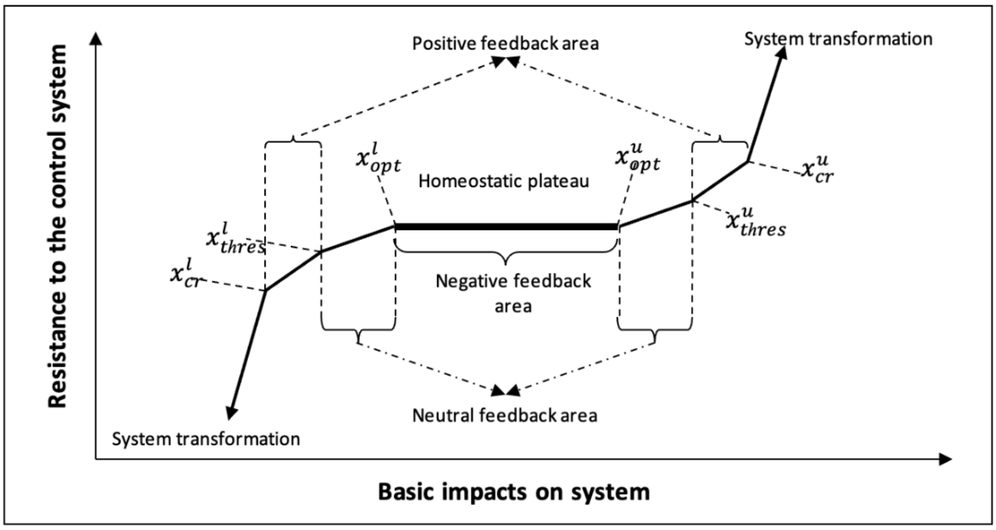
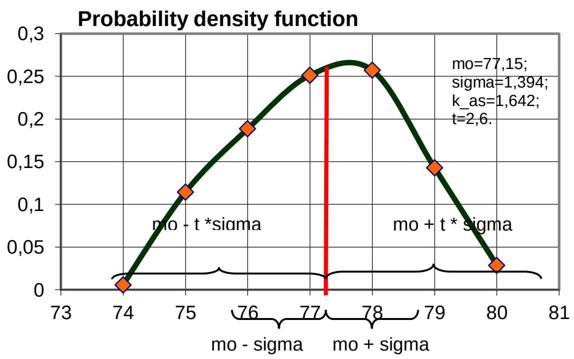


Figure 1. Extended Homeostatic Plateau of the Dynamical System
Source: (Kharazishvili, 2019)

Thus, the number of safety gradations (critical, threshold, optimal) on both sides of the homeostatic plateau is associated with the concept of an extended "homeostatic plateau" and spheres of positive, neutral, and negative feedback.

That is why it is necessary to define a *vector of limit values* for each indicator: lower critical (x_{cr}^{l}); lower threshold (x_{thres}^{l}); lower optimal; (x_{opt}^{l}); upper optimal;(x_{opt}^{u}); upper threshold; (x_{thres}^{u}); upper critical (x_{cr}^{u}). A pair of optimal values defines a homeostatic plateau, within which the best conditions for system functioning and negative feedback exist. That is why, the average value between two optimal values (lower and upper optimal) – the middle of the "homeostatic plateau" can be considered a criterion for achieving the level of sustainable development for both indicators and integral indices.

Quantitative values of security gradations (bifurcation points) are associated with the extension of the "t-criterion" method through the construction of the probability density function, determination of belonging to the type of distribution with the calculation of the statistical characteristics of the "benchmark" sample (mathematical expectation μ, mean square deviation σ, and coefficient of asymmetry k_{as}) and formalized determination of bifurcation points for characteristic types of distribution. From all the variety of types of probability density functions for all studied indicators of sustainable development (> 300), it is possible to distinguish functions with a characteristic type of distribution: normal, lognormal and exponential (Figure 2).



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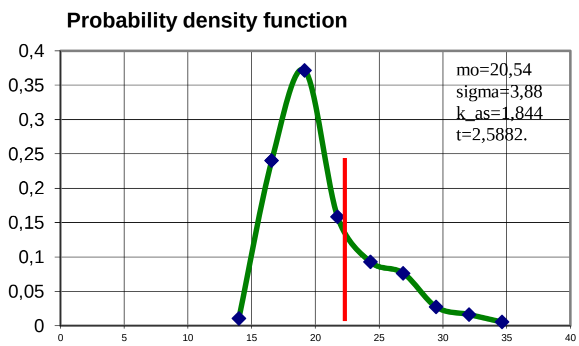

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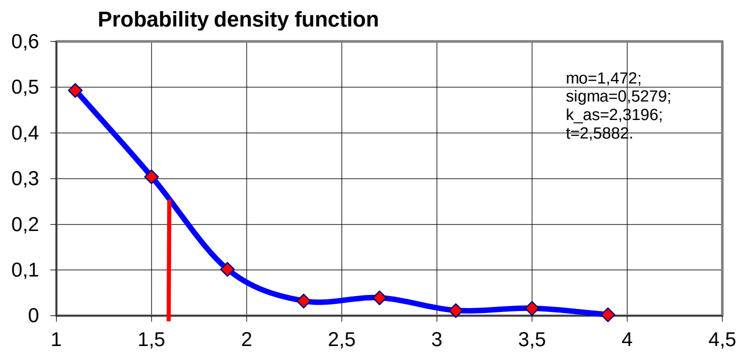

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Figure 2. Typical Types of Probability Density Function Indicators
Source: (Kharazishvili, 2019).

Formulas for calculating the vector of limiting values are derived for characteristic types of distribution (Table 1) (Kharazishvili et al., 2021). Moreover, a "benchmark" sample is formed for each indicator from the list of countries that have the best values of the relevant indicators and can be a promising model for the country under study.

Table 1. Formalized threshold vector values

Type of Indicator Probability Density Function	Lower Threshold	Lower Optimal Value	Upper Optimal Value	Upper Threshold
Normal	$\mu - t \times \sigma$	$\mu - \sigma$	$\mu + \sigma$	$\mu + t \times \sigma$
Lognormal (tail right)	$\mu - t \times \sigma / k_{as}$	$\mu - \sigma / k_{as}$	$\mu + \sigma$	$\mu + t \times \sigma$
Lognormal (tail left)	$\mu - t \times \sigma$	$\mu - \sigma$	$\mu + \sigma / k_{as}$	$\mu + t \times \sigma / k_{as}$
Exponential (tail right)	$\mu - \sigma / k_{as}$	μ	$\mu + \sigma$	$\mu + t \times \sigma$
Exponential (tail left)	$\mu - t \times \sigma$	$\mu - \sigma$	μ	$\mu + \sigma / k_{as}$

Source: (Kharazishvili et al., 2021).

The calculated values σ of the "benchmark" sample are multiplied by the value of the confidence coefficient t (takes into account the dependence between the confidence level and the width of the evaluation interval), which is taken from the Student's t-distribution tables (Turner, 1970).

The calculated values σ of the "benchmark" sample are multiplied by the value of the confidence coefficient t (takes into account the dependence between the confidence level and the width of the evaluation interval), which is taken from the Student's t-distribution tables (Turner, 1970). The t value for a given confidence level is determined not by the sample size, but by a number known as the degree of freedom. When calculating the reduced vector of limit values (Table 1), a confidence level of probability 0.98 or 0.99 can be used. Then, for calculating safety indicators' critical values (lower critical, upper critical) there is a confidence level of probability 0.998-0.999 for threshold value formulas. For the exponential type of distribution, in the absence of the t parameter, the minimum value of the indicator (tail right) or the maximum (tail left) is chosen as critical.

3. Theory

As said earlier, stochastic methods of diagnosis (cluster analysis and the “t-criterion” method) are the most promising in formalizing the definition of the limits of dynamic systems' safe existence. Therefore, the unsolved problem of the complete digitalization of the definition of the safe existence limits is the automatic classification (pattern recognition) of the type of distribution of the probability density function of a given sample, for the solution of which the most suitable are methods of artificial intelligence (Nilsson, 2009; Kornieiev, 2016; Bonabeau et al., 1999; Russell & Norvig, 2009; Bogachov et al., 2020; Canny, 1986; Coban et al., 2022; Drozdz et al., 2020a; 2020b; Dzwigol et al., 2020; Huang et al., 2022; Kuzior et al., 2021; Kuzior & Kwilinski, 2022; Kwilinski & Kuzior, 2020; Kwilinski, 2018; 2019; Kwilinski et al., 2019; 2020; 2021a; 2021b; LeCun et al., 2015; Lyulyov, 2021a; Melnychenko, 2020; Miśkiewicz, 2018;

2021a; 2021b; 2022; Miśkiewicz et al., 2021; 2022; Saługa, 2020; Schmidhuber, 2015; Shafait et al., 2021; Szczepańska-Woszczyna & Gatnar, 2022; Tkachenko et al., 2019), in particular cluster analysis (Blashfield & Aldenderfer, 1988; Hu & Winsch, 2005; Hartigan, 1975; Standford University, 2016; Tryon, 1939). It should be noted that scholars (Petroye et al., 2020; Pimonenko et al., 2021; Melnyk et al., 2018; Lyulyov et al., 2021b; 2015) outline that artificial intelengence and digital technologies allow achieve synergy economic, ecological and social effects at all levels and sectors. A meaningful definition of artificial intelligence for this study was provided by Nils J. Nilsson (2009), "Artificial intelligence is that activity devoted to making machines intelligent, and intelligence is that quality that enables an entity to function appropriately and with foresight in its environment."

Cluster analysis (or automatic classification, pattern recognition) is one of the effective methods of deciding whether an object belongs to one of the previously selected classes of objects (image) and refers to statistical processing, as well as a wide class of learning tasks without a teacher, in this case, a "benchmark" sample of some indicator values to one of the reference types of distribution: normal, lognormal, exponential. The recognition process is based on comparing the features and characteristics of the object (sample) under investigation with the features and characteristics of other known objects, as a result of which a conclusion is made about the most likely correspondence between them.

To determine the correspondence (highest likelihood) of the constructed "benchmark" probability density function to the "reference" as a metric - formulas for evaluating the degree of closeness, the characteristics of plausibility and characteristic features are selected, namely:

1. Euclidean distance (quantitative feature):

$$d_k = [\sum_{i=1}^{N}(x_i - x_{ik})^2]^{\frac{1}{2}} \quad (1)$$

where *N* is the number of benchmark sample points; *k* is the number of clusters (types of distribution).

2. Manhattan metric (quantitative feature):

$$d_k = \sum_{i=1}^{N}|x_i - x_{ik}| \quad (2)$$

3. Rodgers-Tanimoto similarity measure - recognition by characteristic features (qualitative feature):

- a normal type of distribution:

a) clearly expressed maximum (not at the edges of the sample);

b) the same number of points (± 1) with smaller ordinates to the left and right of the maximum point;

c) the distance from the maximum point to the left and right is approximately the same to the extreme points ($\approx \pm 10 - 20\%$).

- a lognormal type of distribution:

a) clearly expressed maximum (not at the edges of the sample);

b) to the left (right) of the maximum point there should be at least 1-2 points with smaller ordinates;
c) most of the points to the right (left) have a decreasing ordinate from the maximum;
d) the distance from the maximum point to the extreme points is significantly different (> 2).

- an exponential type of distribution: clearly expressed maximum at the extreme left (right) point; most points to the right (left) have a decreasing ordinate.

Therefore, one of the well-known clustering methods, namely discriminant analysis, is used to perform automatic classification of the distribution type of the “benchmark” sample, which is used to divide or assign the “benchmark” sample (i.e., “discrimination”) to one of the a priori specified clusters (types of distribution).

4. Calculation

Since part of the indicators of the air transport sustainable development depends on the GDP of Ukraine, there should be made a forecast of the real GDP, assuming the maximum of all expert estimates (-20; -45%) of a drop of 45% and possible scenarios of its recovery (Figure 3).

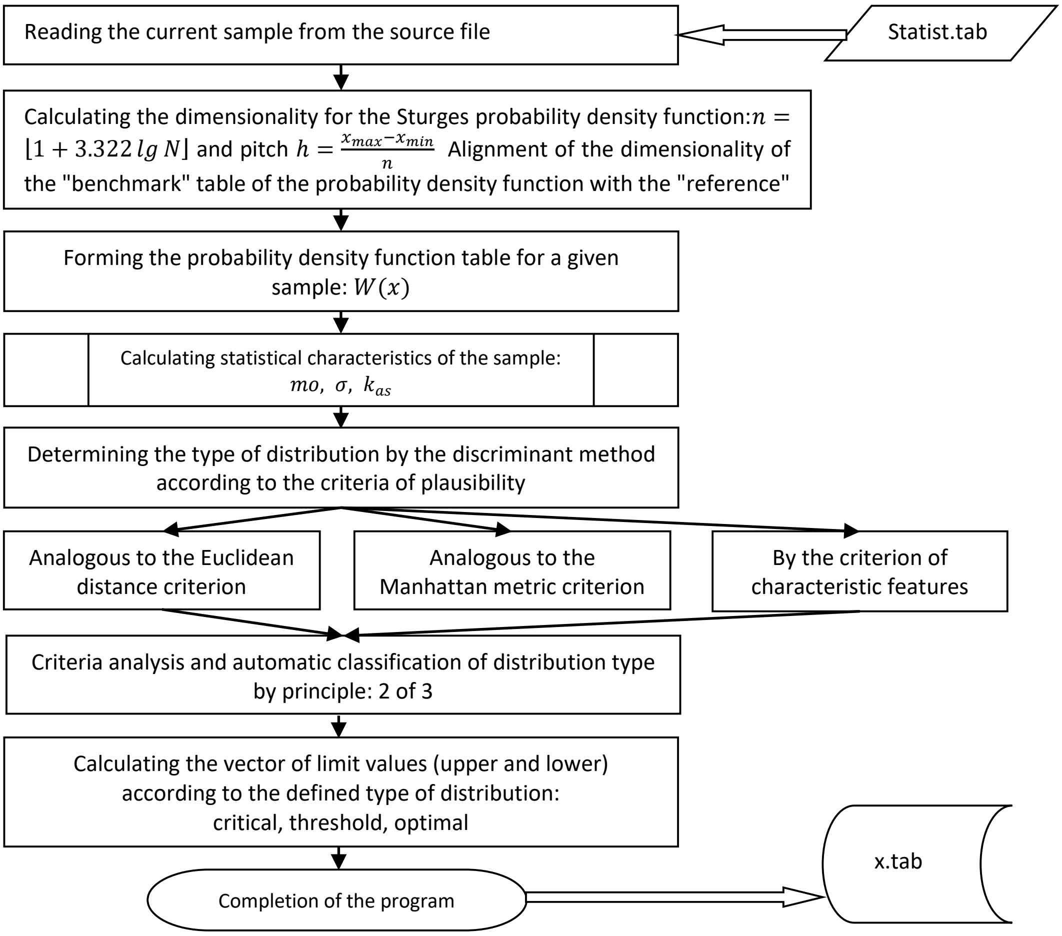

Figure 3. The Structure of the Digitization Program to Determine the Vector of the Limit Values of Safety Indicators
Source: own elaboration.

From this graph, it follows that under the scenario of 2.3% annual growth, reaching the level of real GDP of the pre-war period (2021) is possible only in 2048, so this scenario will not be considered. Having set the forecast values of the GDP deflator, there will be obtained the values of the nominal GDP of Ukraine, which, in combination with official statistical data (2010-2021) and model calculations, make it possible to obtain the forecast values of the indicators of the sustainable development of air transport at the end of 2022. Below there is given a structure of the digitization algorithm for determining the vector of limit values of safety indicators (Figure 3).

Reading of the "*benchmark*" sample from the source file: for each indicator, a "*benchmark*" sample is formed, which has values that correspond to the best values of developed countries and is considered a benchmark. The values of the "*benchmark*" sample are recorded in the file "Statist. tab" 8 numbers in a line, separated by a space.
Calculating the dimension for the probability density function according to (Sturges, 1926): for a given sample, there is applied the empirical rule for determining the optimal number of intervals into which the observed range of a random variable change is divided when constructing a histogram of its distribution density (3):

$$n = 1 + \lfloor 3{,}322\, lg\, N \rfloor \quad (3)$$

where *n* is the number of intervals; *N* is the size of the sample.

This leads to the step h of constructing the probability density function (4). If the dimensions of the constructed and reference tables do not match, their dimensions are automatically aligned for further classification.

$$h = \frac{x_{max} - x_{min}}{n} \quad (4)$$

where x_{max}, x_{min} are the maximum and minimum value of the "benchmark" sample.

Making the table of the probability density function: for a given sample, the number of hits of a random variable in a given range is calculated with a step h and the probability of this hit as the ratio of the number of hits in a specific range to the total number of observations (sample size N).

Calculating statistical characteristics: statistical characteristics of the "benchmark" sample are calculated: mathematical expectation, mean square deviation and coefficient of asymmetry for further calculation of the limits of dynamic systems' safe existence (vector of limit values).

Determining the type of distribution by the discriminant method according to the criteria of plausibility: there is carried out the automatic classification of the probability density function according to one of the types of distribution: normal, lognormal, exponential, using artificial intelligence methods, namely: by the discriminant method of cluster analysis according to three criteria:

1) an analogue of the Euclidean distance (quantitative feature) (1);

2) an analogue of the Manhattan metric (quantitative feature) (2);
3) an analogue of the Rogers-Tanimoto similarity measure – recognition by characteristic features (qualitative feature).

Analysis of criteria and automatic classification of the distribution type according to principle 2 out of 3: the conclusion of the automatic classification software is based on the resulting criterion – the match of distribution types according to at least two of the three criteria. The smallest value of the plausibility criteria for the three types of distribution determines its affiliation.

The value of the variable distribution determines the type of distribution, and the variable subtype determines the subtype of the distribution:

$$Distribution\ law\ type\ (subtype) = \begin{bmatrix} 0; & -Normal; \\ 1; & -Lognormal; \\ 2; & -Exponential \end{bmatrix} \begin{pmatrix} 0-1; & \\ 0; & -tailright; \\ 1; & -tail\ left; \end{pmatrix} \quad (5)$$

For example, the value in the source file of the variable Distribution law type is 1 (0) means that the type of distribution is "lognormal", tail to the right.

Calculating the vector of limit values (upper and lower) according to the defined type of distribution: defining the type of distribution in automatic mode makes it possible to calculate the vector of limit values according to Table 1 formula.

To check the adequacy of the calculations of the digitization model, there were selected some indicators of sustainable development which provide a full functional check of the developed model:

- the level of provision with own resources, % of total consumption;
- energy intensity of GDP, t.o.e./1000 US dollars;
- GDP per person, thousands of US dollars;
- energy consumption per 1 person, t.o.e. per year;
- final carbon content of energy, g CO_2 / MJ;
- the level of CO2 emissions per 1 GDP, kg/US dollars;
- investment level, % before release;
- life expectancy, years.

The calculated probability density functions based on "benchmark" samples of the above indicators are presented in Figure 4. Presented in Figure 4 the structure of the digitization software is implemented in the C++ programming language (version 6.0).

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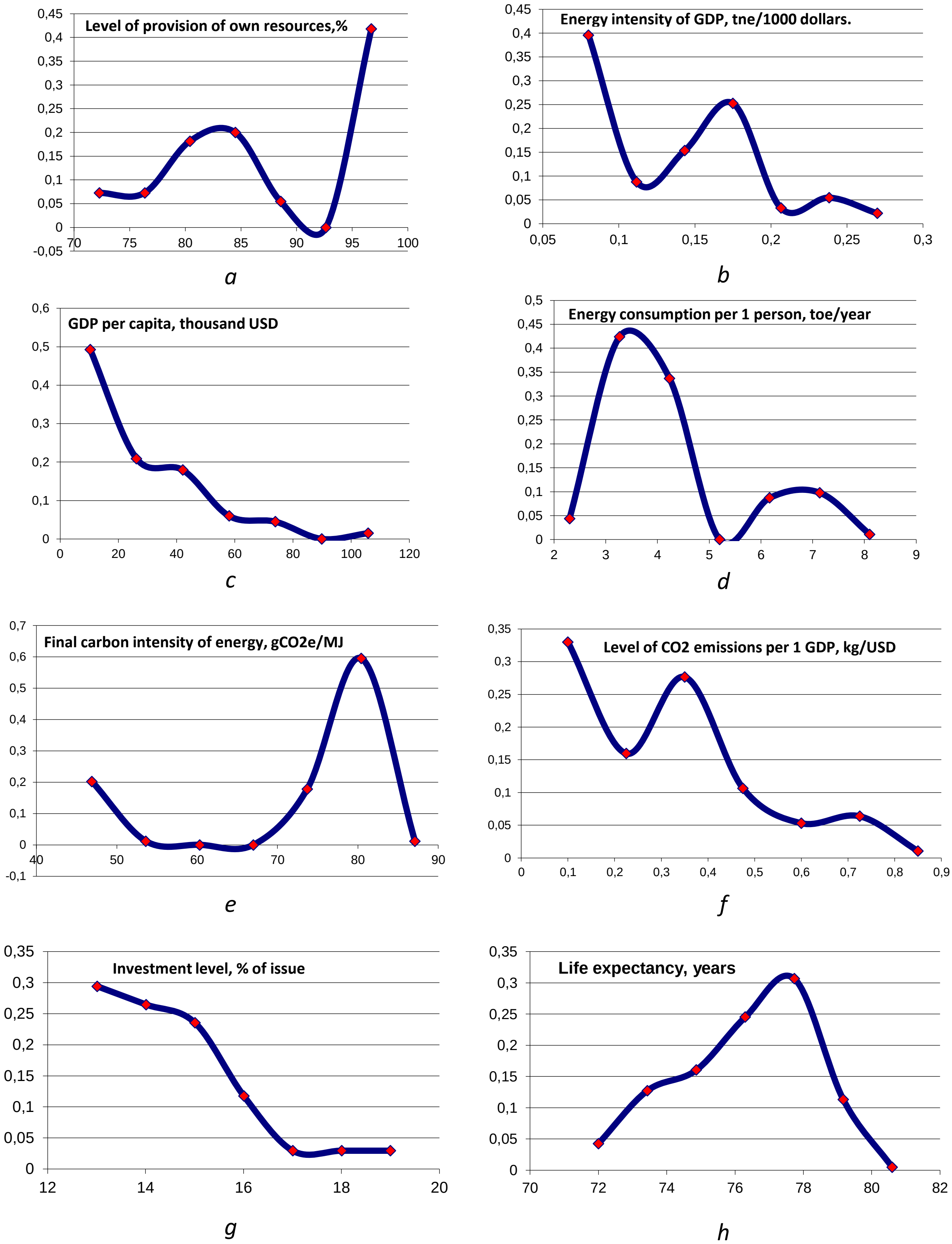

Fig. 4. Probability density functions of sustainable development indicators
Source: own elaboration.

The results of calculations regarding the automatic classification of the distribution types of probability density functions of sustainable development indicators (economic, environmental and social security) prove the effectiveness of recognition according to the specified criteria (Table 2).

Table 2. Results of Automatic Classification of the Distribution Type of Probability Density Functions

Indicators	Actual distribution type	By criterion 1	By criterion 2	By criterion 3	Resultant evaluation
1. The level of provision with own resources	Exponential, tail to the left	Confirmed	Confirmed	Confirmed	Three out of three
2. Energy intensity of GDP	Exponential, tail to the right	Confirmed	Confirmed	Confirmed	Three out of three
3. GDP per person	Exponential, tail to the right	Confirmed	Confirmed	Confirmed	Three out of three
4. Energy consumption per 1 person	Lognormal, tail to the right	Confirmed	Confirmed	Confirmed	Three out of three
5. Final carbon content of energy	Lognormal, tail to the left	Confirmed	Confirmed	Confirmed	Three out of three
6. The level of CO_2 emissions per 1 GDP	Lognormal, tail to the right	Confirmed	Confirmed	Confirmed	Three out of three
7. Investment level	Exponential, tail to the right	Confirmed	Confirmed	Confirmed	Three out of three
8. Life expectancy	Normal	Confirmed	Confirmed	Lognormal, tail to the left	Two out of three

Source: own elaboration.

The result of the digitalization software for determining the limits of the dynamic systems' safe existence is the calculation of the vector of the limit values of the safety indicators (Table 3).

Table 3. The Results of Digitalization of Determining the Limits of the Safe Existence of Dynamic Systems

Indicators	Lower Critical	Lower Threshold	Lower Optimal	Upper Optimal	Upper Threshold	Upper Critical
1. The level of provision with own resources	72.27	80.7	87.6	96.1	108.0	115.3
2. Energy intensity of GDP	0.08	0.0962	0.1336	0.1866	0.26	0.3024
3. GDP per person	10.36	15.72	26.5	47.2	75.74	92.95
4. Energy consumption per 1 person	1.67	2.315	3.428	5.6	7.492	8.58
5. Final carbon content of energy	45.38	52.2	63.8	85.48	103.8	114.6
6. The level of CO_2 emissions per 1 GDP	0.1	0.1788	0.3034	0.4973	0.7644	0.919
7. Investment level	13	13.7	14.5	16.0	18.2	19.5
8. Life expectancy	70.2	71.7	74.4	78.3	80.9	82.4

Source: own elaboration.

Such a definition of the vector of limit values is typical for stimulator indicators, but for de-stimulator indicators, the order of values of the components of the vector is reversed. Given that indicators 2, 5 and 6 (Table 3) are de-stimulators, that is, their reduction is desirable, the final table for further calculations of integral indicators looks as follows (Table 4).

Table 4. The Results of Digitalization of Determining the Limits of the Safe Existence of Dynamic Systems, Taking into Account the Type of Indicator (Stimulator/De-Stimulator)

Indicators	Lower Critical	Lower Threshold	Lower Optimal	Upper Optimal	Upper Threshold	Upper Critical
1. The level of provision with own resources	72.27	80.7	87.6	96.1	108.0	115.3
2. Energy intensity of GDP	0.3024	0.26	0.1866	0.1336	0.0962	0.08
3. GDP per person	10.36	15.72	26.5	47.2	75.74	92.95
4. Energy consumption per 1 person	1.67	2.315	3.428	5.6	7.492	8.58
5. Final carbon content of energy	114.6	103.8	85.48	63.8	52.2	45.38
6. The level of CO_2 emissions per 1 GDP	0.919	0.7644	0.4973	0.3034	0.1788	0.1
7. Investment level	13	13.7	14.5	16.0	18.2	19.5
8. Life expectancy	70.2	71.7	74.4	78.3	80.9	82.4

Source: own elaboration.

Scientifically based determination of the limits of the safe existence of dynamic systems during their integral evaluation makes it possible to adequately identify the safety level by comparing integral indices with integral limit values.

5. Conclusions and Discussion

Knowledge of the safe conditions for the existence of the ecosystems provides a number of more important functions: monitoring the state of the studied system in comparison with the limit values allows evaluating adequately the current state, the level of safety/danger, setting goals, strategizing and objectively determining the effectiveness of the actions by the Government and authorities.

Determining the limits of safe existence is the most important stage of determining the level of security. A systematic study of the problem of sustainable development from the point of view of security should include the definition of the limits of safe conditions for the life of the system, without knowing which it is impossible to protect the vital interests of security objects. Therefore, the definition of limit values should be connected with the concept of dynamic stability of the economic system and its individual components or with the mechanism of homeostasis. Without such a comparison, there will be the dynamics of integral indices of sustainable development, which will determine their increase/decrease in separate periods, which may lead to a false conclusion regarding the maximization of the integral index.

In the vast majority of publications, expert evaluations are used to determine safety gradations and limit values when assessing the safety level, which introduces a certain amount of subjectivity, does not exclude fundamental errors, and undoubtedly reduces the scientific and practical value of the obtained results. Application of the method of expert evaluations in the general case means a "dead end" situation, or the inability to offer something adequate.
An analysis of the approaches used to determine the limits of the safe existence of dynamic systems was carried out, including the following methods: heuristic, stochastic, analytical, and nonlinear dynamics. Among the main shortcomings of the used approaches is the lack of a theoretical basis for determining security gradations and the lack of their theoretical quantitative justification. The most promising are stochastic methods, which have a good theoretical basis and practical significance in processing statistical data, the prospect of further development and are most suitable for formalization and universal application.

Therefore, it is proposed to solve the identified problems by formalized mathematical methods:

- to determine security gradations there is used the concept of an extended "homeostatic plateau", which provides for three levels of security in both directions: optimal ("green" zone), crisis ("orange" zone), critical ("red" zone), which define areas of positive, neutral and negative feedback;
- to determine the bifurcation points (vector of limiting values), there is used the "t-criterion" method, which consists in constructing the probability density function of the "benchmark" sample, determining whether it belongs to the type of distribution with the calculation of statistical characteristics (mathematical expectation, root mean square deviation, and asymmetry coefficient) and formalized calculation of the vector of limiting values for characteristic types of distribution (normal, lognormal, exponential);
- to solve the problem of recognition (automatic classification) of the type of distribution of probability density functions of security indicators, there are used artificial intelligence methods, namely the discriminant method from the class of cluster analysis methods using quantitative and qualitative metrics: Euclidean distance, Manhattan metric and recognition by characteristic features;
- for the digitalization of determining the vector of limit values of safety indicators, there have been developed an algorithm structure and a program in the C++ programming language (version 6), which ensures full automation of all stages of the algorithm and the adequacy of recognising graphic digital data with a predetermined number of clusters (types of distribution).

For each indicator, the "benchmark" sample is formed from the dynamics of similar indicators of economically developed countries, which can be considered a model for the country under study. That is, the process of determining the benchmark sample is similar to the construction of a hypothetical country with the best values of the relevant security indicators.

A distinctive feature of the proposed method of formalized determination of the limit values of security indicators is the complete absence of subjectivity and complete mathematical formalization, which significantly increases the speed, quality and reliability of the results obtained when assessing the level of sustainable development, economic security, national security or national stability, regardless of the level of the researcher's qualification.

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