To the Question of the Development of a Methodology for Assessing the Sustainability of Economic Network Structures

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Abstract: The article is devoted to the issues of mathematical modeling of the network economic structures sustainability. The network form of enterprises organization is a reflection of integration processes and connections. Network sustainability can be viewed from different perspectives, taking into account different aspects, including organizational. Therefore, research in this direction is relevant. The following models have been developed to assess the organizational sustainability of the network: a model for assessing elementary sustainability with an emphasis on the central element of the network, a model and methodology for assessing integration sustainability. The issues of modeling elementary and integration stability have not been studied before. A scale of stability levels of a network enterprise has been developed on the basis of the mathematical apparatus of fuzzy sets theory. Sustainability can be represented as a linguistic variable. The scale in the first approximation contains three levels to determine the degree of enterprise sustainability. To formalize the semantics of the scale values, the adaptation of the standard fuzzy three-level 01-classifier is performed.

1 INTRODUCTION

In the era of economic globalization, the boundaries between the national economies of different countries are erased, the merger of individual national markets into one world market is observed, the role of integration processes is growing. Any enterprise at the stage of formation and development makes the transition from small to medium business and further to large. This transition, as a rule, is carried out through integration processes and connections, thus ensuring the formation of networked business structures (Efanova, 2020; Gerasimova, 2016). Today, the networked form of business organization is considered the most effective and promising form that provides the organization with progressive development and a stable position in the market. Network structures are specific, which allows for a new interpretation of the concept of economic sustainability. A network enterprise is stable when it has enough resources to maintain every aspect of its activities in optimal condition, in the face of resistance to adverse changes in the external environment. Each aspect is important, as the stability of the network as a whole depends on it. Thus, it is important to conduct a comprehensive assessment of the network structures sustainability with an emphasis on various aspects of activities (Baranovskaya, 2017; Melkonyan, 2017; Patalas-Maliszewska, 2020).

The purpose of this article is to study and assess the sustainability of economic network structures as the most promising and little-studied form of organization of small and medium-sized businesses, including the development of new promising methods and techniques to improve the quality of management of such structures.

In accordance with the set goal, it is necessary to solve the following tasks:

1) develop a model for assessing elementary and structural sustainability, as well as propose a model and methodology for integration sustainability assessing;

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2) build a scale of stability levels based on the mathematical apparatus of the fuzzy sets theory as one of the most promising areas of research for weakly formalized concepts and criteria.

2 METHODS

In the process of work, the following methods will be used: analytical (in the process of studying the concept of sustainability in the context of the network form of organization), solving multicriteria problems and mapping (when developing a model for assessing elementary, integration stability), fuzzy sets (to build a scale of levels of stability of the economic network structure).

All definitions of stability (Banerjee, 2011; Efanova, 2020; Thierling, 2020), one way or another, have similar features in a number of criteria. Such criteria are:

- Influence of external and internal environment;
- Stability of economic activity;
- Availability of compensation mechanisms.

According to the structural model of a network enterprise (Efanova, 2020; Pereira, 2019), a business network is considered as an association of business elements (nodes) of a network and subnets with a common central element. The integration of business elements into a network or subnet is carried out on the basis of vertical or horizontal integration (Loyko, 2015). Thus, by integration stability we mean the ability of a business network to function under the influence of internal and external destabilizing factors or to function when an internal crisis occurs in any particular business element (Efanova, 2020). That is, the business network is able to keep in time within the established limits the values of all control parameters characterizing the activities of the enterprise.

By elementary stability we mean the ability of an individual business element of a network or subnetwork to maintain the ability to function under the influence of internal destabilizing factors or to restore its equilibrium state over time when a crisis occurs (Efanova, 2020). The emphasis is on internal destabilizing factors, since external ones are more related to integration stability.

It should also be borne in mind that sustainability can be influenced not only by the current state of activity, but also by its stability.

To assess the integration stability, it is proposed to use the integral indicator S_{int}:

$$S_{int} = f(S_{el}, S_c), \quad (1)$$

whereS_{el} is an indicator of "elementary sustainability " of a separate business element of the network;

S_c – aggregate index of the center element sustainability;

f – functional that allows to determine the value for individual indicators of sustainability S_{el} and S_c.

In the simplest approximation, as the functional f, we can denote the weighted sum over all S_{el} and S_c that form the network, then formula (1) takes the form:

$$S_{int} = \sum_i^n w \cdot S_{el} + w_c \cdot S_c, \quad (2)$$

where w is the weight of the i-th business element, for which the elementary sustainability S_{el} is already calculated; w_c– weight of the central element, for which S_c is already known. The sum of the weights in (2) is equal to one. Towards S_{el}, the weights are distributed in proportion to their share of influence.

The central element plays the role of the main strategic management element. Therefore, to calculate its sustainability, a separate indicator S_c, different from S_{el}, is used. So S_c, is an aggregate indicator for assessing the management aspect, while S_{el} is used to assess the operational or performance aspect. The formation of a set of evaluation criteria depends on this.

If the central element or any other element of the network is presented not just as an abstract entity, but as an object with its own internal structure, then its sustainability depends mainly on the elements that form this structure. The sustainability of the central element is based on the sustainability of departments and key performance indicators.

As a result of the above reasoning, Figure 1 shows a methodology for assessing integration sustainability.

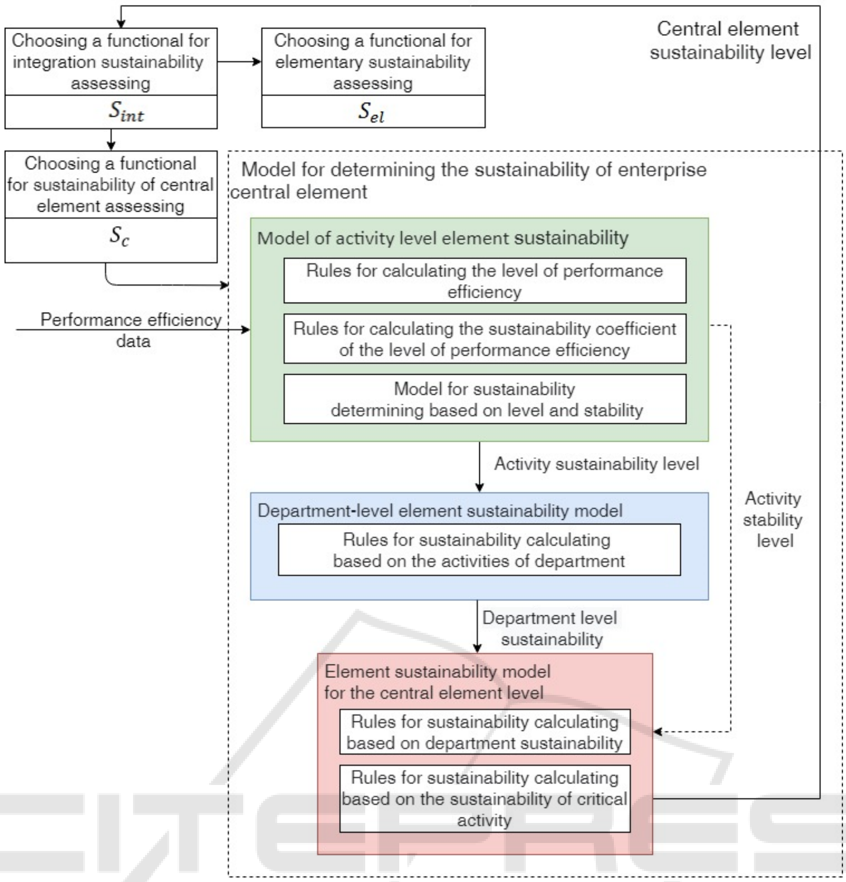

Figure 1: Integration sustainability assessment method.

As can be seen from this figure, in order to assess the integration sustainability, it is necessary to determine the functional for assessing the elementary sustainability and with the functional for assessing the sustainability of the central element.

To assess the sustainability of the central element, we can propose a model based on the data analysis of the organization effectiveness and including:

- Model of sustainability of the activity'slevel element (assumes the calculation of the activity's efficiency level and the stability coefficient of this level according to the given rules, as well as a model for calculating sustainability based on the level and stability);
- Model of a department-level element sustainability (based on the rules for sustainability calculating based on the activities of the department);
- Model of sustainabilityof the element of the central element level (uses the rules for sustainabilitycalculating based on the departmentsustainability, as well as on the basis of the critical activity's sustainability).

The input of the model is information about the effectiveness of the organization, the output indicator is the sustainabilitylevel of the central element.

Figure 2 shows the stages which formalize the model for assessing the central elementsustainability.

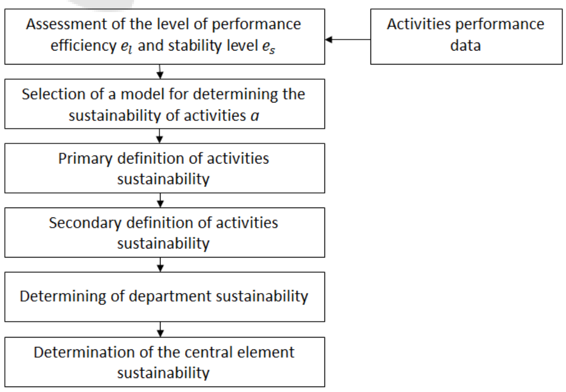

Figure 2: Formalization of the stages of the model for assessing the central element sustainability.

The primary definition of activity's sustainability in this model involves an assessment of its dependence on the efficiency levels of activities and the values of activity levels stability. With the secondary definition, the functional of the dependence of the final indicator on the stability of another activity is added to the calculations, taking into account the influence of various types of activity on each other.

The calculation of the department's sustainability is based on the assessment of its activities sustainability, as well as their weight coefficients.

The central element's sustainability is determined by the dependence on the sustainability of the departments and activities of the organization, also taking into account their weights.

This model can be adapted to assess elementary sustainability, where the focus of attention shifts from the managerial to the executive aspect of the activity.

To determine the level of sustainability, you can use several options for using these indicators as variables.

The main problem in this case is that it is possible to get an answer to the question "How sustainable is the activity?", but it is difficult to give an answer to the fuzzy ambiguous question "Is the activity sustainable?"

This problem can be solved through the use of fuzzy logic methods. In particular, the presentation of the efficiency and sustainability concepts in the form of linguistic variables with their own term-sets and the use of standard 01-classifiers to cover the universal set, where the semantics of the terms meanings is formalized. The first step in this direction is the development of a scale of sustainability levels based on the mathematical apparatus of the fuzzy sets theory.

In the general case, the scale assumes that a mapping is given that sets the corresponding scale value in accordance with real situations. If we consider the concept of sustainability as a linguistic variable, then the term-set, which formalizes the semantic load of terms, will just be the scale of values that completely overlaps the universal set of the linguistic variable. As a first approximation, three levels are sufficient to determine the degree of enterprise sustainability: "critical", "borderline state", "normal". The range [0..1] has some versatility, so it is convenient to use it as a universal set for setting stability levels. This makes it possible to adapt the standard three-level 01-classifier to the selected levels of the sustainability scale (table 1). The membership function formalizes the meaning of the scale values. It should be noted that there can be more scale levels, and other types, for example, triangular membership functions, can also be used. The main thing is that the adequacy of the comparison does not suffer. More fine tuning of the scale levels is possible with the assistance of experts.

Table 1: Comparison of sustainability levels and levels of the standard 01-classifier.

Sustainability level value	01-classifier level value	Designation	Membership function type
Critical	Low	T_1	Z-shaped
Borderline state	Medium	T_2	Trapezoidal
Acceptable	High	T_3	S-shaped

Each of the proposed types of membership functions has its own analytical form, represented by the corresponding formula and depending on certain sets of parameters.

The Z-shaped function is determined by the formula (3), the trapezoidal function – by the formula (4), the S-shaped function – by the formula (5)

$$\mu_{T1}(x,a,b)=\begin{cases}1, & 0\le x\le a\\ \dfrac{b-x}{b-a}, & a<x<b\\ 0, & b\le x\le 1\end{cases} \quad (3)$$

$$\mu_{T2}(x,a,b,c,d)=\begin{cases}0, & 0\le x\le a\\ \dfrac{x-a}{b-a}, & a<x<b\\ 1, & b\le x\le c\\ \dfrac{d-x}{d-c}, & c<x<d\\ 0, & d\le x\le 1\end{cases} \quad (4)$$

$$\mu_{T2}(x,a,b)=\begin{cases}0, & 0\le x\le a\\ \dfrac{x-a}{b-a}, & a<x<b\\ 1, & b\le x\le 1\end{cases} \quad (5)$$

As an example, we can build and visually evaluate the graphs of the reduced membership functions with the following parameter values:

- Z- shaped: a = 0,3; b = 0,7;
- trapezoidal: a = 0,2; b = 0,4; c = 0,6; d = 0,8;
- S- shaped: a = 0,5; b = 0,8.

A universal set in this case will be a certain hypothetical level of sustainability, measured on a scale from 0 to 1. The calculated values of membership functions for three levels of sustainability are shown in Table 2, and the graphs of functions are shown in Figure 3.

For real use, the considered example requires adjusting the parameters of the membership functions in order to comply with the model adequacy.

Table 2: An example of describing the linguistic variable "Sustainability".

Sustainability level (0-1)	Membershipfunctionvalues		
	Critical	Borderline state	Acceptable
0	1	0	0
0,1	1	0	0
0,2	1	0	0
0,3	1	0,5	0
0,4	0,75	1	0
0,5	0,5	1	0
0,6	0,25	1	0,33
0,7	0	0,5	0,67
0,8	0	0	1
0,9	0	0	1
1	0	0	1

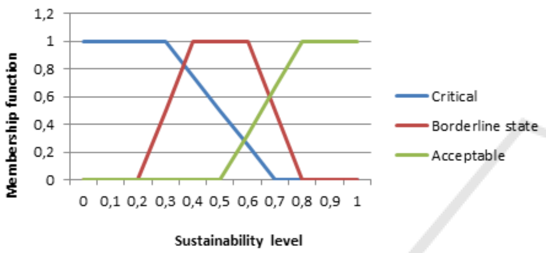

Figure 3: Graphs of membership functions of the stability scale levels.

3 RESULTS

The technique of using a linguistic variable to determine the sustainability of organizations described in the previous section can be applied to both traditional and networked enterprises.

Table 3 shows an example of setting intervals for sustainability levels based on an adapted standard three-level fuzzy 01-classifier.

Table 3: Classification of the sustainability level based on the adapted standard three-level fuzzy 01-classifier.

Interval of sustainability level (SL) values	Sustainability level value	Degree of estimated confidence (membership function)
$0 \leq SL \leq 0,2$	Critical	1
$0,2 < SL < 0,4$	Critical	$\mu_{T1} = 5 \times (0.4 - SL)$
	Borderline state	$1- \mu_{T1} = \mu_{T2}$
$0,4 \leq SL \leq 0,6$	Borderline state	1
$0,6 < SL < 0,8$	Borderline state	$\mu_{T2} = 5\times (0.8 - SL)$
	Acceptable	$1- \mu_{T2} = \mu_{T3}$
$0,8 \leq SL \leq 1,0$	Acceptable	1

Based on the results of the classification carried out, it is possible to calculate the values of the membership functions for different sustainability levels on a universal set of values of the sustainability index from 0 to 1 (Table 4), as well as build graphs of these functions (Figure 4).

Table 4: Setting the linguistic variable "Sustainability" based on the classification carried out.

Sustainability level (0-1)	Membershipfunctionvalues		
	Critical	Borderline state	Acceptable
0	1	0	0
0,05	1	0	0
0,1	1	0	0
0,15	1	0	0
0,2	1	0	0
0,25	0,75	0,25	0
0,3	0,5	0,5	0
0,35	0,25	0,75	0
0,4	0	1	0
0,45	0	1	0
0,5	0	1	0
0,55	0	1	0
0,6	0	1	0
0,65	0	0,75	0,25
0,7	0	0,5	0,5
0,75	0	0,25	0,75
0,8	0	0	1
0,85	0	0	1
0,9	0	0	1
0,95	0	0	1
1	0	0	1

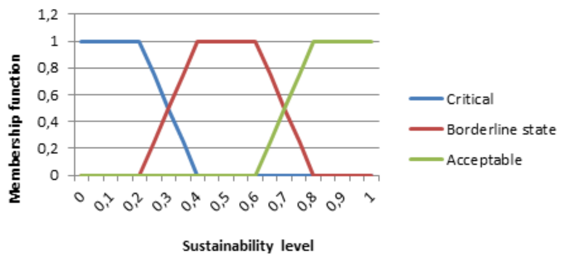

Figure 4: Graphs of membership functions of the linguistic variable "Sustainability" terms (adapted fuzzy 01-classifier).

Based on the obtained membership functions, it is possible to analyze the sustainability indicators of specific enterprises.

For traditional (non-networked) organizations, it is enough to have one single indicator of sustainability to assess it.

Suppose that the sustainability indicator was calculated for enterprise A, and it turned out to be equal to 0.35, and for enterprise B – 0.7.

In this case, the following conclusions can be drawn:

- Enterprise A has a critical sustainability level with a confidence level of 0.75, and with a confidence level of 0.25 it is at the borderline sustainability state;
- The sustainability of enterprise B can be assessed as borderline with a confidence degree of 0.5 and as acceptable with a confidence degree of 0.5.

For network enterprises, as the initial data for sustainability assessing, it is necessary to have data of its individual nodes sustainability indicators, including the central element of the network, and to assess the integral stability indicator, it is necessary to know the weight coefficients of each node.

The initial data and results of the experiment to assess the sustainability of a network enterprise are shown in Table 5.

Table 5: Evaluation of the network enterprise sustainability based on a three-level fuzzy 01-classifier.

Node	Sustainability S	Weight w	Confidence degree for sustainability assessing		
			Critical	Borderline state	Acceptable
Central element C	0,55	0,4	0	1	0
Node 1 El_1	0,35	0,15	0,25	0,75	0
Node2 El_2	0,8	0,15	0	0	1
Node3 El_3	0,65	0,1	0	0,75	0,25
Node4 El_4	0,2	0,2	1	0	0

It can be seen from the table that the central element of the enterprise has a borderline state of sustainability, and, therefore, the remaining nodes can affect the overall stability of the organization, both for the better and for the worse. Their sustainability assessment can be characterized as follows:

- Node 1 is at a critical level of sustainability with a confidence level of 0.25, and in a borderline state with a confidence level of 0.75;
- Node 2 sustainability level – unambiguously acceptable (confidence level is equal to 1);
- Node 3 has a borderline sustainability level rather than an acceptable one (confidence levels are 0.75 and 0.25 respectively);
- For node 4, we can say for sure that its level of sustainability is critical.

Next, we need to calculate and evaluate the integral indicator of sustainability. The calculation will use the linear convolution method given in formula (6).

$$S_{int} = \sum_i^n w \cdot S_{el} + w_c \cdot S_c, \quad (6)$$

Substituting the initial data of the analyzed enterprise into this formula, we can get the following:

$S_{int} = 0,35 \cdot 0,15 + 0,8 \cdot 0,15 + 0,65 \cdot 0,1 + 0,2 \times\times 0,2 + 0,55 \cdot 0,4 = 0,4875 \approx 0,5$

Thus, we can conclude that the value of the integral indicator corresponds to the borderline state of the organization's sustainability.

4 DISCUSSION

The results of the experiment carried out in the previous section indicate some differences in the sustainability assessment of traditional and networked enterprises.

In particular, the case should be highlighted when the calculated value of sustainability turned out to be equal to 0.5 or less. For a traditional enterprise, this situation is critical and requires immediate adoption of appropriate measures to improve the situation. For a networked enterprise, the picture may be completely different, especially if the critical value of sustainability has been identified for an individual node of the organization. Then the overall level of sustainability can be adjusted and compensated for by the rest elements of the network enterprise.

Special attention should be paid to the situation when the value of the sustainability integral indicator for the network enterprise turned out to be equal to 0.5. In this case, a complete analysis of all nodes of the organization should be carried out in order to identify the "weak spot" and plan measures to improve the functioning efficiency of this element, which, in turn, will lead to an increase in its sustainability level.

To determine the sustainability degree of the enterprise in the work, a three-level fuzzy classifier was used. However, in some cases, three levels may not be enough; a more accurate assessment of indicators is required. Then it makes sense to increase the number of levels and go, for example, to a five-level classifier. The linguistic variable terms can be roughly as follows:

- absolutelyunstable;
- critical;
- borderline state;
- acceptable;
- high.

A further increase in the number of fuzzy classifier levels is impractical, as it will lead to "blurring" of the indicators assessment accuracy.

5 CONCLUSIONS

Summing up the general results of the work, it should be noted that the mechanism of the functioning and development of business networks has not yet been sufficiently studied, the paradigm for managing network structures has not been finally formulated. Therefore, these questions require further research. The organizational environment is dynamically changing due to many factors to which the network must respond. Otherwise, it is impossible to ensure the economic sustainability of the network and maintain or accelerate the pace of its development.

The problem of ensuring the economic sustainability of enterprises is especially relevant for enterprises in the small and medium-sized enterprise sector, where today there is the greatest concentration of networks. The methodology for assessing network economic structures is in its infancy. This indicates the advisability of continuing research in this direction.

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