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Framework Conceptual Design of Complex Real-time Management System (CoDeCS)

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ABSTRACT

The modern information management systems are the complicated systems with territorial and by the functionally distributed complexes integrated on the basis of networks technologies and workings in the real time. When designing and developing such systems, the role of their conceptual design increases. A large number of used parameters, incompleteness of data require the use of special techniques and frameworks of the system designing. The work deals with the concept of the modern information management systems architecture and the main stages of system design based on the national standard 34. The methodology of designing complex management (information) systems working in real time is proposed. The methodology is based on ontological models of knowledge about the problem domain.

Key words: conceptual design, management system architecture, real-time systems, system design methodology, ontological knowledge bases

INTRODUCTION

For more than 40 years we have been developing and implementing of automated control systems for railway transport [1]: By tracing the development trends of such systems, we observe not only changes in the architecture of automation systems, but also the emergence of new users' needs based on expanding information resources for decision-making. A survey of 139 business managers in major European cities, conducted by M-Brain in the framework of the program Market Intelligence Trends 2020 [2], identified three key technological trends that will affect information management systems for the next five years:

1. Data collection automation.
2. Information analysis automation.
3. Cross function integration.

All these trends were fully manifested in the creation and implementation of intelligent transport systems (ITS) [3, 4, 5, 6, 7]. Within the framework of the program INTEND (INtentify future Transport rEsearch NeeDs) D2.1 Transport Projects Future Technologies Synopses Handbook the following projects are formulated [7]:

- Artificial Intelligence, big data management and decision support frameworks.
- Development of new train control systems: TCS (European Train Control System) and CBTC (Communications-based train control) architectures; Architecture for future GNSS positioning system.

Next Generation Train Control (NGTC) delivered final architectures and functional allocation to subsystems for a future train control system. Hence, the project delivered specifications for IT Security, IP-Rules, external Interfaces, multisector Architecture for train communications, also created the procedures for GNSS-based positioning performance assessment.

The variety and complexity of systems architectures makes it very important to create a methodology and develop frameworks and tools based on it. The approach to its solution requires the definition and understanding of the concept of the architecture of a computer system as the basis of any information management system. The notion of "conceptual (system) design" is related with this.

INFORMATION MANAGEMENT SYSTEM ARCHITECTURE

First let's define the concept of architecture as the basic characteristic of any computer system. The system architecture, according to the ANSI/IEEE 1471-2000is standard, is "the fundamental organization of the system implemented in its components, the relations of these components with each other and the external environment and the principles that determine the structure and development of the system". In fact, in this definition we are talking about the totality of different structures. This is confirmed by the analysis of materials from various sources, made in [8].

The term "system architecture" is often synonymous with the term "system structure". When using the term "system architecture", a complex, multi-aspect nature of the structure of the system is brought to the fore. Here are some of the most well-known variants of defining the term (concept) "system architecture".

Table -1 Definitions of the information system architecture

Source	Definition
IEEE Recommended Practice for Architectural Description, Draft 3.0 of IEEE P1471, May 1998	Architecture - a high-level conception of the system, taking into account its environment.
ISO-15704, Industrial automation systems – Requirements for enterprise-reference architectures and methodologies. August 20, 1999	System architecture - a description (model) of the basic layout and **interrelations** of parts of the system (physical or conceptual object or entity).
ANSI/IEEE Std 1471-2000, Recommended Practice for Architectural Description of Software-Intensive Systems	Architecture - the fundamental organization of the system, concluded in its **components**, in their **interrelations**, in the environment, as well as the principles governing the design, creation and development of the system.
International Centre for Scientific and Technical Information http://www.icsti.su	Architecture - a conception that defines the **structure** and **interrelation** of **components** for a complex object.
Dictionary http://www.glossary.ru	Information system architecture is a conception that determines the model, **structure**, functions performed and the **interrelation** of the **components** of the information system.

National standards and guidelines [9] do not use the term "system architecture". But they define:

- the structures types of information management systems (IMS) - functional, technical, organizational, software, information;
- the main structural components of IMS - users and a complex of automation tools (automation complex - AC);
- the types of IMS support - software, information, technical, organizational, methodological, mathematical, linguistic, legal, etc;
- the need to identify the structure of functional systems and subsystems of IMS, the description of the composition and characteristics of the automated functions and tasks of IMS.

In fact, in our opinion, **any IMS architecture (AIMS) irrespective of the paradigm** (computer systems, information systems, intelligent systems [1]) **is the set of interrelated structures, which is described by the following expression**:

$$AIMS=Goal \cap (HW \cup SW \cup MW \cup IW \cup LW \cup OW \cup DW \cup mlW), \quad (1)$$

where

$Goal$ – the goal of creating a system;

HW – HardWare, technical support (a set of technical means of the system);

SW – SoftWare (general and special);

MW – MathWare, mathematical support (complex of mathematical models, methods and algorithms);

IW – InfoWare, information support (description of signals, principles of classification and coding of information, description of arrays, forms, reference information and information on regulations and other types of information);

LW – LingWare, linguistic support (a set of language means of communication with the system for personnel);

OW – OrgWare, organizational support (organizational structure and instructions to operational personnel);

mlW – MetrologicWare, metrological support (means of providing specified accuracy characteristics of the measuring functions of the system).

All these types of support are characterized by a set of interrelated static and dynamic structures that are formed in the process of system design and are combined by a common conceptual scheme to achieve the creation goals while minimizing total costs [10, 11]. Depending on the paradigm, this or that part predominates in the above formula. For

computational systems this is HW (performance) and SW (organization of calculations), for **information systems** - IW (databases), SW (network software), HW (network structures), for **intelligent systems** - MW (models and methods of representation and processing of knowledge), IW (knowledge bases), LW (languages for intellectual communication), SW (languages of logic programming and functional programming, expert systems shell), OW (system users), HW (special input-output devices).

The proposed multi-tier formula AIMS can be compared to a train in which there is a locomotive providing movement to the set goal – this is HW. We can not "overburden" the support types in the "rolling stock" without coordinating with the opportunities HW. For example, the use of sophisticated algorithms for speed control of cut of cars rolling at the braking positions based on the simulation of the physical processes of movement of cut of cars at the hump is limited by the speed of the used controllers. Increasing the number of tasks to be solved in existing systems or increasing the number of clients served is dangerous without taking into account the required computational resources and the bandwidth of the channels. Ignoring such estimates leads to system failures under critical loads or to a decrease in the quality of the solutions obtained. Therefore, the choice of a "locomotive" to support the appropriate "rolling stock" of support types is an important task, both in the design and modernization of intelligent control systems, especially those that operate in real time.

CONCEPTUAL DESIGN REAL TIME INFORMATION MANAGEMENT SYSTEM

In information control systems, HW is a kind of "supporting structure", which does not allow increasing the load on the system under conditions of a number of serious time and reliability requirements for the functioning of the system or criteria for its optimization. These criteria are systematized in [12]. The consistency of design decisions made with the formulated criteria and constraints should be analyzed in the early stages of system design, when the cost of correcting mistakes is an order of magnitude lower than the costs required to resolve problems at the stage of industrial operation [13, 14].

What is meant by conceptual design? In [14], features of the conceptual design of IMS are discussed in detail. In practice, there are two basic definitions of this concept.

We will call them a "lightweight scheme" - LiA [15] based on the design of SW with IW, OW, and an "architectural scheme"- ArA [14, 16], that includes all the ware of IMS architecture (1). But in most cases this is not a complete ArA [17, 18, 19]. For example [16], scheme includes such components: Computer hardware (HW) & software (SW); Manual procedures (OW); Models for analysis, planning, control, and decision making (MW); A database (IW). But the obvious difference between these schemes is in the design stages that they cover. The national standard [9] establishes the full and short life cycles of IMS (ArA variants), shown in Fig. 1.

We think that IMS design should include the following minimum set of design stages (in accordance with 9]): TT, TWP, Com (**Fig. 1**). TWP unites TP, in which HW, MW, IW, LW, OW are developed, and WD in which the design of SW is carried out. Recently, to save time and financial resources, specialists develop a minimum TT and begin writing SW. To what it can lead, we will consider in section RESULTS AND DESCUSSION.

CONCEPTUAL DESIGN METODOLOGY AND FRAMEWORK

The architectural scheme of the conceptual design is related to the preliminary research, optimization and selection of rational structures and characteristics: topology of technical facilities at the company, the technical structure, the structure of information flows and the databases organization, processor performance requirements for the modes of their operation in real time and priority processing of applications, indicators of reliability, power consumption and cost of the projected IMS. All these studies and calculations are carried out, as a rule, in the conditions of incompleteness of the initial data and their uncertainty. In addition, many modern IMS go into the category of complex (large) systems, described by a large number of parameters. For example, the control system of a modern nuclear power plant is connected with the input and processing of up to 10,000 signals. For complex systems, an essential characteristic that determines its effectiveness is the structure [20]. In this paper we are talking about a multistructure [21].

Effective implementation of a large volume of analytical work, the use of various models and methods of research, modeling and design, including artificial intelligence (fuzzy sets, genetic algorithms, neural networks, ontologies) is impossible without the methodology of their integration into a single **conceptual framework** (CF) with software tools for automation of design and research works [7, 10, 18].

The authors developed a methodology for the conceptual (system) design of complex IMS based on the scientific-methodical framework for conceptual design (CF), the general algorithm of which is shown in Fig. 2.

The methodology is based on the following statements.

1. The process of research and design of complex systems is presented in the form of a sequential iterative scheme for the step-by-step search for rational design solutions using heuristic optimization methods that can be tuned to the sequence

of early stages, phases and tasks of IMS information technology design in accordance with ГОСТ 34 [9] (Fig. 2). But the structure of CF can be adapted to any methodology of conceptual design.

2. The knowledge base of the methodology is presented in the form of a set of ontologies describing the automatized company and the complex of software and hardware of industrial computers (HSA). For example, HSA Advantech [22] is described to which development of automated systems in Germany, Russia and Ukraine is oriented.

3. The methodology is adaptive to the set of initial data available to the developer when analyzing and designing a particular system. This means that in the knowledge base, the sequence of design stages and procedures for which there is all the necessary data (either in the knowledge base or entered by the designer in the dialogue mode) is activated.

4. The methodology includes software tools to automate the work performed. The program CSI (complex system integrator), the program CSProject for the construction and calculation of information-time characteristics of real-time computer systems' transactions, the program OPTiFLOW for distribution of information flows in real-time systems, the program OPTICOS for optimization of information control systems, the program GAOSIS (based on the genetic algorithm) to optimize the structures of information systems and the program PRIORY to select priorities of application flows in IMS. In addition, tools have been developed to automate the selection of design solutions under uncertainty [23]. To create and edit ontologies in the form of OWL databases, a special program has been developed that makes it possible to use Cyrillic.

5. The initial data and results of system analysis and design are given in table-graphical forms. The initial data for creating IMS are (Fig. 2):

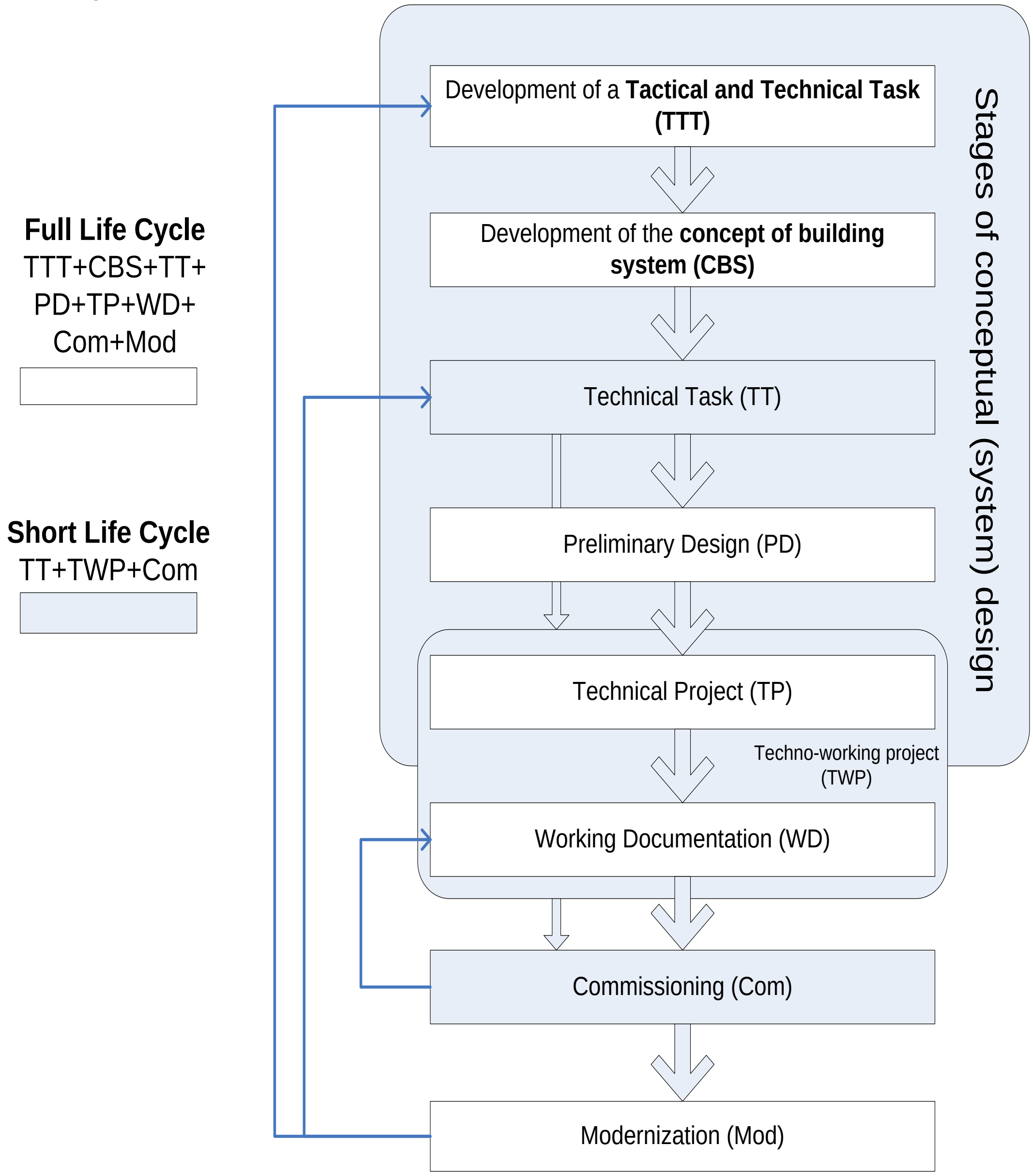

Fig. 1 Variants of life cycle schemes and stages of conceptual (system) design

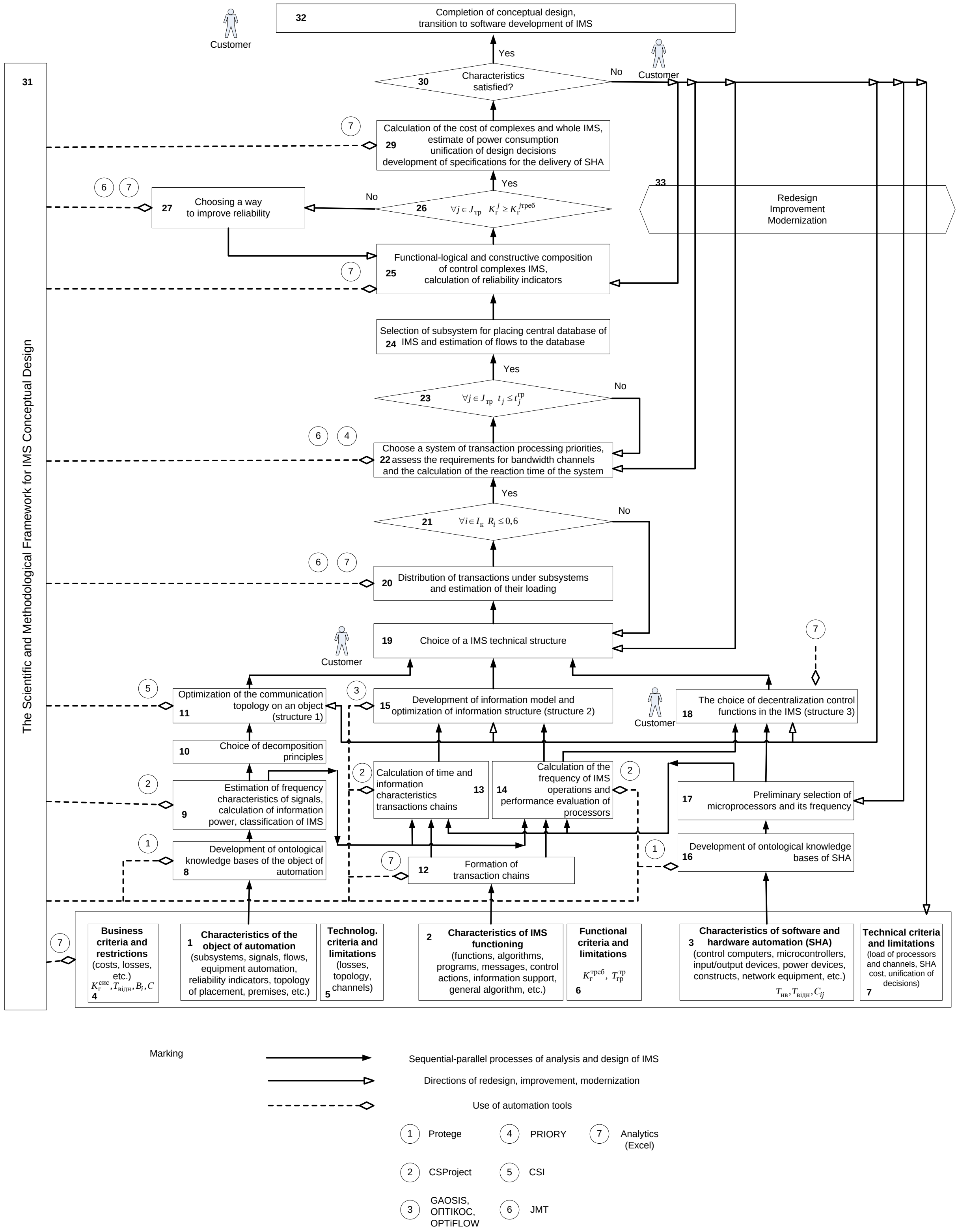

Fig. 2 Scientific and methodological framework for conceptual design IMS (Conceptual Framework – CF)

block 1 - the characteristic of the object of automation: a description of the organizational and technological characteristics of the system that is designed, including the technological subsystems, their structures, sections, flows and characteristics of signals in the sections, mechanization tools and equipment of the bottom automation, the layout of their location, buildings and premises in the company, reliability of devices, the sequence of technological operations, which is performed by the operational staff of the system (flows, location, time); peripheral equipment, which should be serviced by IMS;

block 2 - the characteristic of IMS functioning (in terms of the customer): functions, tasks, algorithms or programs that the projected system should perform; for new systems, this description will be at the level of functions and tasks; for systems that are being improved or modernized are developed algorithms or programs for estimating the frequency composition of operations (commands); for all levels with different layers of completeness and accuracy, the components of information support (variables, arrays) are specified; For each signal (application), the control actions or messages transmitted to personnel are indicated; the description is made in the form of transactions in the dialogue with the CSI program;
block 3 - description of software and hardware automation tools SHA: control computers, microcontrollers, input-output, normalization and switching of signals, power supplies, network equipment, software, reliability and cost indicators of devices and modules;
blocks 4, 5, 6, 7 - describe the criteria and limitations in business: resource saving, costs, losses, system costs, reliability indicators that must be provided, technological constraints (topology elements, channels), functional and technical indicators (workload of processors and channels, cost of software and hardware, unification of solutions);
The design of the system begins with three interrelated directions. The first - blocks 8, 9, 10, 11: optimization of the communication structure at the automation object by the minimization criterion for the total length of communications with fixed channels (the construction of a minimum spanning tree). The second - blocks 12, 13, 14, 15: optimization of the IMS information structure by the minimization criterion for the growth of the total information flow with decreasing the number of information links in the structure). The third direction - blocks 16, 17, 18: the choice of variants for the decentralization of functions in a hierarchical structure by the minimization criteria for the total losses and the cost of IMS.
Within the framework of the first and third directions, the respective ontologies of the company are formed (the ontology for the automation object and the ontology for complex of SHA software and hardware).
The first ontology is used in blocks 9, 10, 11, 19, 24, 25, 29. The second ontology is in blocks 17, 18, 24, 25, 29.
On the basis of the formed three variants of the structure, a variant of the technical structure (block 19) is chosen with the participation of the customer, which represents the current business interests (priorities) for the preselected type of microprocessor (block 17).
In the second direction, transactions (block 12) are generated on the basis of the initial data (block 2) and their time and information characteristics (block 13) are calculated to optimize the information structure (block 15). In addition, the frequency composition of the operations solved in the system of tasks is calculated, and the performance of the processors in the MIPS and in transactions/s for finding optimal hierarchical structures (block 18).
For the chosen variant of the technical structure, the transactions are distributed among the subsystems and their load is estimated (blocks 20, 21). If this restriction is performed for a distributed IMS, then the system response time is calculated for each transaction, the optimal priority is selected and channel bandwidth requirements are calculated (block 22). Further, when the time constraints are satisfied (block 23), based on the data of block 13, a subsystem is selected to place the central database in the decentralized IMS (block 24).
At the next phase (block 25) for each subsystem, the functional-logical and constructive composition of the corresponding computer complex is done using the SHA ontology (block 16). Besides, technology and communication facilities are selected in the system in the same ontology. These means must match the requirements for the channel capacity (block 22). Estimation of availability factors is carried out for the obtained technical structure. If availability factors are not provided (block 26), a weak element reservation scheme is selected (block 27).
If the required reliability is achieved, the unification of the designed hardware-software decisions is carried out for the IMS and the specifications for the SHA purchase are prepared, the cost of the complexes and the whole system, the power consumption and system performance are calculated (block 29). The design results are considered by the customer (block 30) and, if they suit it, the system design is completed and the development of the software for IMS begins (block 32). If "No", the direction of redesign is selected (block 32). From the same place begins improvements or modernization of the system.
On Fig. 2 shows the names of the tools used for the research and conceptual design of IMS.

RESULTS AND DESCUSSION

Developed scientific methodological Framework Conceptual Design of Complex Real-time Management System (CoDeCS) passed practical test in the process of creating a number of first-generation automation systems [1] for marshalling yards Perm-Marshalling and Orekhovo-Zuyevo (Russia), Yasynuvata and Nyzhnodniprovsk-Hub (Ukraine), and in the making of the modern automated system of freight traffic control for railways in Ukraine (АСУГП-УЗ or Automated Managing System for Freight Traffic Control for Railways in Ukraine AMS RWTC-U).
The development of software projects without phases of conceptual design leads to the appearance of systems whose characteristics do not satisfy its users by deadline, latency, jitter etc. An example of such an unsuccessful design is the system for collecting and processing electronic declarations, considered in detail in [24]. The developed CF is constantly being improved and supplemented with new models and methods for solving problems [25].

CONCLUSION

The conceptual design of real-time information management systems (IMRTS) in the current conditions of increasing their dimensionality and multi-structural complexity is a necessary stage of any development. In the process of system (conceptual) design, it is important to represent the IMS architecture as a set of interrelated types of support that are oriented towards the achievement of specific business goals. The proposed CoDeCS methodology is complemented by a set of tool programs for solving practical engineering tasks that can be used autonomously. CF can be adapted to other IMS design standards.

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