Integrated planning and scheduling of enterprise information system modernization

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Abstract

Modern complex technical systems (CTS) consist of many distributed components that receive, process and transmit information. The interconnection between subsystems and elements is the enterprise information system (EIS). Nowadays, this system uses elements that are heterogeneous in composition and functional purpose, large amounts of resources (including material and information) to maintain or improve the quality of functioning (implementation of supported business processes (BP)) and development at each stage of the life cycle of the CTS. To improve the effectiveness of achieving and solving strategic and local goals and objectives of systems, it is necessary to create models that allow to describe the processes of their dynamic adaptation (integrated modernization). It is necessary to develop integrated methods, algorithms and techniques that will allow to fully and proactively control both the processes of functioning and modernization of the EIS in order to increase the efficiency of the BP. This article presents an approach that allow to analyze the structural and functional appearance variants of the implemented EIS and synthesize schedules and plans of its joint functioning and modernization. An illustrative example is given.

Keywords

EIS modernization, integrated planning, integrated scheduling.

1. Introduction

The EIS is the core of critical infrastructure objects. It is an environment for the creating, transmission and analysis of control actions in an information space [1]. Its structural and functional properties should allow to solve a wide range of current and promising tasks that confront the CTS, within which it operates [2]. First of all, it is necessary for maintaining or improving the quality of implementation of supported business processes (BP). BP is a set of logically ordered and interrelated operations performed in objective reality to obtain the required final result that ensures the achievement of the strategic goal of the system.

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Constantly changing requirements for technological, technical and information processes, caused by poorly predicted external and internal impacts on the BP, force decision-makers to conduct continuous reengineering and modernization of the EIS.In practice, we observe

- the increase in the number of element refusals and EIS subsystems;
- delays of synthesis and control programs;
- the increase in consumption of all resources connected with the implementation of the target, providing and supporting operations.

Today, BP, associated with the widespread use of high technologies, are more than ever dependent on the rational organization of the information infrastructure as the quality of functioning and development (modernization) decreases.) EIS can lead to disruption of the implementation of the strategic goals of the CTS [3,4]. In addition, in practice, the cost of maintaining the heterogeneous EIS often exceeds the implementation cost.

This paper is devoted to the proactive search for the appearance of the new information system being implemented and ways of synthesizing integrated plans and schedules for modernization “old” EIS.

2. State of the art

It should be noted that researchers observe a unique attitude of decision-makers to the deployment, support and optimization of information infrastructure. Managers are focused on minimizing the implementation time, simplicity of the user interface, minimum cost of the implemented equipment, without taking into account direct and indirect expenses for further maintenance [4]. This approach caused the development of many products based on the classical office applications or software platforms that are connected using synthetic software "adapters". Such systems cannot form a single information space even within a single CTS [5].

Another important problem is the orientation of the relevant design solutions for complex systems only to meet the standard reliability indicators. This approach does not allow us to scientifically and reasonably optimize the resource expenses for technical solutions. The analysis of modern methods and algorithms of solving problems of optimizing reliability indicators of the CTS has shown that most of the developed methods and algorithms are aimed at solving single-criterion and two-criteria problems of choosing the composition of elements and subsystems [6-7]. We should note that the high speed of obtaining rational (efficient) solutions is due to the monotonicity and convexity of the reliability function and the cost function, as well as the correlation between reliability and cost. However, in practice, the structural reliability function may be non-monotonous, and the specified ratio is not always fulfilled, especially when several resource indicators are used to optimize reliability [8].

A number of approaches has been developed to solve the problems of integrated planning and scheduling of the functioning and development of the EIS. Traditionally, they are based on the methods of the scheduling theory and linear, discrete, stochastic programming. Analysis of modern software and mathematical support of decision support systems and PLM-systems, showed that it cannot effectively and reasonably solve the problems of automated synthesis of the appearance of the implemented information system, as well as integrated plans for the functioning and development of the EIS, which exclude the shutdown of BP.

In addition, we present brief results of the analysis of integrated planning and scheduling tasks the CTS functioning and modernization. Thus, synthesis of the rational modernization plans of the EIS is connected with the search for joint solution of the following main tasks:

1. the synthesis of structural and functional appearance of the upgraded system;
2. the timing of completion of the modernization;
3. the synthesis technology modernization;
4. the synthesis of the joint functioning and modernization plan;
5. the synthesis of control inputs, ensuring the implementation plan and scheduling of modernization [9].

3. Integrated planning and scheduling models

3.1. Structural-Parametric Configuration of the EIS

The authors refer the tasks of determining the list of the implemented elements of “new” EIS and synthesizing integrated programs of joint legacy EIS modernization and functioning to the most important problems of planning and scheduling the development of information systems. This article presents in a generalized form models for the synthesis of the appearance of the “new” EIS and the development of comprehensive plans for the relevant modernization works for legacy system. At the first stage of research, we will focus on the problems of determining the hardware composition of the implemented system for a given architecture. The second stage will be devoted to the searching for a rational plan for the joint functioning and modernization of the EIS elements and CTS subsystems.

Structural analysis of the functioning of the EIS (Fig. 1.) within a given architecture begins with the construction of a functional integrity scheme [10-11].

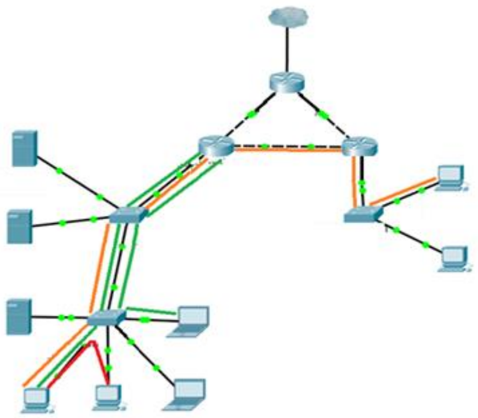

Figure 1:The example of the EIS

During its development, the logical conditions for the implementation of its own functions by the elements and subsystems of the object are graphically described, as well as the goals of modeling are indicated. Figure 2 shows a diagram of functional integrity.

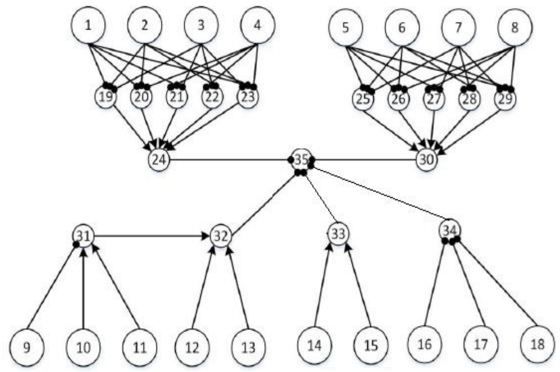

Figure 2: The example of representation of the EIS infrastrucrure in the form of a functional integrity scheme

Elements 1-18 refer to the elements of the executive and operator levels of the information system. 19-34 are message switching nodes. 35 is an access point to the Ethernet.

At the first stage, we introduce the necessary basis sets to solve the problem of synthesis and analysis of the structural and functional appearance of combined EIS. $A=\{A_i, i \in N\}, N=\{1,2,...,n\}$ is the set of elements of the legacy EIS and "new" EIS; $B=\{B_j^i, j \in D^i, D^i=\{1,2,...,m_i\}, i \in N\}$ is the set of existing legacy EIS elements and "new" EIS (B_j^i - j - A_i type of the EIS element). $P_F(\{p_i, q_i = 1-p_i\}, i \in N)$ probabilistic function of failure-free operation of elements for the implementation of the operation modes of the legacy EIS and "new" elements specified by the logical criterion F . $c_{ij}, i \in N, j \in \{1,2,...,m_i\}$ is the cost estimation of used elements during a given lifecycle period; $\vartheta_{ij}, i \in N, j \in \{1,2,...,m_i\}$ a number of implemented EIS elements of each type. $p_{ij}, i \in N, j \in \{1,2,...,m_i\}$ is the probability of failure-free operation of legacy and "new" EIS elements.

The variant of designed EIS is $X = \|x_{ij}\|$ where $x_{ij}=1$ if instead of A_i the element of B_j^i type is used, then in the other case $x_{ij}=0$. $C(X)=\sum_{i=1}^{n}\sum_{j=1}^{m_i} c_{ij} \cdot x_{ij}$ is the cost estimation of the project variant of the developed EIS. $V(X)=\sum_{i=1}^{n}\sum_{j=1}^{m_i} \vartheta_{ij} x_{ij}$ is the quantity of implemented elements of the EIS project variant. $\mathrm{P}(X)=P_F(\sum_{j=1}^{m_1} p_{1j} \cdot x_{1j},...,\sum_{j=1}^{m_n} p_{nj} \cdot x_{nj})$ is the indicator of reliability of operating modes implementation of the developed EIS. It used as the objective function.

We should consider the method of forming the estimation of the cost indicators of used elements. At the stage of synthesis of the structural and functional appearance variants of the EIS, the authors propose using the following formula for an indirect integral assessment of the economic efficiency of the selected components based on a service-oriented approach:

$$c_{ij} = \frac{C_{ij} / T_c + W_e}{\sum_{l=1}^{S} V_{ij}^s / T}, \tag{1}$$

where T_c is the duration of the depreciation period; W_e is total operating costs associated with maintaining the operation of the element for a given life cycle period; V_{ij}^s is the amount of data that the implemented element must process, transmit, and store for supporting the functioning of the specified information service of the EIS. Information service is the service that the information system provides to the BP [4]. T is the value of the time interval for preparing by the element of the required amount of data. The numerator of the equation helps us to describe the generalized economic efficiency of performing operations for supporting related information services. The denominator of the equation presents the intensity of the resource's support for the information service. It is obvious that the use of highly specialized functional elements should increase the value of the presented indicator, but recent studies have shown that such specialization reduces the robustness of the developed plans of CTS and EIS functioning [12].

For considering the duplication, triplication etc. of implemented elements we should additionally introduce the constraint $\sum_{j=1}^{m_i} x_{ij} \le 1, \forall i \in N$. It has the following interpretation: the maximum redundancy rate A_i of the implemented element into the projected EIS is not more than m_i ; at the same time $x_{ij} = 1$ when the redundancy A_i is made by the element with j rate. In this situation, the changing of values goes in the following way: the probability of failure-free operation $p_{i1} = p_i, p_{i2} = 1-(1-p_i)^2, ..., p_{im_i} = 1-(1-p_i)^{m_i}, \forall i \in N$ [8]; the cost estimation of using elements $c_{i1} = c_i, c_{i2} = 2c_i, ..., c_{im_i} = m_i c_i, \forall i \in N$; the quantity of introduced elements $\vartheta_{i1} = 1, \vartheta_{i2} = 2, ..., \vartheta_{im_i} = m_i, \forall i \in N.$

It is important to mention that the reserve elements are introduced into the EIS, but they are not used during the normal operation. This makes it possible to produce the “hot-swap” of elements in the event of equipment failure, as well as to create the main, backup and duplicate control circuits, which is an accepted practice for critical infrastructure facilities.

The number of elements of the implemented EIS should be minimized, because the unused elements are exposed to moral wear and tear, and working with a wide fleet of equipment increases the complexity of maintenance and administration. Additionally, we should note that excessive resources are frozen assets.

The presented constraints define the range Δ of permissible structural and functional features of the considered EIS. The problem of variants synthesis is reduced to a multi-criteria problem of choice on a discrete set of acceptable alternatives:

$$\min_{X \in \Delta} C(X), \ \min_{X \in \Delta} V(X), \ \max_{X \in \Delta} \mathrm{P}(X). \qquad (2)$$

In other words, it is necessary to find effective (Pareto) variants of the EIS project $\Delta^{nd} \subseteq \Delta$ that ensure minimum financial costs, minimum number of EIS implemented elements and maximum reliability indicator of the EIS elements functioning.

For more information about the approach based on the method of constructing a lexicographic relationship of preference and successive concessions, which allows to resolve the criterion uncertainty, see [8]. The presented algorithm allows to develop the variants of the structural and functional appearance for a given architecture of the information infrastructure of the EIS, as well as to determine which elements of the legacy EIS can be used in the "new" EIS.

3.2. The synthesis of integrated programs for the EIS functioning and modernization

Next (the second stage of research), we should present models and algorithms for synthesis integrated programs for the functioning and modernization of the EIS. At this stage, the disclosure of all connections between the physical and executive levels of the information system is pointless, because this will lead to the excessive complication of the model [5,12,13]. In this paper, the authors rely on the principles of a service-oriented approach. To describe the processes of functioning and modernization of the EIS, a complex of logical-dynamic models was developed: the BP-model; the providing information services to BP; the technological cycle of EIS modernization control [14].

We should highlight that the proposed method allows to describe the connections of hierarchical system and rely on the program-target and service-oriented approaches at the planning stage of conducting a “seamless” EIS modernization. At the same time, it is possible to explicitly consider the requirements for minimizing the total cost of ownership at a specific stage of the system's life cycle [15].

Determined at the first stage, an effective variant of the implemented elements (EIS appearance) allows to get the characteristics (the bandwidth of communication nodes, the computing power of new servers, etc.) that are necessary for synthesizing an integrated plan and schedule of the EIS functioning and modernization. The choosing among alternative options is based on the search for the extremum of the combined generalized criterion selection function.

Thus, the model of planning and scheduling of the EIS functioning and modernization has the form (3). Expressions (3) describe the logical-dynamic model of managing the EIS information services.

$$\dot{x}_{ij}^{(o,v)} = \sum_{l=1}^{S_v} r_{lij}^{(o,v)}(t) \cdot u_{lij}^{(o,v)};$$

$$x_{ij}^{(o,v)}(t_0) = 0; x_{ij}^{(o,v)}(t_f) = a_{ij}^{(o,v)};$$

$$\sum_{i=1}^{S_j} u_{lij}^{(o,v)} \le P_j^{(o,v)}; \forall l, \forall j; \sum_{j=1}^{m_i} u_{lij}^{(o,v)} \le P_i^{(o,v)}; \forall l, \forall i; \tag{3}$$

$$u_{lij}^{(o,v)}(t) \in \{0,1\};$$

$$u_{lij}^{(o,v)}\left[\sum_{\tilde{\alpha}\in\Gamma_1}(a_{i\tilde{\alpha}}^{(o,v)} - x_{i\tilde{\alpha}}^{(o,v)}) + \sum_{\tilde{i}=1}^{z_d}(a_{\tilde{i}j}^{(m,v)} - x_{\tilde{i}j}^{(m,v)})\right] = 0,$$

where $x_{ij}^{(o,v)}$ is the variable that characterizes the current state of the service implementation operation; $r_{lij}^{(o,v)}$ is the matrix time function that sets the space-time constraints associated with the provision of the service. It takes the value 1 if the operation can be performed and 0 in the opposite case; $u_{lij}^{(o,v)}$ is the control variable, which takes the value 1 if the information service uses the EIS information resource, and 0 in the opposite case; $x_{ij}^{(o,v)}(t_0)$ and $x_{ij}^{(o,v)}(t_f)$ are boundary conditions at the initial and final time points, respectively; $a_{ij}^{(o,v)}$ is the total volume of the operation; $P_i^{(o,v)}, P_j^{(o,v)}$ are the constants which determine the ability to simultaneously use several information resources for the implementation of the service and characterize technical and technological limitations of the selected architecture and the nomenclature of elements that were defined at the first step; Γ_1 is the set of operation numbers that characterize the state of implementation of the information service and which are directly preceding and technologically related to the current operation using the logical operations "AND"; $a_{\tilde{i}j}^{(m,v)}$ is the specified volume of operations included into the technological cycle of information resources modernization; $x_{\tilde{i}j}^{(m,v)}$ is the variable that characterizes the current state of the operation of upgrading the information resource.

The presented expressions (3) allow to set the inter-level restrictions of the following type: the information service cannot be submitted until the modernization of the information resource is completed see Figure 3.

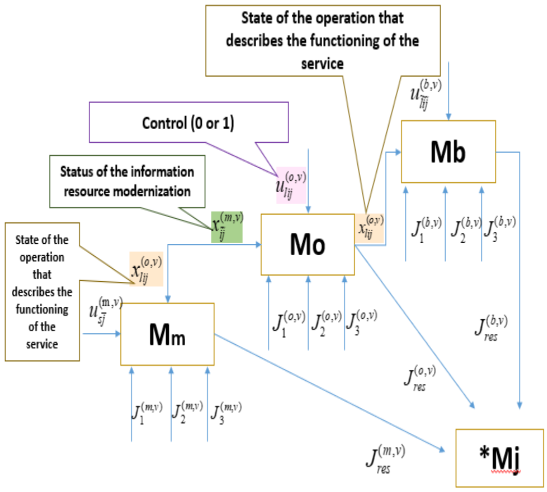

Figure3: The connection of logical-dynamic models

We should present the quality indicators of the coordinated software management of the modernization and EIS functioning for the service model (4):

$$J_1^{(o,v)} = \frac{1}{2}\sum_{i=1}^{S_j}\sum_{j=1}^{m_i}[a_{ij}^{(o,v)} - x_{ij}^{(o,v)}(t_f^{(j)})]^2; \tag{4}$$

$$J_2^{(o,v)} = \sum_{l=1}^{S_v}\sum_{i=1}^{S_j}\sum_{j=1}^{m_i}\int_{t_0}^{t_f}\eta_{lij}(\tau)u_{lij}^{(o,v)}(\tau)d\tau; \tag{5}$$

$$J_3^{(o,v)} = \sum_{l=1}^{S_v}\sum_{i=1}^{S_j}\sum_{j=1}^{m_i}\int_{t_0}^{t_f}[c_{lij}^{(o,v_1)}(\tau)]u_{lij}^{(o,v)}(\tau)d\tau, \tag{6}$$

where the criterial function of the form (4) characterizes the full completeness of operations; (9) helps evaluate the total penalty for the failure of the directive deadlines for providing the service; $\eta_{lij}(\tau)$ is a given time function that characterizes the current downtime price of the information service; The function of the form (10) describes changes in the total cost of ownership of the EIS system at the stage of modernization; $c_{lij}^{(o,v_1)}(\tau)$ are given non-linear time functions, which are used to set the current prices of costs associated with depreciation and maintenance of the service. The presented approach to the EIS modernization works allows to comprehensively get to the problems of the structural and functional appearance synthesis and the development of coordinated work plans. For more information about the algorithm for finding the operation and modernization of the CTS optimal program based on the Boltyansky local cut method, see [16].

Relying on the principles of the service-oriented approach allows the introduction of the abstraction "information service", which leads to a reduction in the dimension of the solvable problems. Due to the minimization of the number of connections between the physical and information levels and the use of mixed constraints in (7). There is a unique opportunity to operate only with an active front of work at the stage of a comprehensive plan and schedule for EIS functioning and modernization synthesis. We consider the constraints that affect the current processes at different levels of the hierarchy. Such a formulation of the problem of program synthesis for the modernization of the EIS gives an opportunity to involve the fundamental results obtained in the modern theory of proactive control of the CTS structural dynamics [9].

4. Example

We should present the initial data for the design and analysis of the implemented system appearance. Table 1 shows the data on the reliability of elements of various equipment manufacturers. In column 1 there is the data for the “old” or legacy EIS elements. In columns 2-4 there is the data on the probability of failure-free operation of elements from foreign and domestic manufacturers.

Table 1
Data on the reliability of “old” and “new” EIS elements

EIS elements	1	2	3	4
SERVER 1	0,75	0,84	0,82	0,97
SERVER 2	0,60	0,73	0,65	0,85
ROUTER 1	0,74	0,91	0,80	0,93
ROUTER (2-3)	0,90	0,99	0,95	0,97
SWITCH (1-3)	0,84	0,82	0,91	0,90
PC 1-6	0,5	0,63	0,79	0,90
DATABASE SERVER	0,75	0,88	0,98	0,99

The data presented in table 2 illustrates the integrated economic assessment of elements from different manufacturers (see formula (1)) for a given EIS architecture (see Fig. 1), where column 1 contains data for legacy EIS elements, and columns 2-4 contain data from different manufacturers.

Table 2
The economic evaluation of EIS elements

EIS elements	1	2	3	4
SERVER 1	3,7	0,8	1,7	1,9
SERVER 2	4,2	0,67	1,12	2,7
ROUTER 1	8,5	5,8	9,6	8,5
ROUTER (2-3)	2,3	2,1	4,4	2,4
SWITCH (1-3)	7,2	4,67	2,4	7,3
PC 1-6	3,4	0,7	1,6	2,4
DATABASE SERVER	0,5	0,2	0,2	0,21

A number of effective variants of the EIS project, obtained as a result of applying the above-mentioned approach, are shown in table 3. The table shows 4 different variants of “new” EIS appearance.

Table 3
Pareto variants of the EIS configuration

№	3	4	8	15
SERVER 1	1-1	1-2	1-3	1-2
SERVER 2	2-4	2-4	1-3	2-1
ROUTER 1	1-2	2-1	1-3	1-2
ROUTER (2-3)	2-3	2-3	2-4	2,4
SWITCH (1-3)	4-3	4-4	3-2	3-2

PC 1-6	7-4	6-3	6-4	6-1
DATABASE SERVER	1-2	2-4	1-3	1-4
Quantity	18	19	15	16
Costs	164.2	200.3	146.3	83.8
Reliability	0.89	0.91	0.84	0.74

The first number indicates the number of elements. The second number indicates the manufacturer.

Further narrowing of the set of non-dominant alternatives is carried out by attracting experts. Clipping is based on the study of Pareto set properties and obtaining the additional information from the decision-makers (the estimation of the set power, the range of changes in the indicators values, their inconsistency). This stage ends with the choice of an appearance variant of the implemented EIS [8].

There is an example of the connection between the BP, the level of services and the modernization of EIS information services of the enterprise warehouse subsystem (see Figure 4)

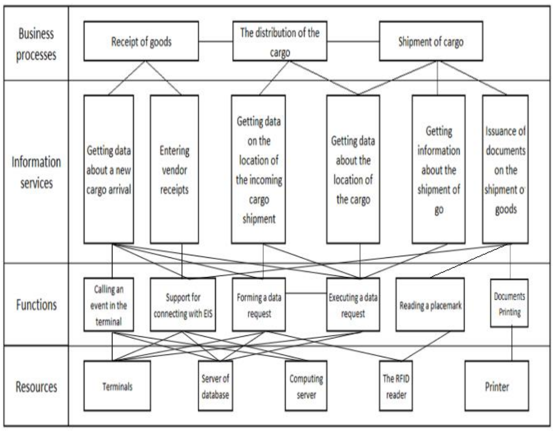

Figure 4: The example of interconnections between different CTS levels

There is a chain of three standardized BP (see Fig. 3). The program of operation and the schedule of production are formed for the period of the EIS modernization. The layout of the order and its delivery to the consumer is a complex process. A special feature of BP is that customers are not only large distributors, but also small grocery chains. In the conditions of cooperation between the enterprise and consumers, the procedure for returning products in case the product is not sold is defined.

Delivery is carried out by road transport. Items are stored in specialized containers. Each "tray " has an RFID tag that stores information about the products inside. Before shipping, the operating personnel must scan all items and link them to the set label. Data is entered in the registry and stored at database servers. Information services support the specified BP, but not more than two of them (see Figure 4).

It is necessary to find such an acceptable control that satisfies the constraints and transforms the dynamic system from a given initial state into a given final state. If there are several control actions, then it is necessary to choose the one among them at which the generalized quality indicator takes the extreme value. In other words, it is necessary to find a valid program of functioning and modernization of the enterprise subsystems, during the implementation of which all operations involved in the corresponding cycles of EIS information resources modernization management will be fulfilled fully and timely, and the reducing of the BP quality would be minimal.

At a given interval, it is necessary to implement modernization (replacement) of 17 EIS elements (database servers, RFID tag readers (including installation of new tags), personal computers) instead of "outdated" hardware new devices of the same manufacturer are installed, but with improved characteristics. The planning step is 1 day.

The working day is 8 hours. There are days off for a given period of work. The "resources" of the modernization are the personnel of the information service of the enterprise. Depending on the qualification, each employee involved in the modernization process was assigned "performance".

Carrying out modernization works has its own technological cycle and regulations, which are determined by the “old” and “new” architecture of the EIS, as well as the nomenclature of elements selected at the first step of the research. Based on the above, we form quality indicators for all levels of the enterprise subsystem (the BP, the level of services and modernization): full completeness of operations; efficiency and cost of works.

As a dispatching solution, a combined heuristic plan developed on the basis of the "FIFO" principle was chosen. The Figure 5 shows the plan as a schedule of work for the modernization of EIS information resources.

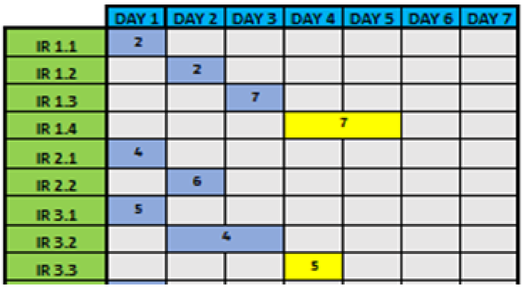

Figure 5: The heuristic plan for the modernization and the functioning of EIS resources

Abbreviations are introduced: IR 1.1 is information resource No. 1.1.; Day 1 is a planning interval; the constant in the center of the rectangle indicates the amount of resources that were allocated for modernization; a blue rectangle stands for ‘operation of information resources modernization has been successfully completed’; a yellow rectangle is for ‘operation of information resources modernization violated the directive deadline; a red rectangle is for ‘failure of the modernization deadline’.

Figure 6 shows the optimal plan and schedule of EIS modernization.

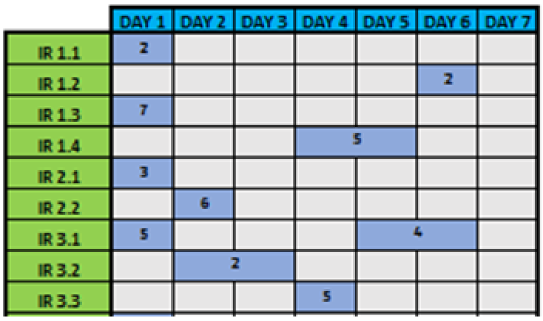

Figure 6: Optimal plan for the information resources modernization.

Figure 7 shows the influence of the heuristic plan on the implementation of the CTS BP

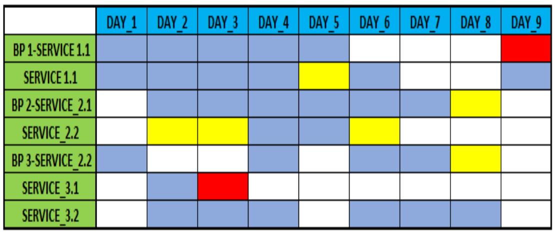

Figure 7: The influence of heuristic EIS modernization plan on BP

“BP-1-Service 1.1.” means that BP №1 uses the Information Service 1.1. The colors of the rectangles have an identical interpretation.

Figure 8 shows the influence of optimal plan on BP functioning.

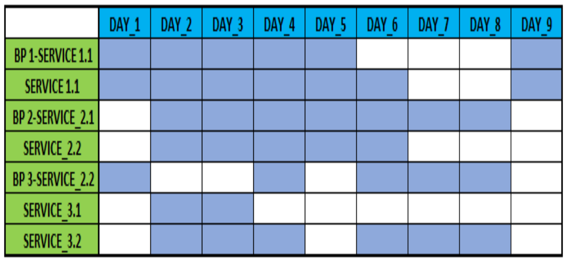

Figure 8: The influence of optimal plan on the BP of CTS.

The implementation of the developed approach allowed to increase in average by 5-15% the generalized indicator of completeness and efficiency of operations. Cost indicators in monetary terms are improved by 10-14% in average compared to the values of similar indicators calculated using traditional heuristic methods and algorithms of solving problems of planning and scheduling.

5. Conclusion

The presented approach allows to increase the validity of management decisions made at the stages of determining the composition of the hardware of “new” EIS and synthesizing programs for joint functioning and modernization of the CTS.

The proposed approach allows to note the high integration of mathematical models within a single combined planning algorithm based on the principles of a service-oriented approach. The study opens up the prospects for forming the reasonable requirements for the characteristics of the EIS hardware complex for CTS.

The paper presents one of the possible ways of analysis the influence of the selected EIS elements on the plans and schedules of information system functioning and development. It is advisable to apply at objects that are at the most modern level of development, otherwise the benefits of optimal functioning and modernization programs of information resources will be offset by organizational and technical shortcomings of the BP.

Integrated planning of the functioning and modernization of the EIS is a time-consuming process that requires the involvement of decision-makers who understand the specificity of the subject area. Thus, the further direction of research is the search for ways of considering the contradictory connections of various quality indicators of the developed plans, as well as the automation of the proposed approach. On the website [17], the reader will find information about the practical implementation of the developed models and algorithms in the framework of solving integrated planning problems.

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