Innovative: International Multi-disciplinary Journal of Applied Technology
(ISSN 2995-486X) VOLUME 03 ISSUE 3, 2025

AUTOMATION OF TECHNOLOGICAL PROCESSES IN DISTRIBUTED DISPATCHER CONTROL SYSTEMS

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Abstract:

This article examines the use of an object-hierarchical data model. At the same time, the application of existing general-purpose analysis and design standards, as well as specialized standards for real-time systems, is being investigated. This set of typical solutions, as well as software processing methods, constitutes a set of basic rules for determining the interrelationship of the subject area in terms of formalizing the requirements for the system and the object model. The use of subject-oriented and aspect-oriented programming and design methods, which allow simplifying the structure of classes by highlighting the general information model of the subject area, is considered. The first of these forms the initial network structure based on the distance matrix between nodes. The second algorithm is designed for iterative optimization of the obtained structure using the assessment of the intensity of technological data flows in the regional data transmission network. Both algorithms take into account the limitation on the maximum number of switching transit nodes and the requirement for mandatory reservation of communication channels.

Keywords: information flows, distributed systems, oil and gas industry, relational, information models encapsulating operational data, data transmission synchronization

1. Introduction

Currently, new complexes of automated technological process control systems (APCS) are being implemented at many production enterprises, in particular, in the oil and gas industry. This is due to the need to increase the manageability and efficiency of production, its safety, including environmental safety, as well as the obsolescence of automation systems installed at enterprises. At the same time, the specifics of production necessitate the creation of a multi-level management system that ensures the exchange of information between technologically connected local control points, as well as consolidates all information on the state of the territorial-distributed technological process in the central dispatch office.

Due to the almost complete transition from custom, often "from scratch," software and hardware complexes of production automation to the use of standard software solutions and serial tools of telemechanics, the implementation of a dispatch point (DP) of the APCS requires logical and physical design of a database (DB) that is part of a certain multiply universal software complex. The author's comparative analysis of database management systems (DBMS) using various data models showed that in the automation of industrial enterprises, the most effective is the use of databases that combine object-oriented and hierarchical approaches. DP APCS software systems using such databases are being widely implemented in production units of a number of oil companies in our country and abroad.

However, there are no automated database design systems, modern theoretical works mainly affect the methodology of programming (proposes to expand the object-oriented approach) or develop relational, postrelyational, object models of data.[1]

Analysis of the works in which the issues of information flows of distributed control systems, as well as the theory of object-hierarchical database design, are considered, substantiates the relevance of their wide practical application in many industries.

Three types of databases are used in APCS DP systems of different manufacturers. However, a number of general requirements are imposed on all of them. Fulfillment of these requirements is necessary regardless of the type of database. These basic requirements are:

- Supporting the "Object" paradigm - a data group that includes the value of the measured or calculated quantity, its attributes, reference data, and the availability of tools for classifying these data groups in the database;
- The ability to recalculate the calculated values every time updates to the operational data are received.

Regardless of the data model, the sequence of design stages given in the literature is applied to all databases.[2]

2. Materials and Methods

Materials and Methods. Each data model requires specific naming methods (which are also used for logical ordering of objects) and ways to access stored data. The high speed of reading/writing operations, the effectiveness of accessing a data group using a designated name or unique identifier, are a necessary condition for the real-time operation of the APCS DP. These conditions are provided by hierarchical databases and database sets of entities. The adopted methods of organizing data storage in relational DBMS reduce the speed of selecting operational data. As a result of a comprehensive assessment conducted by the author, it was concluded that object-hierarchical databases are the most suitable for the function of the DBMS.

Methods of decomposition of the subject area, performed for subsequent reflection in the information model of the technological process and automated production, are analyzed. Decomposition using essence abstractions is considered as the main method of object decomposition. Its use allows for the identification of abstractions corresponding to the essence of the subject area. However, when decomposing the object model, the problem of transferring the established relationships between classes to the next level arises. Three ways to solve this problem are proposed: 1. Creation of homomorphic hierarchies of classes that ensure the compatibility of the derived class interface with the base class. 2. When moving to the next level, consider the detailing of the previous level class both as a container and as a controller implementing the initial interface. 3. Establishing new connections with each of the new classes individually.[3]

Other methods of object decomposition (using behavioral abstractions, virtual machines) are taken into account when analyzing ProT, but cannot be considered primary.

The use of a DBMS allows, using a class system and the inheritance mechanism, to clearly define a metamodel for representing the results of database analysis and abstracting its concepts within the data storage structure itself, requiring software interaction and data access mechanisms, unlike those used in relational DBMS.

Two main operations of database access: selecting data from existing data storage structures (reading/writing) and modifying these structures themselves (changing the data schema in the terms of the DBMS) can be performed in two ways: writing a program that uses the DBMS application programming interface to manage data groups and obtain their values (procedural approach), and using the declarative language of queries - writing a statement interpreted by the DBMS processor, on the basis of which the result is formed. On the one hand, for a programmer using a third or fourth-generation object-oriented programming language, the advantage of the DBMS in the first approach manifests itself: the possibility of direct manipulation of database objects with the tools of the language used. On the other hand, in the procedural approach, creating a query essentially means writing a separate program, which leads to such negative consequences as increasing the dependence of the application algorithm on the given data structure, the need to optimize the query at the level of program code (the practical impossibility of optimizing the query of the DBMS itself), the complexity of each query, and its vulnerability for automatic verification.

Operations performed on the data in relation to DP were considered. The most important of these are the quick entry, storage, and transmission of data to a specific client. Based on the results of the analysis of interactions in the APCS DP software package, three main types of information flows were identified, classified depending on the operations performed on the data: unchanged transmission, aggregation, and need to be combined with stored reference data. In this case, the interacting programs within one DP complex use the same algorithms as two independent DP data transmission network nodes. A comparative analysis of the data flow intensity when using each algorithm is presented. Figure 1 shows the operations performed on the data in relation to the dispatch point.

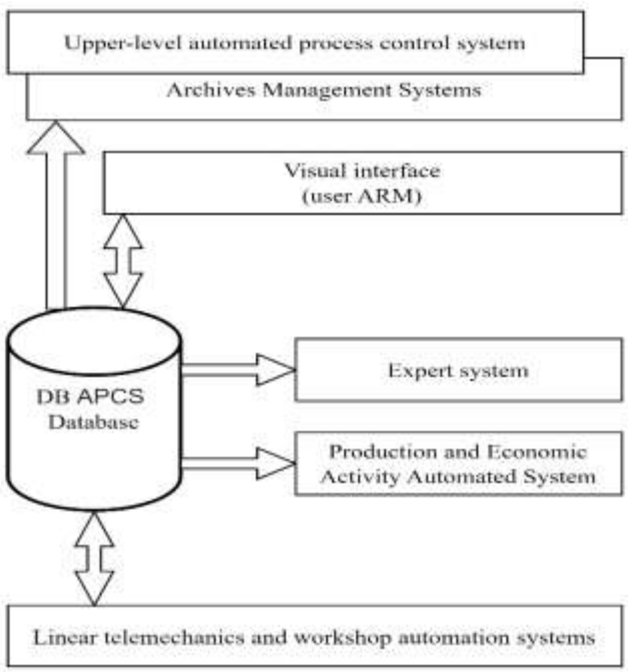

Figure 1. Information interconnections of the components of the APCS DP

The interaction of the DP with lower control levels is determined by the data transfer protocol, in which addressing depends on the address field of the data source controller. Currently, the increasing widespread adoption of UCS (Unified Computing System) technology provides additional evidence supporting the above conclusion about the effectiveness of using object-hierarchical data structures. It is possible to create identical structures in both the data source and receiver, i.e., by replicating the hierarchical structure of the data transmission protocol server's namespace in the APCS DP database, it becomes possible to modify data flows and minimize the logical transparency of data transmission.[4]

A disadvantage of existing query languages is the static nature of the generated sample (to update the data, it is necessary to repeat the entire query that forms an image). For effective access to operational data stored in the APCS DP, it is necessary to take into account and implement one of the proposals in the DBMS "Third Generation Database Systems Manifesto" - "Presence of Updated Concepts."

Unlike the discrete technological processes of construction, transport, assembly production, etc., their management is reduced to a certain algorithm of actions, the current task of management for continuous maintenance is maintaining the established technological regime. Therefore, when creating a APCS DP, the task is to create an information model of the production and technological process and maintain (update) its relevance.

In this work, the problem of designing the internal structure of the DP of the APCS is considered as the problem of designing an object-hierarchical structure. Therefore, the problem of separating abstractions for classification, hierarchical ordering of objects of the subject area, separation and generalization of general features and scenarios of the dynamic behavior and interaction of these objects arises. The problem of adapting modern software design technologies for creating an information model (Language) of a continuous technological process arises.

There can be two approaches to determining the principles of decomposition and modeling of the technological process. In the first case, when formalizing the concept of "technological management object (TMO) " - i.e., "a management object that includes technological equipment and the technological process carried out on it," it becomes possible to create coordinated formal models of the state of the TMO set of the enterprise and thereby store information about the state of the technological process at all production sites. In the second case, it is possible to highlight and formalize the requirements for the information model and methods of managing the production process as a whole, as well as for each of the enterprise's services.

Regardless of the chosen approach, all data stored in the databases of automated systems can be divided into normative-reference (NRI) and operational (telemetric) information types. NRI is characterized by a low degree of variability throughout the entire life cycle of the system and describes the design and operational characteristics of technological equipment, organizational and territorial divisions, and other aspects. Operational data characterize the current state of the automated domain; in the case of TPACS (Technological Process Automated Control System), it describes the state of the technological process, with the frequency of changes measured in seconds. Combining subsets of NRI and operational data allows for the creation of a dynamic model of the technological process based on a formalized description.[5]

Traditionally, when selecting database objects, the results of subject area analysis are used - objects are hierarchically organized according to the "container-element" principle of TOC (Table of Contents). As a principle for organizing them into the DBMS database structure, the use of administrative-territorial or production division is employed (this implements the first of the aforementioned principles of formalizing a continuous database). However, applying hierarchical analysis and "top-down" or "bottom-up" design methods to the overall design of the DBMS allows for a clear reflection of only one perspective on automated production in a single data structure. This approach and the existing methodological apparatus are fully utilized.[6]

When attempting to implement the Technological process(TP) model in the second type of formalization, which takes into account the subjective requirements of various categories of users for the TP information model, the DB designer faces certain problems, similar to the software development of information systems. Their essence lies in the fact that when using object-oriented methods, decomposition is carried out using abstractions of essence or behavior obtained as a result of the analysis of the subject area. This type of decomposition is converted into effective program code, but it does not correspond to the structure of requirements specifications that characterize the characteristics or requirements of users for the entire system - a structural discrepancy arises. This is manifested in the fact that the support of each requirement in the program code is "scattered" over several abstractions of design (scatter); the support of several different requirements in each of the objects "tangles" their structure, which leads to a decrease in the intelligibility of the model and program code, increases the complexity of development, expansion, and reuse of classes and the model as a whole.

In addition to supporting the requirements of different user groups, the complexity of class structure is caused by the support of interaction mechanisms (requirements for security, service quality, data integrity, etc.). The implementation of such operations requires the introduction of specialized functionality, i.e., the uniform expansion of contracts of different, often logically unrelated classes.

To solve these problems, it is proposed to use the principles and methods of subject-oriented and aspect-oriented design.[7]

To support the direct reflection of requirements in project models, the traditional object-oriented project is expanded by adding new decompositions. Clark calls the subject-oriented model "supporting the division of the general structure into several models that meet different requirements and can overlap." Further integration of individual models is determined by the connection relationships that determine the overlapping (or informatively interacting) elements of the model and the methods of their integration. In turn, each of the obtained particular (subjective) models can be subjected to further subject decomposition until full detailing of the requirements for the TP information model is achieved. Only then can the obtained particular models be subjected to traditional object-oriented decomposition.

This approach, reflecting the subject-oriented expansion of design, allows for the creation of specialized information models of technological processes. Each of these models consists of a hierarchically ordered set of objects, which include operational data, their attributes, derived values, as well as two types of methods: methods that modify data within the object and methods that provide information connections (reading, writing) with other objects, including objects existing in other subjects.

In this case, APCS DP DB is an association of several independent entities with completely decentralized data storage. It also allows for more successful application of the possibility of considering each of the objects as a finite automaton, due to the isolation and support of mutually independent subjects of TT, simplification of the structure of objects, and, consequently, the formation of a certain logical representation of their set - as a function of the state of TT in a given subject domain, taking into account the imposed constraints.[8]

In turn, the problem of implementing "intersecting" requirements can be effectively solved by introducing some additional software "layer" where classes are entrusted with fulfilling the same "contractual obligations," abstracting the essence of the subject area.

For this purpose, in 1997, the concept of aspect-oriented programming (AOP) was proposed by a group of Xerox PARC developers led by G. Kiczales. They clearly introduced the concept of aspect, which is a property of the system that cannot be explicitly implemented in the form of a procedure. Aspects are properties that do not tend to be elements of the functional decomposition of the system, but systematically influence the effectiveness or semantics of the components. These aspects are in contrast to components that tend to be units of functional decomposition of the system. The goal of AOP is "to help the programmer clearly separate components and aspects from each other, and to provide mechanisms that allow them to abstract and combine these elements to obtain the whole system.[9]

3. Results

We considered methods of side modeling, which are mainly UML extensions, and proposed a number of models describing the application of sides in performing functional operations, in various modes of data transmission synchronization, in interaction with data sources - subsystems.

The implementation of controlled groups - sets of objects - is a necessary condition for realizing the declarative query language for the APCS DP OOD. This implementation is carried out both within the framework of creating subject-independent models of the production and technological process and for aspect-oriented management of information flows. Additionally, it involves introducing an extra semantic load to the group.[10] Figure 2 shows a number of models characterizing the application of modeling methods, UML extensions, and aspects in the implementation of functional operations.

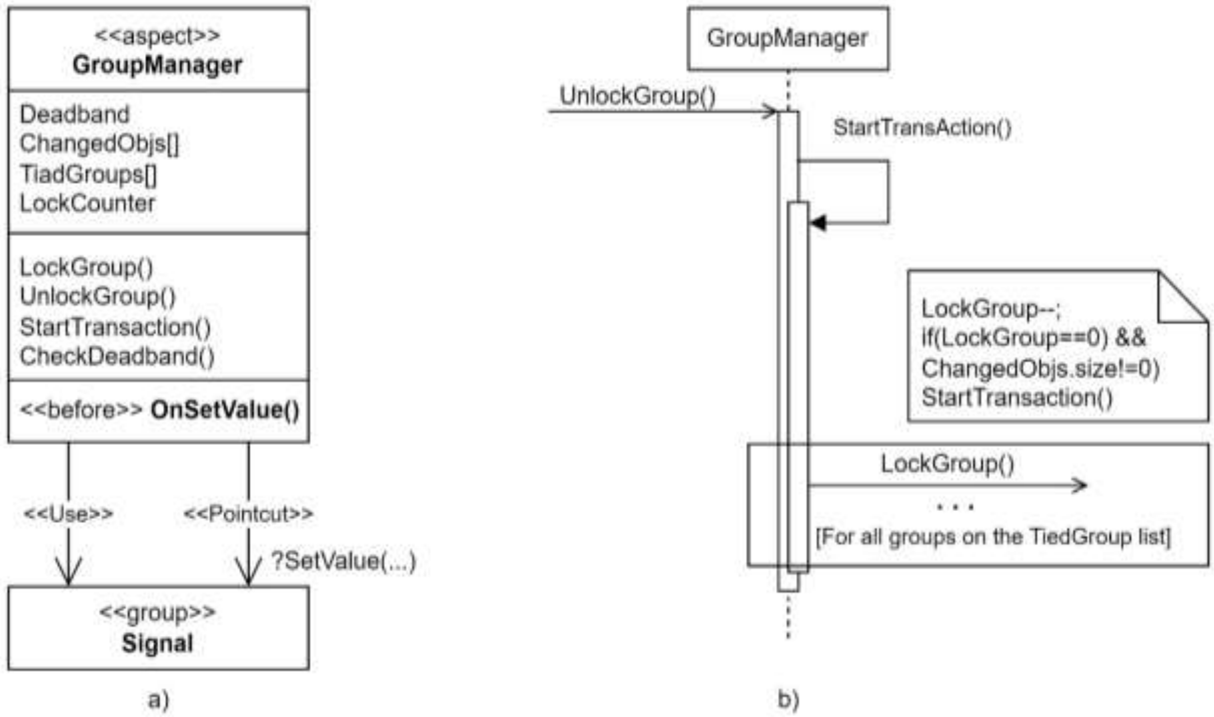

Figure 2. Add an aspect class to control object blocking when transmitting changes.

Due to the specific characteristics of production in the oil and gas industry (high-risk enterprises distinguished by continuous, sharply non-stationary technological processes), high demands are placed on the reliable operation of the entire sector. This necessitates the redundancy of all information communications essential for production: when the main communication channel (CC) fails, operational data should be transmitted through a dedicated backup CC or an alternative route (used for transmitting other data sets), while maintaining the probabilistic-temporal characteristics of message delivery. Significant costs associated with laying and fully replicating all CCs, coupled with the relatively lower cost of increasing bandwidth, lead to the task of synthesizing and optimizing the network structure and bandwidth parameters of communication channels.[11]

Initially, many locations where nodes are located (and, therefore, a matrix of distances between them) are given; the dependency matrix, as well as the characteristics of the communication channels on the basis of which the RDDS (Regional Data Transmission Network) is created: C_Э={c_Эm } - a set of effective bandwidths of communication channels (CC); B={b_m } - set of relative costs for hardware and software for an CC with effective bandwidth c_Эm, m=1, …, M, here, M represents the number of CC types that can be used in the construction of the RDDS.

Using the methods presented below, it is possible to assess the intensity of information flows between both nodes and the distribution of message length μ.[12]

In this case, the problem of constructing the structure of the RDDS is posed as follows. It is required to find $x = \{x_y\}, y = \{y_y\}, i = 1, \dots, N, j = 1, \dots, N, i \neq j$, satisfying the following conditions:

$$x_y = \begin{cases} 1, \text{if there is a channel between } a_i \text{ and } a_j \text{ in the RDDS structure} \\ 0, \text{otherwise} \end{cases}$$

$$y_{ij}^{pk} = \begin{cases} 1, \text{ if the flow } \lambda_{pk} \text{ is transmitted through the channel between } a_i \text{ and } a_j \\ 0, \text{ otherwise} \end{cases}$$

Then the efficiency criterion can be written as follows:

$$F(x,y) = \sum_{(i)} \sum_{(j)} R_{ij} \cdot x_{ij} \to \max \quad (1)$$

where

$$R_{ij} = \frac{C_{ij}}{c_{Эij} \cdot b_{ij} \cdot l_{ij}} \quad (2)$$

$$C_{ij} = \frac{1 + (\sum_{(p)} \sum_{(k)} \lambda_{pk} y_{ij}^{pk}) \cdot T}{\mu \cdot T} \quad (3)$$

Expression (3) establishes a correspondence between the capacity of the communication channel, the parameters of the message flow transmitted through it, and the demand for average delivery time, taking into account the topological structure of the RDDS and the switching mode adopted in it.[9] Expressions (1) - (3) do not reflect the reliability requirements, which are taken into account in the algorithms for generating the initial structure and optimizing the RDDS.

4. Discussion

The general solution to the problem can be divided into two parts:

1. $\|\lambda_{ij}\|, i = 1, \dots, N,\ j = 1, \dots, N, i \neq j$ forecasting the intensity of message streams in the directions between ai and aj, ugun, taking into account the nature of data arrival at the RDDS and the algorithms for their transmission.
2. Implementation of the synthesis of the topological structure of the RDDS, consisting of the stages of generating the initial RDDS structure and its further optimization.

An assessment of the nature of information flows between two nodes of rapid technological information exchange - client and server, receiver and source of rapid technological information - was carried out, and a mechanism for assessing its intensity was proposed, which directly depends on the algorithm of information exchange used.[13] Three such algorithms are distinguished: periodic value query, periodic change query, and spontaneous change transmission. The volume of transmitted information is strictly defined only in the first case, and in the rest, it is only possible to talk about the probability of receiving a certain share of the total volume of information during the survey period.

The percentage of expected changes in the total number of signals in the server database varies and depends on the mode of the technological process (staff, emergency) and the type of signal (telesignaling, telemeasurement). Figure 3 shows the probability distribution of signal variation.

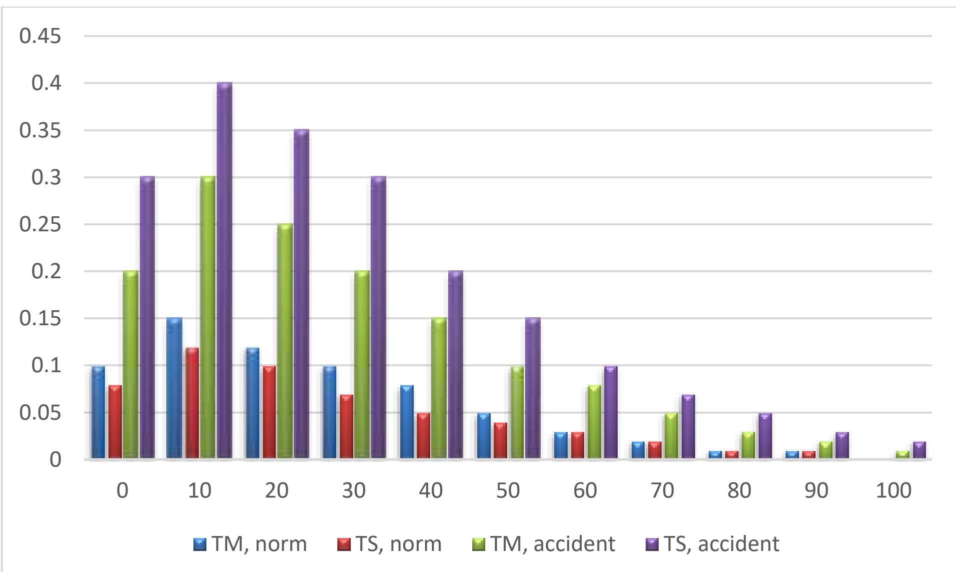

Figure 3. Distribution of signal change probabilities (in %).

To estimate this fraction, we will use the Poisson distribution. The probability distribution graph (see Fig. 3) shows the percentage of the total number of signals of a certain type, the change of which occurs during the survey period, plotted on the abscissa axis) allows one to find the values of the parameter ϕ, corresponding to the expert assessment of the true probability of changes.

Then, neglecting the volume of supporting information at the channel level, the total volume of information received by the RDDS during the survey period will be:

$$Q_{S2} = p_k(\phi) \cdot \sum_{i=1}^{T} (I + S_i \cdot z_i) \tag{4}$$

$$N_{S2} = \left[\frac{Q_{S2}}{D} \right] + 1 \tag{5}$$

(Q_{Si} - the client's actual request volume is negligibly small when periodically querying for changes and non-existent when changes are automatically transmitted.). Then $Q_{ST} = Q_{S2} + (N_{S2}) \cdot H$ and

$$\lambda_S = \frac{Q_{ST}}{T_p - (T_{DS} + T_{DC})} \tag{6}$$

WHere, ***D*** represents the maximum volume of practical data that can be placed in a frame, ***H*** is the size of the frame header, T_p is the standard period for change requests, and T_{DS} and T_{DC} are the time spent by the server and client respectively for processing requests and forming responses.

Based on the fundamental provisions of the theory of computing networks and known algorithms for generating radial-node structures, an algorithm for generating the initial structure of the RDDS is proposed, taking into account the specifics of information flows in distributed dispatch control systems in the oil and gas industry.

A heuristic algorithm is proposed for optimizing the obtained RDDS structure, in which for N points of the set (with a single isolated central switch), communication channels between the given central node and two "adjacent" local nodes are sequentially considered during the N-2 iteration. Taking into account the reliability requirements, taking into account the limitations on the maximum number of transit sections between any interacting RDDS nodes and the results of the previous iteration, a particular optimal solution is found for each step of the algorithm.[14]

The considered type of automated enterprise is characterized by four separate levels of management: technological object, technological zone, territorial management, and the enterprise as a whole; the last two levels belong to dispatch control. At the same time, it is emphasized that the creation of a centralized data warehouse within the APCS DP is a pressing industry requirement, in particular, "special attention should be paid to the formation of a unified database, including operational, balance sheet, and archival information, as well as normative reference data."

The developed methodology allows combining independent subject-oriented submodels in a single structure of an object-hierarchical database by reducing the interdependence of model levels to a matrix form.[15] Also, by applying object-oriented approaches (inheritance, polymorphism) to groups characterizing information connections, the solution of the problem of configuring information exchange with controllers of the telemechanics system, requiring individual connection of signals in the namespace of the controller and the objects of the DB, has been automated.

5. Conclusion.

Adapted and aspect-oriented programming methods for managing information flows and ensuring data integrity of the developed databases of dispatch points of oil transportation enterprises were used, which made it possible to increase the efficiency of organizing the information and software of the APCS DP. In order to perform the task of combinatorial synthesis of the DB structure of the APCS DP, not only design versions of the DB essences were developed, but also design options for performing operations on the data; rules for their combination were also introduced. An original heuristic algorithm for optimizing the initial structure of the regional data transmission network (RDDN) is proposed, taking into account the requirements for mandatory redundancy of communication channels necessary to ensure the established reliable operation of the RDDN DP.

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