Conceptual Model of Self-Organisation and Formalization of Complex Socioeconomic Systems*

Kristina A. Chernogorova [1[0000-0002-2681-4032]], Oleg V. Boychenko [1[0000-0003-3326-1015]] and Ilya V. Gavrikov [1[0000-0002-7047-9059]]

[1] V. I. Vernadsky Crimean Federal University, Simferopol, Russia

bolek61@mail.ru

Abstract. The ability to self-organize is a fundamental property of any open non-equilibrium system. The process of self-organization promotes order, hierarchy, and evolutionary system development. Applying a synergistic approach to investigating socioeconomic systems and formulating control actions based on theoretical models are both innovative technologies and help increase the efficiency of management. Applying a synergistic approach to investigating the attributes of a business as a micro-level socioeconomic system allows leaping a new conceptual framework of management, based not on the management of deviations or current goals, but on the concept of system development that would pre-empt crises. The goal of this study is to create a quantitative assessment instrument that enables assessment of the ability of micro-level socio-economic systems to self-organize. To achieve this goal, the authors develop a conceptual model in the form of a semantic web, which demonstrates the relations between factors influencing the ability to self-organize. Additionally, a formalization of the conceptual system is proposed based on fuzzy set theory. A practical implementation of the self-organization ability assessment technique is also proposed in the form of an intelligent system based on the MathCAD mathematics package.

Keywords: self-organization, the socioeconomic system, business crisis, decision support systems, computer modeling, fuzzy logic, MathCAD

1 Introduction

Any system that has humans as part of the complex system. Complex systems possess certain special properties that ensure their integrity and viability. Businesses are complex socioeconomic systems, and to survive in the highly competitive and turbulent environment of the modern world they must be able to self-regulate, adapt, and self-organize. While the first two abilities have been studied in contemporary research [1], the issue of business self-organization has yet to be studied extensively.

The ability to self-organize is a fundamental property of any open non-equilibrium system. The process of self-organization begets order, hierarchy, and evolutionary system development. The study of self-organization has been made possible due to the development of a new field of science dubbed "synergetic". It stems from Hermann Haken's 1973 report on "Cooperative phenomena in systems far from thermal equilibrium and in nonphysical systems". Today it is an interdisciplinary science with a developed methodology and mathematical tools. Applying the synergetic approach to different systems has caused some breakthroughs in physics, chemistry, and biology. In all of these cases, the object of study was a certain non-linear complex system now of a phase transition caused by changing external conditions – temperature, pressure, magnetic and electrical field, etc. In social sciences, the synergetic approach is traditionally applied to study the evolutionary processes of system development. Additionally, new directions of research have been proposed, as in [2, 3], where the synergetic paradigm serves as a basis for studying self-organization mechanisms in networked structures. The issues of organizing a coordinated and practical group action in a complex social system, defined as "swarm intelligence", are examined in [5]. The science of synergetic has also given rise to a new paradigm of interdisciplinary studies – complexity theory. Complexity theory studies the fundamental properties of complex adaptive systems, like societies and economies. Complexity theory has been applied to studying large-scale socioeconomic systems, and these applications are well described in [6, 7].

Researchers from other fields have also studied the issues of social system self-organization. The idea of system self-organization has been significantly influenced by the work of Chilean researchers H. Maturana and F. Varela, founders of the theory of autopoiesis, and their followers. The theory of autopoiesis is centered around the idea that "living" systems can autonomously replicate their structure, not through simple reproduction, but through supporting their identity. Additionally, N. Luhmann's theory of social communication has also studied social system self-organization. Luhmann's self-organization is comprised of operationally closed self-referential communicative processes. Luhmann asserts that communication in a system begets communication, and the organization of system structure happens to support that communication. Studies in micro-level self-organization processes, such as [8-11] and others, indicate the direction of future study in this field. The authors consider the following issues to be of particular relevance: managing complex self-organizing systems, supporting equilibrium, assessing the risk of integrity loss (system death), as well as issues assessing system self-organization ability. The goal of this study is to create a quantitative assessment instrument that enables assessment of the ability of micro-level socio-economic systems to self-organize.

2 Primary Assumptions and Methodology

This study proposes a model for assessing the ability of a business to self-organize based on self-assessment. This technique assumes the use of expert information, which generally contains subjective assessments that may be uncertain, fuzzy, and incomplete. This peculiarity of available input variables was the motivation behind the choice of fuzzy set theory as the mathematical toolset for this study. Fuzzy set theory has been successfully applied in multiple studies of various socioeconomic systems, as well as in assessing specific business characteristics [12]. One widespread type of fuzzy model is the fuzzy production model. A fuzzy production model may be described using a set of linguistic variables (input and output) and a base of fuzzy production rules, which associate the model's input and output. The formalization of the model proposed in this study was preceded by an analysis of existing literature in the field and conceptual modeling of the subject area, which resulted in a set of linguistic variables for the model. This study does not concern itself with an in-depth look at the steps involved in fuzzy logical output, as this aspect is well studied and executed by experts using specialized software. For a quantitative assessment of a business' ability to self-organize, the authors propose the use of the Mamdani method and the center of gravity method as the defuzzification operator.

3 Modeling the Assessment of Self-Organization Ability

3.1 Conceptual Model of Business Self-Organization Ability Assessment

The conceptual model is comprised of three blocks – structural components of the model. Each block contains variables that best represent it from the point of view of self-organization ability.

Motivation. Motivation generates internal energy in a social system and creates change. Indicators that reflect the level of motivational energy include engagement, professional identity, and loyalty. Engagement is defined as the desire of employees to contribute personally to the business. The professional identity reflects the perception of the goals of a business by employees as their own. Loyalty is defined as employee satisfaction with their career growth and employee trust in the management team.

Organization. The organization block represents a set of indicators that characterize the potential of a business' reproductive capacity. Here, three specific aspects are of particular interest:

- the presence of a concrete foundation in the management system, which would serve as a basis for reformatting the organizational structure of a business. In many businesses, the corporate culture serves as this foundation. Corporate culture, as the "genetic code" of a business, ensures the business' uniqueness and reproduction;
- the ability of a business to evolve, for the complexity of its hierarchy to grow, which is ensured by limiting organizational diversity on the lowest levels. This principle of complex system organization is well-known in general systems theory and cybernetics, and it has been repeatedly formulated and applied to many different kinds of systems by various researchers;
- the presence of a leader or a management team able to assume an "architectural" role and build or rebuild the organizational structure, which would be in line with internal requirements and external demands, and which would ensure growth of the business' competitive ability on the market. In this study, the indicator for this property is defined as the level of professionalism in the management team.

Reflexive connections. Reflexive connections ensure coordination and synchronicity of business activities through an individual's imitation of the logic behind the thoughts and actions of others in their mind. Reflexive connections act as a compensatory, fallback channel in case of dysfunction in the formal management structure. V. Lefebvre introduced reflection as a term in the 1960s, and his theory of reflexive management has been called "second-generation cybernetics" due to its lack of backward linkages in the management process. According to Lefebvre, reflexive processes are included in the self-regulation mechanisms of all social systems. In this study, reflexive connections are characterized quantitively as the level of social intelligence in a group.

3.2 Determining Input and Output Variables

Thus, the conceptual model of business self-organization ability assessment may be represented in the form of a semantic web of the following form (Fig. 1), which demonstrates the relations between indicators:

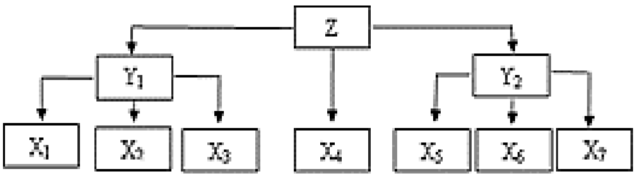

Fig. 1. Relations between indicators and characteristics of the ability to self-organize

Hereafter it is assumed that all variables being introduced are linguistic variables. They are represented in the form (1):

$$<X, T(X), U> \quad (1)$$

where X is the name of the linguistic variable, $T(X)$ is a set of linguistic (verbal) values of variable X, otherwise called the term-set of the linguistic variable, U is its domain.

X_1 = "Degree of employee engagement" with universal set $U_{X1}=[0;1]$. Term-set $T(X_1)$ = {"full", "high", "average", "low", "none"}.

X_2 = "Degree of professional identity" with universal set $U_{X2}=[0;1]$. Term-set $T(X_2)$ = {"full", "high", "average", "low", "none"}.

X_3 = "Degree of employee loyalty" with universal set $U_{X3}=[0;1]$. Term-set $T(X_3)$ = {"full", "high", "average", "low", "none"}.

X_4= "Level of social intelligence" with universal set $U_{X4}=[0;1]$. Term-set $T(X_4)$ = {"high", "above average", "average", "below average", "low"}.

X_5= "Level of corporate culture" with universal set $U_{X5}=[0;1]$. Term-set $T(X_5)$ = {"high", "above average", "average", "below average", "low"}.

X_6= "Level of management process standardization and unification" with universal set $U_{X6}=[0;1]$. Term-set $T(X_6)$ = {"high", "above average", "average", "below average", "low"}.

X_7= "Level of manager professionalism" with universal set $U_{X7}=[0;1]$. Term-set

$T(X_7)$ = {"high", "above average", "average", "below average", "low"}.

Y_1 = "Level of motivation" with universal set $U_{Y1}=[0;1]$. Term-set $T(Y_1)$ = {"high", "above average", "average", "below average", "low"}.

Y_2 = "Potential of business reproduction" with universal set $U_{Y2}=[0;1]$. Term-set $T(Y_2)$ = {"high", "above average", "average", "below average", "low"}.

Output variable Z = "Ability to self-organize" with universal set $U_Z=[0;1]$. Term-set $T(Z)$ = {"high", "above average", "average", "below average", "low"}.

All terms are represented by fuzzy sets, and each of them is represented by trapezoid membership functions. To describe the leftmost term, an expression of the form $\mu^L(a,b,c,d,x)$ is used (2):

$$\mu^L(a,b,c,d,x) = \begin{cases} 1, & x \le a \\ \dfrac{b-x}{b-a}, & x < b \\ 0, & x \ge b \end{cases} \tag{2}$$

for central terms – $\mu^C(a,b,c,d,x)$ (3):

$$\mu^C(a,b,c,d,x) = \begin{cases} 0, & x \le a \\ \dfrac{x-a}{c-a}, & a < x < c \\ 1, & c \le x \le d \\ \dfrac{b-x}{b-d}, & d < x < b \\ 0, & x \ge b \end{cases} \tag{3}$$

for the rightmost term – $\mu^R(a,b,c,d,x)$ (4):

$$\mu^R(a,b,c,d,x) = \begin{cases} 0, & x \le a \\ \dfrac{x-a}{b-a}, & x < b \\ 1, & x \ge b \end{cases} \tag{4}$$

where a,b,c,d are the parameters of the membership function calculated based on the assessment expert of the results.

Specific values of the input variables may be obtained using surveys and special psychological techniques.

3.3 Fuzzy Production Model for Assessing Self-Organization Ability

The relationship between input and output variables is made possible by a system of fuzzy production rules built on a generalization of expert community experience. The rule system imitates expert reasoning and represents a hierarchy of knowledge bases about relations depicted in Fig. 1.

Generally, a system of fuzzy production rules that model an assessment of the ability to self-organize can be represented in the following form (5-7):

$$\bigcup_{p=1}^{e_j}\left[\bigcap_{i=1}^{3}\left(X_i = a^{X_i}{}_{j,p}\right)\right] \rightarrow Y_1 = a^{Y_1}{}_j,\ j=\overline{1,r} \tag{5}$$

$$\bigcup_{p=1}^{w_j}\left[\bigcap_{i=5}^{7}\left(X_i = a^{X_i}{}_{j,p}\right)\right] \rightarrow Y_2 = a^{Y_2}{}_j\ \ j=\overline{1,b} \tag{6}$$

$$\bigcup_{p=1}^{q_j}\left[\left(X_4 = a^{X_4}{}_{j,p}\right)\bigcap\left(Y_1 = a^{Y_1}{}_{j,p}\right)\bigcap Y_2 = a^{Y_2}{}_{j,p}\right] \rightarrow Z = a^{Z}{}_j \quad j=\overline{1,m} \tag{7}$$

where:

- $a^{X_i}{}_{j,p}$ is a fuzzy term used to assess values of input variables X_i in rule number jp;
- e_j is the amount of conjunctions in which the output variable Y_1 is assessed by term $a^{Y_1}{}_j$;
- r is the number of terms for a linguistic variable Y_1, w_j is the number of conjunctions in which output variable Y_2 is assessed by term $a^{Y_2}{}_j$;
- b is the number of terms for linguistic variable Y_2;
- q_j is the number of conjunctions in which output variable Z is assessed by term $a^{Z}{}_j$;
- m - is the number of terms for the linguistic variable Z.

3.4 Results and Further Study

For a practical implementation of the technique used to assess the ability to self-organize, an intelligent system has been developed based on the MathCAD mathematics package, which implements synthesis of the integral variable using the Mamdani method. The developed computer program is, in essence, a decision support system that ensures storage and management of databases and knowledge bases, implements the stages of phasing, aggregation, activation, accumulation, and dephasing, and synthesizes new knowledge – a comprehensive assessment of the ability of a business to self-organize.

The architecture of the decision support system includes standard building blocks: a database, a knowledge base, a model base, the program environment implementing computational algorithms, data control, and user interface. Generally, the decision support system architecture may be represented as in Fig. 2:

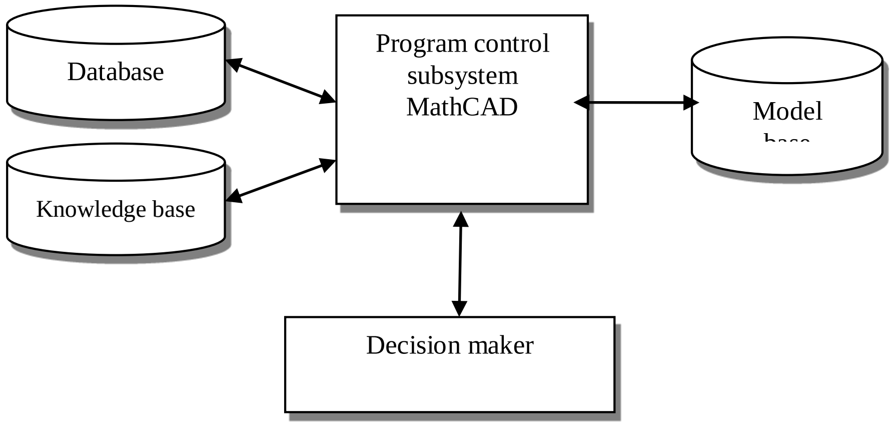

Fig. 2. The architecture of the decision support system

Future studies aim to test the model in action in large engineering industry businesses in the Republic of Crimea, as well as to develop the intelligent decision support system employing creating an advisory subsystem. Additional capabilities will allow to expand of the horizons of analysis available to users and help to construct a set of tactics for management actions.

4 Conclusion

This study proposes a novel approach to quantitative assessment of the ability to self-organize in micro-level socio-economic systems. A mathematical model is developed, which formalizes expert knowledge in the form of a hierarchical system of linguistic variables and fuzzy productions, which associate input and output variables at different aggregation levels. The use of this technique for assessing the ability to self-organize is proposed as the core of an intelligent decision support system, which enables a comprehensive assessment of the ability of a business to self-organize and allows choosing specific tactics for applying management actions.

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