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Advanced Study on Resource-Saving Methods of Forming Information Infrastructure of Sorting Stations

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ABSTRACT

This chapter discusses a resource-saving method for choosing a rational structure of an automated control system when technical structure migration from a centralized system based on a powerful processor to a functionally distributed system based on microcontrollers. The method allows you to determine a rational number of subsystems that effectively use the computing and financial resources of the project. The approach is illustrated by a real example of designing an automated control system for a marshalling yard.

Keywords: Resource-saving design methods; rational system decomposition; migration; technical structure; marshalling yard.

1. INTRODUCTION

The proposed chapter is devoted to solving the problem of determining the rational decomposition of automated systems during their migration from centralized structures based on one powerful computer to modern distributed structures based on microcontrollers, saving computing and financial resources. The work [1] presents a variety of options for structures in projects for automation of marshalling yards. Currently, the transition to smart technologies makes this task extremely urgent.

The theoretical foundations for solving the problem under consideration and a complete set of literature sources are given in [2]. This chapter reveals the theory of solving the problem and its extensions as part of a the author complex methodology CoDeCS [3,4].

2. PROBLEM STATEMENT AND METHOD OF ITS SOLUTION

The hump yard consists of n controlled objects M_i, whose status O_i can be characterized by two parameters: y_i - adjustable parameter; x_i - control action (z_j - controlled, f_g - uncontrolled parameters, see Fig. 1).

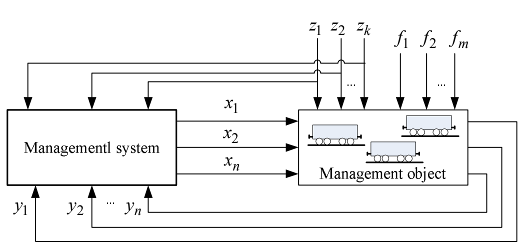

Fig. 1. A marshalling yard as a control object

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Thus, the state of the system at each instant of time can be characterized by vectors: the state of the regulated parameter $Y = \{y_1,...,y_n\}$; of the position of the regulating body $X = \{x_1,...,x_n\}$ and the vector-setpoint $Y' = \{y'_1,...,y'_n\}$. The vector-set Y' is a task in support of a regulated parameter and in general can differ from its true value - the vector Y. If the system does not have local regulators, then MC directly forms the vector X and issues it to the executive bodies. In this case, we have a centralized system (Fig. 2).

In the case of local regulators (LCs) implementing local control functions, MC's functions are simplified to formulate only the settings Y' for the LC. In this case, the hierarchical structure of the MS is discussed (Fig. 3).

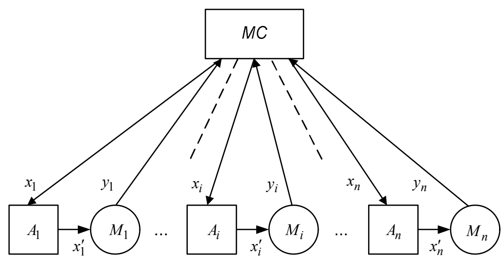

Fig. 2. The structure of the centralized control system

Let the system consist of MC and *n* local subsystems.

In Fig. 2 and Fig. 3 the following symbols are acceptable:

Managing System (MS), Actuator (A), Local Controller (LC), Executive Mechanism (M).

The implementation of the management algorithm is reduced to minimizing (maximizing) the function of the species

$$B = \varphi(Y, X) \tag{1}$$

(for example, minimizing the deviation of the speed of exit from the retarder position from the set by the control algorithm).

Optimization involves searching for such an optimal value of the control vector U*, so that the management function (1) at the given X takes the optimal value

$$B^* = \min(\max)\varphi(Y, X) \tag{2}$$

Or

$$B^* = \varphi(Y, X^*). \tag{3}$$

The evaluation of the variants of structures will be carried out on the criterion of the full cost of resources. To simplify the calculations we assume that all n control circuits are the same, the costs of operating systems are also the same and the unreliability of executive bodies can be neglected.

System management will be presented in the mode of time distribution as follows. According to the scheme in Fig. 2 (centralized control system) MC receives information about the state of the controlled object in the form of vectors Y in cycles in time $T_c\,(T_c, 2T_c,...,kT_c)$ intervals. As a result of information processing by algorithm (2), MC carries out the calculation of the new setpoint Y' and issuance of the control command to the executive bodies - a vector of the X position.

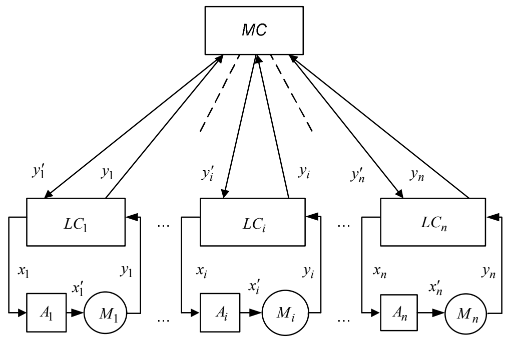

Fig. 3. Structure of the hierarchical system with local control subsystems

According to the scheme in Fig. 3 (hierarchical control system), which also receives information in the form of vectors Y. However, in this case, MC issues only a vector setting Y'. The calculation of the vector X is carried out by the local regulators LC; MCM only coordinates their work by adjusting the vector setting Y'.

Let's see what happens in the case of equipment failure in the kth time interval. In case of failure of MC in a centralized structure, the following situations are possible:

1) the work of the car classification is immediately terminated. Losses p_0 are determined by the downtime of the object and can be estimated as a complete loss of efficiency during the elimination of the malfunction (system recovery) T_{rec}:

$$p_0 = B^* T_{rec}$$

2) For some time after the failure of MC the system continues to function normally and then there is a violation of its work. In this case, the behaviour of the object may vary depending on the position in which the executive bodies will be. They can:

a) Remain in the position in which they were at the moment of the accident t_0, ie $X = X_0$;
b) Translated into a state of emergency $X = X_{\text{em}}$ characterized by values.

In the second situation, the damage p_1 will consist of two parts (Fig. 4), $y_i = v_i$ - speed of exit from the i-th braking position, $v_{i\min} < v_i(t) < v_{i\max}$).

At the moment time t_1, it is proportional to the difference between the optimal and actual values of efficiency:

$$p_{11} = (B^* - B_1)t_1 \,. \tag{4}$$

At the moment time t_2 there is an output parameter $v_i(t)$ at the permissible limits $v_i(t) > v_{i\max}$ and local protection disables the object, i.e., losses in this area p_{12} are determined by the total loss of efficiency:

$$p_{12} = B^* t_2 \,.$$

Complete losses for the second situation

$$p_1 = p_{11} + p_{12} = (B^* - B_1)t_1 + B^* t_2 \;,$$

Where

$T_{rec} = t_1 + t_2; \ \lim_{t_1 \to \infty} p_1 = B^* T_{rec}$

B_1 - Efficiency in case of not optimal control in the centralized system (manual control of sorting out of cars).

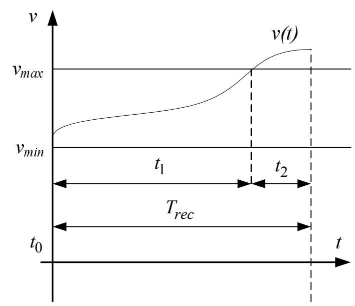

Fig. 4. Example of the behavior of the regulated parameter v (t) within (vin, vmax)

In the hierarchical system, when MC refuses, the control is not lost completely, only its effectiveness is reduced. As a result of the refusal, she takes on meaning B_2. In this case, the loss from the loss of optimal control

$$p_2 = (B_2^* - B_2)T_{rec} \tag{5}$$

This damage, as a rule, is much less than the damage that is obtained when a CM system fails in a centralized system. Reducing the damage to a system with a hierarchical structure is achieved by increasing its value due to the presence of local regulators. In addition, the effect of loss reduction is reduced due to additional losses caused by the unreliability of local regulators. Let's take the following for further analysis

Assumption:

B^* - Loss per unit time when the car classification does not work;
B_1 - Loss per unit of time when the centralized system does not work MC (non-optimal control);
B_2 - Loss per unit of time when the hierarchical system does not work MC (non-optimal control);
b_i^* - Loss per unit of time when the i-th control circuit is not working
b_i - Loss per unit time with a sub-optimal value of the efficiency of the i-th circuit.
$B^* > B_1 > B_2 >> b_i^* > b_i$.
Then the full costs for centralized P_1 and hierarchical P_2 systems can be estimated as follows:

$$\mathrm{P}_1 = \left(B^* - B_1\right)\lambda_0 t_1 + B^* \lambda_0 t_2 + C_0^{\mathrm{centr}}, \tag{6}$$

$$\begin{aligned}\mathrm{P}_2 &= (B^* - B_2)\lambda_0 T_{rec} + \\ &+ \sum_{i=1}^{n} \left[(b_i^* - b_i)\lambda_i t_{i1} + b_i^* \lambda_i t_{i2} \right] + C_0^{dec} + \sum_{i=1}^{n} c_i\end{aligned} \tag{7}$$

Where λ_0 - the intensity of bugs CM in hierarchical and centralized systems; λ_i - intensity of failure of the i-th local regulator; $C_0^{cen}, C_0^{dcen}, c_i$ - the cost of CM respectively in the centralized system, in a decentralized (hierarchical) system and the cost of the microcontroller system of the i-th local regulator.

We will assume that

$$C_0^{cen} > C_0^{dcen} >> c_i .$$

To simplify further analysis, we assume that the system is homogeneous in its composition, i.e.

$$b_i = b_n;\ \lambda_i = \lambda_n;\ c_i = c_n;\ i = 1, 2, ..., n . \tag{8}$$

For the i-th control circuit, taking into account the possible failure of the regulator by analogy with the centralized control system (Fig. 4), we can write

$$t_{i2} = T_{rec\,i} - t_{i1} ,$$

where t_{i2} - the time during which the i-th parameter is within the permissible values; $T_{rec\,i}$ - time of repair of the i-th regulator; t_{i1} - the time during which the i-th parameter does not exceed the permissible limits.

In the first approximation we will accept that

$$\begin{aligned} &t_{i1} = t_{n1} = t_1,\ i = 1, 2, ..., n; \\ &T_{rec}^{cen}(\mathrm{CM}) = T_{rec}^{dec}(\mathrm{CM}) = T_{rec}(c_n). \end{aligned} \tag{9}$$

For further research, we introduce the coefficient

$$t_1 = rT_{rec},\ t_2 = (1-r)T_{rec} .$$

Then we have from (6) and (7)

$$\mathrm{P}_1 = \left(B^* - B_1\right)\lambda_0 r T_{rec} + B^*\lambda_0(1-r)T_{rec} + C_0^{cen} , \tag{10}$$

$$\begin{aligned} \mathrm{P}_2 = &(B^* - B_2)\lambda_0 T_{rec} + (B^* - B_1)\lambda_n r T_{rec} + \\ &+ B^*\lambda_n(1-r)T_{rec} + C_0^{dec} + nc_n. \end{aligned} \tag{11}$$

Let's turn to the integral index of reliability - the readiness factor

$$\begin{aligned} &K_{avail}^{cen}(\mathrm{CM}) = K_{avail}^{dcen}(\mathrm{CM}) = K_0 = \\ &= \frac{T_{mtf}}{T_{mtf} + T_{rec}} = \frac{1/\lambda_0}{1/\lambda_0 + T_{rec}} \end{aligned} , \tag{12}$$

$$K_{avail}(c_n) = K_n = \frac{T_{\mathrm{mtf}(n)}}{T_{\mathrm{mtf}(n)} + T_{rec}} = \frac{1/\lambda_n}{1/\lambda_n + T_{rec}} , \tag{13}$$

where T_{mtf} - mean time to failure.

Where

$$\lambda_0 = \frac{1-K_0}{K_0 T_{rec}};\quad \lambda_n = \frac{1-K_n}{K_n T_{rec}} . \tag{14}$$

Then let's introduce the coefficient α :

$$K_n = \alpha K_0 . \tag{15}$$

We substitute (14) and (15) in (10), (11), normalize full costs and introduce the notation

$$\delta_1 = \frac{B^* - B_1}{B^*};\ \ \delta_2 = \frac{B^* - B_2}{B^*}.$$

As a result, we get

$$\tilde{P}_1 = \frac{P_1}{B^*} = \frac{(1-K_0)(1+r(\delta_1 - 1))}{K_0} + \frac{C_0^{cen}}{B^*}, \tag{16}$$

$$\begin{aligned}\tilde{P}_2 = \frac{P_2}{B^*} = \frac{\delta_2(1-K_0)}{K_0} + \\ + \frac{(1-\alpha K_0)(1+r(\delta_1-1))}{\alpha K_0} + \frac{C_0^{dcen} + nc_n}{B^*},\end{aligned} \tag{17}$$

In Fig. 5, constructed graphs $\tilde{P}_1 = f_1(K_0)$ and $\tilde{P}_2 = f_2(K_0)$ under the following assumptions $r = 0,9$ and $\alpha = 1,1$.

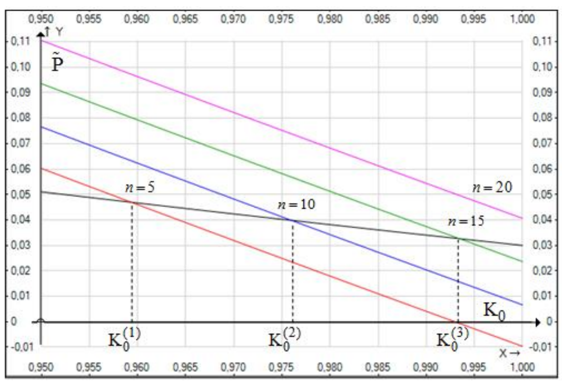

Fig. 5. Dependence of change of systems efficiency on reliability of MC and LC

From the graphs it follows that with the increase of the coefficient of readiness of loss in the hierarchical decentralized system, in comparison with the centralized decreases ($K_0^{(1)}, K_0^{(2)}, K_0^{(3)}$ - points on the graph where losses in both systems are the same). From (17) it follows that the losses in the hierarchical system are linearly dependent on the number and cost of local microcontroller regulators. Given the reliability indices (K_0, α) and the value of the subsystems in the technical structure of the control system (C_0^{cen}, C_0^{dcen} and c_n), the number of contours of local control n can be chosen based on the solution of equations (16) and (17).

If we compare (16) and (17), then introduce normalized coefficients

$$a_1 = 10^{-3}\delta_2 B^*;\ a_2 = 10^{-3} c_n;\ a_3 = 10^{-3}(C_0^{dec} - C_0^{cen}), \tag{18}$$

we can obtain the necessary equations of two variables K_0 and n:

$$a_1(1-K_0)/K_0 + a_2 n + a_3 = 0 .$$

Figs. 6, 7, 8 shows the planes that represent the geometric point of the points $K_0^{(i)}$ in which the losses in the centralized and hierarchical (decentralized) systems are identical and corresponds to the change of priorities in the construction of systems, depending on the readiness coefficients and the number of local regulators. Analysis of the results shows that rational solutions are located in the zone of high readiness and a small number of local subsystems. The zone of rational decisions increases if the value of the coefficient a_1 decreases. The number of local circuits does not exceed 15 subsystems.

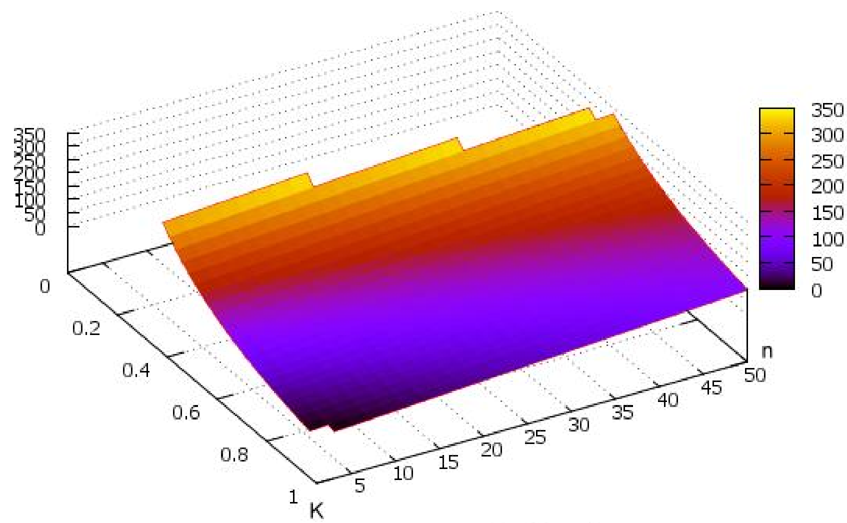

Fig. 6. Plans of equal losses of centralized and hierarchical systems ($a_1 = 200$ **)**

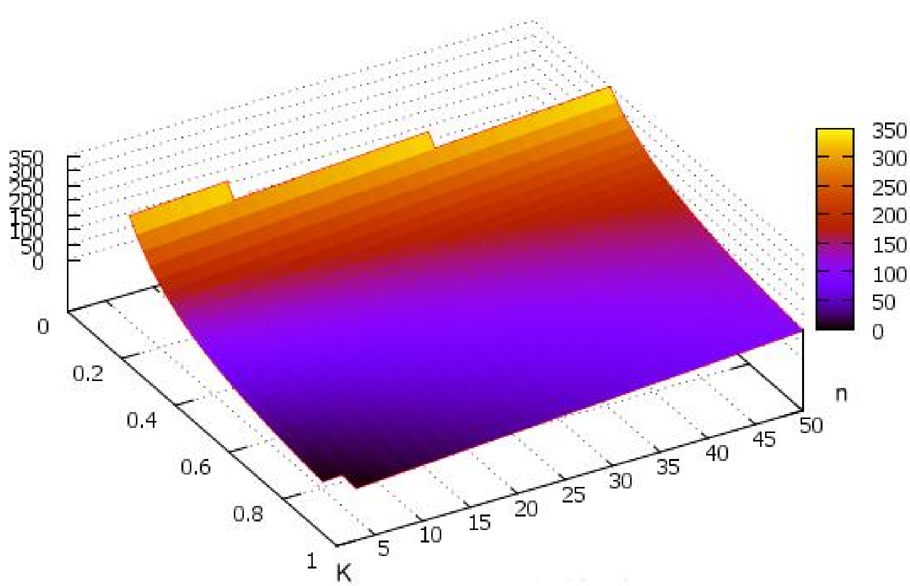

Fig. 7. Plans for $a_1 = 100$

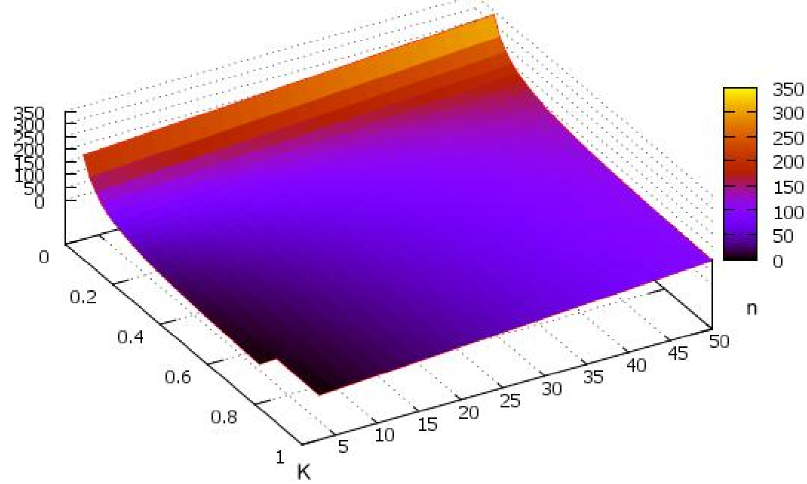

Fig. 8. Plans for $a_1 = 10$

3. RESOURCE-SAVING METHODOLOGY FOR CS SYSTEMS DESIGN

The proposed models and methods are an integral part of a unified conceptual design methodology presented in Fig. 9.

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 CS;

Block 2 - the characteristic of CS 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: 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 CS information structure by the minimization criterion for the growth of the total information flow with decreasing the number of information links in the structure).

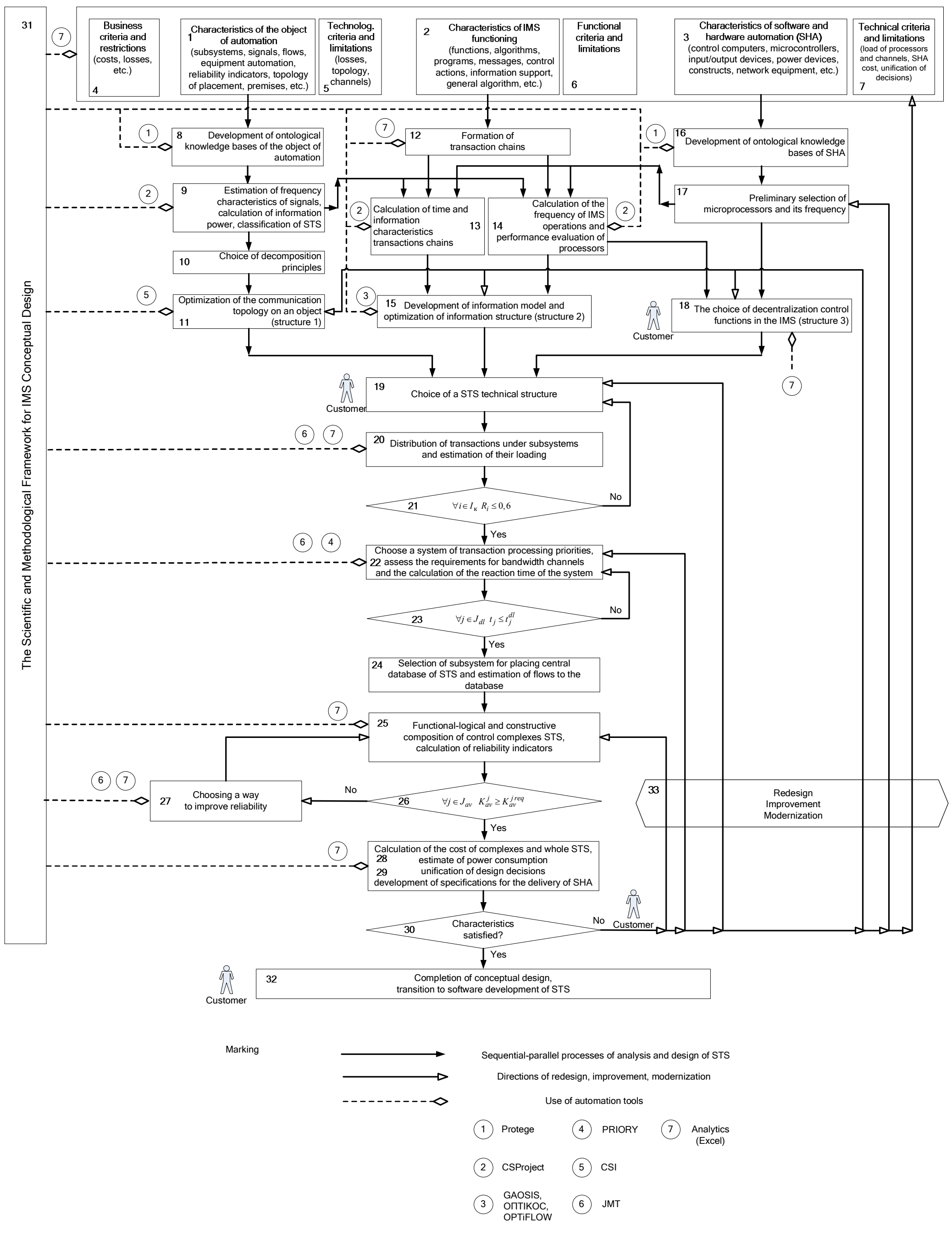

Fig. 9. CS conceptual design framework

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 CS.

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 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 CS, 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 CS (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 CS 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 CS 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. 9 shows the names of the tools used for the research and conceptual design.

4. CONCLUSIONS

IThe resource-saving methods considered in the chapter, combined into a single methodology for the conceptual design of information and control computer systems in the process of migrating their technical structures, will be useful for analysts and developers solving such problems. In general, the technique continues to evolve, acquiring object-oriented features. I hope this chapter will inspire you to come up with new ideas and solutions.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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- Participation in the development of information support of the automated control system for trains disassembling on the hill of Yasinovataya station
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- Development of the technical task for the development of the information management complex for the sorting station Nizhnedneprovsk-Uzel (Ukraine)
- Development and implementation of the university's corporate network on 1200 computers
- Development of a class of remote automated testing on thin clients
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- Invention “A device for controlling the technological process of the trains dissolution on a sorting hill “ (authorship certificate SU № 1073146 A1, МПК B61L17/00)

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