RISK MANAGEMENT IN NATURAL AND SOCIETAL SYSTEMS

Taking into Account Terrorist Threats

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Abstract: The paper presents systemic approach to ensuring safety of natural-manmade-social systems that could be subjected to terrorist impacts. The theory of risks and methods to risk analysis that are used in assessing natural, manmade and societal crises and catastrophes, can be applied to assess risks of terrorist impacts as well. Such approach allows to study cascade-synergetic process, to reveal week elements of a system and to undertake measures for protection against terrorist attacks. The presented systemic description of risk allows to conduct a profound and comprehensive study of interaction between various elements of natural-manmade-social system, to select basic elements and to determine a possibility of terrorist impacts on them at local and systemic (global) levels taking into account the internal characteristics of the system.

Key words: risk analysis, terrorism, cascade-synergetic processes, systems

According to UN data terrorist activity tend to grow steadily during the past 15 years. In the 20th centurpy for the first time in human history terrorism became a global problem closely connected to the problem of human survival. Modern terrorism differs drastically from the terrorism of the past. Nowadays terrorists have the opportunity to make use of innovative technologies and weapons of mass destruction. This opportunity is not an abstract one. 1n 1994 a terrorist was detained in Ukraine who threatened to blow up a reactor in Chernobyl nuclear power plant if his requirements were not satisfied. Poison-gas was sprayed in Tokyo underground.

K.V. Frolov and G.B. Baecher (eds.),
Protection of Civilian Infrastructure from Acts of Terrorism, 7–20.

Modern terrorism acquires a system character; the goal of terrorists is to break a system, to upset the balance, to change its structure and relations between elements. Modern terrorism has several aspects. Thus the new terrorism makes allowance for world interdependence, system character of processes going on the world and offers a corresponding strategy of threats. The actions of terrorism are based on a domino effect. A butterfly effect inevitably arises in the in the complex and globalize society: a fairly insignificant incident at one place cause an event with avalanche-like consequences at another place. Terrorism is seeking new means of intimidation, more cruel and large-scale ones.

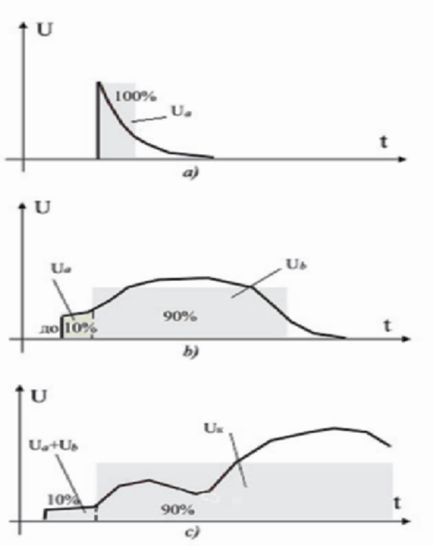

Figure1. Kinds of terrorism. a- traditional terrorism; b- technological terrorism; c- intellectual terrorism; U_a- initial damage; U_b – secondary damage; U_k – cascade damage

Terrorism has proved to be directly connected with the problem of human survival and ensuring national safety. Terrorism is an extreme form of social, ethnic religious extremism and nothing can prevent it from achieving its goals. This criminal phenomenon tends to grow steady everywhere in the world. Criminalists observe that year by year terrorist attacks are becoming more thoroughly organized actions that employ super modern technologies, weapons and means of communication. This kind of activity is now preferable for extremists to solve social, ethnic, religious and other conflicts.

Modern industrial infrastructure in developed countries, especially mega-lopolises, comprising thousands radioactive, chemical, biologic objects, offers terrorists a real opportunity to inflict damage without resorting to weapons of mass destruction, though their efforts to get hold of it are evident.

The nature of a hazard (or an opportunity to inflict damage) is connected with energy, substances or information flows that are inadequate for the infrastructure as an open system. Besides every infrastructure is a compilation of various components that have a common purposes, common condition of functioning and common resources.

System approach to studying any threat implies primarily as complete as possible knowledge of adversary (his objectives, tasks financial and professional potential, materials, equipment, weapon and many other characteristics). Therefore potential targets for terrorists should be systematized according to their accessibility and possible damage in the case of destruction. These are basic data for organizing counteraction.

The modern terrorism can be divided into three kinds: traditional, technological and intellectual (fig. 1) [1] that differ in the character of damage distribution in terms of time (initial, secondary and cascade damages).

Analysis of various kinds of terrorist impacts on natural-manmade system shows that maximal damage corresponds to the secondary damage with cascade-synergetic effect being manifested. Examination of these facts leads us to the conclusion that technological and intellectual kinds of terrorism can be classified as systemic terrorism. Arising and development of initial, secondary and cascade factors of destruction in terrorism are practically governed by the same laws that govern traditional accidents and catastrophes in complex technological systems causing manmade emergencies.

In the view of the above development of methods, means and systems for protection from threats of systemic terrorism comes to two basic tasks: (a) risk reduction or prevention of initiating hazards, threats, and challenges; (b) reduction of risks of further development of natural, manmade and societal emergencies provided that initiating terrorist impacts take place.

The theory of risks and methods to risk analysis are used in order to assess natural, manmade and societal crises and catastrophes [2,3]. They can be applied to assess risks of terrorist impacts as well. It is necessary to take into account systemic characteristics of natural-manmade-social systems. Such approach allows to study cascade-synergetic process, to reveal week elements of a system and to undertake measures for protection against terrorist attacks, which leads to more efficient decisions on primary protection of key assets of infrastructure. which leads to more efficient decisions on primary protection of key assets of infrastructure.

Systemic risks are determined by peculiar interactions of natural, manmade and social spheres. A catastrophe or crisis is a chain of sequential interconnected events. Te number of links in the chain can be fairly big. Analyzing systemic risks in natural-manmade-social systems, the probability that a systemic threat is realized can be presented as a functional [1]:

$P_{sis}=F_{ps}\{P_n, P_m, P_s\}$,

Where

P_n– probability of unfavorable events in natural environment;

P_m – probability of unfavorable events in manmade (engineered) environment

P_s – probability of unfavorable events in social sphere;

Probability P_m is considerably dependant on the level of protection of manmade facilities of military or civil designation from accidents and catastrophes. This protection depends on the extent of degradation of facilities at given stage maintenance, and the level of diagnostics and monitoring which means that P_m and P_s are directly related. Probability P_s is known to be depended on occurrence of natural disasters (P_n) as well as on the state of manmade facilities (on P_m).

Damage U_{sis} caused by realized system threat can generally be presented as a functional:

$U_{sis}=F_{us}\{U_n, Uw_m, U_s\}$

were

U_n is damage inflicted on natural environment

U_m is damage inflicted on manmade (engineered) environment

U_s is damage inflicted on social sphere (primarily on population) when a systematic threat is realized and initial and secondary destructive factors interact;

Values U_n, U_m, U_s can be measured both in terms of physical items (for example, a number of casualties, a number of building destroyed, area of contaminated territory) and in equivalents (for example, pecuniary loss).

To analyze and govern risks R_{sis} with respect to two groups of 3 components one can use limit state surfaces:

- Systemic risks to social environment (R_s), to manmade environment R_m), to natural environment (R_n)
- Integrated damaging factors of crises and catastrophes: energy (E), substance (S), information (I).

Then the state of utmost danger for R_n , R_m, R_s or E, S, I will be at the intersection between the vector of the current state of a system in risk R_{sis} or threats D_{sis} and the surface of utmost danger state.

The state of a system is a function of parameters $\boldsymbol{X}=(\boldsymbol{X_{loc}}, \boldsymbol{X_{sis}})$. Vector $\boldsymbol{X}$ consists of 2 sets of parameters that specify the elements of a system (local parameters) and the links between the elements (systemic para-meters). These parameters can be variable or stationary. They determine the level of risk in a system: $(\boldsymbol{X_{loc}}, \boldsymbol{X_{sis}}) \Rightarrow R$.

The described analysis of systematic concepts of risks and losses in natural-manmade-social systems shows that in order estimate risk in natural-manmade-social systems it is necessary to proceed not only from the probability of occurring of a crisis situation, but also from a degree of vulnerability of its elements, allowing for synergetic cumulative effects. In this case potential complex damage caused by emergency to natural-manmade-social system should be described by a matrix of losses in subsystems and elements of the system. This matrix is to allow for direct losses i.e. levels of destruction, infringement, radioactive and chemical pollution, negative aftermaths of damaging effects on natural and economic objects (land, people, flora and fauna, buildings, equipment, goods, raw materials, plantations, live stock and the like) as well as indirect losses inflicted by the said distractions and infringement on the state and functioning of other objects of nature and economy that did not suffer directly from the damaging factors. A system can be divided into different number of components, the degree of detailing depending on the level of emergency situation danger.

A system is considered as a complex of 3 subsystems at any level of risk described: natural, manmade and social. A natural-manmade-social system of the highest level of danger is considered to include lower level of danger. Each subsystem is divided into subsystems of the next lower levels. Thus hierarchic (multilevel) presentation of a system is built up. When considering a system consisting of subsystems, the matrix of losses is presented as a matrix containing both diagonal blocks (units) and non-diagonal blocks. Diagonal elements of a loss matrix specify potential losses at the given element of the system in the case that an emergency occurs at this element. Non-diagonal elements of a loss matrix characterizing the linkage of the system's elements with regard to criterion for loss, describe synergetic development of an emergency and its distribution onto the system.

This kind of matrix is build up through assessment of maximal potential losses to the elements (subsystems) of a system. All kinds of losses are taken into account. Probability of an emergency occurrence in conformity with such systemic approach is characterized by the matrix of probability of the emergency occurrence that contains probable estimations of emergency effects on the elements of the system, according to the scenario of the emergency development. Risk dependence on the level of protection of the system's elements, on their location relating to the zone emergency occurrence is estimated by matrix of the system vulnerability in case of emergency. (This matrix contains characteristics of the system's elements vulnerability in case of the given emergency). Then the risk for natural-manmade-social system from a specific emergency can be presented as the matrix of the risk:

$$R_i = R_U^T(X_{loc}) \cdot U(X_{sis}) \cdot P$$

were $R_U^T(X_{loc})$ is the matrix that contains vulnerability factors of the system's elements, these factors depending on the parameters of the system's elements X_{loc}; $U(X_{sis}) \cdot P$ - is the loss matrix, consisting of values of maximal losses and this matrix depends on the system's parameters X_{sis}; P - is the matrix of emergency's probability and effects on the system elements. Coefficients of the matrix $R_U^T(X_{loc})$ are variable and vary according to the character of local governing impacts. The matrix of losses depends on the structural properties of the system, interactions of the systems elements and on systemic parameters X_{sis}. The variations of the elements values of the matrix require systematic changes. Thus the risk government in natural-manmade-social systems implies local risk government through reducing vulnerability coefficients of the system's elements, and if possible, of the probability of occurrence of a specific emergency, and of its effects on the system's elements. The decisions on risk management can be made both on local and global (systemic) levels. In case of mature natural-manmade-social systems with strong linkage of elements of natural, manmade, social spheres global decision require high expanse.

Comprehensive risk that comprises all kinds of risks of a system can be presented as:

$$R_s = R_s^* + R_f = \sum_j^n R_j + R_f, \qquad j = 1,\ldots n$$

where R_f is background risk including risks from those emergencies that cause insignificant loss and tend to occur frequently.

The presentation of a risk as a matrix allows to take account of synergic cumulative and self organizing properties of a system for the whole complex of emergencies typical for the given natural-manmade-social system. The structure of the given matrix depends on the kind of considered risks. The presence of nonzero non-diagonal elements (blocks) in a matrix R_S^* characterizes the linkage of the system's elements and corresponds with the principle of reciprocity.

Presentation of a risk as a matrix allows to present the scenario of an emergency by means of its elements. For example, presentation $R_{11} \to R_{12} \to R_{22} \to R_{21} \to R_{22}^*$. In this case an accident occurred in the first element of the system, affects its second element where it causes an emergency that causes a secondary accident in the first element. Here is a graph of emergency development in a natural-social system (fig. 2).

Making up a risk matrix for natural-manmade-social system it is necessary to take into account not only accidents possible in given system but also accidents in surrounding natural-manmade-social systems, especially in those having a common boundary with the given system (transboundary transfers, i.e. external impacts on a system).

Scalar characteristic of a system's risk can be presented as a potential function of risk, considered as a function of the system's parameters and elements (taking into account the matrix of the risk). This is a nonlinear dependence, that can be presented as a surface in the configurative space of system $\boldsymbol{X}_{sis}$ parameters and system $\boldsymbol{X}_{loc}$ elements that determine the matrix of the system's losses and the matrix of its vulnerability as well as the probability of the emergency occurrence. Hypersurface in *n*-dimension space can have local peculiarities (characteristic points of elliptic, hyperbolic and parabolic type).These points and their distribution in the parameters space determine the system's peculiarities. In the theory of catastrophes they are called critical points. The strategy of risk government in a system depends on how close the system is to the critical point.

Presentation of risk as scalar value or as a matrix of risks could be classified as static assessment of the system's risk. The structure of the risk matrix in this case characterizes the organization (self-organization) of the system at the moment of its evaluation. The relation between controllable parameters and uncontrollable ones can be defined trough relation between vulnerability matrix and emergency probability matrix. In order to take into account processes of the system's self organisation it is necessary to consider dynamic risks.

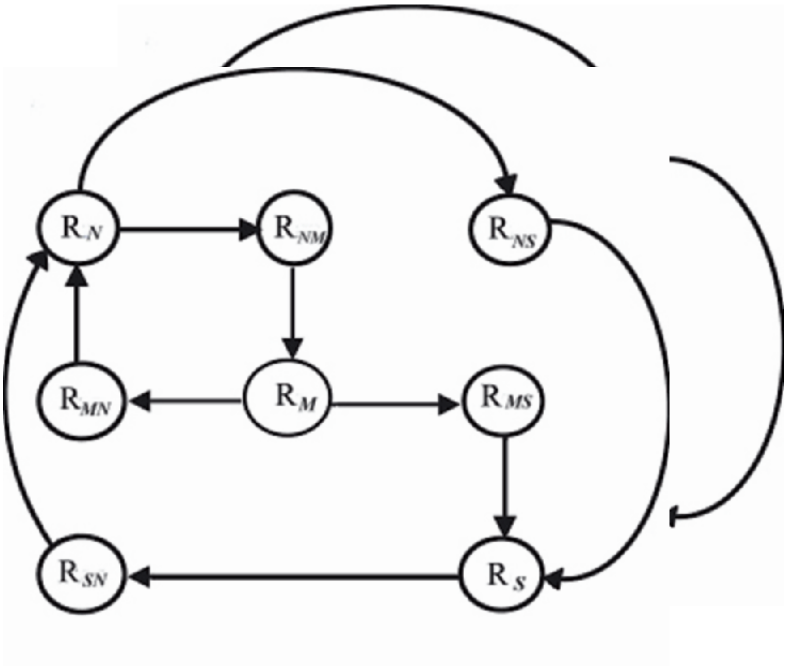

Figure 2. Scenario of emergency development in a natural-manmade-social system. Subscripts: N- natural, M –manmade, S- social

Risk is a function of the system's state and its variable parameters. Its total differential could be presented as:

$$\boldsymbol{dR = (\frac{\partial R}{\partial X_1})dX_1 + ... + (\frac{\partial R}{\partial X_{i1}})dX_{i1} + ... + (\frac{\partial R}{\partial X_n})dX_n + \frac{\partial R}{\partial t}dt},$$
$$i = 1,2,...,n$$

Component

$$\frac{\partial R}{\partial t}dt$$

is to be included since risk R may depend on time as well.

The differential components

$$\frac{\partial R}{\partial X_i}$$

determine the dependence of a risk on the change of the system's parameters (local and systemic ones). The values of partial derivatives on the system's parameters allow to determine the direction of the controllable movement of the system to a minimal risk.

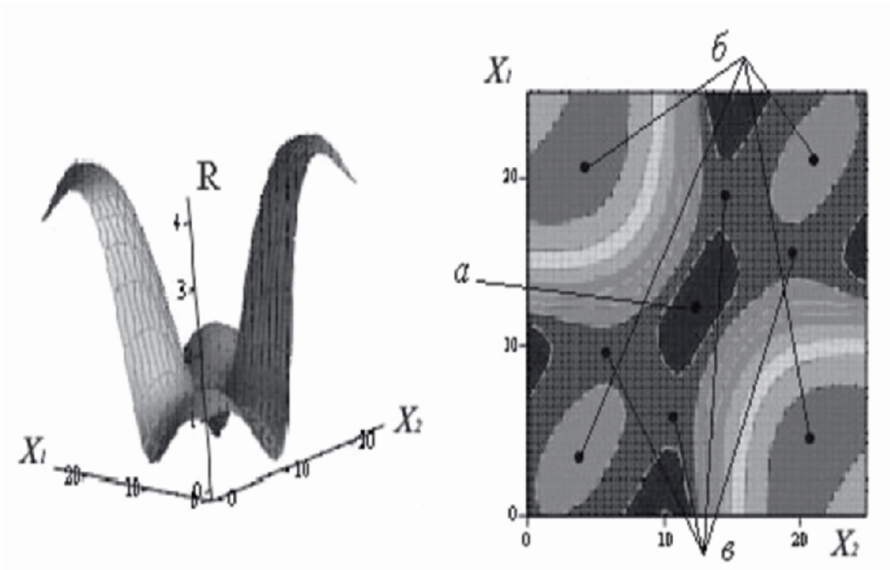

Figure 3. a, b, б – points of local maximums and minimums of R values

If we consider a system, whose parameters vary in terms of time, we will have the dependence of a risk on time R(t). Such presentation of risk depending on the system's parameters an on time allows to make dynamic models of risk; it is the basis of risk management in natural-manmade-social systems with reference of time parameter. It also allows to take account of the system's self-organization and non-linear effects. In this case mathematical apparatus of the theory of catastrophes and nonlinear dynamics can be used.

Potential risk surface for a system consisting of *n* elements will have a compound form were all types of critical points present. For example, in Fig.3 there are potential surfaces of risk in a system consisting of two elements with nonlinear links (X_1 and X_2 – are generalized parameters of the system). The theory of catastrophes, stability of motion, variational principles etc. are based on analyzing properties of potential functions.

The character of measures on ensuring safety in a system is determined by the way the critical points are spread relative to the point of the system state and by the change the surface around this point. Analysis for critical points and the way they are spread in space is necessary to carry out global risk minimization.

Let us consider dynamic singularities of natural-manmade-social system under certain conditions of the interaction between subsystems. The changes of risk in a system can be characterized by the following Rossler's equations:

$$\begin{aligned} &\dot{R}_1 = -(R_2 + R_3), \\ &\dot{R}_2 = R_1 + a(t) \cdot R_2, \qquad\qquad R\,(0) = R_{0i}\ , \quad i=1,2,3 \\ &\dot{R}_3 = a(t) + R_1 \cdot R_3 - c(t) \cdot R_3, \end{aligned}$$

were R_1, R_2, R_3 are risks in natural, manmade and social spheres, *a(t)*- is a coefficient that allows for development of development of the manmade sphere and its vulnerability, *c(t)* -is the similar coefficient for social sphere. These coefficients also depend on the possibility of terrorist effect on social and manmade sphere. Systemic risk is determined by the sum $R_{sis}=R_1+R_2+R_3$**.** The presented model characterizes the variation of the total risk in natural-manmade-social system in relation to the trend value that increases in the system and can exceed the acceptable level. This model illustrates combined interactions between subsystems and conditions under which self-organization is triggered in the system. The model contains only three degrees of freedom, but illustrates wide variety of dynamic singularities of a system.

The absence of R_1 with the corresponding coefficient in the right-side of equation 1 comply with the condition that there are no noticeable changes in the natural sphere during the given period.

Let us consider the condition of a system when the values of coefficients *a(t)* and *c(t)* that determine the level of the system's development are constant. The analysis of properties of a potential function shows that there are two characteristic points *R(a, 0, 0)* and *R(-a+2c, o, 2)*. The location of these points in relation to each other and their form determine the character of geodesic lines on the surface of the potential function and, consequently the system's dynamics. In the given case these two points are of parabolic type (Gaussian curvature of the surface in characteristic points is a zero one) with two coordinates with indifferent stability. The third coordinate for the first point is not stable, but the one for the second point – is stable. Location of these points and their character determine the trajectories of the system's motion and phase space of the system.

The zero point ($R_i(0)=0$) was taken as an initial point to start computation. With certain values of coefficients *a* and *c* the system becomes self-organized in to a system that has a steady cycle of risk changing relating to some average value.

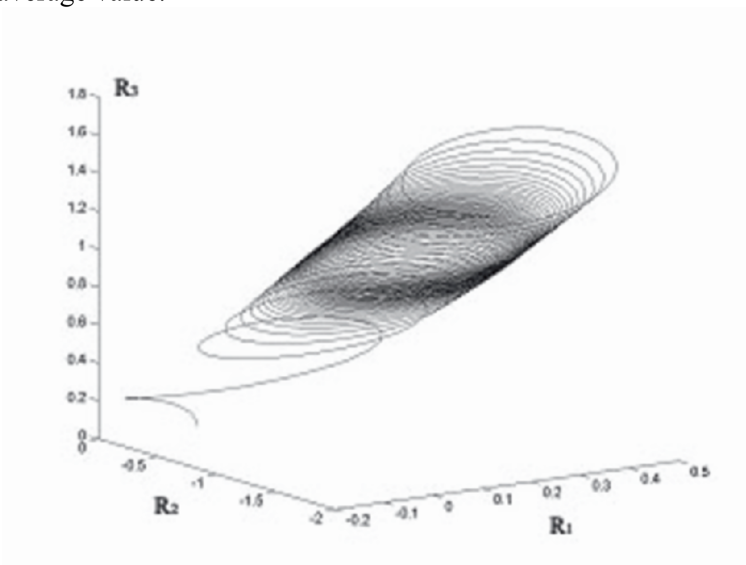

Figure 4. c=0.4; a=0.2

Let us assess system's behavior by means of divergence of phase space.

$$\boldsymbol{D} = \frac{\partial \dot{\boldsymbol{R}}_1}{\partial \boldsymbol{R}_1} + \frac{\partial \dot{\boldsymbol{R}}_2}{\partial \boldsymbol{R}_2} + \frac{\partial \dot{\boldsymbol{R}}_3}{\partial \boldsymbol{R}_3} = \boldsymbol{a(t) + R_1 - c(t)}$$

Having denoted the volume of phase space as *G(t)* we write the equation as:

$$G(t) = G(0)e^{(a(t)+R_1-c(t))t}$$

The expression obtained shows the character of the natural sphere's effect on the risk value in the whole system. The value of the change of natural risk R_1 in this model is characterized as both positive and negative values, therefore phase volume has oscillatory mode. This is expressed as multifrequency interactions. In the case of $a(t)+R_1-c(t)>0$ the systemic risk is growing while in the case of $a(t)+R_1-c(t)<0$ it is reduced. Taking a time averaged of value R_1 over the time T, we have:

$$\overline{R_1} = \frac{1}{T}\int_0^T R_1(t)dt \to 0$$

Then the exponent in the expression of phase volume change is determined by the correlation of coefficients *a(t)-c(t)*. The *a(t)* coefficient characterize the volume of the social sphere and the manmade one with both spheres affect the changing of the risk index. The changing of *a(t)* coefficient depends on how developed the manmade sphere is (its expanding and vulnerability (i.e. protection against terrorist impacts). *c(t)* coefficient determines the level the system can be managed in terms of ensuring its safety. The increasing of this coefficient makes the dynamics of the risk index more complicated, the frequency spectrum included into the description of dynamics of the system's safety index becomes more complicated. Reduction of the *c(t)* coefficient leads to the system's destabilization that is expressed by an abrupt increasing of risk index. In case of weak management a certain frequency becomes dominant in the spectrum, which leads to the growth of the risk in the social sphere (fig. 4) while oscillations in the other spheres remain on the same level. The total systemic risk grows then.

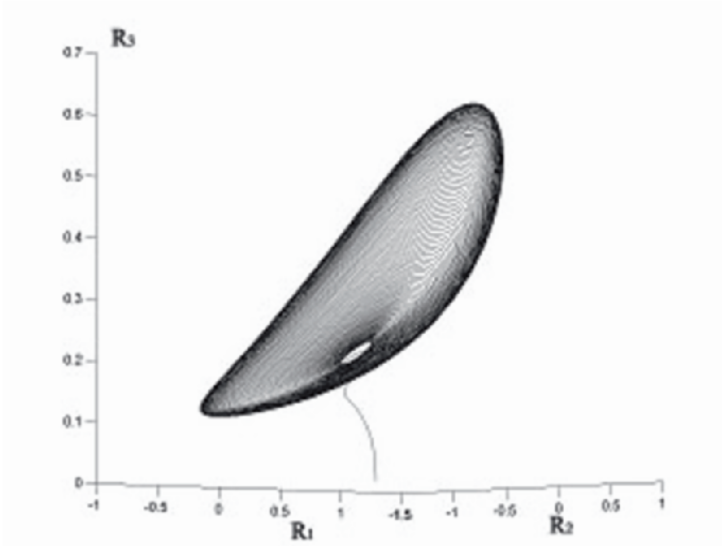

Figure 5. c=0.5; a=0.1

Let us analyze the case when systemic changes take place, that is when *a* and *c* coefficients change in terms of time. For example, coefficient *c=c(t)* is varied. It means that the second characteristic point changes its place in relation to the first one (the distance increases), and the amplitudes of fluctuations in risk values also increase (fig. 6).

Model presentation of interactions in a system shows that in the system there are fluctuation processes characterized by different sets of frequencies and their power (spectral density). The relations between these frequencies can be rational or irrational. These indices determine risk dynamics.

In order to take into account terrorist impacts it is necessary to introduce coefficients that depend on the kind and power of the impact. These impacts change the dynamics of a system and can cause system changes.

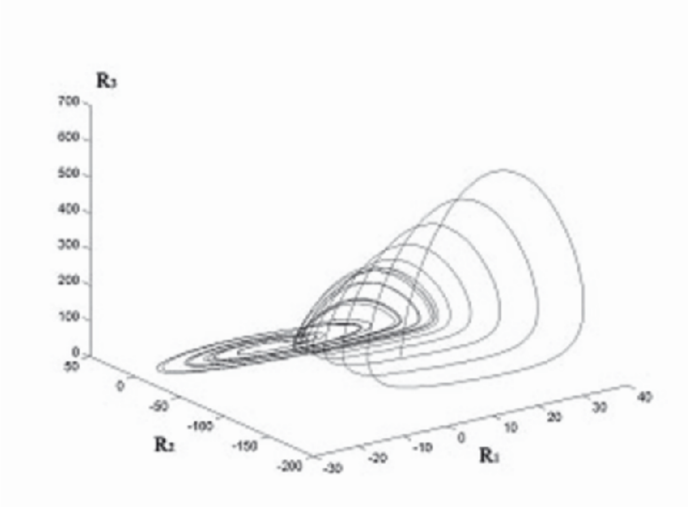

Figure 6. Amplitudes of fluctuations in risk values

The presented systemic description of risk allows to conduct a profound and comprehensive study of interaction between various elements of natural-manmade-social system, to select basic elements and to determine a possibility of terrorist impacts on them at local and systemic (global) levels taking into account the internal characteristics of the system. This approach is a foundation for a comprehensive study of natural-manmade-social systems. To describe and analyze subsystems and their elements various methods can be applied such as methods of nonlinear dynamics, logical-and-probabilistic method, fuzzy sets, fractal analysis, neural networks).

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