Building a tool model for the study of the ecosystem “Coronavirus – vector – human - environment”

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Abstract. Massive contagious diseases (epidemics, pandemics) that quickly spread over large areas and can migrate from one country to another have been studied by such scientists as E. Johnner (1796), P. Louis (1879), I. Mechnikov (1883) and others. I. Mechnikov the immunity to infectious diseases associated with innate and acquired immunity. In turn, both innate and acquired immunity can be natural, if immunity is acquired as a result of a disease, or artificially acquired as a result of preventive vaccinations or the administration of artificial sera. In early 2020, the World Health Organization announced a pandemic of a new coronavirus infection due to its rapid spread in 170 countries. A person can be infected with coronavirus through different biological media, but first of all it is a respiratory disease. Coronavirus CoVID19 is a further mutation of the virus strain – SARS-pneumonia, also known as SARS-CoV-2. COVID19 contains 16 unstructured and structured proteins and has a large genome. Two models of solving the problem with COVID19, adopted in different countries, are considered: the first is complete self-isolation; the second is partial isolation of people with compromised immune systems. A graphic chart of the state and transition model of the Virus Source, Viral Vector, Recipient and Environment (CoV-E-V-P) system was constructed and analyzed. The change in human health state under the influence of the element parameters of the system is researched. The functional structure of the information model for monitoring and decision management system CoV-E-V-P is designed.

1. Introduction
On April 2, 2020, President of the Russian Federation V. Putin issued a decree “On measures to ensure the sanitary and epidemiological well-being of the population in the Russian Federation in connection with the spread of a new coronavirus infection (CoVID-19).” The construction of a model for the development and assessment of the human life and activities in the context of the spread of CoVID-19 is an urgent problem. To date, models for predicting coronavirus infection are known, but they did not consider environmental parameters, the influence of protective mechanisms on the spread of infection.

Mechnikov's theory was based on the fact that immune cells, capturing pathogens, destroy them. From birth, some people are immune to a particular disease due to the fact that their blood contains protective substances also known as innate immunity, which is inherited from parents. After having an
infectious disease, a person develops acquired immunity associated with the development of protective substances in the body, sometimes acting throughout life.

Currently, two models to fight against coronavirus infection CoVID19 are applied in world practice:

- An isolation model aimed at reducing the number of contacts and the risk of a sharp increase in the number of infected people (China, USA, Russia and others), with the search for a vaccine to acquire immunity artificially (vaccination).
- The model of acquired natural immunity in the course of normal life by persons with a string (innate) immune system with a partial isolation of the elderly and humans with compromised immune system and those who are weakened by concomitant or chronic illnesses (Sweden, Netherlands, Belarus).

A lot of viruses which do not manifest themselves live in the human body. As a rule, a weakened body is susceptible to this, while viruses are very resistant to a wide temperature range and are pronounced parasites that feed only on prepared organic matter.

2. Materials and research methods

2.1. Related work

Despite the fact that the problem of CoVID19 is not even six months old, the total amount of research on it totals several tens of thousands of papers. CoVID19 works can be structured into several categories:

- The results of applying the general theory of systems, system analysis, and applied research are presented in [1–5].
- The study of predictive models of CoVID19 development [6–9].
- Development of antibody tests for CoVID19 [10].
- Structural Features of CoVID19 and vaccine development [11–12].

2.2. Methods of research

In developing the models, the general theory of systems, statistical analysis, differential-integral calculus, and theory of sets and graphs were used.

3. The results of the study and their discussion

3.1. Construction of a graphic chart of the state and transition model of the system «CoV-E-V-P»

The proposed models are represented by 4 elements: (E) - a natural environment containing abiotic factors (temperature, humidity, water, light, nutrients, atmospheric gases, edaphic factors) and biotic factors (interaction factors between individuals of the same species and interaction factors between individuals of various species); (CoV) - factors, sources of CoVID19 viruses, as a rule, on infected anthropogenic objects and (V) – viral vectors (infected) coming into contact with all elements of the presented system and (P) - the recipient, on which all elements of the system are interconnected. From fatal consequences and related pathologies, the recipient is protected by two fields: Φ1 - the power of innate immunity and Φ2 - the power of acquired immunity (vaccination). In the presented system, an important process is the adaptation of living organisms to the environment, which always develops under the influence of three factors - variability, heredity and natural (artificial under the influence of man) selection. As a rule, organisms are adapted to constantly acting periodic factors, but in the case of human intervention in biological processes, non-periodic factors begin to act, which can even cause the death of a living organism, but prolonged exposure to periodic factors can cause adaptation, in particular bacteria and viruses, to antibiotics and others drugs that lead to mutations in their body. A coronavirus infection requires a virus source (CoV), a viral vector (V), and a recipient (P). The state of the
environment \((E)\) also affects the viral activity and the spread of a virus. The state and transition graph of the CoV-E-V-P system is shown in figure 1.

![Figure 1. A graphic chart of the state and transition model of the system “CoV-E-V-P”:](image)

3.1.1. Determining the status of the system

When identifying the CoV-E-V-P system a definition of the security status of the system is introduces. The CoV-E-V-P system is considered to be a system that maps the family of sets \(H(t)\) onto the set \(Y\), i.e. \(YRH(t)\). The task of synthesizing a system can be to determine the set of input time signals. \(R\) is decompose into binary sets \(R^1\) and \(R^2\):

\[
Y = R^1[H(t), C], CR^2H(t) \quad (1)
\]

Elements \(C\) describe the state (memory) of the system. The decomposition of the system into two sets shows that \(Y\) does not depend on the prehistory of the state of the system i.e. will be formalized by the semi-Markov process. System inputs and outputs that are available for monitoring and measuring CoVID19 infection are selected as inputs and outputs of the system. This article studies the critical states of the CoV-E-V-P system: safe and dangerous (infected) while taking into account the mutual influence of system elements.

3.1.2. Building a deterministic model for assessing the state of a system

The human safety status of \(C_P\) depends on its intrinsic properties \(S_P\) - health, immunity, environmental parameters, the presence and virulence of coronaviruses

\[
C_P = F_1[\{S_P\}, C_P^{CoV}, C_P^E, C_P^V] \quad (2)
\]

The state of the \(C_V\) carrier depends on the intrinsic properties of the carrier \(S_V\) - the spread of coronaviruses, volume

\[
C_V = F_2[\{S_V\}, C_V^{CoV}, C_V^E] \quad (3)
\]

The environmental state of \(C_E\) depends on the intrinsic properties of the environment \(S_E\) - dispersal of coronaviruses in air, temperature, humidity, air velocity

\[
C_E = F_3[\{S_E\}] \quad (4)
\]

The state of CoVID19 depends on the intrinsic properties of coronavirus \(S_{CoV}\) and the influence of environmental parameters on the spread of infection

\[
C_{CoV} = F_4[\{S_{CoV}\}, C_{CoV}^E] \quad (5)
\]

Thus, the model for assessing the state of the CoV-E-V-P system is described by the function:

\[
C_{CoV\cdot E\cdot V\cdot P} = \Psi[C_P, C_V, C_E, C_{CoV}] \quad (6)
\]
3.2. System state security research

3.2.1. Study of the recipient’s immune system state. A change in person’s (P) health (H) is described by connection:

\[
C_v = \Delta H_{v}(S_v) + \Delta H_{v}(CoV) + \Delta H_{v}(E) + \Delta H_{v}(V),
\]

where \(\Delta H_{p}(S_p)\) – a change in health indicator from person’s individual characteristics, \(\Delta H_{p}(CoV)\) – a change in human health from coronavirus, \(\Delta H_{p}(E)\) – a change in the indicator of human health from the influence of environmental parameters, \(\Delta H_{p}(V)\) – a change in the indicator of human health from the influence of the viral vector.

The individual properties of safety and human health can be understood as immunity (Im), absence of disease (Dis), use of respiratory protection (Br) and hygiene standards (Hy)

\[
\Delta H_{p}(S_p) = \frac{\partial H_{p}}{\partial S_{Im}} \Delta S_{Im}^{Dis} + \frac{\partial H_{p}}{\partial S_{Br}} \Delta S_{Br}^{Hy} + \frac{\partial H_{p}}{\partial S_{Hy}} \Delta S_{Hy}^{Hy}.
\]

The activity of the coronavirus is strongly dependent on environmental parameters, for instance, temperature (Tm), humidity (Hm), wind speed (Sp),

\[
\Delta H_{p}(E) = \frac{\partial H_{p}}{\partial E_{Tm}} \Delta E_{Tm} + \frac{\partial H_{p}}{\partial E_{Hm}} \Delta E_{Hm} + \frac{\partial H_{p}}{\partial E_{Sp}} \Delta E_{Sp}.
\]

The presence of the coronavirus family is the main dangerous source of infection for humans.

\[
\Delta H_{p}(CoV) = \frac{\partial H_{p}}{\partial CoV_{19}} \Delta CoV_{19} + \frac{\partial H_{p}}{\partial CoV_{SARS}} \Delta CoV_{SARS} + \frac{\partial H_{p}}{\partial CoV_{MERS}} \Delta CoV_{MERS}.
\]

The viral vector is an important element in infection, for example, a person without respiratory protection \{1\}, high mobility with the intersection of geographical zones and countries \{2\}, age \{3\} and contacts at the workplace (with doctors, teachers and others)\{4\}

\[
\Delta H_{p}(V) = \frac{\partial H_{p}}{\partial V_{1}} \Delta V_{1} + \frac{\partial H_{p}}{\partial V_{2}} \Delta V_{2} + \frac{\partial H_{p}}{\partial V_{3}} \Delta V_{3} + \frac{\partial H_{p}}{\partial V_{4}} \Delta V_{4}.
\]

3.2.2. The study of the viral vector state. The viral vector is the main link in the spread of the coronavirus. An infected person can act as a carrier of infection, even without signs of illness, as well as the premises, airplanes, trains, buses used by the carrier. Change in vector security state (V) is described by the connection:

\[
C_V = \Delta H_{v}(S_v) + \Delta H_{v}(CoV) + \Delta H_{v}(E),
\]

where \(\Delta H_{v}(S_v)\) – a change in the safety index from own properties of the viral vector, if a person is considered to be a carrier, then a change in properties is described by a similar equation:

\[
\Delta H_{p}(S) = \frac{\partial H_{v}}{\partial S_{Im}} \Delta S_{Im}^{Dis} + \frac{\partial H_{v}}{\partial S_{Br}} \Delta S_{Br}^{Hy} + \frac{\partial H_{v}}{\partial S_{Hy}} \Delta S_{Hy}^{Hy}.
\]

\(\Delta H_{v}(CoV)\) – change in the safety indicator of the viral vector from the influence of coronavirus, \(\Delta H_{v}(E)\) – change in the vector safety index from the influence of environmental parameters.

The differential equations for changing the vector safety index are also described in a similar way.

\[
\Delta H_{v}(CoV) = \frac{\partial H_{v}}{\partial CoV_{19}} \Delta CoV_{19} + \frac{\partial H_{v}}{\partial CoV_{SARS}} \Delta CoV_{SARS} + \frac{\partial H_{v}}{\partial CoV_{MERS}} \Delta CoV_{MERS}.
\]

\[
\Delta H_{v}(E) = \frac{\partial H_{v}}{\partial E_{Tm}} \Delta E_{Tm} + \frac{\partial H_{v}}{\partial E_{Hm}} \Delta E_{Hm} + \frac{\partial H_{v}}{\partial E_{Sp}} \Delta E_{Sp}.
\]

3.2.3. Study of the coronavirus family virulence. The change in the state of coronavirus virulence is described by equation:
A change in the virulence state \((\text{Vir})\) of coronaviruses depends on the intrinsic properties of the coronavirus (14), as well as environmental parameters (15). Figure 2 shows a family of coronaviruses that are dangerous to humans (highlighted in red). The first four coronaviruses: CoV229E, CoVNL63, CoVHKU1 and CoVOC43 are weakly virulent and cause acute respiratory viral infection (SARS). The SARS-CoV and MERS-CoV viruses appeared in the early 2000s and belong to SARS viruses. The 2019nCoV virus is a further mutation of the SARS-CoV virus, also known as SARS-CoV-2, the main source of human damage in late 2019 and early 2020.

\[
\Delta H_{\text{CoV}}(S_{\text{CoV}}) = \frac{\partial H_{\text{CoV}}}{\partial S_{\text{Vir}}} \Delta S_{\text{Vir}}.
\]  

\[
\Delta H_{\text{CoV}}(E) = \frac{\partial H_{\text{CoV}}}{\partial E_{\text{Tm}}} \Delta E_{\text{Tm}} + \frac{\partial H_{\text{CoV}}}{\partial E_{\text{Hm}}} \Delta E_{\text{Hm}} + \frac{\partial H_{\text{CoV}}}{\partial E_{\text{Sp}}} \Delta E_{\text{Sp}}.
\]

3.3. The study of logistic population models CoVID19

To study the dynamics of CoVID19 development, general approaches can be used to analyze the vital functions of populations. An important factor is infection transmission rate \(R_0\):

\[
R_0 = \frac{N_t}{N_0},
\]

where \(N_t\) — CoVID19 population at time \(t\), \(N_0\) — current CoVID19 population.

The calculation of the coronavirus infection transmission rate \(R_0\) from a viral vector to a person was calculated using the example of Wuhan City, China [1] and was 3.58.

The population growth rate is inversely proportional to the duration of the cycle: \(r = \ln R_0 / T\).

The Reimers equation also allows for the capacity of the biological medium.

\[
N_t = \frac{K}{1 + e^{a-r_{\text{max}}}}
\]

In (Ke Wu et al., Generalized logistic growth modeling of the COVID-19, 2020), the Richards model parameter \(p\), \(K\) and \(\alpha\) were refined in the study of COVID-19 diseases in 29 provinces of China

\[
\frac{dC(t)}{dt} = rC(t)^p \left(1 - \left(\frac{C(t)}{K}\right)^\alpha\right).
\]

The dynamics curve of CoVID19 has 3 phases: phase 1 — increase in the population above potential capacity, phase 2 — decrease in the population to potential capacity, phase 3 — extinction of the population. The duration of the phases depends on the measures taken and, in the case of isolation, may be limited to several incubation periods of CoVID19.

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**Figure 2.** Coronavirus family.
An example of the dynamics of the increase in cases of coronavirus infection by the example of Russia in March-April 2020 is shown in figure 3.

3.4. Development of an information model for decision support in managing the CoV-E-V-P system

As mentioned above, there are two directions for making decisions on the situation with CoVID19. The first is to increase the safety indicator $\Theta^*$ by stopping enterprises and transferring personnel to remote work, and the second, the opposite, aimed at developing immunity under a virus attack on the population (for example, the Netherlands, Republic of Belarus, Sweden and a few other countries), which will entail the cost of treatment and the death of the population of these countries with weakened immune system. Thus, a generalized safety indicator is described by a system of equations:

$$
\Theta^* = \begin{cases} 
\Theta_1 = f_1(\text{Exp}) \\
\text{Dam} = f_2(\text{Exp}') 
\end{cases}
$$

where $\Theta_1$ – safety indicator characterizing the prevented damage from possible diseases and deaths; Dam – Coronavirus infection damage indicator; Exp – expenses.

For timely and effective decision-making on monitoring the situation with the coronavirus, an information decision-making model has been developed (figure 4) [13].

**Figure 3.** New confirmed cases of the disease in Russia from March 20 to April 20, 2020.

**Figure 4.** Functional and algorithmic structure of the information model for decision support in the management of the CoV-E-V-P system.
The information on ongoing monitoring $I(t)$ of viral activity and measures taken $O(t)$ using the methods for managing $U(t)$ the emergency with CoVID19 is taken into account. A design of a device for conducting rapid test on CoV has been developed. It is proposed to use nitrocellulose membranes based on solid-phase immunochromatographic analysis as indicators of antibodies to CoV.

4. Conclusions
Based on the approaches of system analysis, a deterministic model for studying the state of the system “Coronavirus-vector-human-environment” (CoV-E-V-P) when changing system parameters has been developed. Two decision-making models for the CoVID19 pandemic, adopted in different countries, were identified.

A technique has been developed for assessing the change in the state of CoV-E-V-P systems based on structural and functional analysis taking into account disease monitoring, which makes it possible to build predictive models for the development of coronavirus infection.

A project has been developed to design a computer information system for determining CoV using industrial test membranes to support decision-making in predicting diseases.

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