UDC 69:002; 69.059

Integrated models of forecasting reliability of decision making of the system of diagnostics of the technical condition of buildings

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Received: 25.02.2025; Accepted: 28.02.2025
https://doi.org/10.32347/gbdmm.2025.105.0501

Abstract. Elements and structures of buildings differ in varying degrees of complexity and uncertainty of the technical condition, as well as a significant number of factors leading to their physical wear, deformation, defects and damage. Information on building defects shall be presented in the form of examination and diagnostics results. Determining the relationship between defects and the causes of their occurrence, predicting the consequences of these defects on the subsequent technical condition of the object is a multifactorial task, therefore, requires detailed study.

This study highlights issues related to the methods of examination and analysis of the causes of detection of damage to the diagnosis of the technical condition of buildings and structures. The information technology of the decision support system has been further developed, which is based on powerful analytical tools that allow experts to make more plausible assessments and management decisions.

The conducted studies allow us to propose an approach to solving the problem of choosing a particular model that describes the change in the dynamics of measured data due to aging and wear of structures, allows us to reasonably choose the degree of complexity of the model, which ensures the highest accuracy of the forecast since the onset of the damaged state.

Keywords: integrated models, diagnostics of technical condition, information technology, forecasting of decision-making reliability.

INTRODUCTION

Currently, the most actively used algorithms for predicting the timing of the operational suitability of buildings, based on the use of methods of mathematical statistics, pattern recognition theory and synergetics. A distinctive feature of these algorithms is to identify the time characteristics of the reliability indicators of the calculated parameters.

The most informative parameters characterizing the level of technical condition of buildings are the stressed state of building elements. In general, the level of complexity of the approximating function depends not only on the variable itself, but also on the level of the noise component of the measurements and the sample size [1, 2].

The choice of a particular model describing changes in the indicators of the reliability of the technical state is the most responsible and complex stage of the prognostic procedure.

Simplification of the model leads to a decrease in the accuracy of predicting the time of occurrence of operational suitability of buildings. Excessive complication of the model can lead to instability of the identification algorithm and deprives the identification models of prophetic power. In addition, it is necessary to take into account that the degree of complexity of the model depends not only on the identified parameter, but also on the level of error of the primary measurements [3, 4].

The actual multi-criteria task of choosing the optimal degree of complexity of models describing the change in the reliability indicators of buildings is presented [5].

When choosing a method for solving the problem, two additional conditions arise.

The first model should correspond to the predictive properties, that is, when extrapolated for a certain period of time, its value should not "get loose." This condition imposes restrictions on the degree of complexity of functions – for a too complex model, small measurement errors that are not noticeable at the interpolation interval can radically change the behavior of the model function at the prediction stage.

Secondly, we assume that the amount of data sample by which the model is built is small. This is due to the fact that the most reliable information is stored in databases of modern information systems, covering a time interval of 5-6 years.

The complexity of the problem of optimal choice of an approximating function describing a particular change in the performance of buildings is aggravated by measurement errors, which manifest themselves as the imposition of noise on the coordinates of experimental points.

Analysis of the presented empirical data shows that the dynamics of data change before different types of damage differs radically [6-8].

Indeed, using one or more classical criteria (minimum adequacy variance, Theil's criterion) and the scheme of the standard least squares method, it is possible to build a model with the desired degree of accuracy without violating the Poincaré principle (the accuracy of the model cannot exceed the accuracy of the primary information). However, this does not provide a solution to the predictability of the problem – determining the moment of damage, since the best model at the training stage is not always a more accurate extrapolation of the future development scenario.

Let's give this as an example of the forecast of the moment of damage. Preliminary selection of elementary functions describing such behavior of experimental curves showed that polynomial dependencies are most accurate (in the sense of adequacy variance).

Analysis of the results shows that the prediction error of the moment of damage occurrence by the linear model is 56%, the polynomial of the 3rd degree 14%, the polynomial of the 2nd degree 2%. At the same time, the magnitude of the adequacy variance of these models at the training stage is almost the same. Thus, it becomes obvious the need to use additional methods of data processing, fully realizing the information capabilities of systems.

PRESENTING MAIN MATERIAL

According to the dynamics of the stress data of the bearing structures of buildings for a certain period of time, it is necessary to build the best model for the development of the defect according to two criteria – the accuracy of approximation plus the accuracy of the forecast.

The most effective tool for solving such problems is the method of structural minimization of average risk. We adapt this method to the conditions of our problem [9].

The information database of the system stores many local databases, $\{x_i\}$, each of which is a retrospective time series of changes in the operation indicator over time i=1,2,...,L, where L is determined by the frequency of polling the primary sensors.

Suppose that based on the analysis of these data arrays, models of the form $y=y(x)$ are built (in the case under consideration $Q=Q(t)$, where $Q(t)$ is the change in the stress state due to the wear of structures, t is time). In this case, at the disposal there is a sample of $\{x_i, y_j\}$, where y_j y – model value of the function corresponding to the experimentally measured value of the parameter x_i.

Given that experimental data are always measured with some error, we introduce into consideration the obstacle of measuring ε_i. Then the model sought will take the final form:

$$y = F(t_i) + \varepsilon_i . \tag{1}$$

Assuming that the class of functions in which the regression $y(x)$ is sought is parametric with parameters a, the problem can be reduced to minimizing the functional of empirical risk:

$$I_o(a) = \frac{1}{L}\sum_{i=1}^{L} (y_i - F(x_i, a))^2 , \tag{2}$$

where y_i – model value of parameter with consideration of measurement interference; $F(x_i, a)$ – modeling function; L – the size of the measurement sample is determined by the frequency of polling the primary sensors.

For criterion (2), upper estimates of the type can be obtained [6]:

$$I(a) \le I_m(a) = I_o(a)\Omega(\frac{1}{h}, \frac{l_{n\eta}}{L}), \quad (3)$$

valid with probability $1-\eta$. The value of h is the capacity of the class of functions $F(x_i, a)$ and determines the complexity of the identified model. In particular, if we consider the class of functions linear in parameters:

$$F(x,a) = \sum_{i=1}^{n} a_i \psi(x), \quad (4)$$

where $h = n$, that is, the capacity of the function class (model complexity) is equal to the number of desired parameters n.

The $1/\eta$ value determines the relative sample size. The structure of the second multiplier (3) is such that with an increase of $1/h$ the value decreases, tending to unity.

Functional (2) with increasing $1/h$, as a rule, increases. Therefore, there is some optimal value of $1/h$ at which the upper estimate of the average risk (its guaranteed value) reaches a minimum. This value is $1/\Omega$ determines the optimal complexity of the desired function.

As recommended for regression recovery in the function class (4) we use the value of Ω:

$$\Omega = \left[\frac{1}{1 - \sqrt{\dfrac{n(l_n \frac{1}{n} - l_{n\eta})}{L}}} \right]; \quad (5)$$

$$[Z]_\infty = \begin{cases} z, z \ge 0 \\ \infty, z \le 0 \end{cases}. \quad (6)$$

The paper notes that the solution of the dual problem can be obtained by using sufficiently large samples of experimental data (volume $L > 20$ measurements). In the case of further development of defects and in the construction of appropriate models, this requirement is not met, and the method of the decision-making system becomes too coarse, deliberately preferring simpler models. The most effective results for overcoming such difficulties in some cases can be achieved by involving methods of fuzzy set theory.

In relation to the problem, under the concept of belonging to an object, we will understand the values $\{y_j\}$ calculated using different models (i – the number of models under consideration) [10, 11].

A fuzzy set A in U is a collection of pairs of the form $(u, \mu_A(u))$, where – $u \in U, \mu_a(u)$ is the membership function of a fuzzy set A. the proximity of the function $\mu_A(u)$ to 1 is a quantitative measure of the certainty that the element belongs to set A.

Using the concepts of the theory of fuzzy sets allows us to reduce the search for a stable solution of a multi-criteria problem to the problem of finding the extremum of the membership function, which is defined as:

$$\mu(a,n) = (\mu_o(I_o(a,n))\mu_o(n))^{0,5}, \quad (7)$$

where $\mu_o(I_o)$ and $\mu_o(n)$ – fuzzy set membership functions "small empirical risk values" and "small model complexity". These functions can be defined as follows:

$$\mu_o(I_o) = \psi(\frac{I_o}{I_i}, m_1), \quad (8)$$

$$\mu_o(n) = \psi(\frac{n}{0{,}5L}, m_2), \quad (9)$$

$$\psi(t,m)=\begin{cases}1-t^{m}, 0\le t\le 0\\ 0, t\succ 0\end{cases}, \qquad (10)$$

where L_i – the value of the functional of empirical risk corresponding to the number of parameters m_1 and m_2 – indicators of the degree that determine the ratio of the algorithm to the reduction of empirical risk and the increase in the complexity of the model.

As an information array for building the best model for predicting the moment of damage, we will use a 30-day measurement of data, and polynomials are considered as competing hypotheses. The results of the calculations are presented in Table 1.

The least squares method recommends the maximum degree of complexity of the approximating function. This is understandable, since the least squares method seeks to minimize the deviation of experimental points from the approximating dependence, and this is realized only at maximum polynomial complexity. The decision system method allows the use of an interpolating polynomial with degrees n=1 and n=2, while the methods of fuzzy set theory uniquely indicate that the polynomial degree n=2 is optimal, which fully confirms the reliability of the results.

Table 1. Rationale for choosing the most appropriate prognostic model for determining the moment of onset of the damaged state

Complexity of the model	Optimal complexity model selection criterion		
n=1	0,024	0,0124	3,44
n=2	0,020	0,0124	2,48
n=3	0,014	0,0126	2,63

Numerical evaluation of the "predictive ability" of the considered models was carried out on the basis of determining the values of the standard deviations of the experimental points from the corresponding model functions, which determines the accuracy of the forecast. In our case, the values of standard deviations are 1,24, 0,26 and 2,31 for polynomials of the first, second and third degree, respectively. Therefore, it is obvious that the prediction ability is highest in a polynomial of the second degree, which coincides with the conclusion obtained on the basis of the theory of fuzzy sets.

Analysis of the obtained results indicates that the proposed method for determining the optimal complexity of the model allows obtaining the highest accuracy of the prediction of the moment of damage. In all cases considered, the increase in forecast accuracy is 20-30%.

It should be noted that the difference in the choice of the model recommended by the decision system method and the methods of fuzzy set theory increases with a decrease in the sample size of data measurements. With sufficiently large samples (usually $L > 20$), the results of calculations for both methods practically coincide.

CONCLUSION

The studies conducted allow us to conclude that the proposed approach to solving the problem of choosing a particular model describing the change in the dynamics of measured data due to aging and wear of structures allows us to reasonably choose the degree of complexity of the model, which provides the highest accuracy of the forecast since the onset of the damaged state.

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Інтегровані моделі прогнозування надійності прийняття рішень системи діагностики технічного стану будівель

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Анотація. Елементи та конструкції будівель відрізняються різним ступенем складності і невизначеності технічного стану, а також значною кількістю чинників, що призводять до їх фізичного зносу, деформацій, дефектів та пошкоджень. Інформація про дефекти будівлі має бути представлена у вигляді результатів обстеження та діагностики. Визначення зв'язку між дефектами та причинами їх появи, прогнозування наслідків цих дефектів на подальший технічний стан об'єкту є багатофакторним завданням, тому потребує детального вивчення.

Дане дослідження висвітлює питання, що пов'язані з методами обстеження та аналізу причин виявлення пошкоджень діагностики технічного стану будівель і споруд. Отримало подальший розвиток інформаційна технологія системи підтримки прийняття рішень, яка базується на потужних щодо інтелектуалізації аналітичних засобах, які дозволяють експертам приймати більш правдоподібні оцінки та управлінські рішення.

Проведені дослідження дозволяють запропонувати підхід до вирішення завдання вибору тієї чи іншої моделі, що описує зміну динаміки виміряних даних внаслідок старіння та зносу конструкцій, дозволяє обґрунтовано вибирати ступінь складності моделі, що забезпечує найвищу точність прогнозу з моменту настання пошкодженого стану.

Ключові слова: інтегровані моделі, діагностика технічного стану, інформаційна технологія, прогнозування надійності прийняття рішень.