ECONOMETRIC ANALYSIS OF MACHINE-BUILDING ENTERPRISES' SUSTAINABILITY IN THE CONTEXT OF NEOSYSTEM PARADIGM

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Abstract: *Sustainability of business entities is one of the most actual unsolved problems in economics and management. Our research was devoted to its elaboration in the context of a new system-structural (neosystem) methodological paradigm, which implies a priori separation of all economic systems into four types depending on their spatial and temporal localization. Thus just a set of four different types of systems may be economic sustainable. The purpose of this work was to test the hypothesis that the economic sustainability of the enterprise caused by the level of balance of its four subsystems and can be determined on the basis of its measurement. It represents the results of the econometric analysis of 16 machine-building enterprises of Ukraine for the period of 2004-2015, conducted by the methods of Data Mining technology. We have determined the indexes of the enterprises' subsystems, estimated their mutual balance and on the basis of all estimates – the indexes of system balance of the enterprises. To test our hypothesis, we have compared the indexes of system balance with the results of traditional estimation of sustainability conducted on the basis of generally accepted financial ratios. This allowed to confirm the hypothesis and to identify the system-structural character of the imbalances of the subsystems inherent to the machine-building enterprises.*

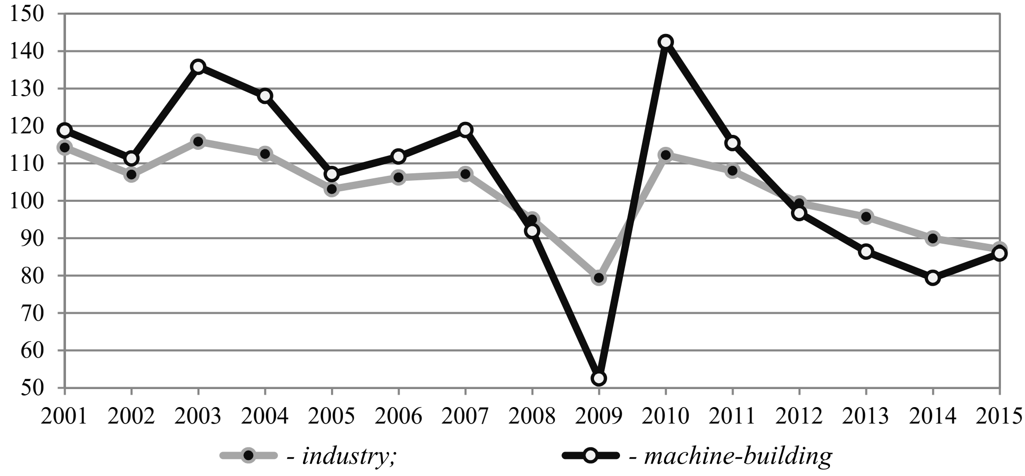
Keywords: *balance of economic system, economic sustainability of enterprise, neosystem methodological paradigm, machine building.*

JEL Classification: *B49, C12, C23, L60*

Introduction

Machine-building has always played an important role in the industrial structure of Ukraine and usually it was an indicator and catalyst of national industrial development. But now, because of the almost complete economic disintegration with the Russian Federation which was the main trade partner of Ukraine in machine-building, the enterprises have lost their capabilities in production and selling traditional products. This, as well as the other consequences of the socio-economic crisis in our country, significantly violated sustainability of the enterprises. Fig. 1 shows the dynamics of the index of machine-building industrial production calculated using Laspeyres formula. But even in the periods of economic growth the development of machine-building enterprises was mainly destructive and had a low technological level. So all of these have led to an increased scientific interest in issues related to sustainability.

Fig. 1. The dynamics of the index of machine-building industrial production



Source: compiled by author according to the statistic data (SSSU, 2016)

The epistemology of economic sustainability is extremely broad. There is not any generally accepted interpretation even in the range of general systems theory, which is the leading paradigm of research of complex objects nowadays. At the same time, regardless of interpretation, systems theory recognizes that spatiotemporal structure of the system plays the key role in ensuring its stability. As a result a new system-structural (or neosystem) theory and methodological paradigm of economic researches have been formed. Our work is devoted to study sustainability of the Ukraine machine-building enterprises based on them.

1 Statement of a problem

To date there is no methodology that allows to describe all economic systems on a unified basis and to derive universal "rule" of their stability in time and space. A neosystemic paradigm is an attempt to do this. Conceptual basis of it is based on a priori spatiotemporal typification of all economic systems. The paradigm mainly was developed in the works of researchers from the Central Economics and Mathematics Institute of the Russian Academy of Sciences (CEMI RAS) under the scientific direction of G. Kleiner (e. g. Kleiner, 2009, 2013, 2016; Rybachuk, 2016).

In the context of this paradigm, the structure of any economic system (including enterprises as a micro-level system) is viewed as a combination of elements with different degree of spatiotemporal limitation. Respectively they relate to one of the four types of subsystems: objects (have limited extension in space and unlimited duration in time), environments (have unlimited both extension in space and duration in time), processes (have unlimited extension in space and limited duration in time); projects (have limited both extension in space and duration in time) (Kleiner, 2009, 2013, 2016). None of the subsystems is self-sufficient and therefore sustainable. So they tend to the formation of donor-recipient pairs to exchange scarce resources and find appropriate empowerment. As a result, the interaction of the subsystems is circular and it leads to the creation of a tetrad – stable form, which can be considered as a result of the systems self-organizing.

If the subsystems is balanced, in interaction and cooperation they provide implementation of full cycles of the basic economic functions and sustainable development processes, mutual provision of resources and properties and as result, as we suppose, – maintenance of economic sustainability of the enterprise.

The paradigm is interesting and credible, but new, so it does not have a proper methods, instrumental base and econometric treatment especially. Therefore, mentioned assumptions are not empirically confirmed or refuted until now and require a more rapid development. The purpose of our work is to verify the hypothesis that the level of economic sustainability of the enterprise depends on the mutual balance of its internal subsystems of four types (objects, environments, processes and projects) and therefore may be determined on the basis of this balance measurement. The hypothesis is being elaborated based on Ukrainian machine-building enterprises' data. We consider that the three tasks must be completed in order to test this hypothesis:

1. Selection of parameters that can be used to describe objects, environments, processes and projects subsystems of the enterprises and assessment of data concerning the values of parameters for the entire sample; selection of methods of data processing and their convoluting to obtain the index of each subsystem.

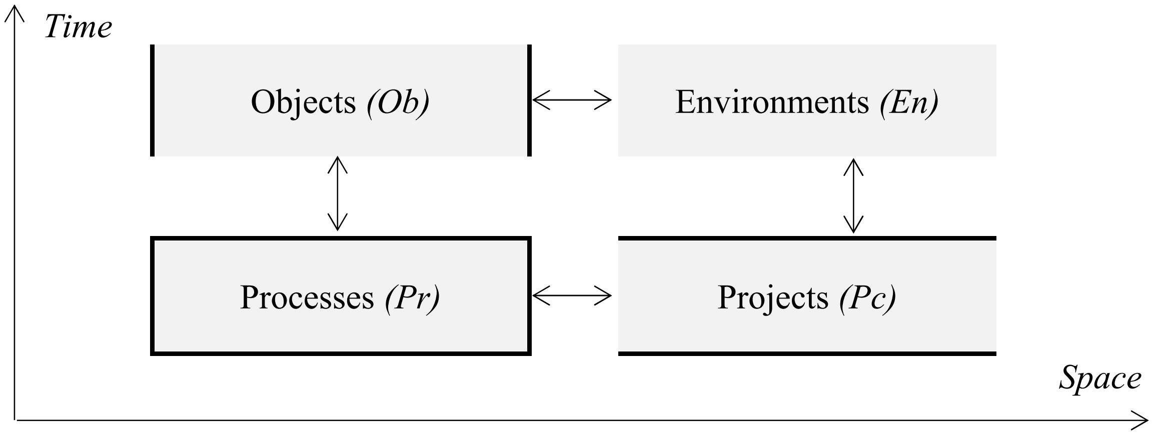
2. Forming of the methods and tools for conducting assessment of the index of system balance of the enterprise as a whole on the basis of indexes of subsystems values.

3. Determination of the statistical relationship between the index of system balance and "traditional" financial ratios that are generally used as the indicators of sustainable functioning of the enterprises.

2 Methods

The work is based on the above-mentioned neosystem methodological paradigm, which assumes a spatiotemporal structuring of economic systems, different from traditional approaches to structuring. It is assumed, that in order to be equally stable both in space and in time, the degree of expression of these subsystems of economic system should be the same, as symbolic shown in Fig. 2.

Fig. 2. The symbolic image of economic system consisting of the four subsystems with different spatiotemporal limitation



Source: (Kleiner, 2009)

Due to the lack of any econometric results obtained in the context of neosystem paradigm, the analysis requires the intelligent processing of large amounts of the panel data from different aspects. Data have been gathered from database of Stock Market Infrastructure Development Agency of Ukraine (SMIDA, 2016) and processed by the statistical program StatSoft Statistica 10.0. In various sources for such intellectual data processing, which is conducted with the involvement of a broad mathematical tools and information technologies, different terms are used: Data Mining, Knowledge Data Discovery, Data Science (e. g. Barseghyan, 2004; Cios, 2007; Ratner, 2011; Stanton, 2013; Witten, 2011). The most accepted by the experts is the term Data Mining. This technology is used to cover three areas of "extracting" the knowledge: classical mathematical statistics, which allows performing of data processing, aggregation and convolution; aggregate data visualization, which allows determination mathematically precise formula of dependencies and analysing trends; artificial intelligence methods, which allows improving of data processing in cases when mathematical statistics does not give adequate results (Ratner, 2011; Tuzovskiy, 2005; Witten, 2011). We have applied the technology in all of these areas to solve mentioned problems:

1. The methods of mathematical statistics, such as Principal Component Analysis (PCA) (e. g. Jolliffe, 2002), have been used to perform processing data concerning the values of parameters of four enterprises' subsystems and to conduct their convolution to obtain the indexes of subsystems. The normalization techniques have been used to bring different data to a single format. The arithmetic mean was used to obtain the generalized indexes.

2. The model of proportions of the subsystems visualization using quadrants, built in the Cartesian coordinate (Rybachuk, 2015), has been used to assess intensity of interaction of subsystems. The method of assessing the distance to the critical level by the formula of the Euclidean metric in the multidimensional space has been used in the calculation of the index of system balance.

3. The method of fuzzy logic (e. g. Chen, 2000; Dadios, 2012) have been used to conduct the financial ratios reduction to a single integral indicator of financial stability. This indicator has been used to determine the level of authenticity of obtained results and to verify the hypothesis – we have determined statistical relations between generalized index of system balance and integral indicator of financial stability for the group of analyzed enterprises.

3 Problem solving

3.1 Assessment of four enterprises' subsystems

In our research we have conducted the econometric analysis of 16 Ukrainian machine-building enterprises for the period of 2004-2015 (total sample consisted of 192 cases) to solve the target problem of their economic sustainability determination. At first, we have determined specific set of the subsystems' elements for an industrial enterprise is listed below:

- Objects subsystem *(Ob)* is represented by staff and departments of the enterprise and includes the totality of its employees, managers and stockholders.
- Environments subsystem *(En)* is represented by the social and cultural spheres

of enterprise and includes its internal standards, regulations, rules, institutions, communication, climate and culture.

- Processes subsystem *(Pc)* is represented by the sphere of industrial and economic processes of the enterprise and includes its technologies, information, management, logistics and business processes.
- Projects subsystem *(Pj)* includes the totality of the investment and innovative projects, programs, events, intentions of the enterprise.

The application of PCA has allowed us to perform processing data concerning the values of diverse parameters of four enterprises' subsystems and to conduct their convolution in order to obtain the index of each subsystem. Convolution of values of parameters was performed in a multidimensional space of principal components, taking into account the values of the eigenvalues of them. Thus, for estimation of objects subsystem index were selected 11 parameters, which were reduced to 6 components; for environments subsystem index – 13 parameters, which were reduced to 8 components; for processes subsystem index – 9 parameters, which were reduced to 5 components and for projects subsystem index – 16 parameters, which were reduced to 8 components.

To determine the index of subsystems based on the results of PCA the method of assessing the distance to the critical level has been used. For each subsystem "the worst sample" has been defined. It is multidimensional critical point, which reflects the worst set of values of all output components. Then the index of subsystem can be interpreted as a function of weighted distance to the critical point. For each subsystem it has been calculated by the formula:

$$I_{sys} = \frac{\sqrt{\sum_{a=1}^{A} \left[\lambda_a \left(t_{a_n} - \min_n t_{a_n}\right)\right]^2}}{\sum_{n=1}^{N} \lambda_a}, \tag{1}$$

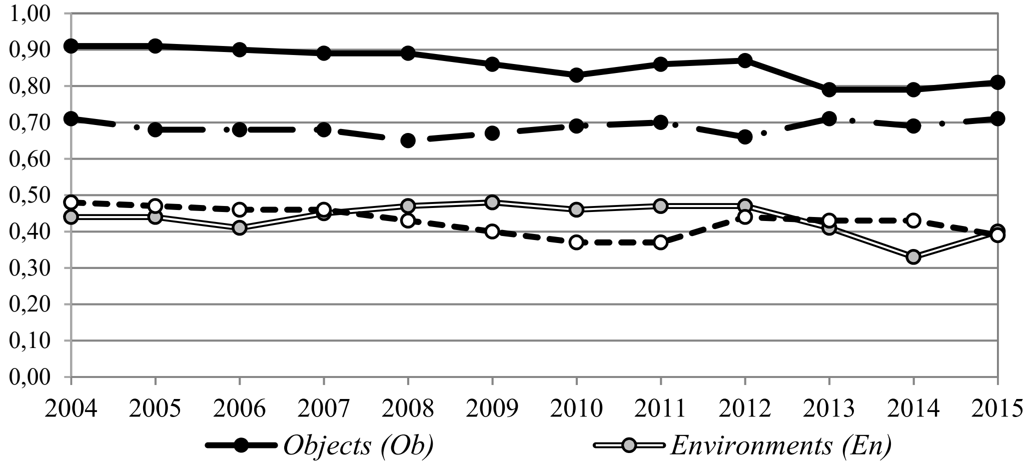
I_{sys} – index of subsystem; λ_a – ratio of eigenvalues for *a*-component of the subsystem, t_{a_n} – coordinate of the n-enterprise in the space of components; $\min_n t_{a_n}$ – minimum value for *a*-component of the subsystem; A – number of components allocated for the subsystem modeling by scree plot instrument, N – number of enterprises.

To integrate the results of modeling generalized indexes of each subsystem have been determined (objects – I_{Ob}, environments – I_{En}, processes – I_{Pc} and projects – I_{Pj}). They were calculated for the group of analyzed enterprises by the arithmetic mean formula. The results are shown in Fig. 3.

3.2 Evaluation of indexes of enterprises' system balance

The visualization of proportions of the subsystems by the ratios of their indexes using quadrants, built in the Cartesian coordinate system, as shown in Fig. 4, has allowed us to conduct assessment of intensity of interaction of subsystems. According to the (Kleiner, 2016) and (Rybachuk, 2016), this intensity may be characterized indirectly by measuring proportions of subsystems. We have adapted and, in our opinion, improved the outlined method.

Fig. 3. The dynamics of generalized indexes of the subsystems for the group of analyzed enterprises

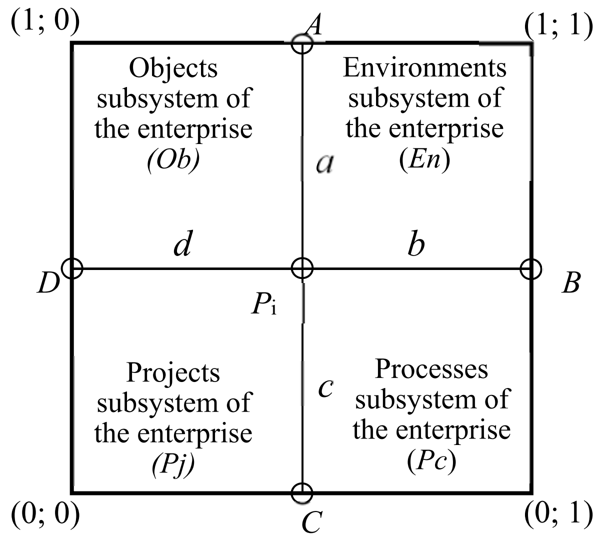


Source: own elaboration

In Fig. 4 the coordinates of points *A, B, C, D* reflect the ratios of the indexes of interacting subsystems. In the proposed coordinates they are defined as $A\,(X_A;\,1)$, $B\,(1;\,Y_B)$, $C\,(X_C;\,0)$, $D\,(0;\,Y_D)$. The values of X_A, Y_B, X_C, Y_D have been calculated by formulas:

$$X_A = \frac{I_{Ob}}{I_{En} + I_{Ob}};\; Y_B = \frac{I_{Pc}}{I_{En} + I_{Pc}};\; X_C = \frac{I_{Pj}}{I_{Pc} + I_{Pj}};\; Y_D = \frac{I_{Pj}}{I_{Pj} + I_{Ob}}. \tag{2}$$

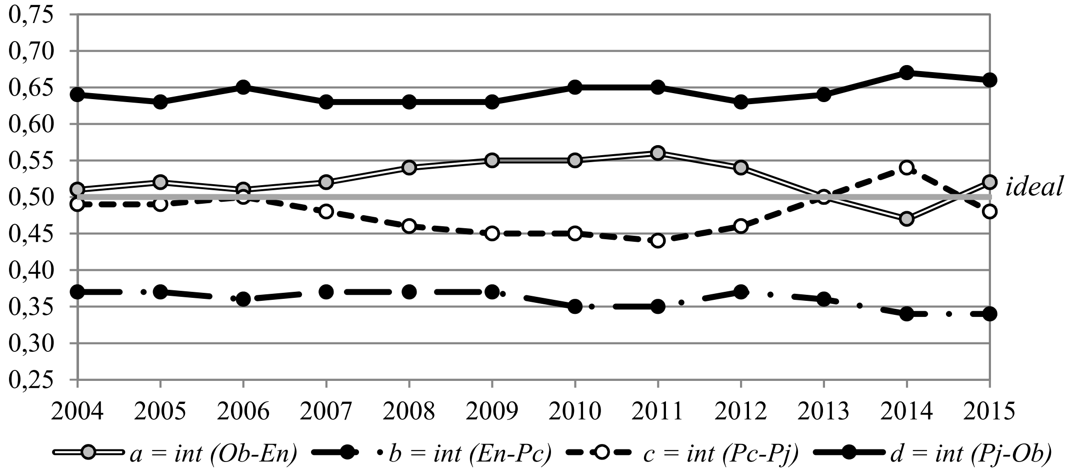
Fig. 4. The method of the proportions of the subsystems visualization (ideal balanced structure of tetrad is present)



Source: modified by author based on (Rybachuk, 2015)

According to this method lengthsof *a, b, c* and *d* show the intensities of interaction between the corresponding subsystems: *a* – the intensity of interaction between objects and environments subsystems (*a = int (Ob-En)*); *b* – the intensity of interaction between environments and processes subsystems (*b = int (En-Pc)*); *c* – the intensity of interaction between processes and projects subsystems (*c = int (Pc-Pj)*); *d* – the intensity of interaction between projects and objects subsystems (*d = int (Pj-Ob)*). Their normalized values may act as the indexes of intensity of interaction between these subsystems. The results of a generalized index of intensity of interaction between the subsystems determination are illustrated in Fig. 5.

Fig. 5. The dynamics of generalized indexes of intensity of interaction between the subsystems for the group of analyzed enterprises

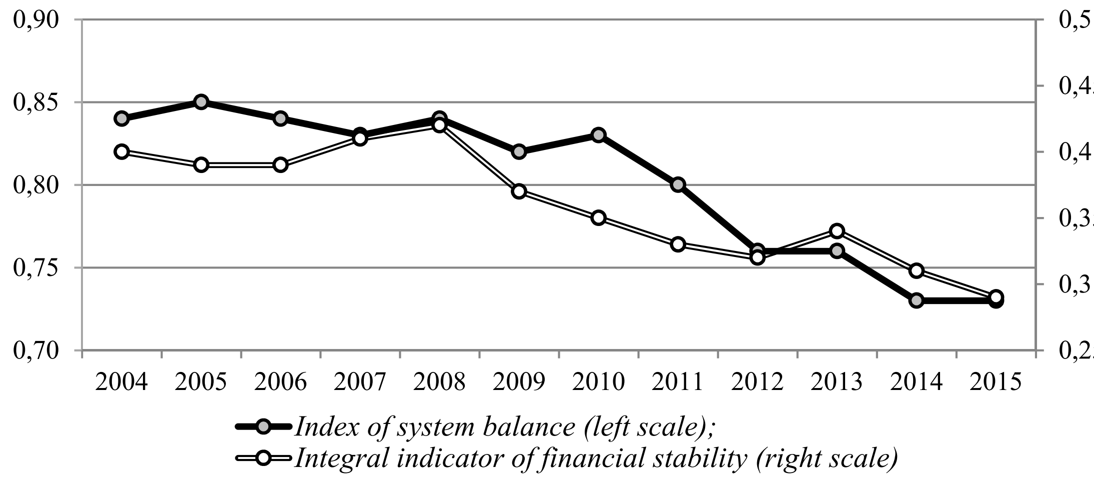


Source: own elaboration

The indexes of intensity of the interaction between the subsystems became the basis for the evaluating of the index of system balance of the enterprises. So the value of *a, b, c, d* form a four-dimensional space, and the point *S* (*a, b, c, d*) in this space indicates the position of each enterprise in terms of its system balance. According to the specific of our methods, the system is balanced, when $a_0 = 0.5$, $b_0 = 0.5$, $c_0 = 0.5$, $d_0 = 0.5$. So the point S_0 (a_0, b_0, c_0, d_0) reflects the ideal position of completely sustainable enterprise.

Based on such considerations, normalized numerical value of Euclidean distance from the point *S* to the "ideal" point S_0, was evaluated. This value acts as index of system imbalance. The index of system balance, as the difference between the maximum possible value of the index of system imbalance and the one that had been calculated for each case, was determined. The results of the calculation are generalized in Fig. 6 (left scale).

Fig. 6. The dynamics of generalized index of system balance and integral indicator of financial stability for the group of analyzed enterprises



Source: own elaboration

3.3 Determination of authenticity and the hypothesis verification

To determine the level of authenticity of obtained results and to verify the hypothesis we have conducted a correlation analysis of the statistical relations between the index of system balance and "traditional" financial ratios that are generally used as indicators of sustainable functioning of the enterprises (MFU, SPFU, 2001). For this purpose, it was necessary to conduct the financial ratios to a single integral indicator of financial stability. There are two possible approaches to do this: limiting the number of coefficients and performing correlation analysis of each of them or carrying out the convolution of a set of coefficients. We have selected the second through its relatively higher information value. The complexity of determining the range of acceptability of many ratios, which are interrelated and interdependent, caused difficulty of the indicator calculation. The range of acceptability and the dynamics of financial ratios are crucial, since the lack of financial stability could result in insolvency and the surplus might slow the development, burdening by the excess inventory and reserves – in either case, the economic sustainability of the enterprise is reduced. Therefore, for the convolution we have chosen the method of fuzzy logic.

The method was applied as follows. A clear set of financial ratios was limited to the fuzzy set of acceptable or unacceptable for the sustainability of the enterprise values. For this purpose each value of financial ratios was considered as linguistic variable defined in the entire range of possible fuzzy values with two terms – "acceptable value" and "unacceptable value". The fuzzy sets that meets these terms were defined based on existing regulations and expert recommendations. Membership functions of fuzzy sets were obtained using the Fuzzy Logic Toolbox for MatLAB R2012a. This is allowed us to obtain a single integrated indicator of financial stability. Its dynamics can be also seen on the Fig. 6 (right scale).

Our next task was to determine statistical relations between the generalized index of system balance and integral indicator of financial stability for the group of analyzed enterprises. Considering the fact that the values of both indexes belong to the interval type, their statistical correlation was assessed using Pearson coefficient. Pearson coefficient, calculated in terms of 2004-2015 is 0.901. Error correlation coefficient is 0.137. The value of t-criterion for the number of periods $n = 12$ ($n - 2 = 10$) is 6.562. It is corresponding to the probability of faultless prognosis $p > 99.9\%$. This indicates that the correlation coefficient is statistically significant. Accordingly, we conclude that the statistical relationship between indicators is a linear, strong and reliable.

4 Discussion

The results obtained from the comprehensive application of Data Mining technology have allowed us to confirm the hypothesis that economic sustainability of the enterprise is caused by the level of balance of its four subsystems. If economic sustainability of the enterprise as the system is provided by the coherent implementation of functions by each of the four subsystems, then dis-functionality (deficit) or hyper-functionality (surplus) some of them, as well as their mutual imbalance, lead to the violation of the economic sustainability. And then causes of instability may be identified depending on the type of imbalance of enterprises' structure and relevant management techniques may be formed.

According to the analysis, fully balanced tetrad structure, which corresponds to approximately equivalent severity each of the four subsystems at the enterprise and provides a high level of economic sustainability, has been observed in 19 of 192 cases – the frequency of its observation was 9.9%.

Unbalanced tetrad structure, when economic sustainability was lowered due to a significant deficit of processes subsystems, has been observed in 24 of 192 cases – the frequency of its observation was 12.5%. Unbalanced tetrad structure, when economic sustainability was lowered due to a significant deficit of environments subsystems, has been observed in 29 of 192 cases – the frequency of its observations was 15.1%. And unbalanced tetrad structure, when economic sustainability was lowered due to a significant surplus of objects subsystems, has been observed in 34 of 192 cases – the frequency of its observations was 17.7%.

Very unbalanced tetrad structure, when economic sustainability was significant lowered due to a simultaneous surplus of objects and projects subsystems and deficit of environments and processes subsystems, has been observed in 76 of 192 cases – the frequency of its observation was 39.6%. Very unbalanced structure, when economic sustainability was significant lowered due to a simultaneous surplus of objects and environments subsystems and deficit of projects and processes subsystems, has been observed in 6 of the 192 cases – the frequency of its observation was 3.1%.

The frequency of observation of other possible types of structures in the sample has been relatively low – not more than 1.0% each.

In general, across the sample deficit of processes subsystems has been observed in 51.0%, deficit of environments subsystems – in 43.8% of cases. Surplus of objects subsystems has been observed in 90.6% – these subsystems were more severe in most cases. The second more severe subsystems were the projects.

Based on the research, we have identified the general systems and structural types of imbalances, which are inherent to Ukrainian machine-building enterprises, and their signs. Surplus of objects subsystems is indicating the ineffectiveness of segmentation of enterprises' employees, their low workload, incoordination of departments, ineffectiveness of administrative and management activities and expenses and so on. Surplus of the projects subsystems primarily is indicating the ineffectiveness of innovation and investment activities at the enterprises, inefficient mechanism of selecting projects for implementation and their discrepancy to strategic priorities of the enterprises. Deficit of the environments subsystems is indicating the weakness of the organizational culture of the enterprises, high degree of uncertainty, unfavourable organizational climate. And deficit of processes subsystems is indicating the fragmentation, diminution of the main production activities of the enterprises and their low efficiency.

Surplus of objects subsystems simultaneously with deficit of environments and processes subsystems indicates that the situation which can be described as "surplus of labour under the deficit of qualification" is formed at the enterprises. This situation is not new, it has historically experienced by majority of countries, especially on the way of transition from one industrial technological structure to another (Gimpelson, 2007). But at the Ukrainian machine-building enterprises this situation has dragged on and become traditional.

Surplus of projects subsystems simultaneously with the deficit of processes subsystems shows that despite the fact that the enterprises show a relatively high level of innovation and investment activity by their formal attributes, its impact and "benefit" for the main productive activity is very low. Because the innovations should meet the basic profile of the enterprises and their technological level or even raise it. But this is not happening.

Conclusion

We have confirmed the hypothesis, that economic sustainability of the enterprise is caused by the level of balance of its four subsystems with different spatiotemporal localization, by processing statistical data on 16 machine-building enterprises. Based on the author's techniques, the index of each subsystem was obtained, their mutual balance was evaluated and the balance index was derived. Then the received estimations were compared with an estimation of level of economic stability of the enterprise defined on the basis of financial ratios which are traditionally used as its indicators. The high level of correlation between these two assessments allowed us to conclude that such an approach is practically valuable and can be used to assess economic sustainability of other systems.

This research allowed us to identify the general system-structural patterns of the functioning of machine-building enterprises and explain many of the destructive processes that occur on them. The situation, which has been identified, as well as the neosystem methodology in general, requires further researches in two parallel directions. The first direction should be focused on the development of theoretical and methodological bases and techniques to managing economic systems, which are differentiated by the type of structure. The second direction should be focused on further elaboration of major theoretical and methodological principles of the paradigm and analysis of the sustainability of specific economic systems in its context. Both directions should be interconnected with each other.

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