INCREASING THE STABILITY OF A SPATIALLY DISTRIBUTED INFORMATION SYSTEM USING A ROBUST ALGORITHM FOR FILTERING ANOMALOUS MEASUREMENTS

Mikhail Vasilchenko, Alexey Zavyalov, Konstantin Zhuchkov

***Abstract*—The paper presents a solution to the problem of monitoring the operation of the spatially distributed information system, which processes an array of heterogeneous data. The algorithm is described for filtering out anomalous measurements of time delays in executing Oracle database procedures. The use of this approach in the information system for assessing the technical condition of technological facilities of Gazprom showed a significant gain in the quality of the system administration and allowed identifying "bottlenecks" in its operation. A mathematical model is described that includes both the noise component of the measured delay values and anomalous measurements caused by irregular external influences. A software module for filtering anomalous measurements based on the proposed algorithm has been developed, which increases the stability of the system and improves the quality of management decision-making in the corporation.**

***Keywords*—binary problem, database, information system, robust algorithm, statistical analysis, the anomalous measurements.**

I. INTRODUCTION

RELIABILITY and the safety of the industrial equipment requires constant technical maintenance, control over the technical properties, and repairs. Traditionally, the industry uses the system of preventive maintenance, which can provide a high level of reliability but is exceedingly costly [1, 2]. Currently many oil, gas, and infrastructure companies are improving the maintenance system, integrating the methods of proactive maintenance, based on the RBI (Risk Based Inspection) [3, 4], as well as the combined maintenance systems based on the RCM (Reliability Centred Maintenance) [5-7]. The aim is to maintain the high reliability indicators, that are characteristic for the systems of the preventative repair, in combination with the optimisation of the expenditure on the achieving the desired standard of reliability.

Practice shows, however, that the control over the reliability of the large production system, built upon the aforementioned systems is largely unrealistic without using the modern analytical systems of decision making in terms of technical maintenance and repair (Enterprise Asset Management - EAM Systems) [8, 9]. For the effective implementation these systems require the usage of the leading IT-technologies, mathematical, and algorithmic support. Oftentimes, developed corporate EAM Systems contain the information of the million counts of equipment, comprising a few dozens of the industrial subdivisions, and tens of thousands of active users. Modern EAM Systems turn into an effective decision-making instrument for the decisions, relating to the control of the product life cycle, which in turn:

- Cut the time of the delays when the management decisions have been made.
- Increase the quality of the management decisions on the account of having more extensive and effective control of the source data.
- Increase the demand and the effectiveness of the data usage for the technical diagnostics of the production objects of gas industry when taking the management decisions.

The main functions of the EAM Systems:

- Organize the collaborative work of the remote users.
- Support the consolidated system of the classification and identification of the technological objects.
- Conduct the support of the management and actualisation of the staff glossary and denomination of the technological objects.
- Accumulate information about the constructive performance of the equipment, and its real time condition.
- Conduct the prognosis of the technological condition of the object, determines the necessity and the optimal time to conduct work for the maintenance and repair.

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- Formulate the reports required in terms of company's business processes.

Over the long course of usage of the equipment in the oil and gas industry, a significant quantity of the unstructured technical information has been accumulated (the information of the equipment construction, usage information, repair logs and technical diagnostics, etc) Considering that the aforementioned data has been collected over the extensive period of time and usually has not been verified, effective usage of the EAM systems for the reliability control will require the creation of the effective algorithms for the filtration of anomalous technical data. The problem is present on different fields of the scientific and manufacturing disciplines [10-12] and for the solution of each specific problem a preliminary examination is required, as for the experience of the different fields, and for the nature of the occurrence of anomalous data.

Since 2001 in JSC Gazprom an EAM System is in place. The system has gone through the evolutionary development path from the program that solves the local data gathering tasks to the corporate program with strict rules and regulations, which were set by the Directive 196 on 29th of June 2009 "Regarding the approval regulation of collection, transfer, and processing of data about technological objects of gas industry, power equipment, and objects of JSC Gazprom in the information system of the evaluation of the technical condition of objects of JSC Gazprom. Novelty of the system is protected by the registrations of programs and databases of Federal Service for Intellectual Property (Rospatent). Primary system platform is Oracle database, geosubsystems, use Oracle Spatial© functions. The system collects and stores data about technological objects of the corporate energy facilities and its affiliates. Grand total over 1 million of the changes to the parameters is processed in one year. Reliability of the system is a major factor when making executive decisions in the corporation.

II. METHODS

A. System Description

Monitoring of the work for spatially distributed system JSC Gazprom (Fig. 1), represents a special technical task, where the correctness of the solution impacts the integrity and reliability of the entire system. Distribution in space [25-28] is defined by the globality of the corporate area (from Eastern Europe to the Far East) and has its own advantages and disadvantages. The advantages of such system include: each terminal works independently within the system, and possibility to work under low-speed data transfer. The primary disadvantage is the need to support lockstep synchronisation and common time systems.

The extent of the reach for the user base of the system (Administration of Gazprom, more than 60 affiliates, and more than 20 thousand active users), the authenticity of the information within the system, the level of security and the integration of the first private cloud service into JSC Gazprom, through the use of the Oracle and Microsoft experience reflect the scale of the project [13].

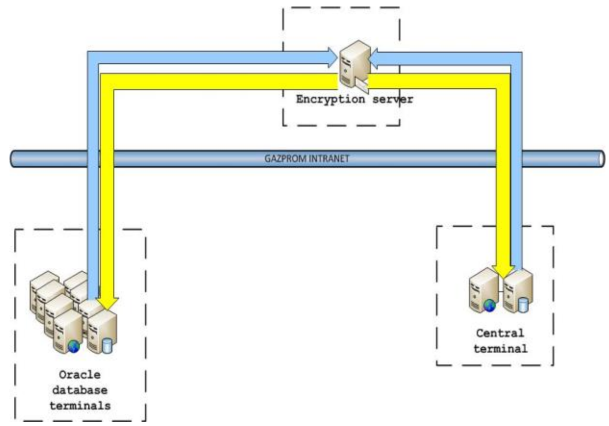

Fig.1. JSC Gazprom information system scheme in Intranet.

Until recently, business applications and corporate portal have been developed within the company in different programming languages. It led to the developers being specialized in only a narrow field and could not be interchanged and were unable to work on the related tasks. Besides, there were frequent major problems in the HR department. Yearly [14], 10 – 15 new employees were recruited, and over the span of few months, they were required to undertake the training in the skills and knowledge needed to operate and develop existing systems. With this taken into consideration, a decision was made to transition to a single platform, which is able to unify the development and control processes, and to ensure the transparency of the management projects, and in perspective was able to support the technology of the virtualisation and allowed the construction of the private corporate cloud. An example of construction of the private corporate cloud is thoroughly described in [29]

The company considered products of various vendors, carried out the pilot projects and finally, the decision was made to go with the Microsoft Platform. Microsoft contains multiple tools which are able to solve a broad range of tasks: The development environment of the Visual Studio © with the support of the C# programming

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language, instruments for the process management for the development of Team Foundation Server © (TFS) and project management of Project Server. In addition to that, on the structural level, it provided the means for virtualisation and construction of the private cloud and management of cloud resources Windows Server Hyper-V and System Centre [13,15].

To develop the information system core multiple examples of the database was used. In order to test the changes, developers and testers were required to temporarily block one of the database examples therefore creating the interference for their fellow colleagues. At the end of their work, environment did not return to its former state, and subsequent changes in the coding were being stacked on top of the previous. This has significantly complicated the testing and lowered reliability of the product.

Getting rid of the problems was possible by using the virtualisation. By creating the virtual machine based on the existing design, specialists were able to instantly able to acquire the typical isolated environment for the development and testing of the application using the minimum required resources. Through the private cloud it was possible to realise the processes in the self-service mode, further increasing its effectiveness.

A pool of resources for the targeted infrastructure of private cloud a fail-safe cluster was deployed under the control of Microsoft Windows Service Data Centre with Hyper-V Role ©. All virtual machines where the process environments or test benches are being executed are cluster services, and in case of fail or increased load on one node of the cluster they automatically redistribute on the other nodes.

System Centre Service Pack 1 controls the virtual machines and virtualisation server. Using the additional capabilities of Windows Server, Service Pack allows to utilize all functions of the private cloud:

- Self-service support of the users' queries is performed through the portal, that creates the request on the users' behalf, built on the foundation of System Centre Service Manager.
- Distribution of the resources is made through the deployment of the virtual Hyper-V machines on the computing virtualisation cluster resources and shared disk storage. In which, through the functions of dynamic disks and dynamic memory, the hardware resources are instead used only for the data required by the users.
- Flexibility – Depending on the load on specific test benches and development environments, they can have additional resources allocated to them, or have the load redistributed between the nodes of the cluster.
- Consumption accounting – the quotas are in place to consider and limit the amount of allocated resources used by a specific developer.
- Increased Accessibility – when one of the nodes of the cluster goes out of order, virtual machines automatically redistribute the load to the other nodes.

On the self- service portal of System Centre Service Manager, the user creates a request for the access to the test bench or the development environment. The properties state the template of the virtual environment along with programs and operation systems (POS). Based on this request, System Centre Orchestrator © launces a process to create the virtual environment in the System Centre Virtual Machine Manager and executes additional set up of the test bench to connect to a selected database. As a result, the user receives a virtual machine with the web server founded on Microsoft Internet Information Services and examples of the database. After the end of the testing process, it deletes the virtual environment using the same self-service portal. For administrator, a separate interface is set up, which allows to monitor cloud resources, properties of critical services, and equipment.

Implementation and the setup of the virtual environment have been done over the course of six months, and currently the setup of the corporate cloud based on it has been completed. To this day, all parts of the system from the development environment to project management exist locally, like separate "building blocks". With the help of the cloud, they are collected and are built into one. Distribution of the needed calculating power now happens quicker and is more transparent, not slowing down the process of the development and testing. Earlier, after the error was identified it is impossible to revert to the previous POS, since it affected results of multiple developers. Now, programmers and testers are working independently, not interfering with each other [14]. Product quality has been greatly increased and the deadline of the new releases has been decreased. Along with it, the development is now done under the clear supervision of versioning. Virtual machines are distributed and are freed on request; therefore, all server resources are used more effectively. On average, there are about 55 virtual machines active, under the control of Hyper-V and System Centre.

In the future, the scale of the decision is planned to be increased and combined with the integrated functions of

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the automated testing system. Using the aforementioned approach allows to take on new projects with more confidence (including those linked to the intersystem integration).

B. Problem description

A significant volume of data is impossible to control without the use of the computer procedures, which determine, based on the given algorithms, conflicts of different nature and visualize them. However, even in this scenario, there are tasks for the analysis of the results of this scan, isolation of the priority problems and source of errors, interactive choice of the direction for the solution, prognosis of the situation development based on the historical data and software project risk management [16]. However, even the robot programs, in the form of Oracle jobs performing the routing tasks of gathering data in the whole spatially distributed system, require automated control with localisation of the identified problems and the feedback in regard to the impact on the source of instability. At its core, constructor of such controlling program module presents itself as a set of logical and statistical blocks for analysis and make decision using complex adaptive system approach [17-19]. The source data of the module are two-dimensional arrays that present themselves as matrix of the calculated delays of the i-th Oracle job on the j-th terminal.

In the matrix, besides the useful signal, there are time indices which represent a periodic set of the amplitudes of true delays of the execution of Oracle job, there are two more noise components of the differing nature. The first component is a regular white noise with the distribution close to normal. However, the second components represent results of the anomalous me, caused by random processes, for example, local increase of the load on Oracle database server. Amplitude of the second noise component can be magnitudes higher than the amplitude of the useful signal in , which is a negative factor when it comes to the construction of the control system with feedback, rendering the system unstable.

C. Model Description

For every set of measurements for the i-th Oracle job on the j-th terminal, the outgoing statistic of the time parameters of $\Delta t_{ij}\, z = \frac{2}{G_0}\int_0^{T_u} \Delta t_{ij}(t)dt$ are described [20] with off centre chi-square distribution with the off-centre parameter of

$$\lambda = \frac{2E_S}{G_0}, \qquad (1)$$

where the E_s represents the energy of the mix of the useful signal and the anomalous measurements with the time period T_u on the width of spectrum W_s, G_0 represents the one-sided spectral density of power of the first noise component. The average figure M and dispersion D of the z value are defined by the formulae:

$$\begin{cases} M = \lambda + 2T_u W_s \\ D = 4\lambda + 4T_u W_s \end{cases}, \qquad (2)$$

In absence of anomalous measurements, the output value z is described by a chi-square distribution with the $2T_u W_s$ degrees of freedom. The probability of the false alarm P_F and correct detection P_D for such and analyser is found with the following equations

$$P_F = \int_{z_0}^{\infty} P_0(z)dz;\; P_D = \int_{z_0}^{\infty} P_1(z)dz, \qquad (3)$$

where $p_0(z)$ and $p_1(z)$ are functions of probability density of the Rayleigh distribution and generalized Rayleigh distribution respectively, that look like:

In the absence of anomalous measurements:

$$p_0(z) = \frac{1}{2^L \Gamma(L)} z^{L-1} e^{-\frac{z^2}{2}}; \qquad (4)$$

In the presence of anomalous measurements:

$$p_1(z) = \frac{1}{2}\left(\frac{z}{\lambda}\right)^{\frac{L-1}{2}} e^{-\frac{z^2-\lambda^2}{2}} J_{L-1}(\sqrt{z\lambda}), \qquad (5)$$

Where $J_n(x)$ is a Modified Bessel Function of the first kind of order n, $\Gamma(L)$ – gamma function, $L= T_u W_s$ is a number of degrees of freedom.

D.Algorithm description

In the constructed filter, receiving the mixture of useful signal with the two noise components, a task of finding the time samples in the Δt_{ij} results of anomalous measurements is established. Considering, that at its core the second noise component has a significantly higher amplitude than that of useful signal, a reasonable solution would be to use threshold solver to filter the anomalous amplitude measurements. A decision to choose the threshold and its adaptability to the varying statistic is incredibly difficult and does not have a definite solution, which is universal for all types of signals and invariant to a priori information about a signal. As a potential solution the choice was based on the Neyman – Pearson criterion [21]. When verifying hypotheses for two classes (binary problem), there are two errors that can occur: filter can miss an anomalous measurement or give a false alarm.

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Regardless of the distribution function, the probabilities of errors of each type will be labelled as ε_1 and $\varepsilon_2$respectively. Neyman – Pearson criterion presents itself as a decision rule which minimizes the probability of the error ε_1 assuming that the probability error is equal to a certain number, for example ε_0. To determine this decision rule, it is required to find the minimum of the expression

$$r = \varepsilon_1 + z_0(\varepsilon_2 - \varepsilon_0), \qquad (6)$$

where Z_0 is LaGrange multiplier. Substituting the values of probability of errors ε_1 and ε_2:

$$r = \int_{\Gamma_1} p(z/\omega_1)\, dz + z_0 \left\{ \int_{\Gamma_2} p(z/\omega_2)\, dz - \varepsilon_0 \right\} = (1 - z_0\varepsilon_0) + \int_{\Gamma_1} \{z_0 p(z/\omega_2) - p(z/\omega_1)\}\, dz, \qquad (7)$$

where Γ_1 and Γ_2 are areas of integration of the variable z, $p(z/\omega_1)$ and $p(z/\omega_2)$ are the probability of the correct detection and false alarm respectively, moreover in the Rayleigh distribution they correspond with $p_1(z)$ and $p_0(z)$ from equations (4) and (5).

Now the task is to choose the are Γ_1 from the minimum risk *r*. Assuming that for the given z the integral in formula (7) is negative. Therefore, the risk can be reduced by attribution of z to the are of Γ_1. However, if the integral is positive, then the risk can be reduced by attributing z to Γ_2. This way the decision rule, that reduces risk, imposes that for the to the area Γ_1 only apply the objects that have negative integral in (7). This decision rule can be presented as:

$$z_0 p(z/\omega_2) \lesseqgtr p(z/\omega_1) \text{ assuming } z \in \begin{cases}\Gamma_1 \\ \Gamma_2\end{cases} \qquad (8)$$

$$\text{or} \frac{p(z/\omega_1)}{p(z/\omega_2)} \lesseqgtr z_0 \; assuming\; z \in \begin{cases}\Gamma_1 \\ \Gamma_2\end{cases}. \qquad (9)$$

Neyman – Pearson criterion is a criterion that reduces the probability of error for a single class, unlike the Bayes criterion. Where in the probability of error of the second class remains unchanged.

For the given error ε_0 the threshold of z_0 the solution of the integration function:

$$\varepsilon_2 = \int_{\Gamma_1} p(z/\omega_2) dz = \varepsilon_0. \qquad (10)$$

If using the probability density from (5) then the equation for the function looks like:

$$\int_{z_0}^{+\infty} p_1(z) dz = \varepsilon_0 \qquad (11)$$

Because the probability density $p_1(z) \geq 0$, then the probability of error ε_1, determined by the expression (11), is a singular function in relation to z_0. In other words, when the threshold z_0 increases, the probability of ε_2 decreases. Therefore, after calculation of the values of ε_2 for multiple values of z_0, it is possible to find z_0 to which corresponds the value of ε_2 equal to ε_0. However getting a definite answer to the equation (11) is difficult, given that in reality $p_0(z)$ is different from the analytical expression (4) and it needs to be analysed, adapting to the changes of the statistical characteristics of the matrix Δt_{ij}.

III. Implementation and Results

The numerical solution of the equation (11) is based on the approximation of the empirical data histogram[22] of the time row of the element of the matrix Δt_{ij} and after it, in the given time interval, the threshold z_0 can be considered a fixed value. It will change after the introduction of the new element to the matrix Δt_{ij}, however given the time frame of the 30- days there was no growth of threshold higher than 20% in a day, that's why the condition can be used approach for one-step processes admitting special interpolating martingale measures [23] Where in the value of ε_0 was fixed in the magnitude of 10^{-4}, which is considered a normal value for the false alarms when solving a binary problem [24].

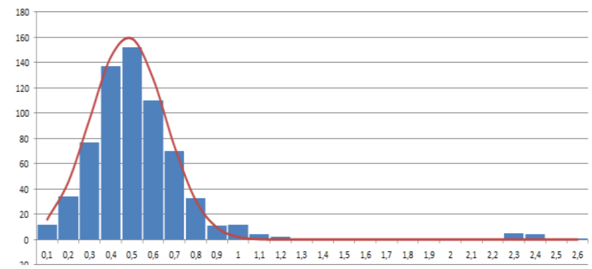

Fig. 2. Histogram of the time row of element of the matrix Δt_{ij} (blue rectangles) and its approximation with the generalized Rayleigh distribution (Red Line). On the abscissa scale, the time is plotted for the execution of Oracle - Job (seconds)

The Fig. 2 shows an example of approximation of the histogram for the time row of Δt_{ij} for a specific situation. On the histogram, a little consideration of the anomalous measurements and enough angular resolution allow to approximate correction and considering the whole statistic of the last month during the formation of the threshold z_0. The shape of the cut of the matrix Δt_{ij} is presented on the screen of developed program module (Fig. 3). The results of the anomalous measurements are highlighted with a brighter colour and show a necessity for the observation

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of the given element. The following system administrating of Oracle jobs are made with the consideration of the growth dynamic of a number of anomalous measurements and increase in the threshold z_0.

№	Oracle job	Central Terminal	Terminal 1	Terminal 2	Terminal 3	Terminal 4	Terminal 5	Terminal 6	Terminal 7	Terminal 8
1	MON3_DOOKS6	00:08	00:00	-	00:01	00:02	00:00	00:01	00:01	00:03
2	MON3_EHZ10	00:54	00:00	00:01	00:03	00:01	00:00	00:00	00:00	00:03
3	MON3_EHZ12	02:36	00:00	00:00	00:04	00:02	00:01	00:01	00:01	00:01
4	MON3_EHZ3	02:34	00:00	00:01	00:07	00:03	00:01	00:01	00:01	00:00
5	MON3_EHZ4	02:31	00:00	00:01	00:02	00:00	00:00	00:02	00:00	00:01
6	MON3_KARM	01:40	00:30	00:22	00:20	00:05	00:02	00:05	00:09	00:10
7	MON3_KK1	00:06	00:00	00:04	00:02	00:02	00:01	00:03	00:01	00:04
8	MON3_KK15	00:26	00:00	00:00	00:01	00:00	00:00	00:00	00:01	00:00
9	MON3_KK7	02:40	00:01	00:14	00:05	00:03	00:01	00:01	00:07	00:01
10	MON3_LCH2	00:35	00:00	00:03	00:09	00:06	00:01	00:02	00:04	00:13

Fig. 3. The view of the screen of the program module with the visualisation of the final elements of the matrix Δt_{ij}.

This way, the program can detect the "bottlenecks" of the system and optimise its work when considering this information. In practice, the use of this module has shown the reduction in time taken to eliminate the problem from 7 to 50 times when using the algorithm.

Experimental measurements during the stage of trial operation were done on 32 system terminals with the threefold actions during the period of 24 hours. In the process of trial operation, a positive feedback was received from the side of the system administrator.

Therefore, the reliability of work in the system in general is increased, which is especially relevant during the peaks of the report formation, when the workload rises manyfold.

IV. Discussion

When analysing the essence of the noise source in the data of the primary measurements for the time required for the execution of oracle jobs in the information system it was possible to determine the interference components of two types on the mathematical model. The first component is the routine white noise with the function of distribution, closer to normal, and the second are anomalous measurements.In the future, it's possible to extend the model using other asymmetric distribution functions for a more precise process description.

Fundamentally it is important to observe the dynamic of the threshold value. Analysis of such dynamic, calculation of periodicity or constant growth of threshold value for terminals for some terminals is the sign of them working outside the norm. Interpreting the dynamic function z_0 (t) is a separate and important task.

V. Conclusion

A robust filtration algorithm was introduced based on the approximation of the probability density of the signal distribution without anomalous measurements and following the use of the Neyman – Pearson criterion for the check of the binary hypothesis. An application of the algorithm allowed to dynamically change the threshold of the solution depending on the incoming result statistic of the initial measurements. A program module was developed in the industrial system, which uses the algorithm. As a result of using the module, it was possible to increase the quality of administrative system and reduce the time required to find the bottlenecks from 7 to 50 times with a significant increase in the reliability of the system.

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