Domestic Intelligent Information and Analytical Platform and Its Use in Transport

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Abstract

This paper presents results of developing smart technologies and computer systems for data and knowledge gathering, integration, interpretation, and visualization, and the implementation of the results as an integrated information-analytic platform (IAP) of complex objects (CO) life cycle (LC) proactive control. The implementation employs an original approach to operation and design of IAP of CO LC proactive control based on use of cyber-physical systems (CPS) and intellectual interfaces (InIf). This combination ensures an effective cooperation between structural or/and functional elements, and facilitates proactive control of those elements' LCs based on a continuous processing of information flow generated by sensors and devices. The created InIfs implementing means of visual programming provide a user with an adjustable environment making interaction between the user and IAP of CO LC proactive control seamless. Simplicity of interaction is increased even further through use of user's subject area terminology. The practical value of the developed IAP is its replicability and multifunctionality that made it possible to implement a broad spectrum of custom-built information systems one of which is the unified spacecraft component electronic passport containing the actual information on the state of the component throughout the entirety of its life cycle, thus eliminating ambiguity and reducing information incompleteness. Another project an IAP was applied in was the production of mobile RFID-based civil airlines service CPSs. The primary advantage of those systems is that they are autonomous and have a capacity for real time system supervision and control. Such IAPs have al-ready been developed and deployed for 17 Roscosmos subsidiary engineering and service companies, as well as for Moscow, Saint Petersburg, and Vladivostok airports having 75 of those in total.

Keywords

information-analytic platform, proactive control, complex objects life cycle

1. Introduction

[1] Currently, in Russia, in the information and communication sphere, one of the main goals can be defined as *the goal* of creating and maintaining at the required level the advanced scientific, methodological, methodological, technological and technical reserve necessary to solve *the problems of ensuring the technological independence* of domestic developers from foreign manufacturers in the field of design, creation, operation and modernization of model-algorithmic, technical, information and software monitoring and management of complex technical objects (CTO) in various subject areas. In the proposed article, these works are concretized in the direction of using the created *unified national intellectual information and analytical platform (IIAP) for proactive life cycle management of complex objects (CO)* in relation to the transport and logistics sphere (TL). At the same time, the purpose of the specifically performed work in relation to this area was to comprehensively increase the level of safety, reliability and increase the efficiency of service maintenance of civil aviation vessels.

The article shows that this goal is achieved through the digital transformation of airport services and the creation of a single information space for proactive management

[1]Intelligent Transport Systems. Transport Security - 2021, May 14, St. Petersburg, Russia.
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of aircraft maintenance, as well as the creation of intelligent complexes of ground transport and technological means [1-4].

2. State of the study

Intensively developed information technologies and corresponding information systems (IS) have become a powerful incentive for the synthesis of new generations of transport and logistics complexes (TLCs) [5-9]. These technologies include, first of all: the technology of combined design; the technology of satisfying constraints; radio frequency identification technologies and mobile information technologies; the technology of system modeling and intelligent proactive management; the technology of creating object-oriented and intelligent databases; the technology of intelligent geoinformation systems; the technology of designing and applying multi-agent and hybrid systems. All these technologies are widely implemented in the framework of such global business projects as the Internet of Things and the Industrial Internet (II), which is associated with the Industry 4.0 program [10-12].

Along with these technologies, it is also necessary to take into account the prospects for their further development, which are based on trends in the IT sphere associated with the transition from classical computing to alternative methods of organizing the computing process; using active object technology; focusing on the priority of models, not algorithms; implementing natural parallelism of computing; proactivity and self-organization of computing [5-10].

The analysis shows that in order to improve the efficiency of modern digital production, it is necessary to create a new architecture, appropriate mathematical support (models, methods, algorithms) and software systems for managing information processes, which, ultimately, has a significant impact on increasing labor productivity at the level of material production. The currently existing gap in the methods of strict formal solution of the problems of reasonable choice of technology and synthesis of plans and programs for managing information processes in the design and operation of these problems is traditionally explained by the complexity of these problems, which have a combinatorial nature and a large dimension. Therefore, in practice, these problems are most often solved using various heuristic methods and algorithms.

Thus, in modern conditions, there is an urgent need for theoretical justification and practical implementation of a new mathematical and software synthesis of technologies and integrated management plans for information processes in the II, which allows combining existing and promising technologies of different types, as well as computing systems, and on this basis to increase the efficiency of industrial production.

The analysis shows that this problem from a formal point of view refers to the problem of multi-criteria dynamic structural and functional synthesis of complex organizational and technical objects (COTO) (in our case, TLC), which are part of certain subsystems of II. As a result of solving this problem, a special model-algorithmic support for proactive monitoring and management of the service station life cycle was created. We will briefly focus on the new theoretical and practical results obtained in the course of relevant research.

3. New theoretical results obtained during the development of AIAP

The development of the proposed IIAP required the development of appropriate scientific foundations, including *two new applied theories: the theory of proactive (proactive) management of the LC CTO*, as well as *the theory of multi-criteria evaluation and selection of the most preferred models and polymodel complexes (PMCs)*, describing the functioning of the CTO and the corresponding information and analytical systems, within which the implementation of proactive management of the CTO at various stages of their LC is carried out. The authors called the latter theory *the qualimetry of models and polymodel complexes* [13-15].

These two theories make a significant contribution to the development of *modern computer science. The contribution of the theory of proactive management of the LC CTO* is that thanks to it, modern computer science is enriched at a constructive level with the methodology and methodological support developed in *classical cybernetics* (generalized control theory). Table 1 in the left column presents the known results of classical cybernetics, which have not been used in computer science until recently. The right column of this table presents the results of the authors obtained in classical cybernetics, which they brought to computer science during the creation of a unified national information and analytical platform (IAP) for proactive life cycle management of complex objects. At the same time, these results have *a broader interpretation* than is presented in the description of the work put forward for the competition.

This is due to the fact that in modern conditions, one of the main trends in the field of information technologies (IT) that exist abroad and in our country is the trend associated with the creation and widespread use of *Internet platforms* in various subject areas of material production and the provision of services, on the basis of which industrial technologies are currently being developed and implemented in practice *The Industrial Internet* and *the Internet of Things*. Created by the authors of the IIAP, it is one of the implementations of the Internet platform. Therefore, the applied theory under consideration and its specific results are focused on a more general perspective (Table 1).

What exactly in relation to the work being nominated for the prize was obtained using the theory under consideration.

The performed studies have shown that within the framework of the proposed new methodology of proactive management of the housing and communal services of the CO and the corresponding methodological apparatus, it was possible to formally describe and simultaneously solve the following list of tasks for the development and implementation of the information and analytical platform (IAP) of proactive management of the CO: the tasks of designing the appearance of the developed/modernized IAP (search for an answer to the question-what and when it is necessary to develop/modernize); tasks of determining the deadline (moment of time) by which development/modernization should be completed; tasks of synthesis of development/modernization technology (search for an answer to the question-in what sequence should development/modernization be carried out); tasks of forming and implementing a development/modernization plan (search for an answer to the question — at what specific points in time, what works (operations), on what resources should be performed and what to do in case of settlement and non-settlement situations when implementing production plans and equipment modernization plans). In the traditional design of information systems (IS), these problems, due to their large dimension, non-stationarity, nonlinearity, and uncertainty, are solved using a series-parallel space-time decomposition of the original general problem of structural and functional synthesis of the image of the IS of proactive control of the LC CTO without estimating errors caused by the use of appropriate heuristics and decomposition procedures. In this case, the most important questions of proving the completeness, closeness and consistency of the proposed design solutions remain open. Within the framework of the proposed new system-cybernetic interpretation of the processes of creating and applying the IAP CTO, based on the fundamental and applied results of classical cybernetics, it was possible to approach both the solution of all the listed tasks of structural and functional synthesis and management of the development of the IAP CTO, and the proof of the correctness of the corresponding procedures at a constructive level. The transition from traditional to the proposed design solutions based not on heuristics, but on fundamental scientific results has allowed in practice to significantly increase the efficiency, validity and overall efficiency of decision-making at various stages of the LCS CTO due to their new system-cybernetic interpretation, multi-criteria evaluation and selection of the appropriate best control models and PMCs)

Table 1
Theory of proactive life cycle management of complex objects

№	Fundamental scientific results obtained in classical cybernetics	New scientific results that the authors bring to modern computer science
1	Conditions of controllability, reachability and observability in dynamic systems control problems	Mathematical apparatus (models, methods, algorithms) for solving problems of verifying the feasibility of technology and complex plans for proactive management of information processes in the industrial Internet. Identification of the main factors (limitations) affecting the indicators that evaluate the effectiveness of proactive management of housing and communal services
2	The condition of existence and uniqueness of optimal control of dynamical systems	Mathematical apparatus (models, methods, algorithms) for solving problems of evaluating the possibility of obtaining optimal solutions in the problems of technology synthesis and integrated information process management plans in the industrial Internet
3	Necessary and sufficient optimality conditions in dynamic systems control problems	Mathematical apparatus (models, methods, algorithms) for solving problems of forming the structure of technology and complex plans for proactive management of information processes in the industrial Internet
4	Methods and algorithms for solving problems of optimal control of dynamic systems	Mathematical apparatus (models, methods, algorithms) for solving complex planning automation problems (at the level of automated enterprise management systems, production and technological processes, production design), monitoring, operational management, coordination of information processes in the industrial Internet
5	Stability and sensitivity conditions in dynamic systems control problems	Mathematical apparatus (models, methods, algorithms) for solving problems of assessing the stability (sensitivity) of synthesized technologies and complex plans for proactive management of information processes in the industrial Internet to possible disturbing influences, to changes in the composition and structure of the source data

4. New practical results obtained during the development of AIAP

A new domestic intelligent information technology (IIT) and a single domestic IIAP implementing it for proactive life cycle management of complex objects have been developed. The main *advantage* of the proposed IIT and the corresponding tools that implement it is that they are based on one of the most promising automation concepts – *"programming without programming"* – which allows end - users-technologists themselves to create and maintain unique software modules for automating control and management of complex technical processes and objects, practically without the participation of professional programmers. The specialized environment developed and presented in the project description, based on the proposed IIT, provides automatic (automated) formation of software modules, with the help of which they were later directly used in numerous projects for creating specific information and analytical systems.

In addition, the considered IIT and the corresponding IAP have acquired *a fundamentally new quality* due to the widespread use at all stages of proactive management of the housing and communal services of the CO, firstly, *cyber-physical systems* that provide, feedback management is not only at the level of technological (traditional approach), but also organizational processes of constantly updated and processed information, and, secondly, *intelligent interfaces* with visual programming elements that allow various categories of users to carry out adaptive interaction with the platform in a professional language during the proactive management of the CO housing and communal services. At the same time, intelligent interfaces ensure the replicability of the knowledge extracted from experts about the state of the CO for their subsequent implementation in similar related systems based on the use of new logical-algebraic and logical-linguistic models created to describe the products under consideration and based on the postulates of the theory of artificial intelligence, knowledge engineering, control theory [1-5].

Proactive management of the housing and communal services allows, in contrast to the reactive management traditionally implemented in practice, to prevent in advance the prerequisites (and not the consequences) of the occurrence of abnormal (critical) situations due to purposefully formed structural and functional redundancy. The developed methodology and technologies for managing the LC CO are fundamentally different from the CL2M (Closed Loop Lifecycle Management) technologies developed abroad in that they are based on the concept of proactive (proactive) management. In Figure 1 the generalized architecture of the created unified domestic IIAP of proactive management of housing and communal services of the CO is presented.

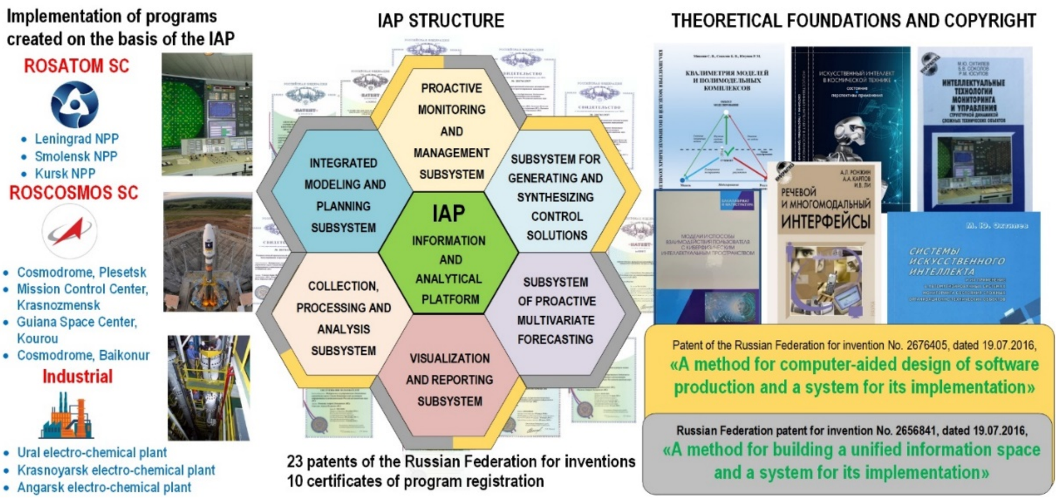

Figure 1: Generalized architecture of the created unified domestic IIAP of proactive management of housing and communal services

The uniqueness of this IAP is that it fully meets the requirements of *import substitution* that are very relevant in modern conditions, since it is an open (conversion) version of software created from the mid-70s of the last century to the present in the interests of solving the tasks of the Ministry of Defense of the Russian Federation (before that, the USSR) *regardless* of foreign information technologies and systems.

Among those presented in Figure 2 main subsystems of the IAP *new subsystems that fundamentally distinguish* it from the existing domestic and foreign IS of this class are: *the subsystem for processing and analyzing data, information and knowledge* (through the implementation of the functions of parametric and structural adaptation of models to past, current and future events, as well as automatic program synthesis); the subsystem of proactive multivariate forecasting (through the implementation of the function of forming predictive analytics models, the function of proactive situational multivariate forecasting); *subsystem of generation and synthesis of management decisions* (through the implementation of the functions of logical and case-based conclusion of recommendations based on domain ontologies, selection of optimal alternative solutions, justification and explanation of these decisions, synthesis of technologies and programs for proactive monitoring and management of housing and communal services).

In conclusion, as a concrete example of the implementation of the IIAP in practice, we will give the created complex of transport and technological means (CTTM) for the maintenance of civil aviation vessels. Figure 2 shows a cyber-physical model of an intelligent transport and technological means developed and implemented in practice.

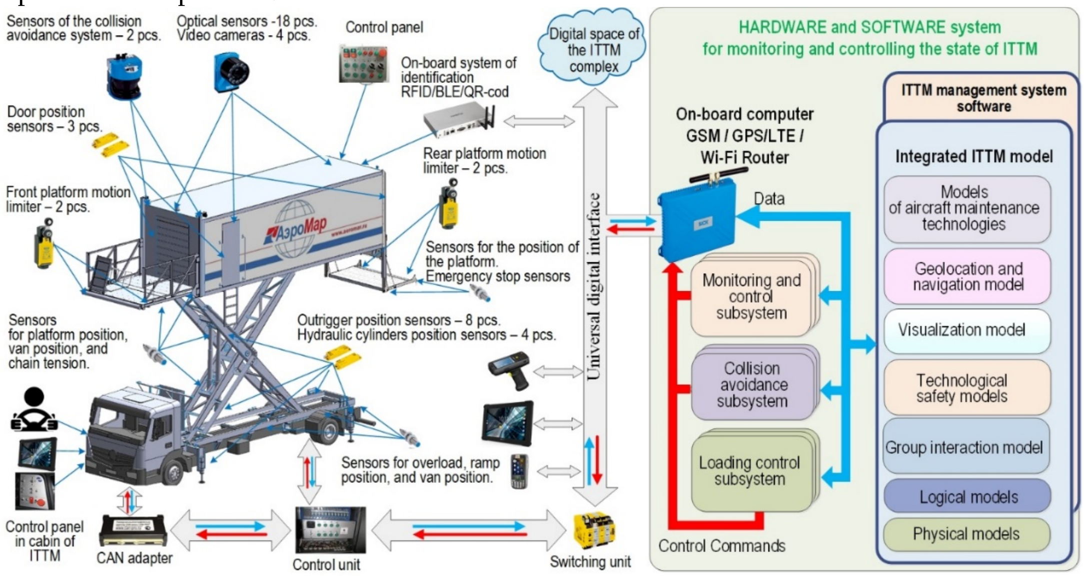

Figure 2: Cyber-physical model of an intelligent transport and technological means (ITTM)

To control the digital autolift (aircraft catering services vehicle), a multi-level model has been developed, which is the intelligent core of the control system and includes: physical-level models that describe the possible values of physical quantities received from sensors and their permissible ranges of changes. Logical-level models that describe the permissible sequences of states of sensors, nodes and aggregates of ITTM and the conditions for the occurrence of transition events from one state to another. According to the combination of physical and logical models, proactive management of the technical condition of the ITTM is carried out, which is performed both locally on the on-board computer and in an external cloud service. Service technology models describe acceptable sequences of technological operations and are used to integrate ITTM with the technological systems of service companies that provide aircraft maintenance. The group interaction model defines the opportunities, conditions and restrictions for the joint use of ITTM. According to this model, dispatching, use planning and proactive management of the ITTM complex is carried out using the appropriate combined algorithms for dynamic resource allocation. The remaining models presented on the slide are used to ensure the comprehensive safety of ITTM operation. All these models, complementing each other, together form a multi-model complex. The digital autolift is equipped with additional systems: a collision prevention system and a loading control system.

Digital autolifts (ITTM) and the central server together with their software, mathematical and information support (databases and knowledge) form the digital space of the ITTM complex. The software of the complex is developed on the basis of the tools of the information and analytical platform. This allows us to use scientifically based methods and algorithms for modeling the behavior of the complex for multivariate forecasting of possible situations, for effective planning of the use of the ITTM complex, for visualizing the current situation and the results of modeling and planning. In addition, the methods and algorithms developed and implemented in the form of special software allow for the operational management of ITTM in real time, as well as to switch to proactive (proactive) management of technological processes of aircraft maintenance, to proactive management of group interaction of technical means and management of the technical condition of ITTM. The open universal digital interfaces created by the digital space of the ITTM complex allow numerous users of other services to connect to it and get access to up-to-date and reliable information. The digital space of the ITTM complex is the core, on the basis of which, in the future, a single digital space of the airport can be created.

5. Conclusion

Implemented in practice on the basis of the developed theory of proactive life cycle management of complex objects, the domestic AIAP is a fundamental scientific foundation for creating trusted intelligent software and hardware platforms for strategic decision-making in the field of critical infrastructure management based on domestic components and software; it has competitive advantages in terms of functionality over analogues, including foreign ones; it was widely implemented in the State Corporations Roscosmos, Rosatom and civil aviation during the development and operation of fundamentally new systems for proactive management of complex technical objects, which provided a total economic effect of 2.31 billion rubles in 2019 from the implementation of new equipment and information technologies.

Speaking about the TLC sphere, 12 airports, including the largest airports in Moscow, St. Petersburg and Minsk, were implemented in the established CTTM. One hundred and twenty-one units of transport and technological means were produced. The total volume of production in 2020 amounted to 1.76 billion rubles. At the same time, the following positive effects were obtained. Reduction of information processing and management decision-making time by 15-20%. Reduction of up to 30% of the cost and timing of software development for information and analytical support for management decision-making. It also provides an increase in the degree of compliance of the developed software with the initial requirements and the task statement, as well as the reliability of the results of its functioning based on formal specifications; a potential reduction in the cost, development time and complexity of scaling and modifying software for information and analytical support of the LC CO; the manufacturability and constructiveness of the processes of extracting and presenting expert knowledge based on the use of graphical notations, the use of a polymodel and multilingual description, a set of verification tools. Reduction of aircraft maintenance time by 15% due to the use of mobile cyber-physical service systems.

6. Acknowledgements

The research described in this paper is partially supported by the Russian Foundation for Basic Research (19–08–00989, 20-08-01046), state research 0073–2019–0004.

References

[1] M. Yu. Okhtilev, B. V. Sokolov, R. M. Yusupov, M. M. Styskin, V.Y-D. Jao, Concept and technologies for proactive product lifecycle management, Journal of Instrument Engineering 63(2) (2020) 158-163. doi: 10.17586/0021-3454-2020-63-2-187-190.

[2] A. L. Ronzhin, B. V. Sokolov, V.Y-D. Jao, E. G. Mironova, M. M. Styskin, Application of radio frequency identification technology to build a control system for the turnover of on-board kitchen equipment, Radio electronics issues. Series. Television technology 1 (2020) 3-10.

[3] V. A. Zorin, N. I. Baurova, P. V. Stepanov, M. M. Styskin, P. G. Tregubov, System for proactive remote maintenance of ground transport and technological vehicles, Repair, Reconditioning, Modernization 5 (2021) 25-27. doi: 10.31044/1684-2561-2021-0-5-25-27

[4] V. A. Zorin, N. I. Baurova, P. V. Stepanov, M. M. Styskin, P. G. Tregubov, System of identification and monitoring of technical state of land transport-processing machines, Tekhnologiya Metallov 5 (2021) 44-49. doi: 10.31044/1684-2499-2021-0-5-44-49

[5] A Product lifecycle management and information tracking using smart embedded systems URL: http: //www.promise.no/

[6] S. Takata, F. Kimura, F.J.A.M. van Houten, E. Westkamper, M. Shpitalni, D. Ceglarek, J. Lee, Maintenance: Changing Role in Life Cycle Management, CIRP annals. 53(2) (2004) 643-655.

[7] J. Moubray, Reliability-centered maintenance, Industrial Press Inc., N.Y., 2000.

[8] Pride Alan. Reliability-centered maintenance (RCM), URL: http://www.wbdg.org/ design/rcm/php

[9] Risk Based Inspection and Maintenance procedures for European industry (RIMAP). Terminology list, The RIMAP Consortium, 2004.
[10] L. Chernyak, From adaptive infrastructure to adaptive enterprise, Open systems, 10 (2003) 32-39.
[11] DynaWeb is an e-maintenance solution to future sustainable industrial and societal challenges, URL: http://dynamite.vtt.fi
[12] L. B. Mirotin, A. G. Nekrasov, P. V. Stepanov, P. G. Tregubov, Increase of efficiency of freight traffic on the basis of creation of steady transportno-logistical system of high-speed processing and delivery of cargoes, Herald of MARC 3 (2013) 34 – 36.
[13] S. A. Potryasaev, B. V. Sokolov, V.Y.-D. Jao, P. V. Stepanov, M. M. Styskin, Features of using bluethooth low energy tags for identification and positioning of objects in the technological process of ground handling of civil aviation aircraft, Informatization and communication 6 (2020) 106-112.
[14] S. A. Potryasaev, A. L. Ronzhin, B. V. Sokolov, V.Y.-D. Jao, P. V. Stepanov, M. M. Styskin, Polymodel complex of a mobile service system intended for servicing aircraft, Informatization and communication 6 (2020) 113-118.
[15] LITSAM. URL: http://litsam.ru.