Efficiency Management System for a Network Virtual Enterprise

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Abstract. The article discusses methodological issues of creating network virtual enterprises and their management. Here, the network enterprise agent is represented as one of the network nodes that implements directed interactions with other nodes in order to produce and sell marketable products. A multi-agent system (MAS) is a virtual enterprise (VE) that is created from various network enterprises on a contract basis. To create an effective VE, we must have a mathematical description of its structure and functions. In this paper, a three-level hierarchical system of diagnostics and performance management for network virtual enterprises is proposed. The functions of the proposed system are described at a formalized level. VE is presented in the form of a set of operators designed to diagnose crisis conditions and manage the effectiveness of its functioning. The main condition for the normal functioning of the VE is the absence of crisis states. Crisis states are manifested in a decrease in output and sales of products, and a deterioration in the financial condition of the VE. A method for diagnosing agents crisis states based on the evidence theory is proposed. It allows you to take into account both stochastic and content uncertainty. A numerical example of using this technique to identify a crisis situation in a certain VE is given. Based on the results obtained, control actions were proposed to remove the entire VE from the pre-crisis state by reengineering it.

Keywords: network structure, virtual organizations, management.

1 Introduction

The information technology development leads to a change in the paradigm [1-4] of the business process management system formation, the development of network virtual structures in the economy, based on the principles of cooperation of legally independent enterprises, geographically distributed and operating in an integrated information space. The issues of information technologies, modern business methods based on them and network virtual enterprises (VE) were considered in the works [5-8]. A significant contribution to the study of the problems of the functioning and development of virtual organizations, the issues of the impact of information technology on the management system was made [9, 10]. The works [11-14] summarize the study of virtual enterprises as a new organizational form of business. As noted in [15, 16], the main idea of the VE is that partner companies create their own resource base. This

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database is available to other members as well as to firms involved in temporary participation. This makes it possible to form a general management system for VE and increase the efficiency of their activities. Another important advantage, in comparison with traditional economic structures, is the ability to dynamically change their structure by commuting the individual competencies of partners. Dynamism is showed in all spheres of activity, including the supplier-consumer relationship.

With the transition to the creation of network virtual enterprises, the issues of the effectiveness of the functioning of such industries force us to reconsider the classical methods of their construction. The solution to this problem is based on a mathematical description of the structure and functions of a network enterprise [12,17,18]. The virtual enterprise (VE) is considered as a network of agents (network enterprises) in terms of the theory of multi-agent systems (MAS). Control mechanisms in network structures and models for the formation of a multi-agent system. are given in [10, 19]. Now, there are many different approaches to the typology, structure, functioning process of a network virtual organization. The issues of creating a unified concept for building VE are relevant.

This article proposes a new approach to building the VE model and managing the performance of virtual network enterprises, based on the use of methods of the theory of hierarchical systems. The issues of monitoring of crisis situations (CS) of the VE in uncertainty conditions are considered in detail, as the basis for managing their effectiveness.

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2 Mathematical description of the structure and functions of a network enterprise

With the transition to computer-integrated (networked) enterprises, the issues of the effectiveness of the functioning of such industries force us to revise the classical methods of building enterprises. To solve this problem, it is necessary to have a mathematical description of the structure and functions of the network enterprise. All enterprises that are part of a network for the production of product are closely interconnected, so the ineffective work of one of them can lead to a crisis state of the other or to the collapse for the entire network of enterprises. The state of the entire network of enterprises is characterized by the values of economic indicators x_1, ... , x_i, ..., x_n, where $x_i \in \overline{X}$ is a set of economic indicators.. Imposing restrictions $\overline{x}$ and $\underline{x}$ on the indicators x_i, ($i = 1,\ldots,n$),we determine the area of normal functioning for network enterprises ($\overline{x}$ and $\underline{x}$ are the upper and lower boundaries of the i - th indicator). The crisis state shows the value of x going beyond the boundaries). The difference between the upper or lower value of the economic indicator border and its actual value will be denoted as a efficiency margin of Δx_i ($i = 1,\ldots,n$), $\Delta x_i \in \Delta X$,where ΔX is a set of values characterizing the efficiency margin with help of operational values of economic indicators. The value of Δx_i is calculated at a certain frequency during operation. These values predict the tendency of Δx_i to zero and determine the control actions of y, $y \in Y$ on the network enterprises. Control actions increase the efficiency margin, i.e. manage the efficiency of the network enterprise. Here Y is a set of control actions that allow to withdrawal enterprises from the pre-crisis state. Consider a network of enterprises A_0, A_1, A_2, …, A_n, where A_0 is the main enterprise. Assembly of the finished installation is performed on A_1, A_2, ..., A_n are network partners enterprises. They supply raw materials and components or consume a finished plant.

Enterprise A_0 can be represented as a set of operators S_0, ..., S_3, designed to diagnose crisis states and manage the efficiency of network enterprises. As a result, we obtain a three-level hierarchical diagnostics and performance management of enterprise network systems (see Fig. 1).

Operator S_1 is used to calculate the economic indicator Z_1. Z_1 is the profitability of the main enterprise A_0 in conditions of significant uncertainty of the initial information.

Uncertainty arises due to the fact that the values ΔX_{1i} arrive at the enterprise A_0 not with exact numerical values, but are determined in the form of probabilities by experts. Experts estimate the impact of the enterprise A_i on the profitability of Z_i with a number in the range from 0 to 100.

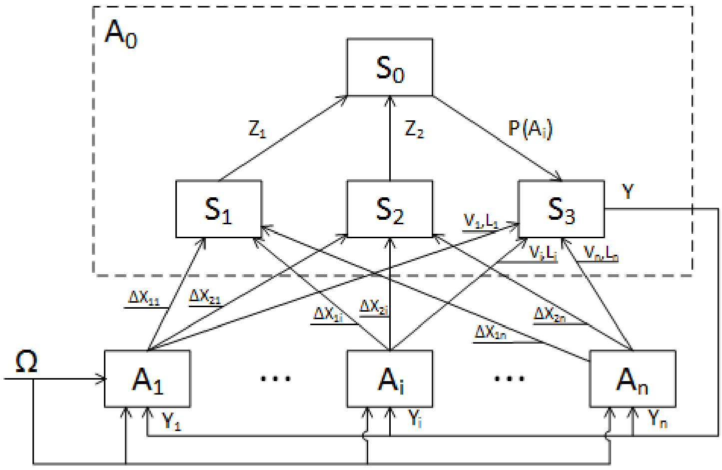

Fig. 1. Scheme of interaction for a network of enterprises, where A_0 is the main enterprise, A_1, A_2, ..., A_n are network partners enterprises, S_0, ..., S_3 are operators implementing interaction functions

Let us describe the interaction between the operators shown in Figure 1 using the set mapping apparatus.

Operator S_1 implements the function of determining the main enterprise profitability Z_1 and is specified as mapping:

$$S_1 \colon \Delta X_{11} \times \ldots \times \Delta X_{1i} \times \ldots \times \Delta X_{1n} \to Z_1$$

where Z_1 is the set of the profitability indicator values of the enterprise A_0;
ΔX_{1i} is a set of values characterizing the efficiency margin for profitability of the en-

terprise A_i; $\Delta X_{1i} \subset \Delta X$.
Operator S_2 implements the function for calculating the cost of the final product Z_2, manufactured by the enterprise A_0, and is described by the mapping:

$$S_2: \Delta X_{21} \times \ldots \times \Delta X_{2i} \times \ldots \times \Delta X_{2n} \rightarrow Z_2$$

where Z_2 is the set of values of the indicator of the cost of finished products for the enterprise A_0; ΔX_{2i} is a set of values characterizing the efficiency margin for the cost of raw materials, components or finished products of network acceptance A_i;

$$\Delta X_{2i} \subset \Delta X.$$

Operator S_0 monitors the crisis conditions of network enterprises. The implementation of the function S_0 is associated with significant uncertainty; therefore, the output of S_0 should not be exact, but probabilistic characteristics. S_0 maps:

$$S_0: Z_2 \times Z_2 \rightarrow P(A_i)$$

where $P(A_i)$ is a set of values of probabilities that determine the crisis state of enterprisesA_1, A_2, ..., A_n.
Operator S_2 implements the function for performance management of enterprise network:

$$S_3: P(A_i) \times V \times L \rightarrow Y$$

where Y is the set of control actions that allow to bring enterprises out of the pre-crisis state, $Y = Y_1 \times ... \times Y_i, \times ... \times Y_n$ (Y_i - a set of control actions for A); V is the volume of products supplied or consumed by network enterprises, $V = V_1 \times ... \times V_i, \times ... \times V_n$ (V_i is the volume of products supplied or consumed A_i); L - cost of products supplied or consumed by network enterprises, $L = L_1 \times ... \times L_i, \times ... \times L_n$ (L_i- the cost of products delivered or consumed by the A_i enterprise).

The functioning of the i - th network enterprise is mapping by the operator A_i, which implements four functions.
The first function A_{i1} determines the margin of efficiency in terms of profitability:

$$A_{i1}: \Omega \times V_i \times S_i \rightarrow \Delta X_{1i},$$

where Ω is a set of external disturbances.
The second function A_{i2} determines the efficiency margin at cost:

$$A_{i2}: \Omega \times V_i \rightarrow \Delta X_{2i}.$$

The third function A_{i3} forms the volume of products supplied or consumed:

$$A_{i3}: \Omega \times Y_i \times \Delta X_{1i} \rightarrow V_i.$$

The fourth function A_{i4} determines the cost of the supplied or consumed product:

$$A_{i4}\colon \Omega \times \Delta X_{2i} \to S_i$$

The presented formulation of the problem of building a computer-integrated enterprise is difficult to implement in practice due to the lack of reliable operational information. However, the use of modern computer technology allows us to solve this problem. The considered approach was partially used in the development of an expert control system for the evolution of continuous multistage processes [20].

3 Monitoring of VE crisis states on the basis of the Dempster-Schafer evidence theory

Monitoring of the CS (crisis states) of the VE consists in the analysis of the financial and economic activities of network enterprises of multi-agent systems. Crisis states of agents cause a decrease in the efficiency of the functioning of the entire VE [20].The crisis state of a network enterprise depends on many internal and external factors that have significant uncertainty, therefore the task of determining crisis states should be based on one of the methods for uncertainty accounting in economic problems. Let us consider the solution for the problem of monitoring the VE crisis states using the theory of evidence. The main idea of the evidence theory is that a certain measure of probabilities can be attributed not only to individual elements of the event set in the subject area, but in general to a certain subset of this set. Moreover, a more detailed distribution of this partial measure of probability over a subset is unknown. At the same time, some probability measures related directly to the elements of the set of events may also be unknown. Some specific measures of probability assigned to individual elements of the set are unknown. However, some conclusions can be drawn based only on the known distribution of probability measures.

According to [21, 22], the distribution of the probability measure will mean the function $m(C_i) \in [0;1]$ such that $m(\varnothing) = 0, \sum m(C_i) = 1, C_i \subseteq A$, where C_i is an event consisting in a crisis state of one or more agents; A is full event group.

Based on the probability distribution, a number of additional characteristics can be calculated to evaluate the results of diagnostic procedures.

The confidence degree in a crisis state for an agent of the subset $m(C_i) \in [0;1]$

$$Bel(C_i) = \sum m(C_j) \quad C_j \subseteq C_i$$

This function has the following properties:

$$Bel(\varnothing) = 0;\ Bel(C_j) \in [0,1];\ Bel(A) = 1.$$

The plausible reasoning degree for a crisis state of an agent in the subset $C_i \subseteq A$

$$C_i \subseteq A \ Pl(C_i) = 1 - Dou(C_i) = 1 - Bel(\overline{C}_i) = 1 - \sum m(C_j);\ C_i \cap C_j = \varnothing.$$

To combine different frame of discernment it is necessary to calculate the orthogonal sums of the base probabilities defined for each of the evidence. For this purpose, the Dempster rule [23, 24] is used, according to which the orthogonal sums are determined by the following expression:

$$m_1 \oplus m_2(A) = \frac{1}{1 - m(\varnothing)} * \sum_{Y \cap Z = A} m_1(Y) * m_2(Z),$$

where *Y* and *Z* are two focal elements distributed on the frame of discernment, generated by different evidence. The probability measure corresponding to an empty set has the form

$$m(\varnothing) = \sum_{Y \cap Z = \varnothing} m_1(Y) * m_2(Z).$$

The Dempster's rule is associative and commutative. It allows a lot of evidence to be combined in this way.

4 The example of the implementation of the method for recognizing crisis states of agents for VE

Let us consider the application of the method, proposed in the article, for monitoring crisis states by the example of building a virtual enterprise (VE) for the manufacture of an installation for vacuum casting UPPF-ZMK. A virtual association is used as the organizational form of this VE, since the sales market for such installations is not large and, in parallel, each enterprise participates in the production of other commercial products.

To make this installation, it needs to have enterprises (agents-suppliers) that will supply raw materials:

- stainless metal rolling (S1 – includes business entities S1.1, S1.2);
- black rolled metal (S2);

and components:

- vacuum techniques (E1);
- electronics products (E2);
- wires (E3);
- other components (E4)

Based on the method of synthesis of basic ideal structures for network enterprises [2, 9], we obtain a network of the star topology (see Fig. 2).

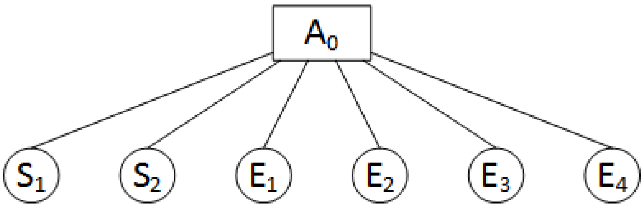

Fig. 2. The structure of VE agents (vendors) for production of UPPF-ZMK

Customers of UPPF-ZMKF can be divided into two groups:
- aviation enterprises C_a;
- other enterprises C_b.

The structure of consumer agents is shown in Figure 3.

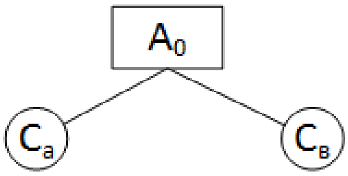

Fig. 3. The structure of consumer agents for UPPF-ZMK installation

The integrated structure of the virtual enterprise is shown in Figure 4.

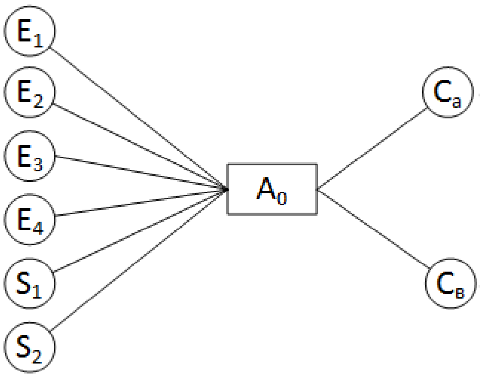

Fig. 4. The VE structure for the production of the UPPF-ZMK

Consider the structure and composition of a virtual enterprise (VP) for the production of SCP in the formulation of multi-agent systems (MAS).
In the fig. 4, vertex 1 denotes the main enterprise. All the work from design to assembly of the UPPF-ZMK unities carried out by main enterprise.

To the left of vertex 1 are the agents-suppliers of raw materials (S1 - stainless metal rolling; S2 - black rolled metal) and components (E1 - vacuum technology; E2 - electronics products; E3 - wires; E4 - other components). To the right of the vertex 1 are the agents-consumers of the produced UPPF-ZMK installations: Ca, Cb. In 2014, there was a favorable economic situation: the aviation industry was in dire need of such installations, and agents-suppliers of raw materials and purchased products offered their products at relatively low prices. Let us consider the reasons for the economic recession in the VE activities by the end of 2015. We use the method for diagnosing the crisis conditions of network enterprises.

A quantitative and qualitative analysis showed that the reason for the economic downturn in the activities of the virtual enterprise was the deterioration of the economic indicators (DEI) of the agents-suppliers of raw materials and components. In the second half of 2015, the VE general manager was forced to continuously monitor the economic state of the VE in two indicators: profitability - *Z1* and actual cost - *Z2*.

The monitoring was carried out under conditions of significant uncertainty; therefore the calculations were performed using the methods of the interval analysis theory.

The monitoring showed information about DEI at profitability of 0.1÷ 0.25% and an actual cost of 24.1÷ 34.0 million rubles. As a result of the examination, the specialists-managers received expert assessments for the agents-suppliers, which may be in pre-crisis or crisis (CS) states in the current economic conditions. The results of the examination are presented in Table 1.

Table 1. A result of the examination.

Indicators	S1.1	S1.2	S2	E1	E2	E3	E4
Profitability (*Z1*)	15	20				10	25
Cost price (*Z2*)			20	25	20	30	15

Based on the data shown in Table1, we define two fuzzy sets of agent-suppliers, suspected of having a CS but each of the DEI: *Z1* - profitability, *Z2* – cost price.

$$C_{Z1} = \{(S1.1;0,15),(S1.2;0,2),(E3;0,1),(E4;0,25)\}$$

$$C_{Z2} = \{(S2;0,2),(E1;0,25),(E2;0,2),(E3;0,3),(E4;0,15)\}$$

Next, the normalized probability distribution for the indicator *Z1* (profitability) is calculated

$$m_{Z1}(S1.1) = \frac{0,15}{0,15+0,2+0,1+0,25} = 0,21\,;\; m_{Z1}(S1.2) = \frac{0,2}{0,15+0,2+0,1+0,25} = 0,29\,;$$

$$m_{Z1}(E3)=\frac{0{,}1}{0{,}15+0{,}2+0{,}1+0{,}25}=0{,}14;\ m_{Z1}(E4)=\frac{0{,}25}{0{,}15+0{,}2+0{,}1+0{,}25}=0{,}36\ .$$

For *Z2* (cost price), the calculation will be as follows

$$m_{Z2}(E1)=\frac{0{,}25}{0{,}2+0{,}25+0{,}3+0{,}15}=0{,}28;\ m_{Z2}(E3)=\frac{0{,}3}{0{,}2+0{,}25+0{,}3+0{,}15}=0{,}33;$$

$$m_{Z2}(S2\vee E2)=\frac{0{,}2}{0{,}2+0{,}25+0{,}3+0{,}15}=0{,}22\ ;$$

$$m_{Z2}(E1)=\frac{0{,}15}{0{,}2+0{,}25+0{,}3+0{,}15}=0{,}17\ .$$

As a result of normalization, the probability distribution for the disturbed diagnostic variables will be as follows:

$$m_{Z1}<S1.1;S1.2;E3;E4>=<0{,}21;0{,}28;0{,}14;0{,}36>;$$

$$m_{Z2}<(S2,E2);E1;E3;E4>=<0{,}22;0{,}28;0{,}33;0{,}17>.$$

Taking into account the interval values of the diagnostic variables *Z1* and *Z2*, as well as the acceptable deviation intervals $\underline{d}_{Z1}$ and $\overline{d}_{Z1}$, we calculate the probability of occurrence of CS P_{Z1} and P_{Z2}. The value of the Z2 index on the observation interval is within the limits of [24.1; 34.0] million rubles. With the regulatory limits of 20.04 - 25.0 million rubles, the probability of CS

$$P_{Z2} = (34.0 - 25.0) / (34.0 - 24.1) = 0.91.$$

The doubt degree in CS: $U_{Z2} = 1 - P_{Z2} = 0.09$
Using the calculated probabilities of CS occurrence, we refine the obtained probability distributions m_{Zl} and m_{Z2}:

$$m_{Z1}{}'<S1.1;S1.2;E3;E4;C>=<0{,}14;0{,}19;0{,}09;0{,}24;0{,}33>;$$

$$m'_{Z2}<(S2,E2);E1;E3;E4;C>=<0{,}2;0{,}25;0{,}3;0{,}16{,}0;09>.$$

Calculations for combining different evidence about the probability distribution in favor of a single hypothesis are shown in table 2.

Table 2. Calculations for combining different evidence.

	S1.1 0,14	S1.2 0,19	E.1 0,09	E4 0,24
S2 ∨ E2 0,2	∅ 0,028	∅ 0,038	∅ 0,018	∅ 0,048
E1 0,25	∅ 0,035	∅ 0,048	∅ 0,023	∅ 0,06
E3 0,3	∅ 0,042	∅ 0,057	E3 0,027	∅ 0,072
E4 0,16	∅ 0,022	∅ 0,03	∅ 0,014	И4.1 0,038
C 0,09	S1.1 0,013	S1.2 0,017	E3 0,008	E4 0,022

A probability measure embedded in an empty set

$$m < \varnothing >= 0{,}028 + 0{,}038 + 0{,}018 + 0{,}048 + 0{,}035 + 0{,}048 + 0{,}023 + 0{,}06 +$$
$$0{,}042 + 0{,}057 + 0{,}072 + 0{,}022 + 0{,}03 + 0{,}014 = 0{,}535$$

The probability measure for hypotheses about the CS of supplier agents is calculated as follows

$$m(S1.1) = 0{,}013 / 0{,}465 = 0{,}028\,;\ m(S1.2) = 0{,}017 / 0{,}465 = 0{,}037\,;$$

$$m(S2 \vee E2) = 0{,}066 / 0{,}465 = 0{,}14\ \ m(E1) = 0{,}083 / 0{,}465 = 0{,}178$$

$$m(E3) = (0{,}027 + 0{,}099 + 0{,}008) / 0{,}465 = 0{,}288\,;$$

$$m(E4) = (0{,}038 + 0{,}053 + 0{,}022) / 0{,}465 = 0{,}243\,;\ m(C) = 0{,}03 / 0{,}465 = 0{,}065$$

$$m(C) = 0{,}03 / 0{,}465 = 0{,}065\,.$$

The resulting probability distribution has the form

$$m < S1.1; S1.2; (S2, E2); E1; E3; E4; C > = < 0{,}028; 0{,}037; 0{,}14; 0{,}178; 0{,}288; 0{,}243; 0{,}065 >$$

The corresponding evidence intervals are

$$S1.1[0{,}028; 0{,}093],\ S1.2[0{,}037; 0{,}102],\ \ \ S2[0{,}14; 0{,}205],\ E1[0{,}178; 0{,}243]\,;$$

$$E2[0{,}14;0{,}205], E3[0{,}288;0{,}353]\ ; E4.1[0{,}243;0{,}308], C[1{,}0;1{,}0]\ .$$

Thus, an analysis of the situation based on the theory of evidence leads to the diagnosis shown in table 3.

Table 3. The result of the diagnosis.

№	Enterprise name	Probability of CS	
		not less,%	no more, %
1	S1.1	28,8	35,3
2	S1.2	24,3	30,8
3	S2	17,8	24,3
4	E1	14	20,5
5	E2	14	20,5
6	E3	3,7	10,2
7	E4	2,8	9,3

It can be seen from the table that S1.1 and SI.2 have the highest probability of CS. As a result of the analysis, the VE managers identified a crisis state with the supply of stainless metal rolling for the production of the UPPF-ZMK installation.To liquidate this CS, another agent-supplier of stainless metal rolling products was urgently involved - S1.3 and the production plan for the UPPF-ZMK installations in 2016 was fulfilled, but profitability the last fourth install was only 1.8%.

5 Conclusions

The proposed new approach to modeling and designing network enterprises based on a three-level hierarchical interaction system allows creating new information models for diagnosing and managing the efficiency of virtual enterprises using digital communication networks.

The presented method of monitoring the crisis States of a virtual enterprise, taking into account the uncertainty of data, allows:

- to provide a consistent and continuous analysis of the state of a virtual enterprise with localization of the source of the crisis state;

- use interval diagnostic variables in its structure to account for both stochastic and content uncertainty and combine the results of analytical and expert analysis of the virtual enterprise state;

- - analyze inefficiently operating structural units of a virtual enterprise with minimal time and resources for conducting diagnostic procedures.

- analyze inefficiently functioning structural units of a virtual enterprise with minimal time and resources for conducting diagnostic procedures..

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