Evaluating the relevance of the elements of distributed computing system infrastructure when solving tasks in managing an economic unit

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***Abstract*—From the point of view of its architecture, any information system (IS) represents a distributed information processing system. IS infrastructure ensures the execution of the enterprise business processes. However, the role played by IS infrastructure elements in the execution of a certain business process is different and can be evaluated with the help of a coefficient of element's relevance. Taking the coefficient of relevance into consideration will make it possible to manage the information flows rationally and to provide the necessary standby equipment.**

Keywords—distributed computing systems, relevance, the Perron-Frobenius theorem, relations matrix, diagram of major automation flows

I. Introduction

The infrastructure of modern enterprise distributed computing systems (DCS) consists of components different both in their function and in design principles. However, there are common points in the structure of all distributed computing systems. So, any DCS includes the following elements:

- data processing server;
- management server;
- data storage server;
- auxiliary/additional (proxy, print, e-mail) servers;
- employees' computer workstations;
- plug-in mobile devices;
- switches;
- routers;
- hubs;
- medium.

A commonly used model of an enterprise distributed computing system is shown in Figure 1. Enterprise departments:

- Management department;
- Accounting department;
- Personnel department;
- Planning department;
- General services department;
- Warehouse department;
- Transport department;
- Manufacturing departments;
- ACS department.

This model represents an infrastructure component of an enterprise automated information system (AIS), where the system is formed by the information flows circulating between the elements (while operating).

II. Problem Statement

According to their structure and content, AIS information flows can be divided into three major categories:

1) the flows which ensure structural integrity of the system;
2) the flows which determine basic system properties;
3) the flows of process automation.

While operating the flow can overlap or branch, but in any case the routes of the flows allow to evaluate the participation of each element in the whole process of functioning. The participation of an element can be evaluated with the help of a relevance coefficient CR, which defines the significance of the element in the execution of IT-processes in the enterprise business system. The CR makes it possible to rationally manage the workload of system components, their maintenance and repair, as well as to determine the necessary cold and hot standby equipment. Thus, evaluating the relevance of the DCS infrastructure elements is an urgent problem which consists in making an analytical model of evaluating the relevance of the DCS infrastructure elements according to their participation in enterprise (organization) business processes.

3. Problem Solution

As the structure represents a totality of stable relations within the system ensuring its integrity and self-identity, the information flows of the enterprise business system can be divided into three major categories:

1) the flows of DCS elements communication;
2) the flows defining the specific application of DCS in the information system;
3) the flows arising when solving tasks on automation of business processes and processes management decision-making.

The flows of the first category arise from the following constituents:

• official traffic: the flows sent by the information interchange participants, comprising of requests about computer network status, number and activity of users, shared resources and responses to these requests. In different

AIS architectures different elements can serve as request sources and receivers. For example, if computer network is based on a workgroup model, each computer sends nearly the same official traffic which requests network resources and informs about its own resources available. A domain model has a more rigorous network, where a domain controller acts as the initiator of information interchange. Information systems based on a workgroup model are usually rather small (10…15 network devices), they are generally used for limited number of purposes, that is why this model will not be taken into consideration in this research. From the viewpoint of evaluating AIS elements interdependency, various domain models appear to be of most interest to us;

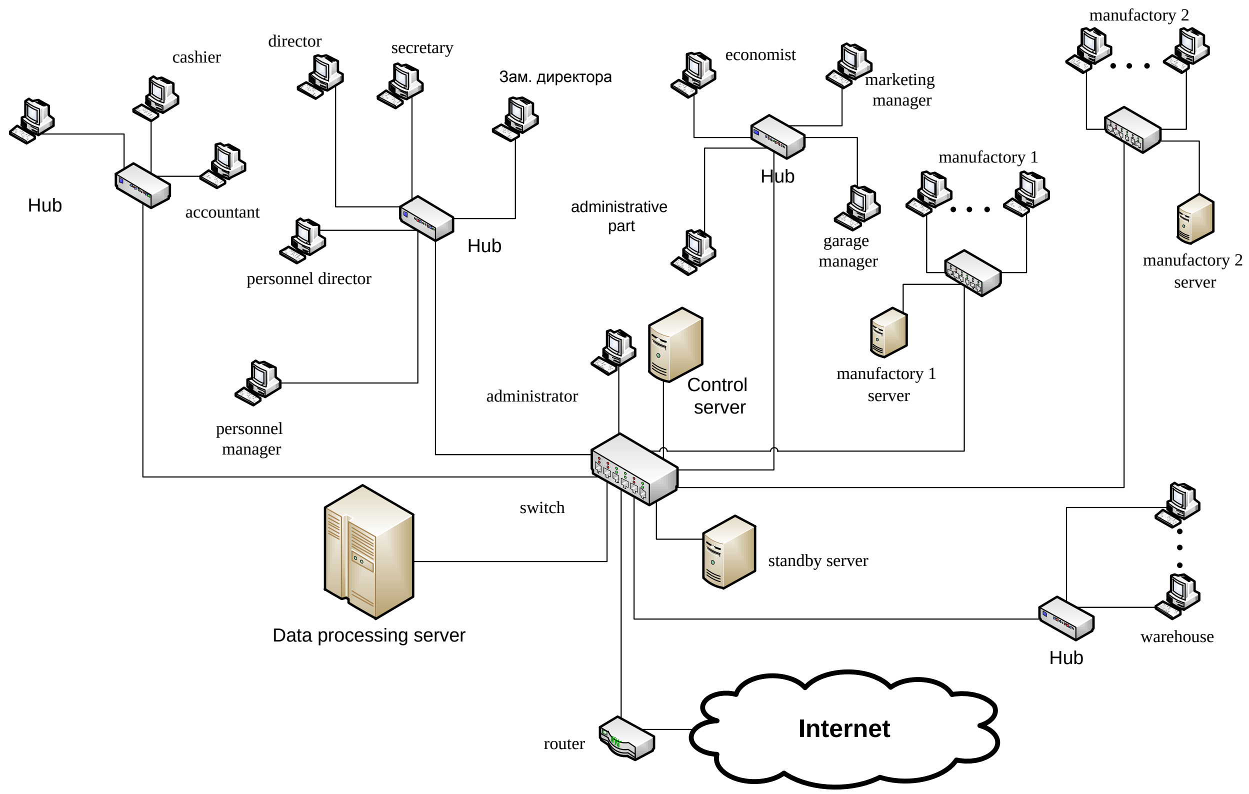

Fig. 1. A model of an enterprise distributed system.

• the flows determined by the information transmitted while AIS functioning. The flows of this category are not regular and proceed from AIS users' tasks. For example, to make a sales report, a manager can use several data bases and his requests physically pass through various communicators, servers, etc. As a rule, request processing results have the route of the request but in a backward direction. So, the structural coherence of elements within the system is determined by the routes of requests and responses.

The flows of the second category condition the system properties which attribute AIS to data processing systems (ADPS), automated control systems (ACS), or to automated information retrieval system (AIRS). Business intelligence systems belong to ADPS, the class of ACS is represented by enterprise resource management systems, for example: ERP, MRP, MRP II. Library information systems fall into the category of AIRS.

Quantitative and qualitative properties of the flow of this category depend on the specific content of users' requests and responses to them and are predetermined by the processes running in the system.

The flows belonging to the third category are determined by AIS automation processes and are formed in accordance with designed-in data processing algorithms. They ensure the conceptual integrity of the system. The content of these of flows is provided by functional, mathematical and software support. These flows arise each time when a user runs a certain pre-programmed information processing model.

Such division of information flows into categories enables us to regard the distributed computing system as an object possessing structure, substrate and concept. This approach allows to evaluate the relevance of the system elements depending on the structure, substrate and concept.

The systemic notion of «relevance» implies a substantial difference between a systemic examination of objects and system parameters. Along with attributive system parameters, which characterize each particular system, there are also relational system parameters, which define the relations between the objects.

One system (one object) can be more significant than another in concept, in structure, in substrate. That is why a relational system parameter is more «relevant», and the respective attributive parameter is a vector [2].

Let

$$(m)S\overset{\rightarrow}{\leftarrow}\left[R(m)\right]P \quad \text{– be a system}$$

where m – is a substrate (the foundation of phenomena and processes, which determine the system properties); R – is a structure (a totality of stable relations between the objects); P – a concept of the system (the content of the notion).

A systemic examination of the object gives the opportunity to classify various types of objects' «relevance» in accordance with the aspects concerned. In the case under study structure relevance, substrate relevance and concept relevance can be distinguished depending on what is being evaluated: *m*, *R* or *P*.

Further on we can evaluate not *m*, *R* or *P* themselves but certain relations of n-order between the AIS elements.

Let us consider the system in Figure 1. This system can be referred to the ADPS class as the main processes running in it are on-line transaction processing (OLTP), online analytical processing (OLAP), generating various reports and documentation processes. The major automation processes are:

- processes of accounting, inventory, documentation and staff control;
- processes of manufacturing tasks planning and designing, as well as project management;
- research and analytical processes.

In topological mapping the model of the enterprise distributed system (see Fig. 1) represents a tree structure overlapped with the information flows of the processes mentioned above (Fig. 2).

The technique of evaluating the system elements relevance is as follows.

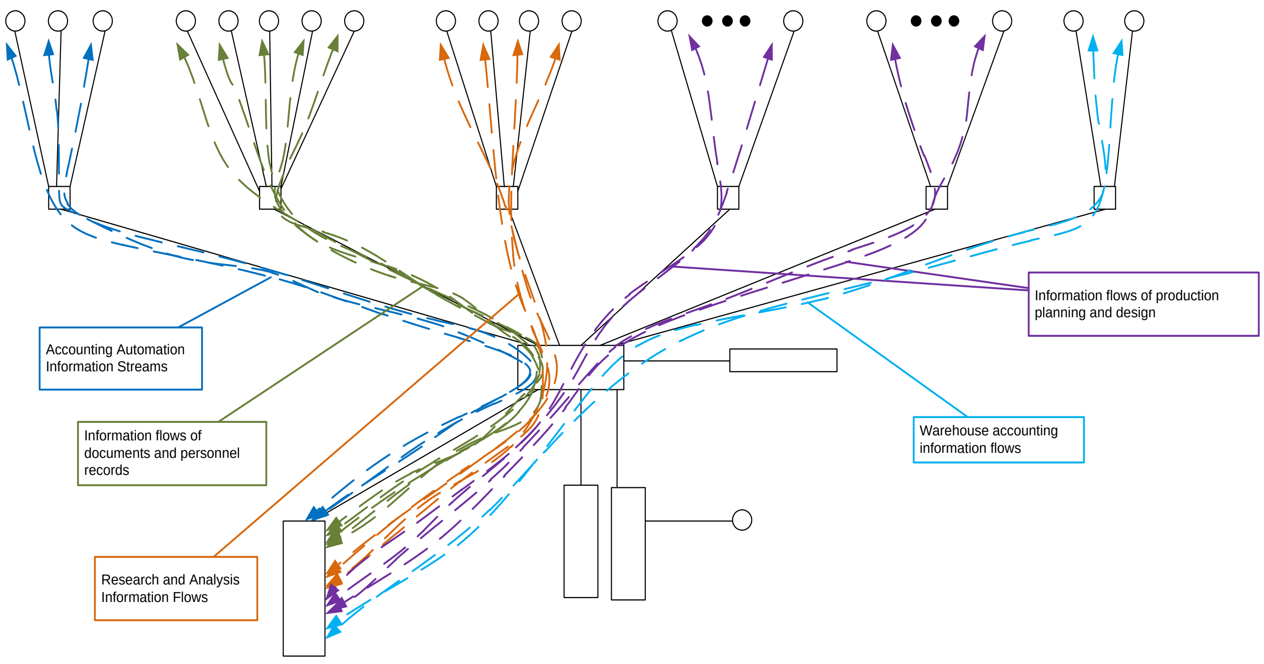

Fig. 2. A simplified diagram of major automation flows.

Firstly, relations register is arranged in accordance with the number of workstations. The sign «=» is used to denote the identity of each object to itself. The relation a «source» of information is represented with «⊕» symbol. A passive relation, i.e. a «receiver» of information, is denoted by «∅» symbol. At the same time the preference is always given to the «source of information» as it is a more active element than the «receiver of information».

Then the notion of «extensional length» is introduced. The extensional length is determined by the total number of active relations of one system element towards the other ones. The system element of the highest relevance is the one that has the biggest extensional length of relations vector, or in other words the one that acts as a «source of information» in regard to other system elements most of the times. In the opposite extreme case the «relevance» of an AIS element should be identified with a «passive» relation towards (i.e. to be a receiver of information).

Having defined extensional lengths of AIS elements vectors, we assign a certain rank of relevance to the objects of different types in accordance with the rank scale (Table 1) and create a matrix of relevance ranks [3].

There are two cases possible here: 1) if the extensional lengths exceed the range of scale, the element obtains maximum relevance rank; and 2) if the extensional lengths of the elements compared are equal, we create a new relations register, which considers only these AIS elements. The results obtained are put into the matrix A of relevance ranks.

This matrix must be consistent, nonnegative, irreducible and have a single rank.

Then

$$A(\omega)=\lambda_{\max}\omega\ , \qquad (1)$$

where λ_{max} – is the largest of matrix A eigenvalues. According to the Perron-Frobenius theorem, the equation (1) has a unique (accurate to the constant factor) nonnegative solution ω [4] The value of ω is taken for a relevance coefficient C_R of the AIS element. For the sake of convenience and clarity C_R is usually normalized.

As applied to the objects of automated information system, the technique of evaluating the relevance is as follows. As applied to the objects of automated information system, the technique of evaluating the relevance is as follows.

TABLE 1. RANK SCALE

Relevance rank	Definition	Explanation
0 3 5 7 9 2,4,6,8	The objects are incomparable. The objects are equally relevant. The object is slightly more relevant than the other one One object is more relevant than the other one (strong superiority). One object is obviously more relevant than the other one. One object is absolutely more relevant than the other one. The values of intermediate results.	It is pointless to compare the objects. The objects have identical (or commensurable) information relations. There is some superiority of one object over the other one on some level of relations. There are compelling reasons that one object is more relevant than the other one. There are irrefutable reasons to prefer one object to the other one. The superiority of one of the object is obvious and lies beyond any doubt.
Reciprocals of the numbers mentioned above.	If object *i* when compared to object *j* obtains one of the relevance ranks mentioned above, then *j* obtains a reciprocal value when compared to *i*.	
Rational numbers.	Rational numbers are the results of arithmetic operations with the numbers of the given scale.	

Let the extensional length Li of the vector of AIS elements information relations be defined on the basis of relations register (Fig. 3).

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}
x_1	=	∅	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_2	∅	=	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_3	⊕	⊕	=	∅	∅	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	○	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_4	∅	∅	∅	=	∅	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_5	∅	∅	∅	∅	=	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_6	∅	∅	⊕	⊕	⊕	=	⊕	⊕	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_7	∅	∅	∅	∅	∅	⊕	=	∅	∅	⊕	⊕	⊕	⊕	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_8	∅	∅	∅	∅	∅	⊕	∅	=	∅	⊕	⊕	⊕	⊕	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_9	∅	∅	∅	∅	∅	⊕	∅	∅	=	⊕	⊕	⊕	⊕	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_{10}	∅	∅	∅	∅	∅	∅	⊕	⊕	⊕	=	∅	∅	∅	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_{11}	∅	∅	∅	∅	∅	∅	⊕	⊕	⊕	∅	=	∅	∅	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_{12}	∅	∅	∅	∅	∅	∅	⊕	⊕	⊕	∅	∅	=	∅	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_{13}	∅	∅	∅	∅	∅	∅	⊕	⊕	⊕	∅	∅	∅	=	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_{14}	∅	∅	∅	∅	∅	∅	⊕	⊕	⊕	⊕	⊕	⊕	⊕	=	∅	∅	∅	⊕	⊕	⊕	∅	∅	∅	⊕	⊕	⊕
x_{15}	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	=	∅	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_{16}	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	=	⊕	∅	∅	∅	∅	∅	∅	∅	∅	∅
x_{17}	∅	∅	○	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	⊕	⊕	=	⊕	⊕	⊕	∅	∅	∅	∅	∅	∅
x_{18}	∅	∅	∅	∅	∅	∅	∅	∅	∅	⊕	⊕	⊕	⊕	⊕	∅	∅	⊕	=	∅	∅	∅	∅	∅	∅	∅	∅
x_{19}	∅	∅	∅	∅	∅	∅	∅	∅	∅	⊕	⊕	⊕	⊕	⊕	∅	∅	⊕	∅	=	∅	∅	∅	∅	∅	∅	∅
x_{20}	∅	∅	∅	∅	∅	∅	∅	∅	∅	⊕	⊕	⊕	⊕	⊕	∅	∅	⊕	∅	∅	=	∅	∅	∅	∅	∅	∅
x_{21}	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	=	∅	⊕	∅	∅	∅
x_{22}	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	=	⊕	∅	∅	∅
x_{23}	∅	∅	○	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	⊕	⊕	=	⊕	⊕	⊕
x_{24}	∅	∅	∅	∅	∅	∅	∅	∅	∅	⊕	⊕	⊕	⊕	⊕	∅	∅	∅	∅	∅	∅	∅	∅	⊕	=	∅	∅
x_{25}	∅	∅	∅	∅	∅	∅	∅	∅	∅	⊕	⊕	⊕	⊕	⊕	∅	∅	∅	∅	∅	∅	∅	∅	⊕	∅	=	∅
x_{26}	∅	∅	∅	∅	∅	∅	∅	∅	∅	⊕	⊕	⊕	⊕	⊕	∅	∅	∅	∅	∅	∅	∅	∅	⊕	∅	∅	=

Fig. 3. Relations matrix (example).

As it is seen from Figure 3, Li is equal for $\{x_6, x_{17}, x_{23}\}$ and $\{x_7, x_8, x_9, x_{18}, x_{19}, x_{20}, x_{24}, x_{25}, x_{26}\}$. That is why a new relations register is being made, but now it is based on the relations within the automation channel system (Fig. 4).

	x_6	x_7	x_{10}	x_{13}
x_6	=	⊕	∅	∅
x_7	∅	=	⊕	⊕
x_{10}	∅	∅	=	⊕
x_{13}	∅	∅	∅	=

Fig. 4. Relations matrix in the automation channel.

Thus, common lengths of the vectors Li are equal for elements of all types:

$x_7 = 8$; $x_6 = 7$; $x_3 = 5$; $x_{10} = 3$; $x_{13} = 2$; $x_1 = 1$; $x_2 = 1$; $x_4 = 1$; $x_5 = 1$.

After that we create a matrix A of relevance ranks (Table 2) and define a set (ω_1, … ω_n) of relevance values of each n element, then the comparative evaluation of the relevance values obtained takes place. The element aij of the comparative matrix A evaluates the relation ω_i/ω_j.

For this matrix to be consistent the following correlations must be fulfilled [5].

$$a_{ij}\, a_{jk} = a_{ik} \tag{2}$$

and in particular

$$a_{ij} = 1 \text{ и } a_{ji} = 1/a_{ij} \tag{3}$$

The fulfillment of the correlation (3) is necessary to define the difference between the objects' relevance values and to calculate the second value's fraction of the first one.

TABLE 2. RELEVANCE RANKS OF THE ELEMENTS (EXAMPLE)

$i \setminus j$	x_7	x_6	x_3	x_{10}	x_{13}	x_1	x_2	x_4	x_5
x_7	=	4	5	7	8	9	9	9	9
x_6	1/4	=	5/4	7/4	8/4	9/4	9/4	9/4	9/4
x_3	1/5	4/5	=	7/5	8/5	9/5	9/5	9/5	9/5
x_{10}	1/7	4/7	5/7	=	8/7	9/7	9/7	9/7	9/7
x_{13}	1/8	4/8	5/8	7/8	=	9/8	9/8	9/8	9/8
x_1	1/9	4/9	5/9	7/9	8/9	=	1	1	1
x_2	1/9	4/9	5/9	7/9	8/9	1	=	1	1
x_4	1/9	4/9	5/9	7/9	8/9	1	1	=	1
x_5	1/9	4/9	5/9	7/9	8/9	1	1	1	=

It is clear that being consistent the matrix A has a single rank because to know only one row is enough to determine the other elements. Moreover, a_{1i} , for every *i*. And the null result of objects pairwise comparison means that they are incomparable, i.e. have no information relations.

For consistent matrix A we have:

$$\sum_{j=1}^{n} a_{ij} \frac{\omega_i}{\omega_j} = n,\ i = 1,\dots, n \tag{4}$$

where n – is maximum eigenvalue A, and all the rest eigenvalues are null because A has a single rank and the sum of all its eigenvalues is equal to the spur of matrix.

$$T_r(A) = \sum_{i=1}^{n} a_{ij} = n \tag{5}$$

In the general case it can be considered that the set should satisfy the equation (1). Then for nonnegative $x' Ax = \sum_{i=1}^{n} \sum_{k=1}^{n} a_{ik}\, \omega_i\, \omega_k \geq 0,\ \forall \omega_1, \dots, \omega_n \neq 0$ (where x′ ≡ ω – is a row vector from A) and for irreducible matrix A, there exists a unique (accurate to the constant factor) solution of equation (1). In other words if matrix A is consistent, we can take the row a_{i1}, a_{i2}, …, a_{in} and multiply a_{i1} by ω_1, a_{i2} by ω_2, …, a_{in}, by ω_n, and thus get ω_i, ω_i, …, ω_i,. So, multiplying matrix A by vector ω we get vector nω Therefore, ω is the solution of the equation

$$A\omega = n\omega$$

In the general case, when multiplying i-row as mentioned above, we do not always get exactly ω_i, ω_i, …, ω_i because of errors of the values a_{ij}. In the theory of matrices it is established that eigenvalues represent continuous functions of the elements [4]. When the perturbation of the consistent matrix elements is small, its largest eigenvalue will be close to n, all the rest will be approximate to zero. Thus, judging by the solution of the equation (1), we can say how close n will appear to be to λ_{max}. That is why to improve consistence it is recommended to fulfill the correlation (3).

As a result we obtain the following set of vectors $\bar{\omega}$ from Table 2:

$\omega_1 = 61$; $\omega_2 = 15{,}25$; $\omega_3 = 12{,}2$; $\omega_4 = 8{,}7$; $\omega_5 = 7{,}6$; $\omega_6 = 6{,}7$; $\omega_7 = 6{,}7$; $\omega_8 = 6{,}7$; $\omega_9 = 6{,}7$.

Having normalized ω according to the condition $\sum_{i=1}^{n} \omega_i = 1$, we obtain numerical values of AIS elements relevance, expressed by the coefficient of relevance (Table 3) [6].

TABLE 3. VALUES OF AIS ELEMENTS RELEVANCE COEFFICIENT (EXAMPLE)

	x_7	x_6	x_3	x_{10}	x_{13}	x_1	x_2	x_4	x_5
C_R	0.114	0.045	0.045	0.115	0.102	0.102	0.236	0.13	0.11

CONCLUSION

One of the advantages of this technique is that experts' subjective opinions are not used here, the whole system is based upon real information relations between the system elements. Knowing precise numerical values of relevance of system elements and their quantity, it is easier to make reasoned decisions while managing a DCS. Besides, on the early stages of designing when a new system is only being built up, there appears an opportunity to evaluate the relevance of each element of each type in the system effectiveness, which will assist in making the right emphasis while designing redundancy subsystems.

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