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Compartment model of informational and suggestive influence

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Abstract

Mathematical modeling use in information operations research makes it possible to qualitatively and quantitatively predict information attack object behavior, as well as to determine and implement effective countermeasures. According to the chosen methodology, a compartmental approach based informational and suggestive influence mathematical model was proposed. The model makes it possible to assess information, communication network participant state and estimate suggestive influence in the moment.

Keywords: Mathematical model, suggestion, information operations, compartment, kinetics

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Introduction

Informatization process characterizing the current stage of societal development, both generates positive phenomena and affects national environment security. It is possible to use the information space as one of the platforms of hybrid warfare through special information operations using propaganda, disinformation, and rumor spreading. This presents researchers with the priority task of developing comprehensive information environment security measures. Primary modeling and research of processes and methods of conducting information operations make it possible to effectively organize countermeasures.

Problem relevance and research analysis

Particularly acute are the issues of information warfare and information dissemination study in hybrid war conditions.

The use of mathematical models for the study of information operations and their countermeasures was considered by both foreign and Ukrainian researchers (for example, [1] and [2]). One of the largest domestic studies on information operations modeling and analysis [3] contains an overview of both implemented and original models of information confrontations, means of social procedures mathematical modeling and analysis.

Despite the sufficient popularity of the research topic, the use of compartmental models in the field of information research is a new approach, as compartmental approach has wider spread in immunology, medicine and pharmacokinetics.

Compartment models

Let's represent some system as a set of subsystems or components with directed connections. Each component of the system has a numerical characteristic describing this component's content. To get a general idea of the functioning of such a system, it will be enough for us to know the dynamics of this characteristic for each component or subsystem over time.

A compartmental model is a representation of the described system as one or more interconnected sections with the arrows showing internal numerical characteristics change directions for the sections. The scheme of the model is given in the Figure 1.

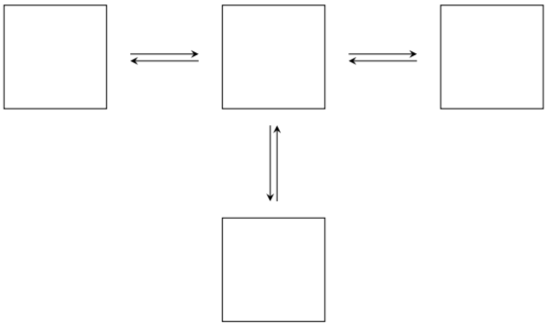

Figure 1: General scheme of the compartment model

A model of this type can represent a physical object (for example, a reservoir - in this case, the components will be tanks, and their numerical characteristic – their water level at a moment in time), or an abstraction of a certain process (rumor or news spread in social networks, as discussed in [4].

1.1. Single-compartment model

Let there be only one compartment changing its internal numerical characteristic during the process where there is «input» and «output» of a certain value, characteristic or object that affects the state of the compartment.

We will call the input process injection, output – excretion, and the current numerical characteristic of the compartment - concentration x_1 at time t. With:

$$x_1(t) \geq 0.$$

$f_1(t)$ – is the injection rate. A single-compartment model will look like as given on Figure 2:

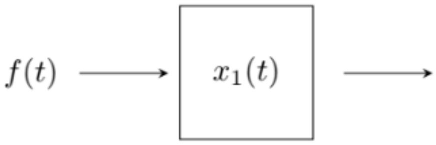

Figure 2: Single-compartment model

Let v_1 be the effective volume of the compartment. The essence of this term will be clear from the mathematical description of the model. In the presence of an excretion mechanism that reduces the numerical characteristic of the compartment at the moment of time t to $1 - k_1 \vartriangle$ (where k_1 is a known constant) for the time interval $[t, t + \vartriangle]$, for small $\vartriangle$ we get:

$$v_1 x_1(t + \vartriangle) = (1 - k_1 \vartriangle) v_1 x_1(t) + f(t) \vartriangle. \quad (1)$$

Let $x_1(t)$ be a smooth function of time, then

$$x_1(t + \vartriangle) = x_1(t) + \vartriangle x_1'(t) + \cdots$$

and the ratio (1) can be written in the form of an equation:

$$v_1 x_1'(t) = -k_1 v_1 x_1(t) + f(t). \quad (2)$$

The parameter k_1 is called the rate constant. When the time scale t is changed, it, like the function $f(t)$, can be excluded from consideration.

The analytical solution of the equation (2) will have the form:

$$\left(x_1(t) e^{k1t}\right)' = f(t) e^{k1t} / v_1$$

where

$$x_1(t) = c_1 e - k_1 t + \int_0^t e^{-k_1(t-s)} f(s) ds / v_1.$$

and $c_1 = x_1(0)$.

If $f(t)$ is excluded from the process, then the concentration of x_1 decreases exponentially, if the initial concentration is zero, then

$$x_1(t) = \int_0^t e^{-k1(t-s)} f(s) ds / v_1.$$

Thus, if the change in concentration in the compartment occurs as shown in the Figure 3, it is possible to give a basic interpretation of the process that reflects the compartment's behavior [5].

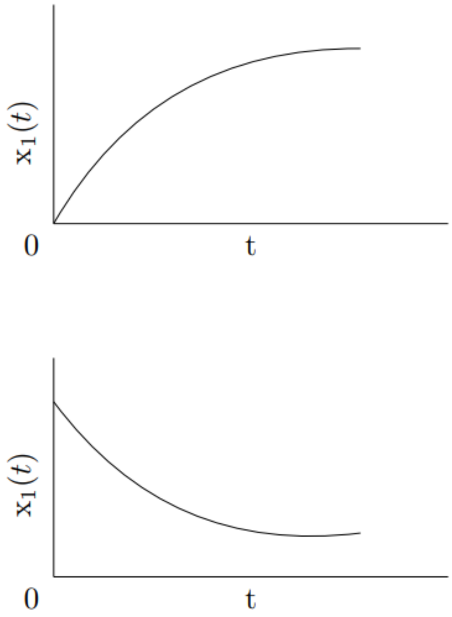

Figure 3: Changes of concentration in the compartment

Injections

The execution of the operation defined as an injection before, at the moment of time $t = 0$ can be described by the equation:

$$x_1'(t) = -k_1 x_1(t), \ \ x_1(0) = 1,$$

which has the solution $x_1 = e^{-k_1 t}$. We will assume that the effect of the injection on the concentration in the compartment occurs instantaneously [5].

When re-injection is performed, the state of x_1 can be described using equations:

$$x_1' = -k_1 x_1, \ \ x_1(0) = 1, \ 0 \le t \le t_1,$$
$$x_1' = -k_1 x_1, \ \ x_1(t_1) = 1 + e^{-k_1 t_1}, \ \ t_1 \le t.$$

So,

$$x_1(t) = e^{-k_1 t}, \ \ 0 \le t \le t_1,$$
$$x_1(t) = \left(1 + e^{-k_1 t_1}\right) e^{-k_1 (t - t_1)}, \ \ t \ge t_1$$

The concentration x_1 in this case will look like the Figure 4:

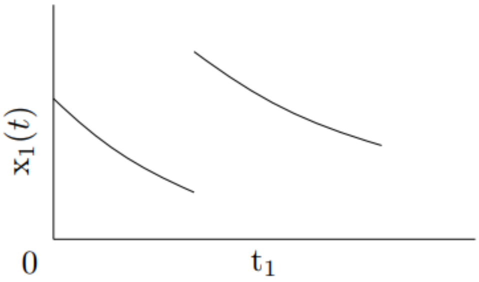

Figure 4: Change in concentration in the compartment after repeated injection

1.2. Single-compartment model of informational and suggestive influence

Suggestion is a process of influencing human psyche, associated with a decrease in consciousness and criticality in perceiving embedded themes, which do not require a detailed personal analysis or motivation evaluation for certain actions, are directed towards individual or public consciousness by informational, psychological or other means, and causes transformation in views, value orientations, stereotypes of the person. One of the varieties of suggestion are information operations [6].

An information operation (IO) is a planned action aimed at a hostile, friendly or neutral audience with the aim of influencing decision-making process or (and) to take actions beneficial to the subject of information influence.

IO methods include disinformation, diversification of public opinion, psychological pressure, and propaganda. Their goal is deceiving or misleading the object of influence, diverting attention from real problems, spreading various political, philosophical, scientific, and other ideas with the aim of introducing them into public opinion and intensifying the use of these ideas in mass applied activities of the population [7]. The abovementioned methods are measures within the «hybrid wars» framework [8] and are means of suggestive influence. In more detail, suggestive influences and the assessment of the strength of informational and suggestive influences are described in [9].

The form of informational and suggestive influence represented by information exchange via the Internet using information resources or social networks will be considered exclusively.

Let's apply the agent approach to determine the object of informational and suggestive influence.

According to this approach, an agent is an abstract entity that has activity, autonomous behavior, can make decisions according to a set of rules, can interact with the environment and other agents, and can also evolve (multi-agent model construction and agent properties description was done in [3]). Then a network user, as a separate agent capable of interaction and behavior, can be described as a model with one compartment. The agent can be both an individual and a group of people united by common characteristics and behavior that forms a collective response.

Let's refer to such a user as C. As a representative of a multi-agent network, it has the ability to elementary react to local changes in the environment and interact with other agents [3]. On the other hand, according to the definitions given in \ref{sec:1comp}, C can be described using its internal characteristic defined as the concentration $X(t)$.

Let's introduce new definitions to describe the C compartment.

- $F(t)$ – a function describing local changes in the environment to which C is able to respond, represented in the information field by the appearance of some amount of information that will be consumed by the user C. Such local environmental changes can have both a positive and a negative effect on the value of the internal characteristic of C compartment.
- $X(t)$ is an internal characteristic of C that changes under the influence of $F(t)$. Within the scope of the research task, $X(t)$ shall be the attitude of C to the information object in $F(t)$, which is formed by reaction of C to the information received from $F(t)$ and internal state changes as a result of its «consumption».

  In the presence of the initial state of the compartment C, which is quantified as $X(0)$, the value $X(t)$ can be interpreted as the state of individual consciousness at the moment of time t, which is formed in response to changes in external information environment, or a value characterizing a personal opinion about a certain object, information about which was obtained from $F(t)$.
- Suppose that the information environment is formed on the basis of information about n objects, and at the moment of time $F(t)$, can transmit the i-th object to C. Then V_i is «intensity» of input information about the object i.

Let's determine how the mechanism of excretion is implemented within the described process of information consumption by user C. According to equation 1, the reduction of the numerical characteristic of the C compartment occurs at the rate of k_1. Then, in terms of information consumption, let K be the speed of "forgetting" information by the user C, or decrease in the sharpness of perception of received information.

We can rewrite Equation 1 for compartment C:

$$V_iX(t+\triangle) = (1-K\,\triangle)V_iX(t) + F(t)\,\triangle.\quad(3)$$

Suppose that $X(t)$ is a smooth function of time, then

$$X(t+\triangle) = X(t) + \triangle\, X'(t) + \cdots$$

and the ratio (3) can be written in the form of an equation:

$$V_iX'(t) = -KV_iX(t) + F(t) \qquad (4)$$

The analytical solution of Equation 4 will have the form:

$$(X(t)e^{Kt})' = F(t)e^{Kt}/V_i,$$
$$X(t) = c_0e^{-Kt} + \int_0^t e^{-K(t-s)}\,F(s)ds/V_i.$$

where $c_0 = X(0)$.

The obtained solution quantitatively reflects the state of the compartment \$C\$ under the influence of the informational and suggestive influence of the environment.

Taking into account the peculiarities of the repeated influence of $F(t)$ on the compartment, it can be seen that through injections of controlled values, it is possible to influence $X(t)$ due to changes in the external environment of the compartment C in the form of keeping $X(t)$ at the desired level or for a controlled decrease/increase of this value.

Thus, this elementary compartmental model can be used to model personal thoughts or mental state of a person or a group of people participating in information interaction on the Internet.

1.3. Two-compartment model

Consider two compartments with internal concentrations of x_1 and x_2. Let the compartments do not have any excretion or other mechanisms of internal concentration loses. Also assuming, that there no any interactions between compartments except flow that directly proportional to concentration in compartments. Compatment interaction diagram is shown in the figure 4:

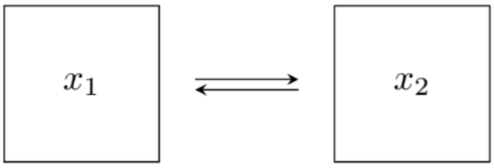

Figure 5: Two-compartment interaction model

This model type can describe a system consisting of two subsystems. When describing such a system through compartments, we will get two elements connected by a common external environment, affecting each other's internal state due to the mutual “spill” of concentration. This way information confrontation process between two sections of the information space can be described.

Depending on the scale of the task, it can be either two individuals or groups of individuals, or two or more states that are in a state of informational confrontation.

Extending the model to the required number of components and injections makes it possible to model information exchange and mutual influence of compartments in the described system, as well as to develop a scheme for effective informational and suggestive influence management.

Let’s describe the concentration dynamics in the compartments for the case of the two-compartment model. We will assume that the concentration in the compartments is due to the injection of same type. Let $x_1(t)$ be the concentration in the first compartment for $t \geq 0$, and $x_2(t)$ will be the concentration in second compartment for $t \geq 0$.

Assuming Δ small, we get

$$x_1\,(t+\Delta) = x_1(t) - \Delta\, k_1 x_1(t) + \\ + \Delta\, k_2 x_2(t) + O(\Delta) \qquad (5)$$

where $O(\Delta)$ – numerical characteristic of compartment, whisch is going close to zero when Δ goes to zero, k_1 and k_2 are rate constants. Same descpription we get for second compartment:

$$x_2(t+\Delta) = x_2(t) - \Delta\, k_2 x_2(t) + \\ + \Delta\, k_1 x_1(t) + O(\Delta) \qquad (6)$$

Using same transformations as for single-compartment model equation:

$$x_1\,(t+\Delta) \;= x_2(t) + \Delta\, x_1'(t) + O(\Delta) \\ x_2(t+\Delta) = \; x_2(t) + \Delta\, x_2'(t) + O(\Delta)$$

and Equations 5 and 6 can be transformed in linear equations system:

$$x_1'(t) \;=\; -k_1 x_1(t) + k_2 x_2(t) \qquad (7) \\ x_2'(t) = \; -k_2 x_2(t) \; + k_1 x_1(t)$$

The aforementioned equations are sometimes called linear kinetics equations. Assume that k_1 and k_2 are not negative.

So, our goal is to determine the concentration in the compartment at any time moment, for example, initial concentration values $x_1(0) = c_1$, $x_2(0) = c_2$, $c_1, c_2 > 0$.

Let’s sum equations from system 7:

$$x_1' + \, x_2' = -k_1 x_1(t) + k_2 x_2(t) \\ + k_1 x_1(t) - k_2 x_2(t) = 0$$

from where we get: $x_1 + x_2 = const.$

Marking this constant as b.

This property follows from the initial conditions of building the model, in which the process of excretion to the outside is not foreseen. In this case b constant represents the sum of the initial concentrations in the compartments. In this manner

$$x_1 + x_2 = c_1 + c_2$$

Expressing x_1 in terms of variables x_2, c_1, c_2 we get equation:

$$\begin{aligned} x_1' &= -k_1x_1 + k_2(\mathrm{c}_1 + \mathrm{c}_2 - x_1) \\ &= -(k_1 + k_2)x_1 + k_2(\mathrm{c}_1 + \mathrm{c}_2) \end{aligned}$$

Let there be a stationary value of the concentration. By the stationary value we will understand the concentration that is reached with an unlimited increase in time t.

This value can be found by equating x_2' to zero:

$$x_1\,(inf) = \frac{k_2(\mathrm{c}_1 + \mathrm{c}_2)}{(k_1 + k_2)}$$

To find an explicit solution, we will replace the variables:

$$x_1 = \frac{k_2(\mathrm{c}_1 + \mathrm{c}_2)}{(k_1 + k_2)} + y_1$$
$$y_1' = -(k_1 + k_2)y_1$$

New initial condition:

$$y_1(0) = x_1(0) - \frac{k_2(\mathrm{c}_1 + \mathrm{c}_2)}{(k_1 + k_2)} =$$
$$= c_1 - \frac{k_2(\mathrm{c}_1 + \mathrm{c}_2)}{(k_1 + k_2)} = \frac{k_1\mathrm{c}_1 - k_2\mathrm{c}_2}{(k_1 + k_2)}$$

is not necessarily positive.

Thus, we see that

$$y_1 = \frac{(k_1\mathrm{c}_1 - k_2\mathrm{c}_2)}{(k_1 + k_2)}\, e^{-(k_1+k_2)t}$$

So, the analytical solution of the equation will have the form:

$$x_1 = \frac{k_2(\mathrm{c}_1 + \mathrm{c}_2)}{(k_1 + k_2)} +$$
$$+ \frac{(k_1\mathrm{c}_1 - k_2\mathrm{c}_2)}{(k_1 + k_2)}\, e^{-(k_1+k_2)t}$$

The function x_2 can be determined from the relation $x_2 = c_1 + c_2 - x_1$ or by substituting in the expression for x_1 [5].

1.4. Two-compartment model of informational and suggestive influence

Consider the form of informational and suggestive influence represented by information exchange via the Internet using information resources or social networks.

Let's apply the agent approach to determine the object of informational and suggestive influence, same as for single-compartment model.

The agent can be both an individual and a group of people united by common characteristics and behavior that forms a collective response [3].

Let's refer to such a agent representative as G. G can be described using its internal characteristic defined as the concentration $X(t)$.

Same as for single-compartment model, let's introduce new definitions to describe the interaction between G_1 and G_2 compartment.

- K_1, K_2 – constant rates characterizing the transfer of concentration between compartments.
- $X(t)$ is an internal characteristic of G that changes under the influence of concentration transfer between compartments. Within the scope of the research task, $X(t)$ shall be the attitude of G to the information object causing changes of concentration in both compartments, which is formed by reaction of G on internal state changes as a result of its «consumption».
  In the presence of the initial state of the compartment G, which is quantified as $X(0) = \mathrm{C}$, the value $X(t)$ can be interpreted as the state of individual consciousness at the moment of time t.
- Suppose that the information environment has no external influence on the compartments. Compartmental internal state is formed on the basis of information about the object.

The concentrations in compartments can be described as:

$$X_1\,(t + \vartriangle) = X_1(t) - \vartriangle K_1X_1(t) +$$
$$+ \vartriangle K_2X_2(t) + O(\vartriangle)$$
$$X_2(t + \vartriangle) = X_2(t) - \vartriangle K_2X_2(t) +$$
$$+ \vartriangle K_1X_1(t) + O(\vartriangle)$$

where $O(\vartriangle)$ – numerical characteristic of compartment, whisch is going close to zero when $\vartriangle$ goes to zero.

As initial concentration values are constants $X_1(0) = C_1,\ X_2(0) = C_2,\ C_1,\ C_2 > 0$, assume that their values show an established opinion within a compartment regarding some information in initial time.

The linear kinetics for $X(t)$ is an internal characteristic of compartment will be described as following:

$$X_1'(t) = -K_1X_1(t) + K_2X_2(t)$$
$$X_2'(t) = -K_2X_2(t) + K_1C_1(t)$$

Performing the steps of concentration equations transformations to find a solution, we get

$$X_1 = \frac{K_2(C_1 + C_2)}{(K_1 + K_2)} + \\ + \frac{(K_1C_1 - K_2C_2)}{(K_1 + K_2)} e^{-(K_1+K_2)t}$$

and resolution for X_2.

These results are identical with pharmacokinetic models. The reason for this is the similar nature of the influence of the information environment in general and a specific element of the information environment on what we have defined as an information network agent before.

Thus, the equations of pharmacokinetics, adapted to the subject environment of the sphere of information interaction, make it possible to assess the mood of a person or a group of persons and its dynamics as a result of exchanging information with another person or a group of persons.

Estimating the concentration of the compartment at any moment of time, including the initial moment of time, makes it possible to predict the dynamics of the attitude of the agent represented by the compartment to a given topic of messages, as well as to determine the initial conditions.

Conclusions

An immunological / pharmacokinetic mathematical model based on the compartmental approach proposed by R. Belman was considered. Based on the parameters of the original model, a set of terms and characteristics to describe information interaction and influence on compartments was developed, a one-compartment model of information-suggestive influence on an information network agent was proposed.

Obtained result makes it possible to use given compartment model for quantitative assessment of informational and suggestive influence, as well as internal compartment state management by applying changes to information environment.

In the future, it is possible to modify this model for a multi-compartment structure and develop a procedure for optimal informational and suggestive influences management within selected information systems.

Such a result can be useful in assessing target groups of influence when using suggestive technologies and propaganda on an individual or a group of individuals through direct or indirect influence other single or multiple compartmental agents.

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