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Cognitive Model of Financial Stability of the Domestic Economy Based on Artificial Intelligence in Conditions of Uncertainty and Risk

Nikolay Lomakin[1i], Maxim Maramygin[2], Alexander Kataev[1], Sergey Kraschenko[3], Olga Yurova[1], Ivan Lomakin[1]

[1]*Volgograd State Technical University, ave. V.I. Lenina, 28, 400005, Russia*
[2]*Ural State University of Economics, 8 Marta st., 62, Yekaterinburg, 620144, Russia*
[3] *Volgograd branch of the PRUE G.V. Plekhanov, st. Volgodonskaya, 11, Volgograd, 400066, Russia*

Abstract. The study's relevance lies in the fact that the important problem is ensuring the sustainability of the development of the Russian economy. Its financial system is influenced by many factors, among which are increased risks and market uncertainty, aggravation of the global military-political confrontation between the largest world powers, and technological innovations associated with the emergence of a new technological order "Industry 4.0". The purpose of the work is to study the financial stability of the state as a complex system based on a cognitive model that involves the use of an artificial intelligence system and a VaR model. The novelty of the study lies in the proposed approach, which involves the formation of a cognitive model of economic processes, which includes the Decision Tree artificial intelligence system and the VaR model, both generate GDP forecasts, then their forecast values are compared. A hypothesis has been put forward and proved that with the help of a cognitive model that includes an A.I. system and a VaR model, it is possible to obtain a forecast of the volume of Russia's GDP, the dynamics of which allows us to assess the sustainability of the development of the country's economy.

Keywords: Cognitive model; Financial stability; Market uncertainty; Risk; Decision tree

1. Introduction

The purpose of the work is to study the state's financial stability as a complex system based on a cognitive model that involves the use of an artificial intelligence system and a VaR model. Calculate the forecast values of the volume of the gross domestic product of the Russian Federation using artificial intelligence systems and the VaR method.

To achieve this goal, the following tasks were set and solved. 1) The theoretical foundations of the financial stability of the country's economy, the formation of GDP and the value of exports were studied. 2) The factors that determine the sustainability of economic development are identified. 3) The forecast values of the GDP volume were calculated in two different ways: both using the Decision Tree neural network and using the VaR model. 4) The accuracy of forecasts obtained by different methods is compared.

The relevance of the study comes from a problem of ensuring stability of the development of the Russian economy in the face of increasing market uncertainty and the action of a number of factors due to the consequences of the COVID-19 pandemic, increased economic sanctions

[i]Corresponding author's email: tel9033176642@yahoo.com, Tel.: +79033176642
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from the United States and the eurozone countries, the aggravation of the global military-political confrontation, the changing economic landscape, the emergence of a new technological way of "Industry 4.0" and others. The study's novelty is determined by the fact that an approach is proposed to fill the gap, which concerns the problem of the lack of a reliable approach to using a cognitive model to form an accurate forecast of GDP to achieve sustainable development of the domestic economy. Getting a correct forecast of the volume of gross domestic product in the face of market uncertainty is essential.

The paper attempts to put forward and prove the hypothesis that in the face of uncertainty and intensification of all types of risk, based on the application of a cognitive. Model , using the artificial intelligence system "Decision Tree" and the VAR model, it is possible to obtain predictive GDP values to support managerial decision-making to ensure the sustainable development of the economy.

The practical significance of the study lies in the fact that in the course of the study the prerequisites for solving an important national economic problem were formed - forecasting the value of GDP and ensuring the sustainable development of the country's economy. The action of the above factors requires an assessment of global risks, and the capabilities of A.I. systems as elements of cognitive modeling.

As you know, the economic development of countries largely depends on exports. The export of goods and services gives impetus to the growth of national production, income and employment of the population, contributing to the growth of the economy and GDP. The coronavirus pandemic resulted in an 8% trade in goods and a 21% year-on-year decline in trade in commercial services in 2020. Thus, global exports of manufactured goods decreased by 5.2% in 2020, while total exports of goods decreased by 7.7% overall.

Russia's trade turnover for 2021 amounted to $784.4 billion (of which exports - $491.2 billion, imports - $293.1 billion), an increase of +38.1% compared to the same period last year. Exports from Russia in 2021 amounted to $491.2 billion, an increase of +46% compared to last year's period. The dynamics of Russia's exports are presented below (Figure 1).

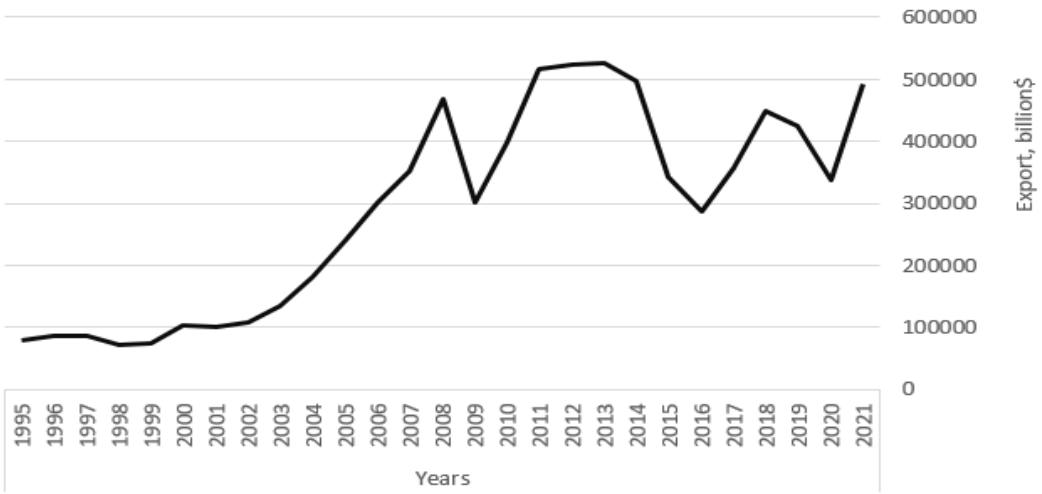

Figure 1 Dynamics of Russian exports, billion$

Studies have shown that the stability of the Russian economy is largely affected by partner countries. The economies of different countries have shown different economic stability. Russia's merchandise exports remained below their level of two years ago (-8

percent) while those of China were up sharply (+31 percent). The standard deviation calculated from the results of fluctuations in quarterly parameters of the gross domestic product of countries for 2020 reflects the amount of financial risk, which can be used in assessing the country's stability.

Studies show that this "economic sustainability" category is a complex and multifaceted concept. Many works of Russian and foreign scientists are devoted to the study of the problem of stability of economic systems. These problems have long been reflected in the works of economists, for example, Gurvich, Prilepsky, Bobylev, M.A. Konishchev, others. (Abdrakhmanova et al., 2019).

Kleiner proposed a normative model for the distribution of the role functions of subsystems over the stages of the crisis cycle of the economy. The problem of developing a cognitive model of the national financial market, considering the peculiarities of its construction and the possibility of using it to assess the security of its functioning, was studied by Loktionova (Loktionova, 2022).

The works are devoted to the study of issues of ensuring financial market stability based on cognitive modeling (Badvan et al., 2018). Cognitive modeling of financial market stability factors, and constructing cognitive maps was considered in their works by Emelianenko and Kolesnik (Emelianenko & Kolesnik, 2019).

Mohammed Ali Berawi has established that many industrial sectors are in the middle of a digital transformation that has emerged from the advancement of information and data technology, enhancing the use of computers and automation with smart and autonomous systems powered by data and machine learning. This revolution has been broadly adopted in the industry by using digital technologies, sensor systems, intelligent machines, and smart material s in its processes. (Berawi, 2020)

In modern conditions, it becomes relevant to study the issues of using artificial intelligence to ensure the sustainable development of the economy, and reduce financial risks in the face of increasing market uncertainty. Abdalmuttaleb and Al-Sartawi reviewed the latest research in the application of artificial intelligence for stable financing and sustainable technologies (Abdalmuttaleb & Al-Sartawi, 2021)

Burova's paper suggests a mechanism for managing the costs of I.P. of an industrial enterprise, which: (1) considers the high level of volatility of the external environment common to the digital economy and the effects exerted by risks on cost management; (2) can be used for controlling the level of target costs and introducing corrections made to the costs in due time according to the changing external and internal conditions so that the target profitability can be ensured; and (3) is based on using up-to-date and high-precision tools and methods for assessing risks and their effects on the costs and profitability of the IP (Burova et al., 2021)

The materials are presented at the International Conference "Global Economic Revolutions: The Era of the Digital Economy". The Lomakin et al. developed a neural network model that makes it possible to forecast the profit of enterprises in the real sector of the economy that is at risk. The analysis showed that the risk of financial income of enterprises (sigma) in chronological sequence increased unsustainably from the level of 0.4 in the second quarter of 2015 to a maximum of 3.1 with subsequent consolidation to 2.8 billion rubles, while its average value was 2.09 billion rubles (Lomakin et al., 2019).

The study of Nadezhina aims to evaluate the risks of integration processes in the EU. Two indicators were used to quantify the degree of convergence: 1) convergence and 2) convergence. This is very important in today's environment (Nadezhina et al., 2021)

Certain aspects of the use of neural networks in the financial sector intersect with issues of economic analysis in the financial management system. Morozova et al. note that

in the conditions of the development of the modern economy, for the effective operation of an enterprise in the face of ever-increasing competition, it is necessary to respond in a timely manner to various kinds of changes in all factors affecting the enterprise. (Morozova et al., 2022).

An important factor in the financial stability of the economy is the reliable operation of the banking sector, and preventing the growth of overdue debt is one of the most pressing issues for ensuring reliability. To prevent the development of outstanding loans in the credit sector, it is important to assess the creditworthiness and financial stability of the enterprise. Rybyantseva et al. considered separate approaches for assessing the financial stability of an enterprise (Rybyantseva et al., 2017).

In the deep risk model proposed by Lin et al., a deep learning solution is proposed to analyze latent risk factors while improving the ovariance matrix estimation. Experiments were carried out on stock market data and demonstrated the effectiveness of the proposed solution. The method allows you to get 1.9 % higher than the identified variance and reduce the risk of the global minimum variance portfolio (Lin et al., 2021).

The risk is identified by estimating the standard deviation based on the biased estimate of the variance, which can be calculated using the formula:

$$S = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (x_i - \underline{x})^2} \quad (1)$$

Of practical interest are the studies of Zhan et al. in the development of graphical models for financial time series and portfolio selection. The authors explored various graphical models for building optimal portfolios. Graphical models such as PCA-KMeans, auto-encoders, dynamic clustering, and structural learning can capture time-varying patterns in a covariance matrix and allow you to create an optimal and robust portfolio. When comparing derived portfolios from different models with the underlying methods, charting strategies produced steadily increasing returns at low risk and outperformed the S&P 500 index. This work suggests that charting models can effectively learn time dependencies in time series data (Zhan et al., 2021).

Financial risk assessment using the VaR model provides high performance to support managerial decision-making in the financial sector. A team of scientists consisting of Kei Nakagawa, Shuhei Noma, and Masaya Abe proposed an approach based on the use of the RM-CVaR model. It is known that dispersion is the most fundamental measure of risk that investors seek to minimize, but it has several drawbacks. Notional Value at Risk (CVaR) is a relatively new risk measure that overcomes some shortcomings of well-known variance risk measures and has gained popularity due to its computational efficiency (Nakagawa et al., 2020).

2. Methods

In the presented work, such research methods were used as monographic, analytical, statistical, and cognitive models, including the artificial intelligence system "Decision Tree" and the VaR model. The neural network model includes indicators that reflect the dynamics of the development of the domestic economy. The studies reflected in this article relied on the research methodology followed by the authors. This study's methodology involves using the main research method - a cognitive model. Modeling financial and economic stability based on a cognitive model allows us to develop a new model for the task of supporting managerial decision-making in terms of the financial and economic stability of the Russian financial system, the most important prognostic parameter of which is the value of GDP. The cognitive model acts as a kind of trigger, which in turn launches methods

as independent model programs: Decision Tree VAR-model, which allows you to get the forecast value of GDP and compare the results. The Decision Tree model dataset is shown below (Table 1).

Table 1 The dataset of the AI-model Decision Tree (fragment)

Year	Key rate	Growth of bank assets, %	Share of overdue loans, %	GDP, billion rubles	RTS Index	Dollar exchange rate
2021	8.5	16	23.5	131015	1608	73.7
2020	4.25	16.8	17.8	1073015	1376	73.8
2019	7.25	10.4	5.9	109241	1549	61.9
2018	7.75	6.4	7.5	103861	1157	69.8
2017	8.25	-3.5	9.3	91843	1154	57.6

Continuation of table 2

Investments in assets in GDP, %	Share of robots on exchange, %	The capital outflow of billion rubles	Risk (VaR) banking system, billion rubles	Bank assets, trln. rub.	GDP forecast, billion rubles
21.2	58	72	-108.5	120	130015.0
16.5	55	53	-72.7	103,7	107315.5
20.6	55	25,2	-77.5	92,6	109241.5
20.6	51	60	-77.1	92,1	103861.7
21.4	51	33,3	-58.8	85,2	91843.2

The neural network dataset includes data for the period 2010-2021. The statistics are given in Table 1 to use these data to train the neural network model.

Decision trees (D.T.) are based on a non-parametric supervised learning method that is used for classification and regression. The goal of the method is to create a model that predicts the value of the target variable based on the study of simple decision rules derived from the data's characteristics. The tree can be viewed as a piecewise constant approximation.

The deeper the tree, the more complex the decision rules, and the fitter the model. Decision trees are used for both classification and regression problems. Understanding the Importance of Variables in the forests of random trees is presented in many works, including Louppe et al. (Louppe et al., 2020).

A binary classification (resp. regression) tree (Breiman et al., 2022) is an input-output model represented by a tree structure, T, from a random input vector $(X_1 \ldots X_p)$ taking its values in $(X_1 * \ldots * X_p)$=X to a random output variable $Y \epsilon Y$. A tree is built from a learning sample of size N drawn from $P(X_1 \ldots X_p, Y)$ using a recursive procedure that identifies at each node t the split $s_t = s^*$ For which the partition of the N_t node samples into t_L and t_R maximizes the decrease

$$\Delta_i(s,t) = i(t) - p_L i(t_L) - p_R i(t_R) \quad (2)$$

of some impurity measure *i(t)* (e.g., the Gini index, the Shannon entropy, or the variance of Y), and where $p_L = N_{t_L}/N_t$ and $p_R = N_{t_R}/N_t$. The tree construction stops, e.g., when nodes become pure in terms of Y or when all variables Xi is locally constant.

3. Results and Discussion

As a result of the study, forecast values of Russian GDP were obtained based on a cognitive model that includes the Decision Tree neural network and the VaR model. The

artificial intelligence system "Decision Tree," and the VaR model were formed based on financial and macroeconomic indicators obtained at the World Trade Statistics Review.

3.1. Cognitive model

Results should be clear and concise. Show only the most significant or main findings of the research. Discussion must explore the significance of the results of the work. Adequate discussion or comparison of the current results to the previous similar published articles should be provided to show the positioning of the present research (if available).

To form a cognitive map and conduct a scenario analysis, it is necessary to select criteria for evaluating the effectiveness of the Russian financial market, which should act as the peaks of the map is created. The solution to this problem will require a search for different approaches to the very concept of financial market efficiency and indicators of its assessment. According to Paul Trejo (M.A. from California State University Dominguez Hills) semantics is the study of meaning and relationships between the world, and the human mind. (Trejo, 2021). There are several classes of relationships: ancestral relationships; relationship "whole-part"; synonymy and antonymy; logical relationships; functional relationships; attribute relationships; quantitative relationships; spatial relationships; temporal relationships; linguistic relations. Much knowledge can be represented in the form of hierarchical structures.

It seems appropriate to use an approach that involves the use of a semantic model of knowledge representation regarding the sustainability of the economy in order to forecast GDP based on the A.I. system and the VaR model. The developed cognitive model of economic sustainability is based on the approach proposed by Matokhina with a team of authors (Matokhina et al., 2022).

Graphviz is a package of utilities developed by AT&T labs for automatically visualizing graphs given as textual descriptions. The package is distributed with open-source files and works on all operating systems, including Windows, Linux/Unix, and Mac OS. The code script in the Dot language is shown in Figure 2.

```
digraph G {
Algorithm_AI_forecasting_GDP->Data_collection->Dataset_AI_systems->Architecture_AI_systems-
>Neuroprediction_GDP;
Dataset_AI_systems -> Data_collection;
Architecture_AI_systems->Dataset_AI_systems;
Error_level->Dataset_AI_of the system;
Neuroforecast_GDP->Level_error;
Error_level->AI_system_architecture}
```

Figure 2 Code script in the Dot language of the semantic model of knowledge representation

The package's main program is "dot", an automatic visualizer of directed graphs, which takes a text file with the graph structure as input, and generates a graph as a graphic, vector, or text file as output. The main program of the package is "dot", an automatic visualizer of directed graphs, which takes a text file with the graph structure as input, and generates a graph as a graphic, vector or text file as output. The archive with the program contains the file bin/gvedit.exe. As a result of execution, a dialog box appears with the ability to edit the dot file and view the resulting semantic network. DOT is a graph description language. A graph described in the DOT language is a text file with a.gv or .dot extension in a format that is understandable to a person and a processing program. Below is a visualization of forming a semantic model for representing knowledge about GDP neuroprotection using graphs (Figure 3).

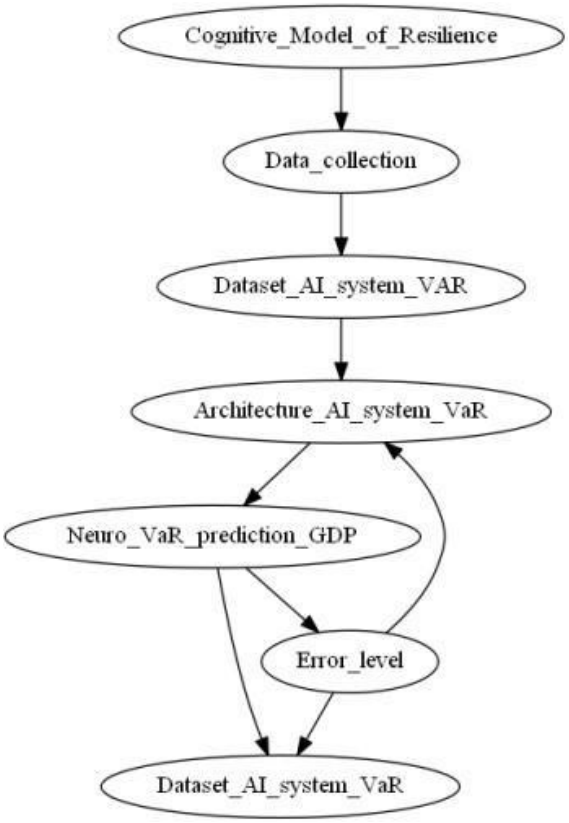

Figure 3 Cognitive model of Russian GDP

The cognitive model allows you to optimize the factors, and the architecture of the Decision Tree and compare the forecast values of GDP with the results of the forecast of the VaR model.

3.2. Development of the AI-system "Decision Tree"

The following factors were included in the Decision Tree neural network model: key rate; Growth of bank assets, %; Share of overdue loans, %; GDP, billion rubles; RTS Index; dollar exchange rate; Investments in fixed assets in GDP, %; Share of robots on the exchange, %; Capital outflow, billion dollars; Risk (VaR); banking system, billion rubles; Bank assets, trln. rub.; GDP forecast, billion rubles.

The AI-model Decision Tree was successfully formed on the Deductor platform. The neural network graph is shown below (Figure 4).

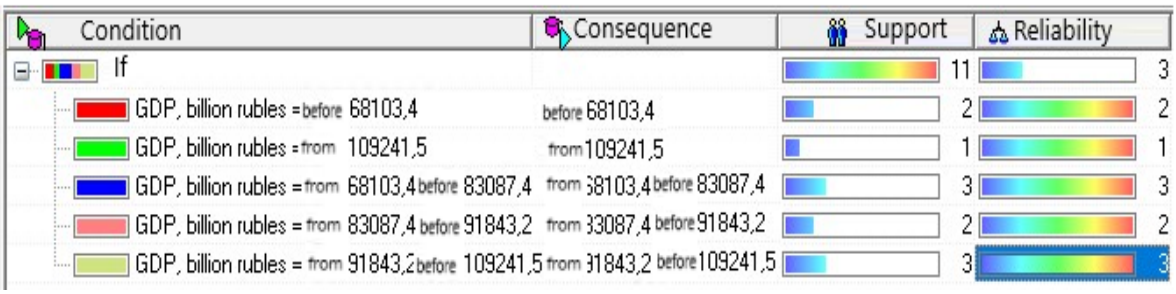

Figure 4 The structure of the Neural network "Decision Tree"

Using the "What-if" function, the forecast value of Russia's GDP for the next year was obtained. The forecast value of Russia's GDP will be from 109241.5 billion rubles by 2023. With an actual value of 131,015 billion rubles, the neural network predicts a decrease in GDP by $21,773.5 billion, or 16.6%.

3.3 VAR – Model

VAR models are often used to predict interrelated time series systems and analyze the dynamic impact of disturbances (shocks) on a system of selected indicators. The initial parameters of the various series of the value of Russian GDP for forecasting using the VaR model are presented below (Table 2).

Table 2 The initial parameters of the variation series of the value of Russian GDP

Year	GDP, billion rubles	Change, %	Year	GDP, billion rubles	Change, %	Year	GDP, billion rubles	Change, %
2021	131015	0,220842	2017	91843.2	0.07273	2013	72985.7	0.07169
2020	107315.3	-0.01763	2016	85616.1	0.03043	2012	68103.4	0.132904
2019	109241.5	0.051798	2015	83087.4	0.05134	2011	60114	0.351138
2018	103861.7	0.130859	2014	79030	0.08281	2010	44491.4	0

The calculation of financial risk by the VaR model was performed using the Data Analysis package in XL tables. Risk assessment is essential in predicting financial parameters. Risk assessment is essential in all areas of activity. Fauzi N. and colleagues concluded risk management is a constant effort that must be carried out throughout the life of a project.

Due to work involved, the administration of each risk management stage is important for construction and property development projects (Fauzi & Jahidi, 2022)

According to the VaR model, with a probability of 99%, the absolute value of the financial risk of a reduction in Russia's GDP may amount to 17,093.03 billion rubles in 2022 or 13.0 %, and the forecast value of GDP may amount to 113,921.97 trillion rubs. Using the VaR model, a table chart was formed with the frequency of deviation (percentage of GDP change) falling into one or another interval.

After substituting the parameters into the equation, the forecast value of Russian GDP for the next period (year) was obtained based on the VaR model: Pt+1=(-0.130466179+1)*131015 = 13921.97 billion rubles. An objective assessment of the quality of the forecast will be obtained at the end of the 2022 year. The calculations show that both models predict a decline in GDP, so the forecast value of GDP for the next 2022, calculated by the A.I. system, was 83.38% relative to the actual one, while that calculated by the VaR model was 86.95%.

Further research into the problem of sustainable development of the domestic economy can be continued in the following areas. Firstly, the use of cognitive models to assess the state and forecast the future sustainability of the domestic economy as a complex system. Secondly, monitoring and improving the capital structure to reduce the share of bad loans. Thirdly, it is important to study and take into account cognitive intellectual models, global challenges, and trends in world politics - how strong their impact on economic processes, world trade, and production.

The conducted research allows obtaining an increment of knowledge, allowing us to close the scientific gap regarding the influence of factors influencing the complex formation processes of export earnings in modern conditions. In this case, two approaches were used: an artificial intelligence system - a perceptron and a VaR model.

4. Conclusions

The study's novelty is in a proposed approach that involves the use of the cognitive modeling of the processes in the interaction of elements of the economy as a complex economic system using the artificial intelligence system "Decision Tree" and the VaR model

to obtain a forecast of domestic GDP. A forecast of the GDP value was formed both with the help of the neural network software on the Deductor platform and with the help of the VaR model with a given probability level. A hypothesis has been put forward and proved that using the A.I. system and the VaR model; it is possible to obtain a forecast of the volume of Russian GDP, the dynamics of which make it possible to assess the sustainability of the development of the country's economy. According to the VaR model, with a probability of 99%, the absolute value of the financial risk of a reduction in Russia's GDP may amount to 17,093.03 billion rubles in 2022, or 13.0 %, and the forecast value of GDP may amount to 113,921.97 trillion rubs. This study provides an increase in scientific knowledge, which allows closing the scientific gap in terms of identifying and assessing the influence of factors that determine the formation of domestic GDP and the financial risks of this process in modern conditions.

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