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INNOVATION PROCESSES IN COMPLEX SYSTEMS: ISSUES OF SYSTEMS ANALYSIS AND MODELING

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Abstract:
This article analyzes the essence of innovation processes, their structural elements, interconnections, and self-organization mechanisms from the perspective of complex systems theory. The processes of generation, diffusion, and adoption of innovative ideas within a systemic approach are examined. A comparative analysis of modern methods for modeling and forecasting complex systems - agent-based modeling, system dynamics, network analysis, nonlinear dynamical systems, and machine learning approaches - is presented. The findings are of practical significance for managing complex information systems and enhancing innovation potential in the digital economy.

Keywords: Complex Systems, Innovation, Self-Organization, Emergence, Systems Approach, Innovation Diffusion, Agent-Based Modeling, System Dynamics, Digital Economy

Introduction

Modern digital economy under the circumstances economic, technological and social processes increasingly complicated, mutual deep integrating Transport networks, energy infrastructure, financial markets, social networks and artificial to the intellect based platforms — these all many mutual related from elements organization found complicated systems is considered Such systems understand, manage and develop for traditional linear thought enough no , this and complicated systems theory and systematic approach relevance defines.[1][2]

The problem relevance from that consists of innovative of processes most part exactly complicated systems inside - elements between mutual impact as a result - to appear Innovative of the idea creation of the process only elementary stage is, its real to innovation rotation for system inside spread and acceptance to be done necessary. Therefore innovative processes only a separate element or linear cause and effect attitude as no, maybe whole system within analysis to do demand is being done.[3][4][5]

The research goal - complex systems structural characteristics, in which passing self organization to grow processes, innovation of ideas generation, diffusion and adaptation stages and this systems modeling and forecasting modern methods systematic analysis from doing consists of.[6][7]

Materials and Method

The study employed a systematic approach, logical and comparative analysis, complexity science (the theory of complex systems), and the diffusion of innovations within the framework of E. Rogers' theory. These methods were used to generalize and synthesize scientific and theoretical sources related

to the research topic and to identify the main principles governing the development, interaction, and transformation of complex systems. The systematic approach made it possible to consider the studied phenomenon as an interconnected system consisting of structural elements, relationships, processes, and feedback mechanisms. Logical analysis was applied to identify cause-and-effect relationships, while comparative analysis was used to examine similarities and differences among existing approaches and modeling methods.

The analysis was conducted in three main directions:

1. Description of the structural elements and interrelationships of complex systems. Particular attention was given to the identification of the main components of complex systems, their functional relationships, interactions, and the influence of individual elements on the overall behavior of the system.
2. Identification of the mechanisms of self-organization, development, and diffusion of innovative ideas. The study examined how self-organization processes contribute to the emergence and development of new structures and how innovative ideas spread among system participants. In this context, the principles of E. Rogers' diffusion of innovations theory were used to explain the adoption and dissemination of innovations within interconnected environments.
3. Comparative assessment of existing modeling methods. Different approaches to modeling complex systems were compared according to their applicability, methodological characteristics, ability to represent dynamic interactions, and potential for describing nonlinear processes. This comparison provided a basis for identifying approaches that are most appropriate for analyzing complex and evolving systems.

In addition, the methodological framework considered the dynamic and nonlinear nature of complex systems, where changes in individual elements may influence the behavior of the entire system. Particular emphasis was placed on interactions, feedback, adaptation, and the emergence of new properties as important characteristics of complex systems. The combination of these methods allowed the study to integrate theoretical analysis with a comparative evaluation of modeling approaches and to develop a more comprehensive understanding of the mechanisms underlying innovation diffusion and system development [8].

Results

1. Complex systems structural elements and connections nature

Complex system is many mutual influential composed of elements (agents) found, elements between mutual dependency as a result separately into parts typical not been new, emergent features manifestation to be system as is described. Research to the results according to, system elements active agents, passive elements and mediator to the elements divided and micro and macro in degrees hierarchical to the structure has will be.[9]

Elements between connections direction (one two-sided/two-sided sided), character (positive/negative) communication) and strength (strong/weak) connection) by Network theory point of view from the point of view system nodes (elements) and set of edges (links) as is expressed, this and centralization, clustering and network density such as indicators through system structure quantitative assessment opportunity gives.[10]

2. Self-esteem organization to grow mechanism

Research as it turns out, it is complicated. In systems order and innovative potential often central without control, only elements between local mutual effects as a result This process is local mutual impact, positive and negative communication mechanisms, random vibrations and many stable through states (multistability) it will be over. Primary from chaos pull new order until stabilization was stages innovative clusters (e.g. technological ecosystems) formation theoretical basis organization will reach.[11]

3. Innovative of ideas generation, diffusion and adaptation

Innovative process three step by step cycle as seeing comes out: idea appearance to be (generation), its system along diffusion and agents by acceptance adaptation. E. Rogers diffusion to the theory according to the news acceptance those who do innovators, early acceptance those who do, early many, late many and behind the rest categories is divided, this and spread S- shaped dynamics curve line through description opportunity gives.

Network structure diffusion to the speed directly impact shows: centered nodes (idea leaders) through spread speed increases, clustered on the networks idea group inside fast, but groups between slowly spread. Network due to the network effect digital on platforms positive communication mechanism to work "fall down, "winner" all of them "gets" status create possible, agains, path dependency dependency) and lock-in effects even objective in terms of column innovation acceptance to be done obstacle to do possible.

4. Modeling and forecasting methods comparative analysis

Complex systems modeling one how many main approach there is is, their every one different goal and to the conditions suitable comes. The following in the table main methods and their application sectors compared.

Table 1. Comparison of Computational Modeling Methods and Their Applications

Method	Home idea	Application field
Agent-based modeling (ABM)	Every one the element as a separate agent modeling	Social systems, markets, epidemiology
System dynamics	Backup and currents through feedback contours description	Economics, ecology, strategic management
Network models	The system knot and edges through to describe	Social networks, innovation diffusion
Nonlinear dynamic systems	Time according to change differential equations through expression	Economic cycles, population dynamics
Cellular vending machines	On the fence local rules based on development	City growth, epidemic spread
Machine-made study	From the data patterns automatic	Big information analysis,

	determination	prediction

Analysis this shows that it is complicated systems nonlinear nature and elementary to the conditions sensitivity ("butterfly effect") due to far term clear prophecy to do in principle limited. Same because of modern in practice clear one prophecy instead of scenario analysis, probability distribution and of the system stability stress test to do from the methods use recommendation is being done.[12][13]

Discussion

Transferred analysis complicated systems theory innovative management practice for important methodological basis be to take In particular, the network structure and self organization to grow mechanisms understanding enterprises and state to the institutions innovative of ideas spread speed management, critical to the mass to deliver and lock-in the risk reduce according to strategic decisions acceptance to do opportunity gives.[14] Digital economy under the circumstances big information and artificial intellect technologies development agent-based and hybrid models practical application circle is expanding, this and "digital" twin" (digital twin) like solutions promising direction that confirms.[15]

Conclusion

Transferred research as a result following to conclusions bride:

1. Complicated systems emergent, mutual dependency and nonlinearity such as features innovative processes only systematic approach based on analysis to do requirement will come;
2. Self organization to grow mechanism central innovative even without management ecosystems formation providing main factor is considered;
3. Innovative of ideas successful spread and acceptance to be done network structure, positive/negative communication mechanisms and path dependency factors related;
4. Complicated systems in modeling the only universal method there is not - agent- based modeling, system dynamics, network analysis and with a car study methods harmonization the most effective result gives;
5. Fundamental nature of systems come outgoing uncertainty into account received without, in forecasting scenario analysis and stability from tests use to the goal is appropriate.
6. Received results complicated information systems design, innovation strategies working exit and digital transformation processes management in the field next research for theoretical-methodological basis become service to do possible.

References

[1] M. Mitchell, *Complexity: A Guided Tour*. New York, NY, USA: Oxford University Press, 2009. (OUP Academic)

[2] H. Sayama, *Introduction to the Modeling and Analysis of Complex Systems*. Binghamton, NY, USA: Open SUNY Textbooks, State University of New York, 2015. (bingdev.binghamton.edu)

[3] G. West, “Introduction to the Modeling and Analysis of Complex Systems by Hiroki Sayama: A proper undergraduate textbook,” 2018.

[4] Y. Bar-Yam, *Dynamics of Complex Systems*. Reading, MA, USA: Addison-Wesley, 1997. (WorldCat)

[5] J. H. Holland, *Complexity: A Very Short Introduction*. Oxford, U.K.: Oxford University Press, 2014. (OUP Academic)

[6] M. E. J. Newman, *Networks: An Introduction*. Oxford, U.K.: Oxford University Press, 2010. (OUP Academic)

[7] S. H. Strogatz, *Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering*, 2nd ed. Boulder, CO, USA: Westview Press, 2015.

[8] J. H. Miller and S. E. Page, *Complex Adaptive Systems: An Introduction to Computational Models of Social Life*. Princeton, NJ, USA: Princeton University Press, 2007.

[9] S. A. Kauffman, *At Home in the Universe: The Search for Laws of Self-Organization and Complexity*. New York, NY, USA: Oxford University Press, 1995.

[10] E. Bonabeau, M. Dorigo, and G. Theraulaz, *Swarm Intelligence: From Natural to Artificial Systems*. New York, NY, USA: Oxford University Press, 1999.

[11] R. V. Solé and S. C. Manrubia, *Order and Chaos in Complex Systems*. Princeton, NJ, USA: Princeton University Press, 2000.

[12] G. Nicolis and I. Prigogine, *Exploring Complexity: An Introduction*. New York, NY, USA: W. H. Freeman, 1989.

[13] H. A. Simon, "The architecture of complexity," *Proceedings of the American Philosophical Society*, vol. 106, no. 6, pp. 467–482, 1962.

[14] S. Wolfram, *A New Kind of Science*. Champaign, IL, USA: Wolfram Media, 2002.

[15] G. West, *Scale: The Universal Laws of Growth, Innovation, Sustainability, and the Pace of Life in Organisms, Cities, Economies, and Companies*. New York, NY, USA: Penguin Press, 2017.