Prediction of the space-time state of systems using geospatial data for assessing technological risks

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Abstract. The article deals with the tasks of mathematical modeling and forecasting of the space-time state of systems using geospatial data for assessing technological risk. Predicted functions of changes in the space-time state of the system, obtained by the exponential smoothing method, are constructed. The article provides an example of options for changing the space-time state of an object based on the exponential smoothing method.

1. Introduction

In the twentieth century, the intensive development of new technologies led to the outstanding results in all spheres of the man-made technogenic activities, creating an unprecedented potential and real threats to humans. Many emergency situations happen in the world every year. Sources of accidents and disasters are geodynamic processes and improper operation of man-machine systems consisting of hardware, computers, software and personnel actions [1]. In the aggregate, geodynamic and man-made systems are complex systems, the main security problem of which is the inability to completely eliminate the risk of emergency situations in such systems and the need to minimize this risk. Therefore, the main objective of studying the problem of man-made risk assessment is not to determine the damage to an object as an already accomplished fact, but to prevent a dangerous situation, search for managing the space-time state (STS) of the system, ensuring that the risk is reduced to a minimum.

2. Materials and Methods

The achievement of the stated goal is based on the principles of the system-target approach and is carried out as a result of solving the following set of interrelated tasks:

1. Development of a mathematical model for determining the spatial-temporal state of the system according to geodetic data for the assessment of technological risk.
2. Development of a forecast model of the space-time state of the system, the ability to predict scenarios of changes in its state to reduce risk and select alternatives.

The initial data for modeling STS are the time series of coordinates of the set of control points of the object (system) under investigation, obtained from the results of repeated cycles of geospatial measurements.

The model of the dynamic system is adopted as a formal model of the object [2].
Where $X$ is the set of input signals; $Y$ is the set of output signals; $S$ is the system state space; $\varphi$ is the display of the transition of the system from state to state as a result of the flow of input information; $f$ is the system output display.

The task of determining the STS system is reduced to a meaningful finding of the elements of the model (1). The array of the height coordinates of the control points of the object was taken as the source data for solving this task, i.e. the state of the object at the moment $t_j$ is determined by the height coordinates of the points. Consequently, the set $X$ consists of scalar functions:

$$H_i = H_i(t)$$  \hfill (2)

The state space of an object is defined as the Cartesian product of all elements of this set. The dimension of space $n$ is equal to the number of control points.

Each cycle of observations with a number $j$ in the state space has a corresponding point, the radius vector of which

$$\overrightarrow{H(t_j)} = \sum_{i=1}^{n} \overrightarrow{k_i} \cdot H_i(t_j),$$  \hfill (3)

where $\overrightarrow{k_i}$ are the ort-vectors of the basis of $n$, a dimensional state space.

Thus, the function $\varphi$ is a mapping that puts the phase point of the state space in accordance with the set of input signals $H_i(t_j)$. This point represents the state of the system in the loop with the number $j$. The set of points whose radius vectors are determined by the vector function (3) in each observation cycle forms a phase trajectory in phase space, which is an explicit function of coordinates and time characterizing the change in the state of the system from cycle to cycle. An important step in the assessment of technological risk is the prediction of changes in the space-time state of systems.

There are various options for solving this problem. One of the simplest and quite effective methods for its solution is the exponential smoothing method [3], [4], [5].

We assume that in the prediction interval, the evolution of the state of the system looks like this:

$$y = A + \eta,$$  \hfill (4)

where $\eta$ is a random stationary uncorrelated process with zero expectation. Let the value $A$ occasionally change in steps. The magnitude of the change in $A$ and the moment of change are unpredictable, and the time interval during which the value of $A$ remains unchanged significantly exceeds the interval between our observations. Under these assumptions, the smoothed observation function is:

$$S_t = A \cdot y_t + (1 - A) \cdot S_{t-1}.$$  \hfill (5)

3. Results and Discussion

As a result of research, the predictive functions of the change in the space-time state of the system, obtained by the exponential smoothing method, are constructed (Figure 1).
Figure 1. Predicted functions of changes in the space-time state of the system, obtained by the exponential smoothing method.

Here, $A \in [0,1]$ is the smoothing constant, $S_t$ is the smoothed value $y_t$, referred to the moment $t$; $y_t$ is the state of the object at the moment $t$.

We assume that the “degree of stochasticity” (entropy of the process) is known, and it is determined by the probability value $P \in [0,1]$ (Figure 2).

\[
P = \begin{array}{cccccccccc}
0.1 & 0.2 & 0.3 & 0.4 & 0.5 & 0.6 & 0.7 & 0.8 & 0.9 \\
\end{array}
\]

Deterministic

\[
A = \begin{array}{cccccccccc}
0.1 & 0.5 & 0.9 \\
\end{array}
\]

Stochastic

Figure 2. Probability $P$ of the origin of random events.

Figure 3. An example of options for changing the space-time state of an object based on the exponential smoothing method on the interval $t=0..3$.

The most important characteristic in this model is the smoothing constant $A$, the largest by which the forecast is carried out. The closer the value of this parameter is to 1, the greater the likelihood of the occurrence of random events, and vice versa. Therefore, the choice of the value $A$ depends on the value of the probability $P$. The change in the space-time state is determined by the function, where the state of the object at a fixed time $t$ is represented by a point.

At each time interval $t_i$, where $i=0..n$, the value of $P$ can change and then for prediction the value of $A$ needs to be changed.
To assess the technogenic risk, we need to know not only the spatial-temporal state of the system, but also possible scenarios for its change, as well as the probability distribution of scenarios [3] (Figure 3).

Thus, knowing the degree of “stochasticity” of the process, we can choose the optimally “safe” strategy for changing the space-time state of an object.

4. Conclusion

Determining the future of the STS system is always based on some plausible hypotheses, the reliability of which is unknown, as a rule. To reduce the measure of uncertainty when choosing the most useful solution, the concept of risk is introduced, which is characterized by the magnitude of the damage due to the choice of decision.

References

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