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Quality Assessment of "Stress-Strength" Models in the Conditions of Big Data

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Abstract: ***The conceptual approach to assessing the quality of complex structural systems based on the large data generated during the monitoring of structures of controlled objects is justified. The methodological basis of the proposed study is the big data analytics, the methods of processing unstructured information, the technology of representing the process of changing structures of complex objects in the form of a Markov's type sequence, as well as methods of statistical analysis. It is proposed: to structure monitoring data by time slices (in the form of subsets of "stress" level measurements of controlled parameters) corresponding to a certain stage of the object's life cycle; to simulate a change in the structure of an object in the form of a dichotomous Markov chain; on the basis of the "stress-strength" model, to evaluate probabilistic quality indicators of the structural state of the controlled object, while the indicator of the transition from state to state is the fact that the level of "stress" exceeds the value of "strength". The study of the "stress-strength" model is reduced to the problem of finding the extremum of a definite integral with equality constraints, which is one of the isoperimetric problems. The results can be used in decision support systems during the structural analysis of complex systems. The effectiveness of the investigation is confirmed by a numerical example.***

Index: Terms: Big Data, Quality Indicator, Cumulative Distribution Function, Extreme Estimates, Moments.

I. INTRODUCTION

Data mining has extensive applications in business, in communication technologies, in particular in social networks, in search engines, in forecasting, in machine learning, and in other areas. However, more and more often for a number of practical problems there is a need for an integrated approach: a combination of data mining with traditional research methods. In this case, the collection, preliminary analysis of data with their preprocessing, recovery of possible omissions caused by data loss becomes the prerogative of data mining.

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So for the Statistical Analysis System (SAS) Institute approach in the form of SEMMA methodology (including stages "**S**ample" → "**E**xplore" → "**M**odify" → "**M**odel" → "**A**ssess"), these are steps up to the modeling stage (Model).

Big data analysis technologies are developing both in the direction of creating new computational methods based on existing classes of algorithms (neural networks, genetic algorithms, rule induction, case reasoning, and so on) and in the direction of preliminary structuring of the data itself, for example, due to data clustering, which in some cases increases the efficiency of solving target problems.

The purpose of this article is based on the ideas of conceptualization of the subject area – big data to show the possibility of using preprocessed big data to solve the problems of assessing the quality of complex technical and information systems.

II. CONCEPTUALIZATION OF RESEARCH

The work [1] presents a wide range of applications of big data analysis methods thanks to advanced technologies (e.g. NoSQL databases, Hadoop, wibidata, and Skytree and others) to extract new knowledge. As a result of the conceptual approach, researchers form a common value-semantic platform of actions aimed at extracting new knowledge from data [2], taking into account structural complexity of data (a variety of data formats), as well as the requirements for reducing the time of analysis, the need for pre-processing of data. However, in some cases, a significant part of the data remains unclaimed for further knowledge extraction, as it requires the development of new methods for extracting semantic features from unstructured datasets [3].

The structure of the proposed conceptual scheme in the form of *stages A-D* is shown in Fig. 1. The contents of the stages correspond to the sections A-D of the same name given below.

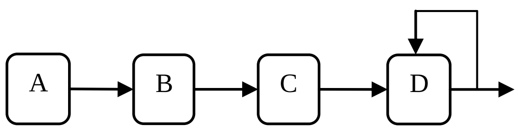

Fig. 1. The structure of the conceptual scheme

A. Big Data

Big data (BD) research is expanding its sphere of influence every year. In the 70-80s, these were highly specialized tasks for complex computer systems control [4] dynamic objects (aerospace direction) [5] with centralized information systems [6] or decentralized construction of information structures [7].

With the development of the direction of BD, they were actively used in medicine, biology, business, industry, science and in a number of other areas [1].

And if earlier researchers complained about the limited amount of data, which is often not enough, but now they are looking for ways to effectively reduce them due to restrictions, for example, on data warehouses [7].

Let's use Gartner's definition of BD as “a collection of high-volume, high-velocity and/or high-variety information assets that demand cost-effective, innovative forms of information processing that enable enhanced insight, decision making, and process automation” [8].

Therefore the following operations are important for BD:

- *editing* - at detection and processing of anomalies;
- *linking* data and *consistency* them with other data sets;
- *generating* of data sets depending on the described economic or social phenomena [9], including in the conditions of existing risks of influence of external and internal factors on infrastructure of systems [10] and on a signal (content) component of network intersystem communications, for example, in problems of preparation and conduct telemetric measurements [11].

B. Big Data Opportunities and Trends

Effective risk management, able to identify, assess, rank and prioritize risks, is based on a sustainable infrastructure, modern analytics and reliable data [12], interconnected in the process of solving targets, which can be represented in the following form (see Fig. 2).

Fig. 2: Structure of effective risk management

Infrastructure will be identified with hardware, communication equipment and related organizational support.

Analytics combines software and mathematical support of information processes, including modelling and analysis of results.

Data includes extensive input analysed information, we combine the concept of Big Data, as well as the results of analysis and modelling.

The optimal strategy in data mining sphere for today is determined the successful for most of all companies on future. Surveys have identified the most popular areas in which data mining (DM) has a positive impact on their business (Fig. 3) [13].

One of the problems of BD analytic is to develop effective indicators to assess the quality of the analyzed data [14]. For this purpose, data mining and machine learning methods [15] are actively developed, which include the following -

(i) Clustering,
(ii) Classification,
(iii) Association Rules,
(iv) Regression,
(v) Sequential Patterns,
(vi) Prediction.

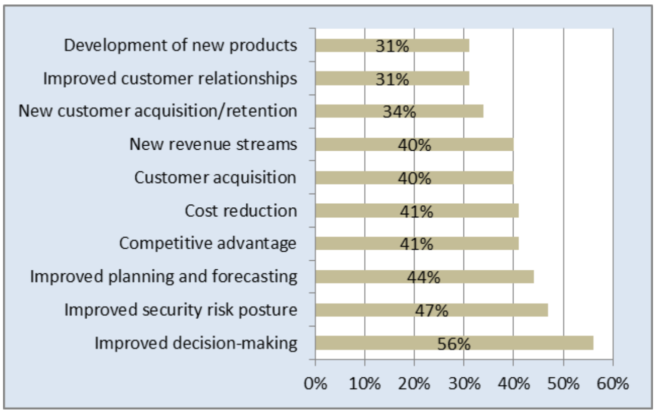

Fig. 3: Most popular ways that DM positively impacts on the businesses

In this paper, we will consider the problem of grouping the initial set of data only in the formulation plan, denoting the problem, focusing on probabilistic estimates of quality indicators on the selected data segments.

C. Changing Structures As Markov Chain

Suppose that the entire array of measurement information obtained as a result of monitoring a complex object of control (architectural structure, remote robotic object) is structured depending on the data type as D_i , $i = \overline{(1, n)}$, where n is the total number of data partition classes. The described actions correspond to the *stages*: *A* – database formation and *B* – data segmentation by accepted features (temporary, technological or constructive), (see Fig. 1). The composition of D_i includes the vectors of 'stresses' of the corresponding structural elements of the construction – Y_i components of which components are random variables, and the corresponding vector of random parameters X_i, representing the 'strength'.

One of the ways of formation of D_i is temporary. It is always possible to select a group of parameters with the same periodicity of control and whose state determines the structure of the construction – s_i that also called index of the structure. s_i – discrete-time Markov chain with a finite number of states,

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with the probability of transitions $p(s_{i+1} \mid s_i)$ from the structure s_i to the structure s_{i+1} [16]. In the simplest case, s_i, $s_{i+1} = 1, 2$, which corresponds to the structures 'norm' and 'not norm', which will be characterized by the failure of the structural element. Monitoring the state of the structure corresponds to *stage C* (Fig. 1)

The relation between 'stress' and 'strength' in technology is one of the decisive factors in the occurrence of failures.
In some cases, a measure of quality is the probability that one random variable is larger than another random variable.

D. "Stress-Strength" Models

The models in which such indicators are analyzed are called "stress-strength" models. Such models were considered in [17], [18], a number of various applications for stress-strength models can be found in the monograph of Kotz et al. [19], where a fairly complete analysis of the stress–strength models state is given, it is assumed that there is complete information about each of the random variables.

The calculation of probabilistic indicators for the "stress-strength" models corresponds to *stage D* (Fig. 1), which acts as a control feedback to *stage C*.

Such models are used in various fields, including engineering statistics, where it is also called the load-bearing capacity model [20], investment management [21], reliability analysis of complex architectural structures, in problems of analysis of supply and demand correspondence, including in the conditions of big data [22], as it is necessary to take into account data on vibrations, temperatures, reliability, seismic resistance of buildings, and so on.

III. STRESS-STRENGTH SIMULATION OPTIMIZATION METHOD

In stress-strength simulation, the reliability is determined by using the known the following equation [19], [20] -

$$R = P(X > Y) = \int_0^\infty (1 - F(t))\, dG(t), \tag{1}$$

where X and Y are independent random vectors, such that X represents the 'strength' of the system (construction), and Y is the 'stress', which is subjected to this structure, notation ith for simplicity, hereinafter omitted; $F(t)$ and $G(t)$ is known up to k fixed-end moments cumulative distribution functions (CDF) for X and Y respectively.

If at some point in time the applied 'stress' (or load) exceeds the 'strength', the structural element (component) will fail. We can consider 'stress' as a function of the environmental impact on the structure under study.

Let us represent CDF $F(t)$ and $G(t)$ as the following sets

$$\mathrm{F}_0 = \left\{ F(t) : \int_0^\infty t^j \, d\,F(t) = m_j,\ j = \overline{1,k} \right\}, \tag{2}$$

$$\mathrm{G}_0 = \left\{ G(t) : \int_0^\infty t^j \, dG(t) = \mu_j,\ j = \overline{1,k} \right\}. \tag{3}$$

Where m_j, and μ_j are the j-th moments of the CDF $F(t)$, and CDF $G(t)$, respectively.

It is required to find the extremal assessment for the selected quality indicator (1), provided that $F(t) \in \mathrm{F}_0$, $G(t) \in \mathrm{G}_0$, as follows form

$$R_{ext} = \max_{\mathrm{F}_0, \mathrm{G}_0} P(X > Y) \tag{4}$$

In other words, it is necessary to find the extremum of a definite integral from equation (1), under the conditions when $F(t)$, and $G(t)$ are continuously differentiable functions defined on the intervals $[0, t_f]$, and $[0, t_g]$, respectively. Under these conditions, the problem of finding the extremum of a definite integral is one of the isoperimetric problems [23]. To solve it, the Lagrange variation method is used.

Assuming that there is a solution to the problem, then we apply the Lagrange principle to the hypothetical solution, define the saddle points, and examine them for a minimum or maximum by comparing them with known results.

A. Calculation of Lagrange Multipliers

The CDF $F(t)$ and $G(t)$ must satisfy the Euler system of differential equations [24]:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial F'(t)}\right) - \frac{\partial L}{\partial F(t)} = 0,$$
$$\frac{d}{dt}\left(\frac{\partial L}{\partial G'(t)}\right) - \frac{\partial L}{\partial G(t)} = 0.$$

Where $F'(t) = {dF(t)}/{dt}$, $G'(t) = {dG(t)}/{dt}$,

L is a Lagrangian defined for $F(t)$ and $G(t)$, respectively, by the following relations

$$L = G(t)F'(t) + \sum_j \lambda_j t^j F'(t) + \sum_j \eta_j t^j G'(t),$$
$$L = (1 - F(t))G'(t) + \sum_j \lambda_j t^j F'(t) + \sum_j \eta_j t^j G'(t).$$

Where λ_j, and η_j, $(j = \overline{1,k})$ – are undefined Lagrange multipliers.

After performing the corresponding differentiations and taking into account the initial conditions $F(0) = 0$, $G(0) = 0$, we obtain the following equations

$$F(t) = \sum_j^k \eta_j t^j, \quad 0 \le t \le t_f, \tag{5}$$

$$G(t) = -\sum_j^k \lambda_j t^j, \quad 0 \le t \le t_g, \tag{6}$$

following which, we calculate m_l, and μ_l

$$m_l = \sum_j^k \frac{j}{j+l} \eta_j t_f^{j+l}, \quad l = \overline{1,k}, \tag{7}$$

$$\mu_l = -\sum_j^k \frac{j}{j+l} \lambda_j t_g^{j+l}, \quad l = \overline{1,k}. \tag{8}$$

The values t_f, and t_g are determined from the conditions $F(t_f)=1$, $G(t_g)=1$, respectively.

Consider the case when $F(t)$ and $G(t)$ are known up to the final 1st moment (Expected value). After performing the necessary transformations, we find the CDF that the extremum of the quality index by equation (1) is reached

$$F(t)=\frac{t}{2m_1},\ 0\le t\le 2m_1, \tag{9}$$

$$G(t)=\frac{t}{2\mu_1},\ 0\le t\le 2\mu_1. \tag{10}$$

When $t_f < t_g$, or $m_1 < \mu_1$, and using (9) and (10) we calculate

$$R_{ext}=m_1/2\mu_1. \tag{11}$$

For the case when $F(t)$, and $G(t)$ are exponential CDF with Expected value m_1, and μ_1, respectively, then

$$R_{ext}=m_1/(m_1+\mu_1).$$

When $t_f \ge t_g$, or $m_1 \ge \mu_1$ we calculate

$$R_{ext}=1-\mu_1/2m_1.$$

For the case when the first two moments of the distribution are known, and taking into account equations (5), and (6), undefined Lagrange multipliers can be determined by solving the following system of equations (12)

$$\begin{cases} \eta_1=26m_1/5t_f^2-8m_2/5t_f^3 \\ \eta_2=18m_2/5t_f^4-12m_1/5t_f^3 \\ \lambda_1=24\mu_2/t_g^3-18\mu_1/t_g^2 \\ \lambda_2=12\mu_1/t_g^3-18\mu_2/t_g^4 \end{cases} \tag{12}$$

B. Formalization for Domain of CDF

Let's define the upper bounds of the domains of definitions of CDF $F(t)$ and CDF $G(t)$.

We define the form of the functions $F(t_f)$, and $G(t_g)$ by solving the differential equations (5) and (6):

$$\frac{dF(t)}{dt}+\lambda_1+2\lambda_2 t=0$$
$$\frac{dG(t)}{dt}-\eta_1-2\eta_2 t=0$$

by integrating which for starting conditions ($F(0)=0$ and $G(0)=0$) are calculated $F(t_f)$ and $G(t_g)$:

$$F(t_f)=\left(\frac{26m_1}{5t_f^2}-\frac{8m_2}{5t_f^3}\right)t+\left(\frac{18m_2}{5t_f^4}-\frac{12m_1}{5t_f^3}\right)t^2, \tag{13}$$

$$G(t_g)=\left(\frac{24\mu_2}{t_g^3}-\frac{18\mu_1}{t_g^2}\right)t+\left(\frac{12\mu_1}{t_g^3}-\frac{18\mu_2}{t_g^4}\right)t^2. \tag{14}$$

Solving the equations (13), and (14) we get the following values t_f and t_g:

$$t_f=1{,}4m_1+\left(1{,}96m_1^2+2m_2\right)^{1/2}, \tag{15}$$

$$t_g=\left(9\mu_1^2+6\mu_2\right)^{1/2}-3\mu_1. \tag{16}$$

IV. RESULTS AND DISCUSSIONS

The resulting expression for the extreme evaluation of the quality indicator R_{ext} (for $t_g \le t_f$) we get from the (8), (5) and (6)

$$R_{ext}=1+\frac{\eta_1\lambda_1 t_g^2}{2}+\frac{2}{3}t_f^3(2\eta_2\lambda_1+\eta_2\lambda_1)+\frac{\eta_2\lambda_2 t_g^4}{2}.$$

Where

$$t_g=t_{g\min}=\frac{18\mu_1 t_g^2-24\mu_2 t_g}{12\mu_1 t_g-18\mu_2}-t_g.$$

The dependences of the extreme estimation of the R_{ext} quality index on the first moment m_1 at different values of the second moment m_2 are shown in Table 1.

Table 1: Values evaluation of the R_{ext} quality indicator from the first moment m_1

1st moment m_1	R_{ext}		
	m_2=1,5	m_2=2,0	m_2=3,0
0,2	0,48	0,58	0,68
0,4	0,73	0,76	0,815
0,6	0,89	0,895	0,897
0,8	0,92	0,93	0,933
1,0	0,94	0,945	0,948

In Table 2 for the probability (1), the dependences of the values of the extreme estimates of the quality index in comparison with the normal distribution are shown as functions of the 1st moment of the distribution of the random variable X at different values of the 2nd moments of the distributions. Note that when getting estimates, the expressions for calculating R_{ext} are selected depending on the relationship between t_f, and t_g.

Table- 2: Comparison estimates of the quality index: R_{ext} and the normal distribution – R_G

Quality index	1st moment m_1					
	0,2	0,25	0,5	0,75	1,0	2,0
R_{ext}	0,24	0,53	0,82	0,91	0,93	0,95
R_G	0,42	0,47	0,53	0,61	0,63	0,83

The obtained relations for calculating R_{ext} are based on the finite CDF $F(t)$, and CDF $G(t)$, which are bounded on the right by the values t_f, and t_g.

The calculations take into account that for Gaussian law of random variables X and Y, the probability value (1) is equal to:

$$P(X > Y) = 0{,}5 + \Phi\left(\frac{m_x - m_y}{\sigma_x^2 + \sigma_y^2}\right).$$

Where Φ is the Laplace function,

σ_x^2, σ_y^2 – variances of random variables X and Y,

m_x, m_y – expected value of X and Y.

The dependence between the 2nd moment of the Gaussian law and the variance is also taken into account:

$m_{2_x} = \sigma_x^2 + m_{1_x}$.

Thus, knowledge of a priori information about the form of the distribution function of the observed random variables allows us to increase the sensitivity of models.

V. CONCLUSION AND FUTURE STADY

The proposed conceptual scheme of structural analysis of big data for structures of complex objects includes a composition of methods for identifying the state of the structure and calculating probabilistic indicators for "stress-strength" models.

Knowledge of the dynamics of changes of the first moments of the studied random parameters of products allows you to predict and ensure the properties of strength and structural reliability of complex constructions.

Analysis of the simulation results shows that the proposed approach allows you to build models that are sensitive to data, on the basis of which we can carry out an adequate structuring of the data taking into account the probabilistic characteristics of the parameters ‘stress’ and ‘strength’.

The issue of developing methods for structuring (segmentation) of data sets for the tasks to be solved, taking into account the instability (skip) of data caused by various, including deliberate actions, becomes urgent.

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