Designing Socio-Technical Systems Using the System Paradigm in the Context of Nano-, Bio-, Information Technology and Cognitive Science Convergence

DOI: 10.12776/QIP.V26I2.1637

Elena Sydorova, Antonina Pahomova, Sandor Halász

Received: 2022-01-20 Accepted: 2022-07-05 Published: 2022-07-31

ABSTRACT

Purpose: The purpose of the study is to develop a methodology for designing socio-technical systems using the system paradigm in the context of nano-, bio-, information technology and cognitive science convergence.

Methodology/Approach: The systemic paradigm is used. The optimization is carried out according to the integral indicator of resource consumption and system energy efficiency. Fractal socio-technical systems are created that provide the maximum correlation between the needs of individuals and the activities of society, taking into account the dynamics of the formation of needs for the purpose of self-development with restrictions on safety factors and material resources.

Findings: The proposed methodology makes it possible to develop socio-technical systems with a high level of security, ensuring sustainable spiral self-development and integration of scientific knowledge on the basis of adaptive, innovative, intuitive and analytical elements of the system.

Research Limitation/Implication: A general concept for designing socio-technical systems using the system paradigm in the context of nano-, bio-, information technology and cognitive science convergence is presented that requires further research.

Originality/Value of paper: A methodology for designing socio-technical systems using the system paradigm in the context of nano-, bio-, information technology and cognitive science convergence was first proposed.

Category: Conceptual paper

Keywords: socio-technical system; system paradigm; nano-, bio-, information technology and cognitive science convergence; quality of life; self-development

1 INTRODUCTION

In socio-technical systems, the nature of effective nano-, bio-, information technology and cognitive science convergence (NBIC convergence) should imply the following principles:

- multifactorial generation and modification of products by means of nanotechnological principles used in physicochemical and biological production systems;
- renewability of resources;
- increasing energy efficiency;
- obtaining, analyzing and synthesizing data on system components in real time;
- high level of security in decision making;
- increased correlation between consumer and producer;
- integration of scientific knowledge;
- development of cognitive human and machine processes.

To ensure NBIC convergence and to solve many of the presented issues, the design of systems should be carried out, taking into account the entire complex of existing processes. The systemic paradigm mentioned in the works of J. Kornai (Kolbachev, Halász and Fedorchuk, 2019) makes it possible to implement such an approach.

In addition, the optimization of technical systems currently involves mainly minimizing resource and energy investment (Winkler-Goldstein et al., 2018). Modern digital technologies make it possible to quickly obtain data, including in real-time and calculate the energy and resource consumption of technological processes and production facilities throughout the PLM cycle. In view of the existing potential threats, it is important to create principles that allow the socio-technical system to develop steadily.

The purpose of the study is to develop a methodology for designing socio-technical systems using the system paradigm in the context of NBIC convergence. To do this, it is necessary to solve the following tasks:

- to ensure the implementation of nanotechnological principles of physical, chemical and biological production systems;
- define criteria for assessing resource consumption and energy efficiency, calculated on the basis of data on system components in real-time;
- to develop mechanisms for creating fractal socio-technical systems that provide a high correlation between the individual, production systems and society, based on the dynamic criterion of the quality of life;

- to propose a structure with a high level of security, ensuring sustainable spiral self-development and integration of scientific knowledge based on adaptive, innovative, intuitive and analytical elements of the system.

2 PRINCIPLES FOR THE DESIGN OF PRODUCTION SYSTEMS BASED ON NANOTECHNOLOGY

Nanotechnology has both technological and social benefits (Aithal and Aithal, 2016):

- providing a wide range of functional properties of materials;
- the possibility of reducing the size of products;
- production efficiency and reduction in the use of energy and other resources;
- the ability to change the human technological environment;
- after full implementation, ensuring the security of the world economy;
- solving the problems of social interaction and health problems.

Nanotechnology is fundamentally transforming existing production systems by applying the following principles to their design:

- management of functional characteristics at the nanoscale;
- parallelization of the processes of material and product formation;
- self-organization of the system, including cognitive artificial intelligence.

Thus, the main tasks in the design of such systems are:

- assurance of the effectiveness of application in various industries;
- ensuring productivity;
- safety and manageability.

The efficiency of production systems developed on the basis of nanotechnology directly depends on the availability of mechanisms that ensure the rapid integration of scientific achievements.

In ideological terms, nanotechnology offers a certain perspective that will allow:

- drastically minimize resource consumption with the possibility of raw materials recovering;
- to unify the applied technological tools as much as possible;
- to shorten the technological process of manufacturing products, ensuring high energy efficiency.

The possibility of developing production systems based on nanotechnology is primarily due to the socio-technical paradigm within which they exist. Thus, at present, the use of nanotechnology has found itself in medicine, electronics, and the chemical industry but is still poorly expressed in other areas of industrial production. This is due to the fact that the main target factor of production is productivity and financial profit, while in this case, it is necessary that the production system, when designing, be focused on the quality of life of consumers and manufacturers, as the main task, and take this into account in the parameters of its efficiency. Here, quality and functional orientation, intellectual self-organization and modification should be considered as complex system parameters, the analysis of which considers the impact on all elements of the socio-technical system, including the factor of inheritance.

3 CRITERIA FOR ASSESSING RESOURCE CONSUMPTION AND ENERGY EFFICIENCY

It makes sense to assess resource costs in terms of resource efficiency and the circular economy, in particular, the retention of resources within the economy (Di Maio et al., 2017).

In terms of resources, the circular economy focuses on reuse and recovery. In some cases, creating a closed loop requires more energy. Waste, loss and degradation of resources are never zero, so additional resources and materials are required to close the loops. All of this additional effort needs to be evaluated and compared with the benefits of closed resource savings. To assess resources, global indicators are being developed that, in addition to simple depletion potential, take into account the impact of resource life cycles, recyclability and geopolitical availability, covering all types of resources (renewable and non-renewable) (Adibi et al., 2017).

The integral indicator of resource consumption should take into account the following characteristics of resources in the system under consideration, expressed through weight coefficients:

- geopolitical accessibility,
- existing volume,
- cost of production,
- cost of processing,
- renewability,
- cost of the renewal.

In the context of NBIC convergence, the formation of resources should be as flexible and diversified as possible in terms of obtaining them.

Energy efficiency and energy flexibility are becoming increasingly important. Energy management is often based on ISO 50001:2018 standards and norms. Within Industry 4.0, manufacturing plants use cloud-based energy monitoring and management systems. This solution enables real-time production control, enabling flexible energy planning based on historical data and energy management (Javied et al., 2018). Systemic energy efficiency is the next criterion to be applied is the efficiency of using energy, material and cognitive resources. The same systemic energy efficiency can be provided with a different percentage of one or another component.

4 MECHANISMS FOR CREATING FRACTAL SOCIO-TECHNICAL SYSTEMS

Quality of life is a complex concept that includes not only economic factors but also intangible components (Girard et al., 2017). The Commission on Basic Indicators of Economic Performance and Social Progress (Stiglitz-Sen-Fitoussi Commission cited in Eurostat, 2017) measures 9 factors (Table 1).

Table 1 – Factors & Indicators that Determine the Quality of Life (Eurostat, 2017)

Factor	**Index**
Material housing conditions	Average income
	Income inequality quintile S80 / S20
	Material deprivation index
Industrial or other main activity	Employment rate
	Job satisfaction
Health	Average life expectancy
	Self-reported health status
Education	Percentage of people with higher education
Leisure and social interaction	Time satisfaction
	Help from others
Economic and physical security	Inability to afford incidental expenses
	Number of murders
	Perception of crime, violence or vandalism in a residential area
Public administration and fundamental rights	Trust in the legal system
Natural and living environment	Urban pollution
	Perception of pollution or other environmental issues in a residential area
Shared life experience	Life satisfaction

ISSN 1335-1745 (print) ISSN 1338-984X (online)

Table 1 contains both objective and subjective indicators. Satisfaction with life, work and quality of free time are not directly a function of economic and social well-being. In this case, the psychological perception of the world, conditioned by the comparison of the level of one's own development and the possibilities of realization provided by society, will be decisive.

The quality of life is a concept that is rather amorphous, difficult to measure, multifaceted, influencing and interacting with various environments and habitat, and can be defined as the sum of the biological and physiological states of a person, lifestyle, as well as personal and social relationships. Due to the fact that people differ from each other in their preferences, needs, economic opportunities and many other aspects, the environment does not provide them with an equal living environment that best suits their unique characteristics and aspirations. (Erdoğan and Namlı, 2019)

Assessment of the quality of life, therefore, should reflect in the dynamics the realization of the needs of an individual and society, since in the process of his development, a person's perception of the world transforms and needs change. In classical socio-technical systems, we contemplate the hierarchy of needs by A. Maslow (2008), based on behaviourist, Freudian and humanistic philosophy. Needs are presented in the form of a hierarchical structure: physiological needs and four levels of psychological needs (safety, love, respect and self-actualization). Satisfaction of higher needs brings greater happiness and contributes to the development of personality, which is the basis of psychological health. S.B. Kaverin (1987) proposes a matrix classification that indicates the need for parallel rather than sequential shaping of needs. Factors associated with work, communication, cognition and recreation go through four stages of their evolution: biogenic, psychophysiological, sociogenic and higher. In the context of NBIC convergence, when the integration of scientific knowledge (Sydorova et al., 2020) becomes a determining factor, a person's needs should, to a greater extent, include a cognitive component. The intellectual, cultural and creative development of an individual enriches the perception of the world around; thanks to the evolution of psychological perception, it becomes more voluminous and multifaceted. Basic human needs do not disappear but are qualitatively transformed and redistributed as a percentage.

Classical social and production systems focused on increasing production, and consumption volumes cannot meet these challenges. For example, forming certain niches to satisfy the needs of self-actualization, only the creation of certain conditions expressed by goods and services occurs, and not the real development of this factor, which ultimately will give low indicators in satisfaction with the quality of life. Thus, when building socio-technical systems should provide for fractal principles for the integration of the system paradigm: the conditions of an individual's existence should imply a complex perception of the world, on the basis of which his needs should be formed, and the system itself should integrate personal needs and the individual, offering an appropriate level of quality of life for their implementation.

Figure 1 shows the matrices of the needs of *N* individuals *I*, including physical needs N^p, cognitive needs N^c and social needs N^s. The activity of individual *A* is respectively represented by physical activity A^p, cognitive activity A^c and social activity A^s. The totality of the needs and activities of individuals determines the matrix of needs and activities of the society. The needs of the society are realized through the activities of individuals, and the activities of the society meet the needs of individuals. In this case, the system should be self-developing and create conditions for the qualitative development of the needs of individuals.

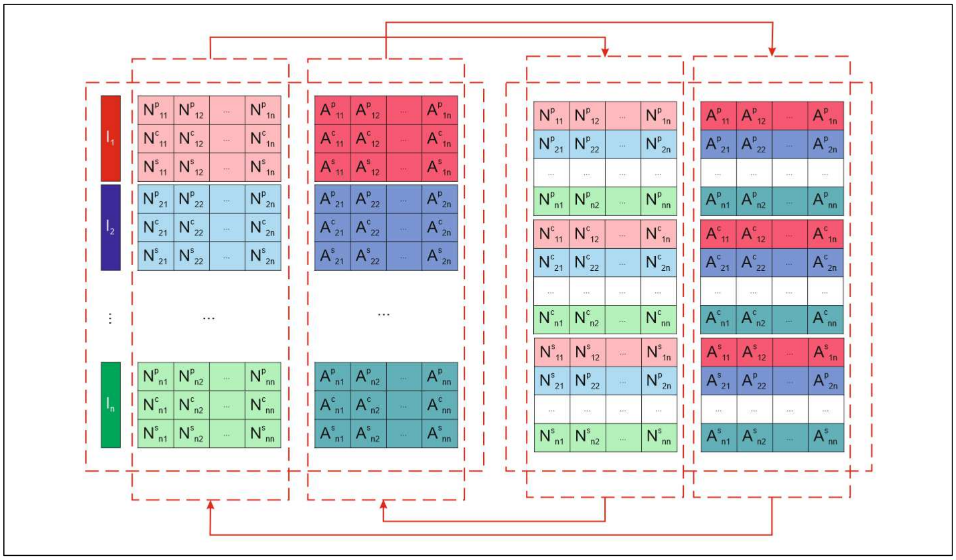

Figure 1 – Fractal Principles for the Integration of the System Paradigm in Socio-Technical System

The next important issue is to determine the mutual influence of the physical, cognitive and social needs of individuals in society. The formation of needs can be carried out along different paths. Human evolution generates new needs, which, in turn, can exclude old ones. The needs matrix is dynamic and changes over time. For example, cognitive needs can diminish physical ones. At the same time, material resource costs are reduced. The problem of optimizing the socio-technical system will be to ensure the maximum correlation between the needs of individuals and the activities of society, taking into account the dynamics of the formation of needs for self-development. The constraints are safety factors and material resources.

The dynamics of the formation of needs can be studied in different time frames (Figure 2). The time cut can be considered as a certain time interval *t* in which an individual realizes physical N^p, cognitive N^c and social N^s needs:

$$t_i(N^p) + t_i(N^c) + t_i(N^s) = const. \quad (1)$$

The percentage of time spent on meeting needs may vary, but their sum is always constant. The change in the function *t(N)* may be due to the evolution of the activity function *t(A)*:

$$t(N) = f(t(A)). \tag{2}$$

If the content of demand *N* remains the same:

$$N = \sum_{i=1}^{n} N_i, \tag{3}$$

then we will talk about a change in its "density": the same needs are realized in a different form over a different period of time.

Nevertheless, the content of the need *N* can change qualitatively and quantitatively, while the function *t(N)* can remain constant or change.

Taking into account the systemic paradigm, the evolution of any need goes through the following stages:

- change in the "density" *N*, provided by the evolution of the activity function *A*;
- quantitative change in *N*, allowing the accumulation of experience;
- qualitative change for the transition to a new stage in the evolution of *N*.

The stable dynamics of the formation of needs and the correlation of activities in socio-technical systems can be implemented on the basis of the principles of spiral self-development.

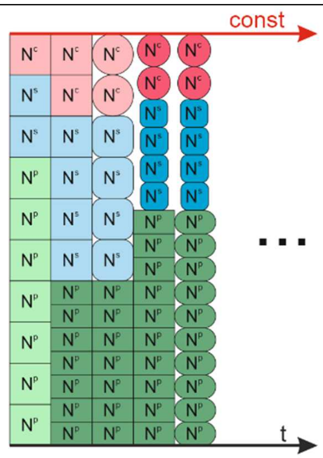

Figure 2 – Evolution of Needs: A Change in the Shape of Elements Indicates Their Qualitative Transformation, And The Lightness of Colour Indicates a Change in "Density"

5 SYSTEM STRUCTURE FOR SUSTAINABLE SPIRAL SELF-DEVELOPMENT

Due to the complexity of the created systems within the framework of NBIC convergence and the global level of potential threats, security can be guaranteed through a decentralized system of collective decision-making in the blockchain (Sydorova et al., 2021). Depending on the nature of the problem, a combination of decision-making experts is automatically determined based on a rating system. An expert can be either a person H or a machine M. The rating for each set of competencies is formed on the basis of the performance assessment by pairs H-H, H-M, M-H, M-M. Man evaluates the performance of machines and other participants in the same way that a machine evaluates the performance of humans and other machines. This is how an integrated rating is formed for the sets of competencies for humans and machines.

In addition, the design of socio-technical systems should imply the presence of mechanisms for introspection and self-development. It is important to determine the optimal conditions for the integration of innovations based on two fundamental points:

- innovations make it possible to meet new needs of individuals or provide old ones in a new qualitative form;
- innovation can shape new needs of individuals.

To ensure the self-development of the system, a qualitatively new formation of the needs of individuals should be formed, allowing to move to the highest stage of development, according to S.B. Kaverin (1987).

The cognitive style of an employee determines the way of searching, processing, evaluating, processing, systematizing and interpreting information. Analysts prefer linear logic and orderliness, methods of analysis. Intuitives take a holistic approach, methods of synthesis, and consideration of the environment or the situation as a whole. Such forms are rare in their pure form. As a rule, they are presented in some combination. They also distinguish between analytic thinkers and innovators. Analytic thinkers prefer to work within a consistent paradigm and are adept at improving existing ways of doing things. In contrast, innovators are more likely to solve the problem by changing the existing paradigm. (Güngör and Alp, 2019)

The socio-technical system should be based on the optimal cognitive structure of analytic and intuitive workers, analytic thinkers and innovators (Figure 3). Analytic thinkers ensure the stability and safety of the system, and innovators ensure its high-quality self-development.

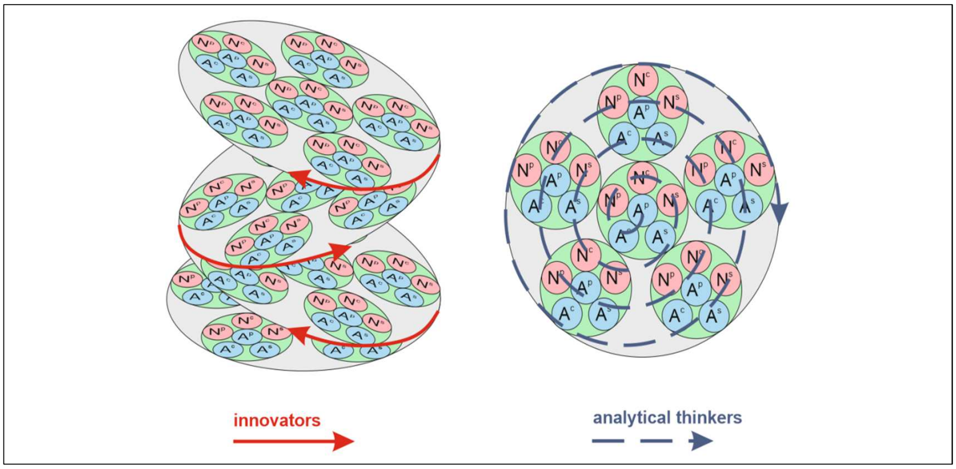

Figure 3 – Innovators and Analytical Thinkers in Fractal Socio-Technical Systems

Such a system will ensure sustainable self-development since each turn will create a stable base for the transition to the next level, while the correlation of activities and needs will be maximum.

6 CONCLUSION

The developed methodology for designing socio-technical systems using the system paradigm in the context of NBIC convergence includes:

- implementation of the principles of designing production systems based on nanotechnology with a radical minimization of resource consumption and the possibility of recovering raw materials, maximum unification of the applied technological tools, reduction of the technological process of manufacturing products and ensuring high energy efficiency;
- optimization according to the integral indicator of resource consumption and system energy efficiency;
- creation of fractal socio-technical systems that ensure the maximum correlation between the needs of individuals and the activities of society, taking into account the dynamics of the formation of needs for the purpose of self-development with restrictions on safety factors and material resources;
- creation of the structure of the system, ensuring sustainable spiral self-development.

The proposed methodology makes it possible to develop socio-technical systems with a high level of security, ensuring sustainable spiral self-development and integration of scientific knowledge on the basis of adaptive, innovative, intuitive and analytical elements of the system.

ACKNOWLEDGEMENTS

The reported study was funded by RFBR and FRLC, project number 20-510-23002 "The development of Janos Kornai's system paradigm is the fundamental basis for the creation of production and technical systems in the conditions of NBIC convergence".

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ABOUT AUTHORS

Elena Sydorova[0000-0002-8898-0909] (E.S.) – Assoc. Prof., Platov South-Russian State Polytechnic University (NPI), Department of Oil and gas equipment and technology, Novocherkassk, Russia, e-mail: sidorova_ev@npi-tu.ru.

Antonina Pahomova[0000-0002-4261-3097] (A.P.) – Prof., Platov South-Russian State Polytechnic University (NPI), Department of Production and Innovation Management, Novocherkassk, Russia, e-mail: tivano@yandex.ru.

Sandor Halász[0000-0002-5880-7048] (S.H.) – Prof. emeritus, Budapest University of Technology and Economics, Department of Electric Power Engineering, Budapest, Hungary, e-mail: halasz.sandor@vet.bme.hu.

AUTHOR CONTRIBUTIONS

Conceptualization, E.S.; Methodology, E.S.; Software, E.S.; Validation, E.S., A.P. and S.H.; Formal analysis, E.S.; Investigation, E.S.; Resources, E.S.; Data curation, E.S.; Original draft preparation, E.S.; Review and editing, E.S. and A.P.; Visualization, E.S.; Supervision, E.S.; Project administration, A.P. and S.H.; Funding acquisition, A.P. and S.H.

CONFLICTS OF INTEREST

The author declares no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.