Modeling the change in the state of a natural-technical system with a power facility

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Abstract. The paper studies the issues of computer modeling of changes in the state of a natural-technical system with a power facility. The paper studies the concept of "natural-technical system" in the context of the problems of the impact of human economic activity on the environment. A list of indicators that can be used in modeling a change in the state of a natural-technical system with a power facility is highlighted based on the analysis of scientific publications. A formal description of the used matrix model is given. A hydroelectric power plant was chosen as an example of a power facility. The result is the software product which gives the possibility of modeling of changes in the state of a natural-technical system with a power facility according to the values of the entered indicators.

1. Introduction
Scientific and technological progress is accompanied by the constant impact of human economic activity on the natural environment. As a result of the technogenic transformation of the natural environment, new dynamic systems appear that are designated by the term "natural-technical systems" (NTS) [1].

NTS is a natural complex within which engineering objects created by man are located. A distinctive feature of NTS is the presence of a spatial-temporal relationship between natural and engineering objects [2]. The types of NTS are extremely diverse. NTS subsystems always have a unique structure, since both the natural ecosystem and the technical object have specific features. The natural ecosystem, its landscape, chemical and biological components differ in different regions. The uniqueness of the natural system is ensured by the peculiarities of mountain, plain and other surfaces included in it, as well as by the peculiarities of the climate. In turn, the technical subsystem is formed from a certain complex of objects associated with a certain field of human activity. Such objects can be divided according to their industry focus into industrial, power economy, transport, and so on.

Monitoring and modeling the state of such systems is an important area of scientific research necessary for making effective management decisions in the field of environmental management. Among the NTS, the NTS with power facilities are among the most intensively affecting the biosphere. The construction of power facilities directly depends on the geological, chemical and biological components. Power facilities include thermal power plants (TPP), nuclear power plants (NPP), oil stations (OS), hydroelectric power plants (HPP). When studying a class of NTS with power facilities, the attention of scientists is more often focused on the risks of negative impact on the biosphere of NPP, TPP, OS.
The purpose of this paper is to develop a toolkit for modeling the influence of external and internal factors on the change in the state of a natural-technical system with a power facility. A hydroelectric power plant was chosen as an example of a power facility. The research subject is the application of the modeling method in the study, assessment and forecasting of the natural-technical system state as a whole, as well as its individual components. In the course of achieving this purpose, abstract-logical, analytical and statistical research methods were applied. The information and methodological base of this study was made up of the modern scientific researches devoted to the formation of the concept “natural-technical system” as a combination of a natural ecosystem and a technical superstructure [3, 4], the use of modeling methods in assessing and predicting the natural-technical systems state [5-7], issues of negative phenomena prevention in the natural environment [8], as well as statistical data [9, 10].

The paper is as follows. Section 1 substantiates the relevance of the research topic. Section 2 describes materials and methods. Section 3 presents the results of the software product development that makes it possible to modeling changes in the state of a natural-technical system with a power facility according to the values of the entered indicators. Section 4 draws conclusions on the work done.

2. Materials and methods

The object of the study was the NTS in the area where the Novosibirsk hydroelectric power station is located. It is located on the Ob River. The sources of information for the study were statistical data on changes in the levels of reservoirs of hydroelectric power station provided by RusHydro for 2018-2020 [9], data on precipitation for the same period in the area where hydroelectric power station are based [10], as well as a matrix mathematical model for assessing the state of natural-technical system presented in [5]. The main principle of the model formation is the presentation of the NTS as a single object that is influenced by the groups of factors $A_1, A_2, A_3, \ldots, A_n$. Groups of factors are significant for the NTS.

The simulated NTS consists of a natural ecosystem and a technical system represented by a hydroelectric power station. When compiling the model, five influencing factors $a_1, a_2, a_3, a_4, a_5$ are considered (the water level is average along the length of the reservoir, inflow, total water discharge, discharge through spillways, and the amount of precipitation [4]). Modeling is performed by year. In general, the group of factors for the $q$-th year is given as:

$$A_q[k] = \{a_1^q, a_2^q, \ldots, a_k^q\}$$

where $\{a_1^q, a_2^q, \ldots, a_k^q\}$ is the state vector for the set $A_q[k]$, $k$ is the number of influencing factors in the group of factors. For a natural subsystem, the state vectors for set $A_{NS}[k]$ is defined as:

$$\begin{align*}
    &\{a_1^l, a_2^l, \ldots, a_i^l\} \\
    &\{a_1^r, a_2^r, \ldots, a_j^r\}
\end{align*}$$

where $i$ and $j$ are the numbers of the first and last sets included in the $A_{NS}[k]$. For a technical subsystem, the state vectors for set $A_{TS}[k]$ is defined as:

$$\begin{align*}
    &\{a_1^e, a_2^e, \ldots, a_{k_e}^e\} \\
    &\{a_1^r, a_2^r, \ldots, a_{k_r}^r\}
\end{align*}$$

where $e$ and $r$ are the numbers of the first and last sets included in the $A_{TS}[k]$. For a NTS, the state vectors for set $A_{NTS}[k]$ is defined as:

$$\begin{align*}
    &\{a_1^l, a_2^l, \ldots, a_{k_1}^l\} \\
    &\{a_1^n, a_2^n, \ldots, a_{k_n}^n\}
\end{align*}$$
After calculating all the vectors for the sets, it is necessary to calculate the matrices. Matrices, unlike vectors, are set by time points - the values of the q-th year, when the parameters were changed. Time is set as \( t = \bar{t}, z \), where \( z \) is the last time point in the q-th year. From here we get the general view of the matrix:

\[
A_q[k] = \begin{pmatrix}
a_{11}^{qt_1} & a_{12}^{qt_2} & \cdots & a_{1k}^{qt_z} \\
a_{21}^{qt_1} & a_{22}^{qt_2} & \cdots & a_{2k}^{qt_z} \\
\vdots & \vdots & \ddots & \vdots \\
a_{k1}^{qt_1} & a_{k2}^{qt_2} & \cdots & a_{kk}^{qt_z}
\end{pmatrix}
\]

where \( t_1, t_2, \ldots, t_z \) are numbers of time points (months) in the q-th year,

\[
a_{11}^{qt_1}, a_{12}^{qt_2}, \ldots, a_{1k}^{qt_z}
\]

\[
a_{21}^{qt_1}, a_{22}^{qt_2}, \ldots, a_{2k}^{qt_z}
\]

\[
\vdots \ldots \vdots
\]

\[
a_{k1}^{qt_1}, a_{k2}^{qt_2}, \ldots, a_{kk}^{qt_z}
\]

are values of time points (months) in the q-th year,

\[
a^{qt_1}, a^{qt_2}, \ldots, a^{qt_z}
\]

\[
k_1, k_2, \ldots, k_z \] are number of influencing factors in vectors.

For a natural subsystem, the matrix is defined as:

\[
A_{NS}[k] = \begin{pmatrix}
a_{11}^{it_1} & a_{12}^{it_2} & \cdots & a_{1k}^{it_z} \\
a_{21}^{it_1} & a_{22}^{it_2} & \cdots & a_{2k}^{it_z} \\
\vdots & \vdots & \ddots & \vdots \\
a_{k1}^{it_1} & a_{k2}^{it_2} & \cdots & a_{kk}^{it_z}
\end{pmatrix}
\]

where \( i, j \) are number of vectors \( A_i, A_j \).

For a natural subsystem, the matrix is defined as:

\[
A_{TS}[k] = \begin{pmatrix}
a_{11}^{et_1} & a_{12}^{et_2} & \cdots & a_{1k}^{et_z} \\
a_{21}^{et_1} & a_{22}^{et_2} & \cdots & a_{2k}^{et_z} \\
\vdots & \vdots & \ddots & \vdots \\
a_{k1}^{et_1} & a_{k2}^{et_2} & \cdots & a_{kk}^{et_z}
\end{pmatrix}
\]

where \( e, r \) - number of vectors \( A_e, A_r \).

For a NTS, the matrix is defined as:

\[
A_{NTS}[k] = \begin{pmatrix}
a_{11}^{kt_1} & a_{12}^{kt_2} & \cdots & a_{1k}^{kt_z} \\
a_{21}^{kt_1} & a_{22}^{kt_2} & \cdots & a_{2k}^{kt_z} \\
\vdots & \vdots & \ddots & \vdots \\
a_{k1}^{kt_1} & a_{k2}^{kt_2} & \cdots & a_{kk}^{kt_z}
\end{pmatrix}
\]

where \( a^1, a^2, a^k \) are the numbers of the vectors, respectively \( A_{NS}, A_{TS}, A_q[k] \),

\( k_n \) is the number of influencing factors in the vector \( A_{NTS} \).

To evaluate the given matrices, it is necessary to determine the specific weight of each set. The values obtained by the method of expert assessments are used as the specific weights of the influencing factors. The general formula for calculating the specific weight of the parameters of the q-th set is defined as:

\[
Y_{A_q} = \frac{\sum_{j=1}^{k_i} \beta_i^{(j)} a_i^{k_i}}{\sum_{j=1}^{k_1 + \cdots + k_n} \left( \beta_1^{(j)} a_1^{k_1} + \beta_2^{(j)} a_2^{k_2} + \beta_n^{(j)} a_n^{k_n} \right)}
\]

where \( \beta_1^{(j)}, \beta_2^{(j)}, \beta_n^{(j)} \) is the value of specific weights for the i-th, j-th, n-th sets,

\( k_1 + \cdots + k_n \) is the sum of the dimensions of the sets;
\( k_j \) is the dimension of the \( j \)-th set.

Based on the data on the specific weights of the influencing factors, the specific weights in vectors and matrices are calculated, an assessment of the influence of each set on the NTS, NS and TS is given. This will ultimately allow predicting its changes of NTS.

3. Results

In the course of the study, a software product was implemented that automated the application of the above mentioned model. The summary table of the influence of factors on the NTS obtained after expert assessment is given in Table 1. These data are used to make a forecast.

Table 1. Summary table of the influence of factors on the NTS.

| Parameter name                                      | Influence of factors on the NTS |
|-----------------------------------------------------|---------------------------------|
|                                                     | \( A_1 \) | \( A_2 \) | \( A_3 \) |
| Average water level along the length of the reservoir, m | 2        | 3        | 2        |
| Inflow, \( m^3 / s \)                                | 3        | 2        | 2        |
| Total water consumption, \( m^3 / s \)              | 1        | 1        | 1        |
| Discharge through spillways, \( m^3 / s \)          | 1        | 1        | 1        |
| The amount of precipitation, mm                     | 1        | 1        | 1        |

To test the operation of the software, we used the statistics of changes in various indicators of the Novosibirsk HPP for the period from 2018 to 2020 [9]. The following parameters were taken as the average water level along the length of the reservoir, daily water inflow, total water consumption (including discharges), the amount of precipitation in the radius of the hydroelectric power station and its reservoir. Each indicator was taken over equal periods of time. Using the data presented above, the values of the vectors of the sets, as well as the matrices of the sets, were obtained. The data were visualized using the graphs of the correlation of indicators, after which a diagram of the influence of each factor on the NTS and its components was formed. The result of the software is a predictive assessment of the influence of each factor on the NTS. Figure 1 shows a screen form with an example of the assessment of the condition of the NTS.

Figure 1. Screen form of the software
The program window shows a summary diagram of the influence parameters, which shows how much each of them affects the NTS and its subsystems. The final forecast reflects expert assessments and the calculation of the specific weight for the selected parameter for the reporting period.

The software product is designed to perform the following tasks:

- ensuring the ability to track all the necessary parameters of studied NTS;
- creation of a matrix mathematical model of the influence of each factor on the NTS;
- creation of a predictive assessment of changes in NTS based on a matrix mathematical model;
- creation of graphical and textual reports on influencing factors.

4. Conclusion

This paper was devoted to a relevant research topic in the field of computer modeling of natural-technical systems. The paper presented a software product that implemented the modeling of changes in the NTS with a power facility. The experiment was made to evaluate the performance of the program on existing NTS using statistical data from 2018 to 2020.

The implemented software product used a matrix mathematical model for assessing the change in NTS under the influence of external and internal factors. The developed program was applicable for monitoring changes in the state of NTS in research organizations. The plans for the development and expansion of the chosen subject area included investigating the impact on the quality of forecasting data for various NTS using combined forecasting methods.

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