Conceptual Design of Complex Integrated Systems

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***Abstract*—The article describes the problems of digital transformation of the Republic of Belarus. The ways of solving the problem are proposed. A new approach to the design and development of complex information systems is proposed – the design of complex integrated systems. The basic properties of complex integrated systems are determined**

***Keywords*—System design, complex systems, digital transformation, system of systems, interoperability, integration**

I. Introduction

Currently, it is difficult to overestimate the importance of digitalization of key processes in any state. Digital technologies make it possible tooptimize many management processes in the economy, healthcare, education, and industry. The development of the modern economy is largely based on the processes of digital transformation. Until 2020, digitalization was an evolutionary process, but the COVID-19 pandemic radically changed the role and perceptionof digitalization in the state and society and accelerated its pace. Digital technologies are now essential for work, learning, entertainment, communication, shopping, and access to everything from health services to culture. One of the important conditions for successful implementation of the digital transformation strategy is the development of new approaches to the design and development of information systems. As such an approach, it is proposed to use the design of complex integrated systems [1], [2].

A. Digital transformation of the Republic of Belarus

Despite the undoubted successes in the development of the information and communication infrastructure of the Republic of Belarus, the creation of individual elements of e-government, it is premature to talk about significant progress in the digitalization of the public sector of Belarus for a number of reasons:

- Many platforms and systems were originally developed to solve specific tasks and did not provide for the possibility and necessity of integration, as well as integration into the chain of industry, country and supranational platforms. Often the developed solutions were not integrated with each other.
- Digitalization in our country has developed chaotically and sometimes uncontrollably from the point of view of embedding in a single strategy of digital transformation of the country.
- Currently, there are practically no industry platforms into which digital platforms of enterprises can be integrated.
- Many institutions and departments use proprietary software to digitalize key processes. Often, when using such software, enterprises have to adapt their business processes to the functionality imposed by the manufacturer, and not vice versa.
- Comprehensive information security is not fully ensured. This problem includes both the development of software and hardware solutions and security in the information space.

The digital transformation of the economy and society of Belarus should contribute to the achievement of the following goals:

- Ensuring the digital sovereignty of the country.
- Creating conditions for the introduction of innovative solutions in the sphere of economy and society, as well as for the integration processes of both internal and external country digital platforms
- Implementation of the import substitution strategy in the field of digitalization of key processes of the economy and society.
- Creation of complex information security systems.
- Creating conditions and guidelines for young people.

One of the significant factors of ensuring the sovereignty of the state in cyberspace is the desire for independence (sovereignty) ICT or more broadly digital sovereignty. Securing digital sovereignty is becoming increasingly difficult in a globalized world. At the same time, there is currently no clear definition of the digital sovereignty of the state. The author Ashmanov I.S. defines digital sovereignty as the right of a state to determine its information policy independently, manage infrastructure, resources, ensure information security, etc. From the point of view of staffing digital sovereignty, this process involves high-quality personnel rotation (the arrival of

responsible specialists in the relevant ministries who are thoroughly versed in the processes of digitalization and IT industries), the creation of educational programs at universities that train multidisciplinary specialists – at the junction of IT technologies and public administration, public policy, innovative economy, the creation of new jobs in the country, providing the state with useful innovations in the field of artificial intelligence, e-government, the Internet of things, electronic services, new weapons systems, etc. From a technological point of view, digital sovereignty is determined by the presence of a sovereign complex of integrated and complementary digital services and platforms in all key spheres of the life of the state and society, including its own hardware base, technological solutions in the field of content delivery, as well as national digital platforms (social networks, cloud storage, messengers, information storage services, etc.). Thus, the digital sovereignty of a country is closely linked to the ability to independently form an information policy, manage information flows, ensure information security, and ensure the storage and processing of digital data regardless of external influence. Achieving these goals requires increased expertise in the digital sphere. The rules of behavior in the virtual space are being actively discussed now. Probably, partly because of the insufficient expert level, the world community as a whole, and ours in particular, have not made much progress on this issue. Currently, no State has been able to fully achieve digital sovereignty. For example, China, which has one of the most technologically advanced and developed economies in the world, is heavily dependent on a number of Western technologies (microchips, processors, etc.). The USA is a world leader in creating ICT solutions. At the same time, a number of high-tech industries have been transferred to other states.

B. Conditions for the introduction of innovative solutions in the sphere of economy and society

Currently, many countries, including the Republic of Belarus, are striving to create conditions for the introduction of digital innovative solutions in the sphere of economy and society. As a rule, these issues are regulated by various fundamental documents such as the Digital Development Strategy, various state digitalization programs, etc. In the Republic of Belarus, the issues of innovative development are reflected in the Resolution of the Council of Ministers of the Republic of Belarus No. 66 dated February 2, 2021 on the approval of the State Program "Digital Development of Belarus for 2021-2025". This state program was adopted in order to ensure the introduction of information and communication and advanced production technologies in the branches of the national economy and the sphere of life of society. The program provides for the implementation of measures for the introduction of digital innovative solutions in the sphere of economy and society. But for the successful implementation of innovative solutions in the sphere of economy and society, the following conditions must be met:

- Development and implementation of new approaches, methodologies in the field of design, development, standardization and implementation of industry and digital platforms.
- Training of elite specialists in the field of development and implementation of innovative solutions in the sphere of economy and society.

The analysis of successful examples in the field of digital transformation of the state shows that one of the important conditions for the introduction of innovative solutions in the sphere of economy and society was the development of unified country approaches to the design, development and implementation of innovative solutions. When developing such solutions, it is advisable to use the experience of leading countries, the existing level of digitalization of the country, as well as the conditions and features of the development of the economy and society of the Republic of Belarus.

C. Approaches to system design

The rapid development of global networks in the late 90s - early 00s, primarily the Internet, created the prerequisites for a sharp increase in the needs for various information systems, in fact, the process of their creation began to be massive. This was due to the massive introduction of computer technology in various spheres of government and society, the development of data transmission networks. At the initial stage, digitization of existing documents and automation of individual processes took place. One of the first directions of automation of business processes was the development of information systems for managing individual processes of enterprises, such as automation of accounting, personnel accounting, material values, etc. As information technologies were introduced into production and business processes, the complexity of information systems and services grew. For this reason, approaches to the design and development of information systems have changed. Classical approaches no longer allowed the effective development and implementation of complex systems. New design approaches were required that could take into account the complexity of systems, the possibility of scaling, integration with other systems. A separate scientific and methodological discipline, system engineering, is devoted to the issues of designing complex systems. As the complexity of information systems and services grew, not only approaches to system design evolved, but also processes in the digital sphere. In general, it is possible to identify the main processes of digitalization, which were formed as digital technologies penetrated into various spheres of the economy and society:

- Automation. Currently, there are many definitions of this process: from general conceptual definitions to descriptions of specific processes of an enterprise or organization. For example, in [3], the automation process is defined as "a direction of scientific and technological progress that uses self-regulating technical means and mathematical methods in order to free a person from participating in the processes of obtaining, converting, transmitting and using energy, materials, products or information, or significantly reducing the degree of this participation or the complexity of the operations performed." According to GOST [4], automation is the introduction of automatic means for the implementation of processes; a system of measures aimed at increasing human productivity by replacing part of this labor with the work of machines. It is based on the use of modern computer technology and scientific methods. In [5], automation is described as the first stage on the way to digital transformation, when human labor is replaced by machine labor. Summarizing the considered approaches to the definition of the automation process, it can be concluded that automation is a business or production process that is digitized, while there is no optimization or change in the business or production processes themselves.
- Computerization. The widespread introduction of computer technology is closely connected with the process of computerization. According to GOST [4], computerization is the process of automating any processes in any field of human activity through the use of computers. In [6], it is defined that computerization is the widespread introduction of computers into various spheres of human activity (for example, for the management of technology, transport, energy, etc. production processes). In the encyclopedia [7], computerization is described as a process of expanded introduction of electronic computing technology into all spheres of human activity. Based on the results of the analysis of the presented definitions, it can be concluded that computerization is the process of mass introduction of personal computers for the purpose of full–scale use of automation in production or business processes.
- Informatization. Many authors associate the next stage of development and implementation of digital technologies in the state and society with the process of informatization. At the same time, there are various definitions of this process in the literature. Thus, in [8] informatization is described as an organizational, socio-economic, scientific and technical process that provides conditions for the formation and use of information resources and the implementation of information relations. The Law of the Republic of Belarus "On Information, Informatization and Information Protection" [9] provides the following definition: informatization is an organizational, socio–economic, scientific and technical process that provides conditions for the formation and use of information resources and the implementation of information relations. According to [10], informatization is an organizational, socio-economic, scientific and technical process of creating favorable conditions for meeting information needs, realizing the rights and freedoms of subjects of the information sphere, which is based on the mass application of information systems and technologies in all types of activities of individuals and legal entities. The author [11] gives the following definition: informatization is an unprecedented increase in the speed and quantity of production and dissemination of information, as well as the increased role of information processes, systems and networks using ICT in society. Based on the results of the analysis and generalization, it is possible to define informatization as a scientific and technical process for the creation and implementation of information systems and services in various fields of activity, characterized by the massive penetration of information technologies into all spheres of the economy and society.
- Digital transformation. Currently, many institutions, departments, companies, and industries have developed a digital transformation strategy. However, there are many definitions of this process in the literature. As a rule, definitions of digital transformation are based on the size of the object of digital transformation (institution, industry, country). Thus, in [8], the authors define digital transformation as a manifestation of qualitative, revolutionary changes, consisting not only in individual digital transformations, but in a fundamental change in the structure of the economy, in the transfer of value-added centers to the sphere of building digital resources and end-to-end digital processes. The following definition is given in [12]: digital transformation is the process of introduction of digital technologies by an organization, accompanied by optimization of the control system of the main technological processes. Digital transformation is designed to accelerate sales and business growth or increase the efficiency of organizations that are not purely commercial (for example, universities and other educational institutions). In [13], the authors conclude that digital transformation is simultaneously aimed at improving existing business processes and creating competitive advantages by changing and creating new business processes within the enterprise. Based on the results of the analysis, we will determine that digital transformation is a process of integrated

implementation of information technologies in all spheres of activity, enterprises, institutions, industries, countries, which is characterized by optimization and change of existing business, production and other processes, as well as a high level of integration processes between them.

Information system design methodologies have evolved in stages. The following stages can be distinguished:

- The first stage was associated with the digitization of the main local processes. This stage was characterized by the creation of information systems on a local scale. Various programs, as a rule, digitized a specific organizational process and worked locally on separate computing stations. Instances of the system were run on various workstations. With this approach, digital data was not accumulated in a single data warehouse. These programs did not assume and did not have the possibility of integration with other systems. The methodology of designing such information systems was quite simple. The main functions of the system under development, input and output data, processing algorithms were determined. Based on these data, a system was developed. This approach can be conditionally attributed to the classical methodology on the principle of "bottom-up". This stage is closely related to the automation process in the early stages of development.
- The second stage of the development of the system design methodology is closely related to the development of technologies for organizing local area networks. During this period, systems were created that worked on a client-server architecture, in which the storage and processing of information was carried out on a dedicated server. Client instances of the program were launched on local computing stations. These programs provided an interface for working with the server part of the program, while some of the computing functions could be performed locally. At this stage, only individual business and production processes were subject to automation. Information systems did not involve integration with other systems. As a design methodology at this stage, the classical version of system design based on the "bottom-up" principle was also used. The basic design principle at this stage was that the system being designed is created by summing up individual subsystems. Accordingly, the functionally new system consisted of the functions of the subsystems included in it. This stage is closely related to the processes of automation and computerization.

D. Complex integrated system

A complex integrated system is a system that consists of many elements and has a multi-layered structure both in the software-technical plane and in the organizational-legal one. A multi-layer structure has many integrated relationships both between multiple elements and in a multi-layer structure. As a result, a complex integrated system acquires new functions and capabilities that are not typical for individual elements of the system. A complex integrated system can consist of independent autonomous systems, as well as subsystems and other components. Components of a complex integrated system can be fully integrated into a complex integrated system or partially integrated. Figure 1 shows a complex integrated system.

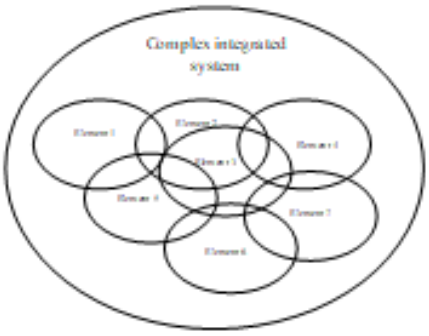

Figure 1. Complex integrated system

In a broad sense, various processes and objects can act as a complex integrated system. Examples include the construction of power plants, the creation of a complex traffic management system, and the design and construction of new city neighborhoods. However, within the framework of this work, the processes of designing and creating information systems of various scales are considered: information systems at the enterprise level, industry, country, and supranational. As such a campaign, it is proposed to consider all the processes of digitalization of the state and society as complex integrated systems. The main focus when developing a methodology for designing complex integrated systems is the integration processes of various systems, processes and services. Complex and integrated systems design is the process of designing and developing complex systems, taking into account the current state of elements, integration processes between elements and functions, as well as identifying new functions and properties obtained as a result of creating a complex integrated system. According to the definition, any sociotechnical system, biological system, etc. can act as a complex integrated system. Within the framework of this work, the object of research is information systems and platforms of various levels, as well as digital transformation processes of various levels. For this reason, research has been con-

ducted in relation to information systems and platforms. A complex integrated system has all the properties of complex systems discussed earlier. With this in mind, any complex system is a special case of a complex integrated system. As noted earlier, a complex integrated system has a number of distinctive properties. The main properties of a complex integrated system are:

- Integration. This is a key property of complex integrated systems. Currently, for complex systems, there is a concept of interoperability. According to [14], interoperability is the ability of two or more information systems or components to exchange information and to use information obtained as a result of exchange. The key difference between integration and interoperability is that interaction and integration occurs not only between systems, but also between different elements of a complex integrated system on different layers and planes. Systems and platforms of various levels can act as a design object: from composite subsystems to super-country platforms. And when assigning such systems to complex integrated systems, the main criterion will be the presence of the integration property. Figure 2 shows the set of connections of a complex integrated system.

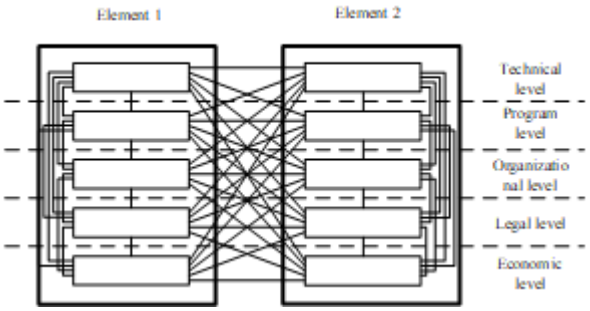

Figure 2. Multiple connections of a complex integrated system

- Temporality. In the process of designing complex integrated systems, it is necessary to take into account the current state of individual elements, which was achieved both through the evolutionary development of various processes and systems, and as a result of combining various elements into one system. This property characterizes the degree of development of individual elements of a complex integrated system.
- Distribution. The distribution property is inherent in the SoS model discussed earlierSoS. However, when applied to complex integrated systems, this property is more extensive and includes the following types of distribution: geographical, logical, physical, software-technical, and legal.
- Ownership. Elements that are part of a complex integrated system can have different owners in the following areas: owners of individual systems, owners of individual processes.
- Emergence. This is a property of a complex integrated system, when when creating a system, new functions and capabilities appear that are not inherent in individual elements of the system
- Evolutionary development. Complex integrated systems can acquire new functions and capabilities as a result of evolution, both with external intervention and independently.
- Complexity. a system consisting of many interacting components (subsystems), as a result of which a complex system acquires new properties that are not present at the subsystem level and cannot be reduced to the properties of the subsystem level. The complexity of a system is determined by the number of its constituent elements and possible connections between them. The degree of complexity is measured by the diversity of the system. Diversity characterizes the number of possible states of the system.
- Stress tolerance and self-adaptation to external changes.

When designing complex integrated systems, the following approaches can be used, which depend on the input parameters of the model:

- Designing a complex integrated system from scratch. In this case, the main input parameters will be the requirements for the characteristics and integration relationships of the designed system.
- Designing a complex integrated system based on existing systems and services. In this approach, the current state of functioning systems and services is added as input parameters in addition to the requirements for the characteristics and integration relationships of the designed system.

From the point of view of the scale of the object of designing a complex integrated system, the following levels can be distinguished:

- Subsystem level. If a complex integrated system is a subsystem, it must have many integration links both within the system of which it is a part and with external systems.
- Process level. In the case of designing a complex integrated system at the process level, the object is a dedicated process of an enterprise, company, industry, or country. At the same time, integration with other processes of the designed level should be ensured.
- The level of an enterprise or company institution. In this case, as a rule, platforms take into account production and business processes in the industry and include solutions for integration with all digital platforms at the enterprise, institution, department, and company level.

- Country level. As a rule, this level includes various industry and departmental platforms and systems and accumulates all the main information flows and digital data of the designed platform at the country level. At this level, the emergence properties of complex integrated systems are most clearly manifested.
- Super-country level (super-country level). When designing complex integrated systems at the supranational level, the main emphasis is shifted towards data format harmonization, organizational and legal aspects of integration. At this level, complex integrated systems usually have all the basic properties of a complex integrated system.

A complex integrated system includes many different systems and subsystems with varying degrees of integration at different levels.

II. Conclusion

Currently, various industry-specific and corporate digital platforms have already been created in the Republic of Belarus, and some elements of e-government have been created. But the level of development of digital platforms in different spheres of the economy and society, and in different regions, can vary greatly. In this regard, it is proposed to develop new approaches that can take into account and integrate into the overall strategy of digital transformation of the state already created and functioning platforms and services, as well as create conditions for further development of industry, country and supranational systems and services as a whole. As such a campaign, it is proposed to consider all the processes of digitalization of the state and society as complex integrated systems. The main focus when developing a methodology for designing complex integrated systems is the integration processes of various systems, processes and services. Applying the proposed approach will allow achieving the goals set in the field of digital transformation of the country.

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Концептуальное проектирование сложных интегрированных систем

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В статье описываются проблемы цифровой трансформации Республики Беларусь. Предлагаются пути решения поставленной проблемы. Предложен новый подход к проектированию и разработке сложных информационных систем — проектирование сложных интегрированных систем. Определены основные свойства сложных интегрированных систем.

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