Development methods of implementing analytical management information systems for technological monitoring of complex industrial purposes

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Abstract
Modern technologies requirements aim at improving the efficiency and safety of managing industrial facilities to a sharp increase in the information load of technological information systems (IS). These features of complex TSs are in the context of the general results for studying complex systems, which show that with increasing a complexity of the structure, the share of information contained in the system's connections increases significantly, in order to give a general description of tasks that require joint analysis of the interrelated parameters of complex technical systems and the use of appropriate process models in the TS. The work is aimed to develop methods for the construction and implementation of an analytical information system as part of a technological management system.
Keywords:
analytical information systems, technological monitoring, Supervisory Control, Data Acquisition, DBMS.

1. Introduction

The most noticeable problem situation manifests itself in the tasks of monitoring the state of complex technical systems (TS), for which not only the monitoring of the state of large volumes of technological parameters is relevant, but also their joint analysis, obtaining, on the basis of the initial data, some cumulative analytical information necessary for making decisions on control of dynamic processes occurring in the system [1].
The system studies carried out in the work show that with an increase in the number of controlled parameters of the TS and their interrelations, there is a need for a qualitative change in the organization of information processes in technological ISs, since the architecture of the SCADA (Supervisory Control And Data Acquisition) systems used at the technological management level is significantly limited analytic functionality[2]. The effectiveness of technological monitoring can be enhanced by introducing into the general system of technological management of information systems that perform analytical processing of initial information, transforming its volume and structure into a form optimal for the stage of situational analysis and decision making. This allows staff to present the most important information more compactly and systematically regarding specific production tasks[3].

The object of the research is an analytical information system for technological monitoring of complex industrial facilities[4]. The concept proposed in the work can be represented as an extension of a sufficiently well-studied and widely practiced IS class on process analysis using operational data as applied to technological monitoring tasks[5],[6]. Development of principles for constructing systems of this class - analytical information systems (AIS) and their subsequent implementation at large industrial enterprises can significantly increase the efficiency of processing technological information, and as a result, increase the efficiency and safety of operating complex industrial facilities[7, 8].
In the industry there is a large number of open source software with a high level of automation and complexity of the implemented technological processes (TP) [9]. One of the examples is various transport TSs, which are characterized not only by a large number of composite automation objects and a significant amount of controlled parameters, but also by the real spatial distribution of the objects constituting the system and, accordingly, of technological processes[10],[11]. In particular, such characteristics as the main pipeline, with an example of which can be used to study various aspects of the functionality of the associated technological information systems, with the aim of further summarizing the results obtained. In this regard, in the present work it was decided to focus on the general issues of analysis and synthesis of AIS, and for practical verification of the research results confined to the implementation of one analytical task[12] [13]. At present, the problem of prompt detection of leaks arising from the violation of tightness of oil trunk pipelines and causing great environmental and financial damage is of great relevance for pipeline transportation. Subsequently, the results of the study can be generalized to solve other pressing problems of technological monitoring of open source software.

2. Research Methods

The theoretical part of the study was carried out on the basis of the theory of information systems and systems analysis methods using the functional-structural approach

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(defining the problem situation, setting goals and criteria for the system, analyzing and synthesizing the system) [14]. The task of optimizing the structure of the AIS is solved with the involvement of the mathematical apparatus of decision theory, set theory, probability theory, mathematical analysis, and mathematical statistics. When developing a specific analytical module, the methods of hydrodynamics, mathematical modeling, mathematical statistics, and decision theory were used. The practical implementation of AIS is made using the methods of object-oriented programming and database theory[15],[16].

3. Scientific novelties of the research

Based on experimental studies and analytical observations this research illustrated the following new scientific results that were achieved depending on pure scientific and investigational basis:

- The class of analytical problems of technological monitoring of open source software and the class of IS of automating task data are highlighted.
- The concept, methods of analysis and synthesis, as well as the principles of constructing AIS that performs analytical processing of information systematically with respect to TP, have been developed.
- Synthesis of universal complex distributed architecture of AIS for technological monitoring of open source software was performed.
- A statistical-parametric model and a method for detecting leaks in main oil pipelines have been developed.
- Using the example of the problem of detecting leaks in main oil pipelines, the general principles of the organization of information processes in analytical modules are investigated.

4. Practical significance

- Methods of building AIS technological monitoring open source software
- Software implementation of the AIS shell, a single module for collecting technological data and a single software template of analytical modules.
- Analytical module for leak detection in main oil pipelines.

At the first stage of the work, the classification of TP management tasks was carried out, which showed that for simple TPs, the concept of a process can be uniquely associated with the concept of an object that implements this process. The standard task is to control the current n-dimensional vector of TP parameters P to find the n-dimensional sphere of permissible values of N. The architecture of SCADA systems is suitable for automating such a task, since it allows the semantic grouping of parameters through the logical convolution operation F, thereby reducing the cardinal number controlled set V:

$$\mathbf{P}=\{p_i : i \in I\}, \mathbf{N}=\{n_k : k \in K\} : \mathbf{N} \subset \mathbf{P}, \exists \mathrm{F} : \mathbf{P} \to \mathbf{V}=\{v_j : j \in J\} \Rightarrow \sum i > \sum j \quad (1)$$

On the contrary, monitoring the state of complex TP requires consideration of the whole process as a whole, since their information flows are not amenable to unambiguous decomposition with respect to technological objects. For analytical tasks, in addition to standard functionality (1), it is necessary to take into account the interrelationships of the process and to identify, based on known interrelationships, some critical states of process X, possible even for the case when all controlled parameters are in the range of acceptable values [17]. Consequently, the analytical processing of the initial data and the synthesis G of the new analytical information flow A are necessary, the set of parameters of which not only has a smaller cardinal number, but also a fundamentally different structure that is optimal for the stage of situational analysis and decision making:

$$\exists \mathbf{X} : \mathbf{X} \subset \mathbf{N} \subset \mathbf{P}, \exists \mathrm{G} : \mathbf{X} \to \mathbf{A}=\{a_l : l \in L\} \Rightarrow \sum i > \sum j > \sum l \quad (2)$$

The study allows us to distinguish a class of analytical problems of technological monitoring of open source software and a class of relevant information systems optimized for automating this class of tasks [18].

Further research was aimed at analyzing and synthesizing the optimal information model of AIS. Using the procedures of system analysis, from criteria for reducing production risks due to loss of control over the TP [19], and reducing the total cost of ownership of IP, a hierarchical tree of performance criteria of the studied class of IP was built. Due to the scale of the risks, the criterion for maintaining control over the TA was taken as a priority. This criterion was decomposed into sub criteria:

* Probability of loss of control over the TP - W_o due to the delay in information processing time - T_a.
* Probability of loss of control over the TA due to the degree of reliability of the information - W_c.

According to the above criteria, optimization was carried out and a model of analytical data processing was constructed. The result of the optimization is illustrated in Figure 1, which represents the cumulative expansion **Δn** of the scope of applicability of the AIS by the number **n** of parameters of the analytical task if there are interconnections, relative to the aggregate probability of loss of control over the TP - $\mathbf{W}\ \mathbf{T}_x$, the average times of a single sample are $\mathbf{t}_v$, the calculation is $\mathbf{t}_p$, the analysis is $\mathbf{t}_i$ data, and the corresponding confidence levels of the sample are $\mathbf{w}_в$, the calculation is $\mathbf{w}_p$ and the analysis is $\mathbf{w}_a$ data.

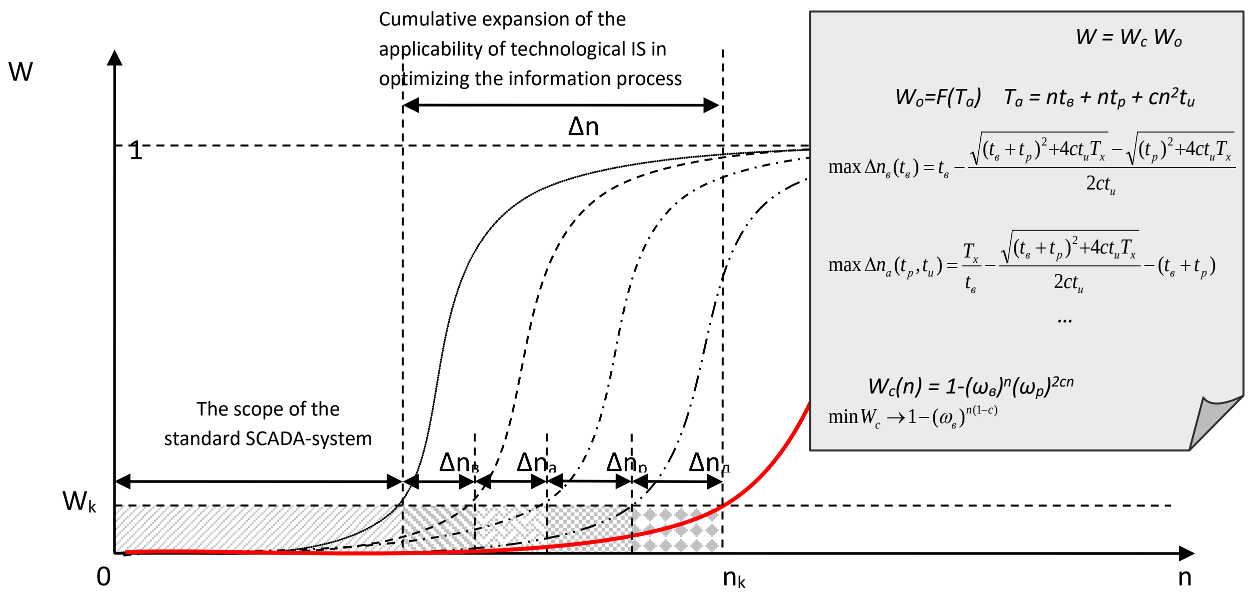

Fig. 1 Expanding the applicability of AIS for solving n-dimensional analytical tasks, while optimizing the process data processing model

On the basis of the conducted system research, a number of conceptual principles for constructing the AIS architecture have been formulated, the main of which are: modular information processing, unity of processing of operational and retrospective data, organization of information exchange through a common database managed by an external DBMS[20].

The final part of the presented stage of the study was the synthesis of a common information model of the system (Figure 2). The synthesized information process AIS has a clear logical structure and can be represented in the form of several successive levels of information processing.

In the general architecture of the developed AIS (Figure 3), three main subsystems can be distinguished: the core of the AIS, analytical modules, DBMS. The AIS database contains data structures of three types: technological, analytical and service. Appreciations to the organization of information exchange involving the DBMS functional and the implementation of the modular information processing principle, the AIS architecture allows synthesizing efficient distributed analytical information processes, flexibly taking into account modern practical needs. The high efficiency of the AIS architecture is achieved due to the following capabilities: integrated automation of analytical tasks, integration into the general information process of an enterprise, multi-user mode, hot backup of all components, system performance in case of failures or corrections, ease of maintenance, low hardware requirements, balanced load on resources, good scalability, information security.

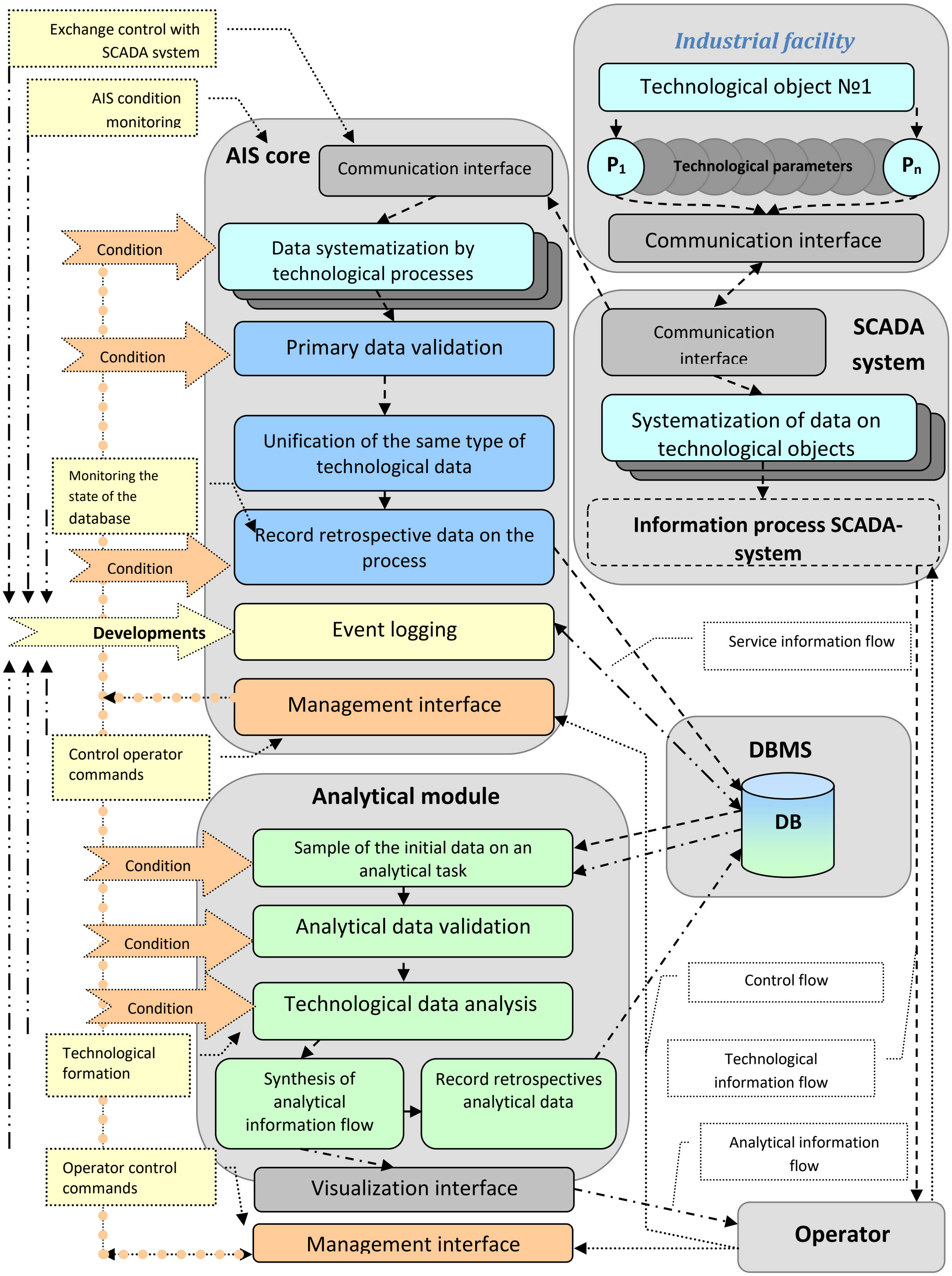

Fig. 2 Information model of analytical IP

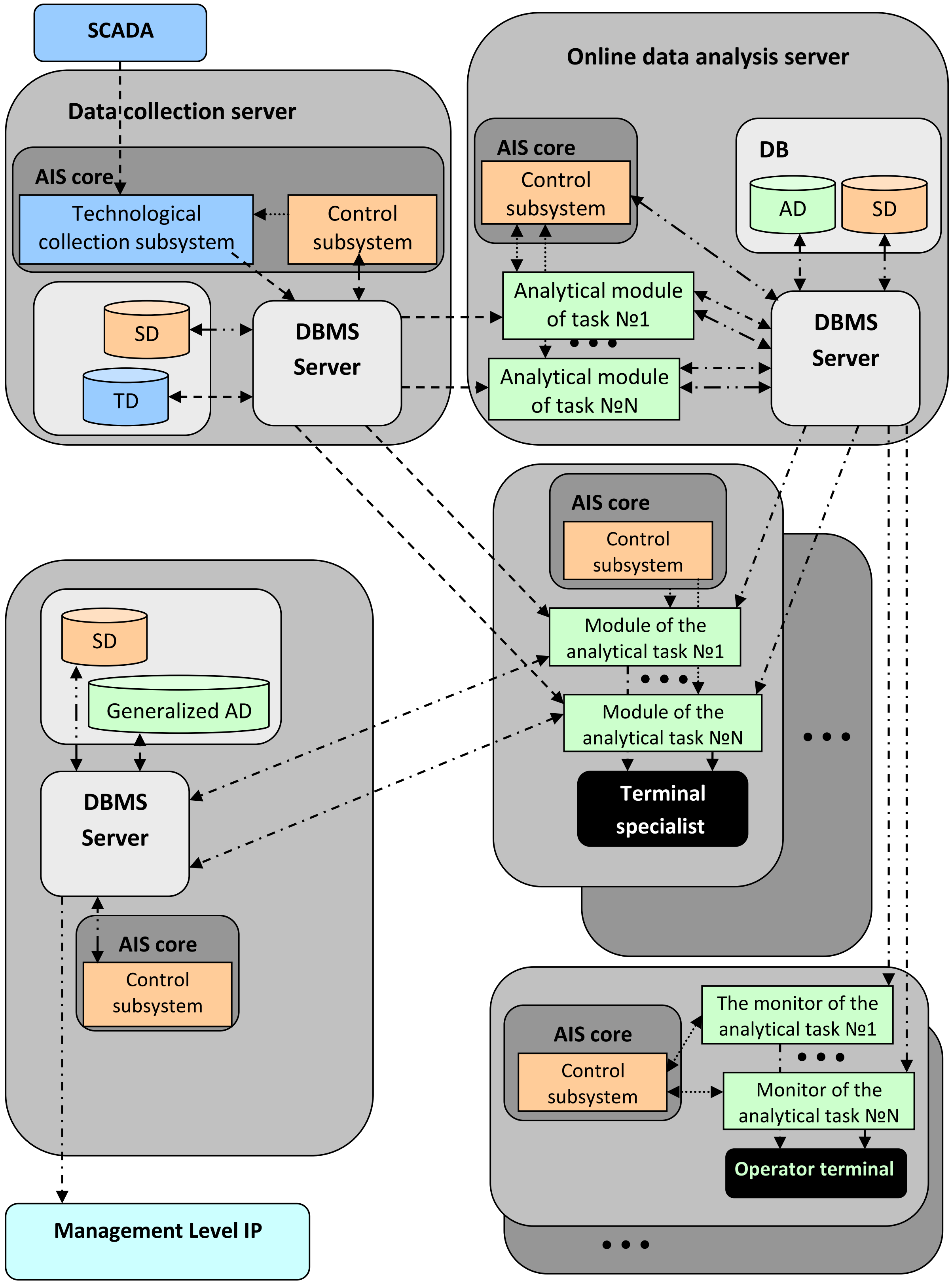

Fig. 3 Universal Integrated Distributed AIS Architecture

The result of further research was the synthesis of the structure of all basic AIS subsystems, conducted on the basis of the developed information model and the principles of the system design. The AIS core contains six main subsystems: technological data collection, module management, system event recording, configuration, database interfacing, and user interface. Module management is organized on the basis of the standard operating system message mechanism within a single control shell. Information exchange with SCADA is implemented on the basis of the OCR protocol as the actual standard for intersystem exchange of process data.

Any analytical module as part of the AIS contains seven main subsystems: management, synchronization, configuration, interfacing with the DBMS, computational analysis, user interface, event registration. The unification of analytical modules based on a single template that was carried out in this way allows us not only to standardize and logically separate service functions and basic interfaces from the implementation of analytical tasks, but also to significantly increase scalability while maintaining the functional stability of AIS.

From the point of view of the physical and mathematical model, the oil pipeline is a single system, the parameters of which are closely interrelated and a violation in one point of the established mode of operation, receives a response over the entire length of the pipeline. Despite the sufficiency of technological information, the hydraulic model of leakage is rather complicated for application in manual analysis of data on TP. Consequently, in the context of an oil pumping TA, leak detection is a typical practical example of the analytical task of technological monitoring of open-area sewage.

There are two main approaches to the construction of leak detection systems (LDS). These are distributed LDS, requiring the installation of special interconnected sensors and parametric LDS, based on the standard amount of technological information and hydraulic model of TP in the pipeline. In addition to the essential advantages of the economic plan, from the point of view of implementation within the framework of the analytical module, the ideology of parametric LDS is the closest and most interesting.

The basis of the standard parametric model of oil pumping over the pipeline section (x1, x2) is the Bernoulli equation describing the pressure loss Δh during the flow of a viscous fluid in the pipeline:

$$\Delta h = \frac{p_1 - p_2}{\rho g} + (z_1 - z_2) = \lambda \frac{8lQ^2}{\pi^2 d^5 \rho g} \qquad (3)$$

in which p1, p2 - pressure in sections x1, x2, respectively; z1, z2 - elevations of these sections; Q is the specific productivity of the pipeline, l is the length of the section of the pipeline, λ is the coefficient of hydraulic resistance, d is the diameter of the pipeline. For the convenience of analyzing the distributed processes in the extended sections of the pipeline, a dimensionless amount of hydraulic slope (hydro-inclination) - I is introduced, which characterizes the rate of linear pressure loss. For a turbulent mode of oil flow that is an actual in practice, the following approximate formula for a hydro-gradient is usually used, depending on the flow rate and viscosity ν of the pumped liquid:

$$I = -\frac{dh}{dx} = \lambda \frac{8Q^2}{\pi^2 d^5 \rho g} \approx 43{,}77 \frac{Q^{1,75} \nu^{0,25}}{d^{4,75}} \qquad (4)$$

In accordance with the above hydraulic model, the standard parametric method consists in registering a pressure drop along the pipeline’s route, the cause of which is the change in its hydraulic resistance to fluid flow caused by leakage. Since a different volume of fluid is passed through the same section of the pipe before and after the leak, the hydrostatic line has a break in the leakage area; therefore, knowing the pressure distribution along the pipeline’s route p (x), and determining experimentally the appearance of the hydrostatic line I, we can calculate the leakage point:

$$L_x = \frac{(g\rho(p_2 - p_1) - l \times I)}{\Delta I} \qquad (5)$$

Since the problem of leak detection is about changes in the technological parameters of less than 1% of the absolute value, the stage of increasing the reliability during the analytical processing of the initial data is very important. In this direction, the standard parametric model has been improved by moving to the model [2], which describes the behavior of the differential values of pressure reduction by the sensors {Δpi} in the leakage process:

$$m_i = \Delta p_i = 1 - (1 - \frac{aL_0}{L_x + bL_0}) \frac{L_x - l_i}{L_x}; a, b = const \qquad (6)$$

which eliminates systematic errors, as well as the use of digital filtering of sets of readings of sensors of the form P (t) = {Pi}:

$$P_f^i(t) = (1 - \alpha) P_f^{i-1} + \alpha P(t) \qquad (7)$$

with adjustable constant α, which reduces random errors.

In the direction of improving the quality of analytical processing, the standard parametric model has been improved by applying correlation analysis methods ρ for probabilistic estimation of **W** sets of characteristic values $\{\mathbf{x}_i\} = \{\mathbf{\Delta p}_i\}$, derived from processing experimental data on the process model $\{\mathbf{m}_i\}$, assuming a leak point with $\mathbf{L}_x$ coordinate:

$$\max W(x) = \max \rho_{M,X}(i) = \max \left\{ \frac{\sum(\Delta x_i - \bar{\Delta x})(m_i - \bar{m})}{n\sum(\Delta x_i - \bar{\Delta x})^2 \sum(m_i - \bar{m})^2} \right\} \quad (8)$$

as well as the synthetic application of several leakage feature extraction algorithms in order to extract as much as possible information on the leakage from the total technological data.

Within the meaning of the optimization carried out, the model for determining and calculating the characteristics of leakages in oil pipelines was developed and presented by expressions (3) - (8) and was called statistical-parametric. Based on data processing using the presented model, a set of analytical values that is compact and optimal for the situational analysis stage is synthesized: pressure reduction distribution $\{\mathbf{\Delta p}_i\}$, volume unbalance $\mathbf{\Delta Q}$, change in head $\mathbf{\Delta H}$, fact Al, time T, value $\mathbf{Q}_y$, coordinate $\mathbf{L}_x$, probability **W** leaks in the pipeline.

Since experimental verification of AIS functionality should include simultaneous verification of all parts of the analytical information process from collecting technological data to obtaining an analytical information flow for a specific task that is closest to the conditions of actual operation is a test in which conditions that requires analyzing data within the system module are simulated.

The experimental verification carried out at the stage of commissioning showed the effectiveness of the information process of processing technological data, the normal management of AIS components, the synthesis of an adequate analytical information flow by the analytical module. By the decision of the production commission, the developed AIS were put into operation.

Since initially an important role in the synthesis of the system was assigned to the criterion of scalability in terms of functionality, an objective assessment of economic efficiency is probably possible only at the final stage of the system life cycle. In a numerical form, the calculation of the economic efficiency of the implementation was carried out relative to one developed analytical module on a scale of one basic enterprise. To this end, on the basis of existing industry-specific methods, an assessment has been made of reducing the production and environmental risks of an enterprise.

5. Conclusions

As a result of the conducted system study, it is shown that the architecture of standard technological IS is ineffective for the tasks of analyzing large volumes of interconnected data of complex technical systems, as well as the class of analytical tasks and the corresponding class of AIS technological monitoring of open source software are highlighted. A system of criteria has been developed and the synthesis of the optimal information processing model in the AIS of technological monitoring of open source software, including the stages of systematization regarding TP, unification and analytical validation of input data, synthesis of analytical information flow, has been carried out.

Based on the developed information model of analytical processing of technological data and formulated principles of building AIS, the main ones are: modular processing of information, unity of processing of operational and retrospective data, organization of information exchange through a common database managed by an external database management system, synthesis of a universal integrated architecture is performed , which allows you to increase functionality as production needs, as well as apply AIS to other industrial particular objects.

Effective mathematical models and algorithms for information processing in analytical modules are studied on the example of developing a statistical-parametric model. The basic AIS components have been implemented: a control shell, a unified template of analytical modules, a single module for collecting technological data, as well as an analytical module for leak detection. The structure of the AIS, in accordance with practical needs, can be integrated with any industrial database management system that supports the standard structured query language.

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