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National Security Indicators Forecasting through the Pandemic

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Abstract: We consider the actual task of developing a mathematical apparatus for quick assessment of the political, social, and economic situation by analyzing the most significant security indicators, taking into account the impact of the pandemic. Therefore we have developed a model concept for predicting national security indicators based on systemic dynamics. Mathematical models created under this concept will consider national security indicators used in some countries’ documents (White Papers) and a set of factors describing the situation with the spread of Covid-19. We selected these factors on the basis of a systematic analysis of the most commonly used pandemic spread models. The concept will allow us to evaluate national stability and security at present with acceptable accuracy and make a short-term forecast. The models constitute causal complexes based on analyzing the relationship between national security indicators and external factors in previous periods. They also will help us to assess the impact of the pandemic on these indicators. With such complexes, we will build a system of differential and residual equations, which will allow us to forecast and analyze the dynamics of national security indicators in the pandemic. Using the concept we have built, it is also possible to develop a scenario approach that examines the hypothetical consequences of different scenarios under variable conditions. We illustrate the solution by Germany’s example, but we can adapt the model for other countries.

Keywords: Safety, System Dynamics, Covid-19, Decision Making, International Stability, National Security.

1. INTRODUCTION

In developing pandemic conditions within large-scale systems (country, region), complex processes (epidemic, social, economic, etc.) arise. Due to the high complexity and complex nature of the problems under consideration, there will inevitably be a whole set of tasks related to developing modified models, methods, and algorithms. Researchers conditionally divide models for solving these problems into three types.

The first type consists of epidemiological models that assess the epidemic’s development within the population (number of cases, deaths, rate of epidemic spread, etc.) and make the prediction. The result of such modeling helps the public and health authorities to struggle against the epidemic. The Imperial College (UK) Report #9 (Fergusson, 2020), which significantly influenced the British governmental approach to combat Covid-19, is an example of such a study. Besides, this type of model also deals with priorities for the quick detection of the infected persons, tracking their contacts, and quarantine application (Kahn, 2020), (Ferretti, 2020). Such measures usually affect a small proportion of the human population.

The second type of model used when we fail to stop the epidemic in the initial stage. Such models are responsible for managing social and economic activity and population mobility to reduce the rate of the epidemic spread within the population. This type includes, in particular, the task of prioritizing restrictions (and subsequent openings) of social and commercial activity and the medium-term strategy of such rules (Chowdhury, 2020), (Benzell, 2020). It also deals with a more complicated problem: to minimize social and economic damage caused by sectoral or even full-scale restrictive measures to specific categories of the population or sectors of the economy.

We would call the third type of models strategical, as the need to address them arises when an epidemic escalates into a pandemic. These models are used to assess the influence of the pandemic on entire societies of different countries and the world community as a whole, taking into account the magnitude and duration of the external impacts and their consequences. The general definition of the relevant problem is proposed in (Budish 2020), where he considers optimizing the public welfare function under epidemiological restrictions.

In this paper, we consider the task to forecast and analyze the pandemic’s influence on the socio-economic situation,
usually described by national security indicators adopted in different countries. Models for this task in terms of the typology discussed above refer to the third type.

Assessment of economic security through various indicators has long been under consideration. For example, in (Levchenko, 2019) an analysis of the dynamic of integral indicator (developed by the authors) responsible for national economic security is proposed. The authors form an integral indicator from the direct and indirect economic security factors selected by the principal components method. Then the authors characterize chosen indicators in terms of opportunities and risks.

The socio-economic security assessment method was developed using a matrix model for risk evaluation (Shvaiba, 2018). The article considers the possibilities of a particular threat origin, level of appropriate impact on national security, duration, and speed of the consequences. In another article (Shvaiba, 2020), the same author proposes to use trend models to analyze socio-economic security. The mathematical model for studying the system dynamics of the national security indicators is investigated in the works (Yandybaeva, 2019, 2020). However, these works do not take into account the pandemic factor. In this regard, we consider the following approach to be relevant.

Separately, we note that the IFAC works considered tasks that are significant for national security: education (Gurban, 2016), training and learning (Musatova, 2016), (Zakharova, 2019), production (Dolgui, 2018), (Dranko, 2020), (Morozov, 2015), transport (Kortcheva, 2018), trade (Kitavea, 2016) and Energy Saving (Burkov, 2021). However, these studies do not take into account the dynamics of national security indicators in the complex under the influence of the pandemic. Therefore, we believe it would be appropriate to pay more attention to this area, especially at the Conference on Technology, Culture and International Stability.

2. THE PROBLEM, CONCEPT AND EXAMPLE

Definition of the problem. We need to develop the concept of mathematical models for the assessment and prediction of national security indicators’ trends. This concept should take into account the impact of the pandemic.

Concept of the problem solution. We developed the idea of building the required mathematical models, which consist of the following steps:

- firstly, we determine the set of system variables based on the current national security strategy, present threats, and challenges. Then with the help of experts, we choose a set of external factors which influence system variables. This set should include factors responsible for the pandemic;
- secondly, we make both variables and factors measurable, find sources of statistical data and expert assessments. Then we should decide how to put them into equations of system dynamics. For instance, we can normalize and make them nondimensional;
- thirdly, we determine cause-effect relations between system variables and external factors over the fixed period to develop appropriate cause-effect schemes. We need to find a correlation between the two sequences of data, accompanied by expert conclusions with the phenomena’ physical interpretation. So the results of mathematical calculations must be in agreement with relevant model verification;
- fourthly, we draw cause-effect graphs and matrixes based on the developed cause-effect schemes and then build residual or differential equations in compliance with system dynamics principles.

Further operations related to the usage of developed mathematical apparatus include methods of the equations’ solution, verification of the model and consequent correction, numerical experiments for the following forecasting of observable trends, results of control actions, determination of numerical parameters of external factors’ impact, etc.

An example of the problem solution. In various countries of the world, the regulatory framework of national security is the so-called «White Papers» (Summary of the USA 2018 National Defense Strategy, 2018), (National Security Strategy and Strategic Defense and Security Review 2015 A Secure and Prosperous United Kingdom, 2015), (Strategic review of defense and national security, 2017), (Das sind die groessten Risiken fuer Deutschlands Sicherheit, 2016), (On the National Security Strategy of the Russia Federation, 2021). They contain the main strategic development priorities in the medium and long term. We analyzed similar documents for several countries and identified the following system variables for the example under consideration:

\[ X_1(t), \ldots, X_{50}(t): \]

- unemployment rate (%); 
- decile factor (%); 
- inflation rate (%); 
- level of national external debt (% of GDP); 
- level of national internal debt (% of GDP); 
- expenditures on national heath system (% of GDP); 
- expenditures on culture (% of GDP); 
- expenditures on education and science (% of GDP); 
- size of the armed forces (pers.); 
- number of engineering personnel (pers.); 
- citizens’ satisfaction with the degree of protection of their constitutional rights and freedoms, personal and property interests, including criminal encroachments (expert assessment); 
- share of modern weapons, military and special equipment in national armed forces; 
- life expectancy (years); 
- GDP per capita (USD); 
- share of the country’s territory that does not meet environmental regulations (%); 
- number of terrorist attacks; 
- number of cyberattacks on the Internet; 
- number of military conflicts in neighbor states; 
- number of uncontrolled immigrants; 
- number of acts of nationalism; 
- national defense expenditures (% of GDP); 
- number of violations of fuel and energy supplies; 
- the nature of climate change in the form of fluctuations in the average annual temperature; 
- number of deaths due to disease/epidemics; 
- number of criminal cases initiated on the fact of plagiarism; 
- USA influence on the world matters (expert assessment); 
- number of armed conflicts.
within the country to protect territorial integrity; 
\(X_{3d}(t)\) – number of malnourished people in the country; 
\(X_{3n}(t)\) – size of national nuclear forces; 
\(X_{3d}(t)\) – expenditures on international cooperation; 
\(X_{3b}(t)\) – number of internal conflicts over the partition of territories; 
\(X_{3t}(t)\) – number of proxy wars; 
\(X_{3f}(t)\) – number of ethnic conflicts; 
\(X_{3i}(t)\) – illegal financial flows; 
\(X_{3f}(t)\) – illegal trade in arms, people, drug trafficking; 
\(X_{3d}(t)\) – number of natural disasters; 
\(X_{3b}(t)\) – number of conflicts of the country’s most influential countries for regional leadership; 
\(X_{3b}(t)\) – number of conflicts of non-regional forces for access to oil and gas resources; 
\(X_{3d}(t)\) – number of real and potential hotbeds of armed conflicts in the Gulf region and related regions; 
\(X_{3d}(t)\) – number of international organized crime groups; 
\(X_{3f}(t)\) – number of new energy companies on the global market; 
\(X_{3d}(t)\) – national expenditures on elimination of damage due to Caspian oil production; 
\(X_{3d}(t)\) – size of water resources of the country; 
\(X_{3d}(t)\) – number of international military conflicts; 
\(X_{3b}(t)\) – number of attacks and pressure acts on the allies; 
\(X_{3d}(t)\) – GDP losses due to 2008 financial crisis; 
\(X_{3d}(t)\) – expenditures on elimination of the effects of radioactive/chemical pollution; 
\(X_{3d}(t)\) – number of social unrest acts in the country; 
\(X_{3d}(t)\) – expenditures due to elimination of the weather threats; 
\(X_{3d}(t)\) – number of acts of force display in Europe.

Simulated variables are quantitative, and we use their normalized values in calculations: 
\(X_i^*(t) = \frac{X_i(t)}{X_i^m}, \quad i = 1, \ldots, 50\), where 
\(X_i(t)\) – simulated variable, 
\(X_i^m\) – factor of normalization (thresholds of variables or their values at a particular moment).

Besides systemic variables, the model considers the influence of external factors 
\(VF_i(t)\), \(i = 1, \ldots, w\). Based on correlation analysis and analysis of interconnected time data series, we identified external factors which influence simulated variables 
\(VF_i(t)\), \(i = 1, \ldots, 68\), 
\(VF_{11}(t)\) – Gross Domestic Product (USD), later after the unit of measurement for every 
\(VF_i(t)\) we use the identifier, for instance for GDP-
\(VF_{11}(t)\) – inflation rate (%), 
\(VF_{21}(t)\) – economically active population (pers.), 
\(VF_{31}(t)\) – taxes (USD), 
\(VF_{41}(t)\) – Labour supply (pers.), 
\(VF_{51}(t)\) – Population (pers.) etc. External factors can be in qualitative or quantitative form. The former is introduced into the model using an expert assessment (on a scale between 0 and 100), the latter uses normalization similar to the case of systemic variables.

Then we draw the graph 
\(H_{SSI}\) with cause-effect relations between systemic variables and external factors. Based on it, we build the equations of systemic dynamics, the solutions of which allow us to forecast values of systemic variables over the fixed periods. These equations determine functional relations 
\(f_1(F_1), \ldots, f_w(F_w)\), which characterize the causal relationship between variables. Let us build the equation for 
\(X_{3d}(t)\) – the number of deaths due to disease/epidemics. The graph of causal relationships between variables 
\(X_{3d}(t), X_{3t}(t), X_{3f}(t)\) (Fig. 1).

![Fig. 1. Graph of causal relationships between variables](image)

We use the 24th row of the causal graph 
\(H_{SSI}\) matrix to build the appropriate differential equation, Table 1:

\[
\frac{dX_{3d}(t)}{dt} = -\frac{1}{X_{3d}(t)}(A(t) + B(t) + C(t) + D(t) + E(t) + F(t) + G(t) + H(t) + I(t) + J(t) + K(t) + L(t) + M(t) + N(t) + O(t) + P(t) + Q(t) + R(t) + S(t) + T(t) + U(t) + V(t) + W(t) + X(t) + Y(t) + Z(t))
\]

where 
\(Tz(t)\) – total number of Covid-19 cases, 
\(Re(t)\) – number of survivors and 
\(Du(t)\) – number of deaths from covid-19 at moment \(t\), 
\(M(t)\) – Migration (pers.), 
\(Ik(t)\) – share of busy ICU for covid-19 hospitalization.

\[
\Delta I = I(t) - I(t - 7)
\]

\[
\Delta Him = Him(t) - Him(t - 7)
\]

\[
\frac{dX_{3d}(t)}{dt} = \frac{N_{sca}(t)}{N_{ica}}(A(t) + B(t) + C(t) + D(t) + E(t) + F(t) + G(t) + H(t) + I(t) + J(t) + K(t) + L(t) + M(t) + N(t) + O(t) + P(t) + Q(t) + R(t) + S(t) + T(t) + U(t) + V(t) + W(t) + X(t) + Y(t) + Z(t))
\]

where 
\(P(t)\) – population, 
\(Va(t)\) – number of vaccinated by the time \(t\), 
\(Zd(t)\) – national expenditures for the treatment of Covid-19 patients (USD), 
\(SB(t)\) – share of the population with income below the subsistence level (pers.), 
\(Him(t)\) – increase rate of the herd immunity. We form the rest of the system variables, graphs, and differential equations similarly.

The mathematical model developed constitutes a system of non-linear, multi-tempo, heterogeneous, non-stationary differential equations.
When we add to the model binary structural coefficients \( k_i \), \( i = 1, \ldots, 50 \), given in Table 2, we obtain particular decisions for such countries as Russia, Germany, the USA, India, China, Great Britain, France, etc.

### Table 2. Structural coefficients for different countries

| \( X_i \) | Structural coefficients \( k_i \) |
|---|---|
| | United Kingdom | Russia by strategy-2021 | France | Germany |
| \( X_1 \) | 0 | 0 | 0 | 0 |
| \( X_2 \) | 0 | 1 | 0 | 0 |
| \( X_3 \) | 0 | 1 | 0 | 0 |
| \( X_4 \) | 0 | 1 | 0 | 0 |
| \( X_5 \) | 0 | 1 | 0 | 0 |
| \( X_6 \) | 0 | 1 | 0 | 0 |
| \( X_7 \) | 0 | 1 | 0 | 0 |
| \( X_8 \) | 0 | 1 | 0 | 0 |
| \( X_9 \) | 0 | 1 | 0 | 0 |
| \( X_{10} \) | 1 | 1 | 1 | 1 |
| \( X_{11} \) | 1 | 1 | 1 | 1 |
| \( X_{12} \) | 0 | 0 | 0 | 1 |
| \( X_{13} \) | 0 | 0 | 0 | 1 |
| \( X_{14} \) | 0 | 0 | 0 | 1 |
| \( X_{15} \) | 0 | 0 | 0 | 1 |
| \( X_{16} \) | 0 | 0 | 0 | 1 |
| \( X_{17} \) | 0 | 0 | 0 | 1 |

Functional dependencies in the developed model allow us to consider the complex causal relationships between simulated variables. A particular form we determined by correlation-regression analysis. We approximate them by polynomials of 3-4 degrees.

For verification of the developed model, we use the values of national security indicators in retrospect.

The developed model includes the following functional dependencies: \( f_1(X_3,t) \) – dependence of unemployment rate on inflation; \( f_2(X_{27},t) \) – dependence of unemployment rate on the number of conflicts within the country; \( f_3(X_{28},t) \) – dependence of unemployment rate on the number of malnourished people; \( f_4(X_{31},t) \) – dependence of unemployment rate on the number of internal conflicts due to the division of territories; \( f_5(X_{32},t) \) – dependence of unemployment rate on the number of proxy wars, etc. Let us consider the procedure of building a forecast model for Germany from the developed model. To do this, we select from the list of simulated variables \( X_i(t) \) – \( X_{50}(t) \) the following variables from German White Papers:

- \( X_{12}(t) \) – share of modern weapons, military and special equipment in the Russian Armed Forces and other military troops;
- \( X_{16}(t) \) – number of terrorist attacks;
- \( X_{27}(t) \) – number of cyberattacks on the Internet;
- \( X_{28}(t) \) – number of military conflicts in neighbor states;
- \( X_{31}(t) \) – number of uncontrolled immigrants;
- \( X_{32}(t) \) – number of acts of nationalism;
- \( X_{33}(t) \) – national defense expenditures (% of GDP);
- \( X_{35}(t) \) – number of violations of fuel and energy supplies;
- \( X_{36}(t) \) – nature of climate change in the form of average annual temperature fluctuations;
- \( X_{37}(t) \) – number of deaths due to disease and epidemics.

We presented an graph of causal relationships between simulated variables \( X_{12}(t) \), \( X_{16}(t) \) – \( X_{37}(t) \) for the case of Germany (Fig. 2).

![Fig. 2. Graph of causal relationships between variables](image-url)
3. NUMERICAL EXPERIMENT

In our calculations for Germany, we used indicators from the Robert Koch Institute reports (Coronavirus Disease 2019 (COVID-19) Daily Situation Report of the Robert Koch Institute, 2021). We calculate the forecast of the variable $X_{23}(t)$ for three covid-19 spread scenarios:

- in consideration of vaccination and coronavirus restrictions, i.e., without the impact of migration $M(t)$;
- in consideration of vaccination and removal of coronavirus restrictions;
- excluding vaccination and coronavirus restrictions (self-isolation).

We used the figures for the date (18.01.2021) when statistics on the number of vaccinated with the second dose first appeared as initial forecasting conditions. Their values normalize the other external factors in equation (1) due to this date. The number of deaths on 18.01.21 – 362, the total number of fatalities – 46633. Number of vaccinated with second dose – 6581\(^1\), number of survivors – 19700, number of cases – 9253\(^2\). Time range $t$ = 7 days.

We made a forecast up to 26.04.21, i.e., seven weeks in advance. $X_{23}(t)$ forecast graphs due to all three covid-19 spread scenarios (Fig. 3).

![Fig. 3. Forecast graphs for $X_{23}(t)$. Initial values of functional dependencies: $f_{131}(X_{15},t)=0.1$; $f_{132}(X_{26},t)=0.08$; $f_{133}(X_{16},t)=1.0$; $f_{134}(X_{18},t)=0.9$; $f_{136}(X_{22},t)=0.15$; $f_{136}(X_{6},t)=0.97$.](image)

We interpret the simulation results in the following way. If vaccination is carried out and the restrictions are observed (first scenario), then the number of deaths is predicted by almost 40% in seven weeks (the value of $X_{23}(t)$ falls from 1 to 0.63). If self-isolation is abolished and external borders are opened (the second scenario), the number of deaths increases by 2% (the value of $X_{23}(t)$ increases from 1 to 1.02). If there is no vaccination and restrictions are not respected (the third scenario), an increase in the number of deaths is predicted by 70%.

To carry out computational experiments, we can change the mutual influence of the model variables. For this, the functional dependencies range from 0 to 1. For example, when increasing $f_{134}(X_{18},t)$, $f_{135}(X_{22},t)$, $f_{136}(X_{6},t)$ to 1, an increase in the values of $X_{23}(t)$ will be observed.

4. CONCLUSION

The article proposes the concept of building models of systemic dynamics to study the impact of the Covid-19 pandemic on the socio-economic situation described by a set of national security indicators.

Pandemic spread rates are updated quite frequently compared to many national security indicators. So we should talk about the pandemic’s impact on more minor parameters used in the construction of national security indicators.

Besides, different countries often calculate national security indicators differently. The proposed concept, therefore, includes the possibility of harmonizing the data used in the study.

The spread of pandemics often has an immediate impact on the socio-economic situation. With the developed concept, we can quickly adjust the forecasting in agreement with the changing causal relationships.

The concept proposed in this article provides a mathematical apparatus for the future short-term forecasting and modeling of the pandemic’s impact on national security. Such systems can also be used in the work of expert groups, including department, governmental and intergovernmental meetings, as well as in the educational and scientific institutes, situational centers related to the analysis of national security in current conditions.

In future studies, we plan to research the impact of herd immunity on national security. We plan to model the dynamics of changes in national security indicators depending on the rate of vaccination. The results of these simulations will be used by governments in planning their response to the pandemic. Such measures will help to avoid colossal social and economic losses in many countries.

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