Management model in digital ecosystems

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Abstract. Rapid pace of digitalization of ecosystems in the modern world affect social and economic systems. State-of-the-art web technologies, a huge information system, have an increasing impact on human life. The information environment undergoes adverse effects during its functioning. To maintain functioning of the system information component, a properly constructed system and an adequate model of response to external effects are required. The response model in digital ecosystems will be designed with regard to three processes, namely: the problem formation process, the problem identification process, and the problem neutralization (elimination) process. An indicator of the efficiency of ecosystem functioning will be identification and neutralization of each problem. Simulation results confirmed the main trends in digital ecosystems functioning. The development and subsequent application of methods and techniques to achieve the set goal in a shorter time will always be relevant and in demand. To implement a rational approach to making managerial decisions, the leader responsible for digital ecosystem functioning can use network planning as a plan for the entire cycle of processes for maintaining the information security of the ecosystem as a whole.

1. Introduction

Currently, the Internet plays an ever-increasing role in the life of a person and the entire society. The Internet as a global data system of interconnected computer network with arrays intended for storing and transmitting data is becoming more widespread. The Internet creates digital ecosystems and penetrates into social and economic systems such as education, health, defense, law and conservation. The Internet provides great opportunities for digital ecosystems, such as society-ecology-economy. Its integration into social life associated with hardware and software development is indisputable [1].

New digital ecosystems will pose new challenges facing humans and societies related to interaction with the changed environment (innovations caused by new information technologies). Web technologies and artificial intelligence (AI) designed for control and interaction will be implemented in digital ecosystems. However, hacker attacks that aim to destructively affect information web resources increasingly necessitate timely decision-making by decision maker (DM) to counter this impact, and in case of adverse aftereffects to promptly eliminate them, that is, to detect (identify) them in the shortest possible time, and to use available resources to overcome them. Resolution of this issue will be a primary task for digital ecosystems since negative impacts can affect all spheres of social life, including the economy and the environment. Many modern scientists discuss the prospects of AI-based digital systems [2–8].

Maintaining continuous functioning of the digital ecosystem is a purposeful activity of DM aimed to form a mathematical model of his decision based on the use of resources available at a given time in

order to preserve the operability of the digital ecosystem. However, we cannot guarantee achievement of the goal without the methodology developed to solve management problems in the form of conditions for the process existence [9].

For DM, the goal such as uninterrupted control is a primary task that requires a well-constructed model allowed to timely respond to adverse effects of the external environment. Development and subsequent application of methods and techniques to achieve the set goal in a shorter time will always be relevant and in demand [10].

2. General approach to constructing a managerial decision model

To implement a rational approach to managerial decision-making, the manager must have an analytical and dynamic model of managerial decisions aimed at achieving the management goal. DM can use network planning to plan the entire cycle of processes in order to maintain information security of both the digital ecosystem and its functioning as a whole.

Therefore, two issues should be considered:

1. Approaches used to develop the system;

2. Development of an adequate model for making managerial decisions.

The first issue implies two known and used approaches to system development: analysis-based approach and synthesis-based approach [9, 10], which are schematically shown in Figure 1.
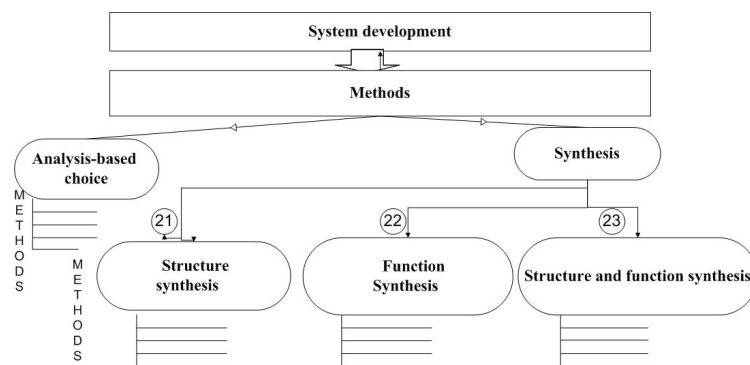

Figure 1. Two approaches to system development.

With regard to the actions of a person, famous academicians P.K. Anokhin and M.A. Arbib identified three categories of the DM's action: system, model and purpose [8, 11].

Print and digital publications consider mainly analysis-based approaches; however, to build a digital ecosystem management model we need a synthesis-based approach, which requires knowledge of the law of construction and functioning of the developed system. The so-called law of object integrity preservation (OIP) that implies an indestructible, integral and repeating relationship between the properties and objects affected by the investigated object during its implementation, which allow preservation of its original properties and do not collapse under adverse effects [9, 10].

As a result, we use a synthesis-based method in our study. The analysis-based method does not ensure formation of processes with the specified efficient properties; therefore, it cannot be used for management model development.

The second issue implies development of an adequate model for a digital ecosystem managerial solution. The model is based on the system integration of three processes:

- formation of a problem (task) for DM;

- identification of the problem (task) for DM;

- neutralization (solution) of the problem (task) for DM.

As noted earlier, a person operates with three categories during his life: system, model and purpose. Therefore, it is particularly important to consider and use these categories. Figure 2 shows a detailed content of the 'activity' concept [10].
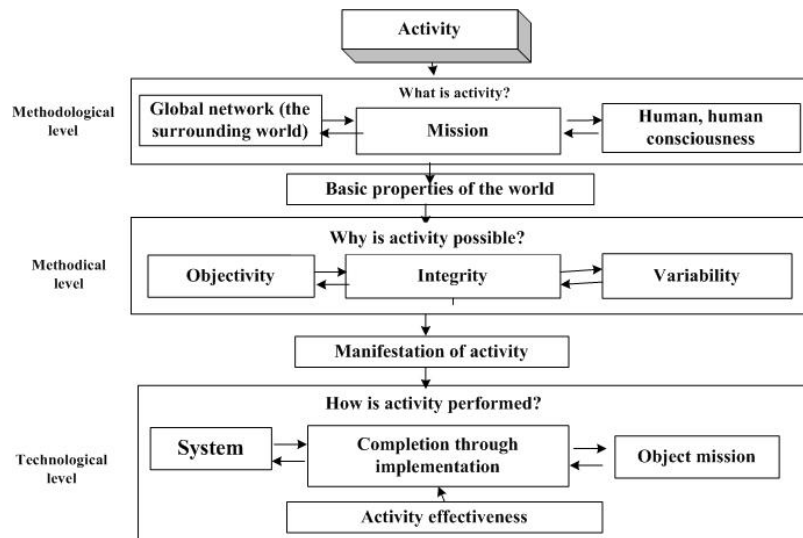
Figure 2. Two approaches to system development.

When synthesizing a management model, the object adequacy (process, functions, characteristics) and its corresponding properties must be taken into account. Adequacy is a key point in this study, since it guarantees achievement of the management goal. Figure 3 shows a diagram of the basic assessment of the management model adequacy.

Management is always based on the decision of DM, a person who manages the process. Making decisions based on a model is natural to human. Thus, it is necessary to note that the process model DM deals with will be the decision.

The managerial decision is developed by DM based on knowledge gained with regard to the current environment for implementation of activities and based on the resources available to the person. These resources include:

- hardware complex or technical means;
- software package;
- human resource (staff held by the head).

It can be concluded that the DM's managerial decision will include the availability and coordinated work of the resources involved, and the psychophysiological qualities of the manager.
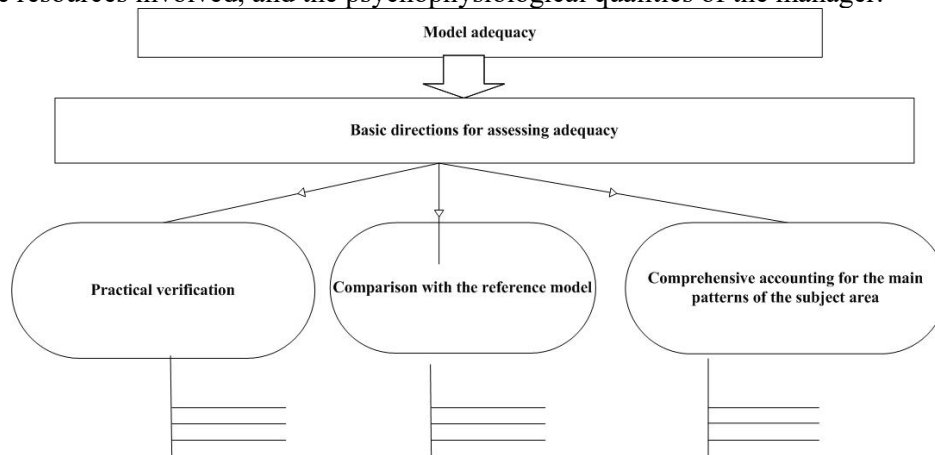

Figure 3. Basic directions for assessing the adequacy of the management model.

The above conditions are formed to achieve the management goal [9].

3. Synthesis of a model of DM's managerial decision in a digital ecosystem

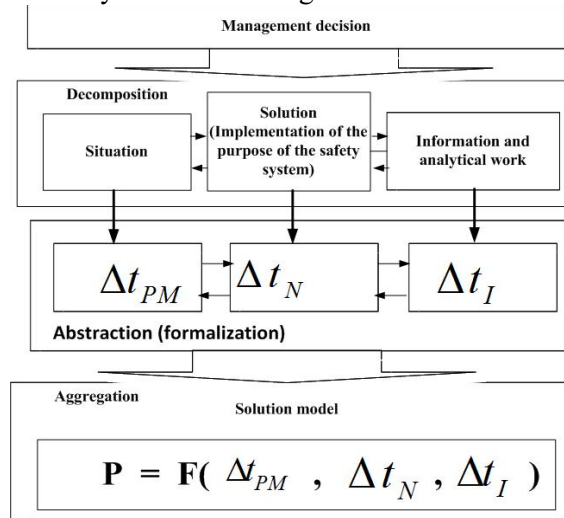The flow diagram of the detailed synthesis of managerial decisions is shown in Figure 4.

Figure 4. A detailed scheme for synthesis of managerial decisions.

At the top stage, the process of decomposition takes place and the managerial decision forms three elements: situation, decision, and information and analytical work. The abstraction method used at the intermediate stage yields the following:

- the environment or situation is identified with the frequency of the problem manifestation for DM – Δt_{PM};

- the solution is identified with the frequency of the problem neutralization (the average time of an adequate response to the problem) by DM – Δt_N;

- information and analytical work is identified with the frequency of the problem identification (the average time for recognizing the situation to neutralize it) – Δt_I.

At the final stage, aggregation procedure is used to form a model for managerial decisions in digital ecosystems in the following form: $P=F(\Delta t_{PM}, \Delta t_I, \Delta t_N)$

P.K. Anokhin contributed to development of the theory of functional systems, he scientifically described that a person's decision is formed according to the scheme excitement – recognition – response to the situation [9, 11].

The obtained mathematical condition for the existence of the process ensures effectiveness of the managerial decision. The management flow diagram is presented in Figure 5.
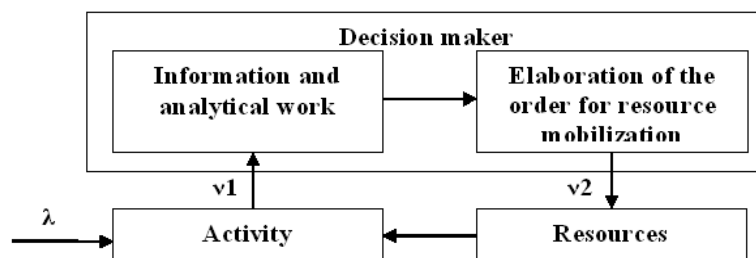

Figure 5. Management flow diagram.

Figure 5 uses the following notations:

- λ is the reciprocal of the average time of the problem manifestation ($1 / \Delta t_{PM}$);

- v1 is the reciprocal of the average time of the problem identification ($1 / \Delta t_I$);

- v2 is the reciprocal of the mean time of the problem neutralization ($1 / \Delta t_N$).

Thus, there are four states in which DM either recognizes or does not recognize a threat and neutralizes or does not neutralize it. These states are shown in Figure 6.
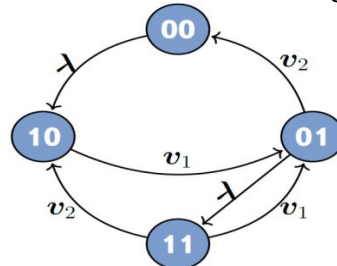

Figure 6. States of a decision maker.

In Figure 6, S1 indicates that DM does not recognize and does not neutralize; S2 – DM does not determine but eliminates; S3 – DM identifies but does not eliminate; S4 – DM identifies and eliminates.

To consider the dynamics of the decision making process, it is reasonable to use a continuous-time Markov chain. To implement this approach, it is necessary to form a system of Kolmogorov-Chapman differential equations. [10, 12]. Therefore, the characteristics of the system transitions are shown in Figure 5.

We identified the states of the system being in four probabilities, namely P00, P10, P01, P11, which correspond to the system in states S1, S3, S4, S2, respectively [13–16].

For mathematical modeling, the system is represented in the form of differential equations:

$$\frac{d}{dt}P_{00}(t) = -P_{00}(t)\lambda + P_{01}(t)\nu_2$$

$$\frac{d}{dt}P_{01}(t) = -P_{01}(t)(\lambda + \nu_2) + P_{11}(t)\nu_1 + P_{10}(t)\nu_1 \tag{1}$$

$$\frac{d}{dt}P_{10}(t) = P_{00}(t)\lambda - P_{10}(t)\nu_1 + P_{11}(t)\nu_2$$

$$\frac{d}{dt}P_{11}(t) = P_{01}(t)\lambda - P_{11}(t)(\nu_1 + \nu_2)$$

For system of differential equations (1), the following restriction is imposed:

$$P_{00}(t) + P_{10}(t) + P_{01}(t) + P_{11}(t) = 1 \tag{2}$$

System (1) is solved for the given initial conditions:

1. In the general case, equation (3) was used, where the right-hand sides are constants – probabilities of being the system in the corresponding states [17].

$$P_{00}(0) = P_{00}^*; P_{10}(0) = P_{10}^*; P_{01}(0) = P_{p10}^*; P_{11}(0) = P_{11}^* \tag{3}$$

2. State S1, when the system is not negatively affected, and it does not require any action.

$$P_{00}(0) = 1; P_{10}(0) = 0; P_{01}(0) = 0; P_{11}(0) = 0; \tag{4}$$

We will take into account and assume that this process is static, and the system of differential equations will be represented by a system of linear homogeneous algebraic equations (SLAE) in the form:

$$P_{00}(0) = 1; P_{10}(0) = 0; P_{01}(0) = 0; P_{11}(0) = 0;$$

$$-P_{01}(t)(\lambda + \nu_2) + P_{11}(t)\nu_1 + P_{10}(t)\nu_1 = 0;$$

$$P_{00}(t)\lambda - P_{10}(t)\nu_1 + P_{11}(t)\nu_2 = 0; \tag{5}$$

$$P_{01}(t)\lambda - P_{11}(t)(\nu_1 + \nu_2) = 0.$$

We obtai SLAE with probabilities that will not depend on the time resource. As a result, we have the following equations:

$$P_{oo} = \frac{\nu_1 \nu_2}{\lambda(\lambda + \nu_1 + \nu_2) + \nu_1 \nu_2} \tag{6}$$

$$P_{10} = \frac{\lambda \nu_2 (\lambda + \nu_1 + \nu_2)}{(\nu_1 + \nu_2)[\lambda(\lambda + \nu_1 + \nu_2) + \nu_1 \nu_2]} \tag{7}$$

$$P_{01} = \frac{\lambda \nu_1}{\lambda(\lambda + \nu_1 + \nu_2) + \nu_1 \nu_2} \tag{8}$$

$$P_{11} = \frac{\lambda \nu_1}{(\nu_1 + \nu_2)[(\lambda + \nu_1 + \nu_2) + \nu_1 \nu_2]} \tag{9}$$

The equations obtained show that requirements can be developed for properties of the process of identification of the problems arisen in the system, and for properties of neutralization processes [9].

$$P_{00} = \frac{\nu_1 \nu_2}{\lambda(\lambda + \nu_1 + \nu_2) + \nu_1 \nu_2} \tag{10}$$

In equation (10), the performance factor P_{00} relates the parameters of the main processes with regard to situations faced by DM in the digital ecosystem. Based on equation (10), DM determines which resources should be used to solve problems in the future [18].

4. Conclusions

Increasing load of web technologies on human processes, social life and digital ecosystems in general creates a prerequisite for the mathematical model used by DM in the digital ecosystem to adequately manage a situation. Well-known published studies address the issues of resolving a critical problem based on analysis but not synthesis. In this study, we examined synthesis of the managerial decision in a digital ecosystem with regard to a unified scientific approach and the law of the object integrity employed by the leading scientific and scientific-pedagogical school of St. Petersburg System Integration of Public Administration Processes included in the register of leading scientific and scientific pedagogical schools of St. Petersburg [9].

The resulting performance factor P_{00} indicates the probability that each problem decision maker encounters in the digital ecosystem will be identified and eliminated.

Based on the data obtained, the available resources (hardware complex (technical means), software complex, and human resources (staff subordinate to the manager in different fields of activity) required to achieve the management goal and provide a continuous operation of the digital ecosystem) are redistributed, and weak points are analyzed. The proposed model considers the likelihood of events and facts in order to achieving the management goal of the decision maker in the digital ecosystem.

It should be noted that for a rational approach to making managerial decisions, the decision maker responsible for the digital ecosystem operation can use network planning in his work as a plan for realizing the entire cycle of processes to maintain information security of the ecosystem. These network processes will be further investigated in more detail [19].

References
[1]   Akatkin Y M, Karpov O E, Konyavskiy V A, Yasinovskaya E D 2017 Business Informatics, 17–28 doi: 10.17323/1998-0663.2017.4.17.28
[2]   Luger G F 2003 *Artificial Intelligence: Strategies and Techniques for Solving Complex Problems,* 4th ed. (Moscow: Publishing house "Williams")
[3]   Bredt S 2019 Frontiers in Artificial Intelligence **2** doi: 10.3389/frai.2019.00016
[4]   Miller T 2019 *Artificial Intelligence* **267** 1–38
[5]   Soni N., Sharma E., Singh N., Kapoor A. 2020 *Procedia Computer Science* **167** 2200–2210 doi: 10.1016/j.procs.2020.03.272
[6]   Barenkamp M, Rebstadt J, Thomas O 2020 *AI Perspect* **2** doi: 10.1186/s42467-020-00005-4
[7]   Arbib M A 1964 *Brains, machines and mathematics* (New York: McGraw-Hill Book Co)
[8]   Good H H, Machol R E 1957 *Systems Engineering. An Introduction to Large-Scale System Design* (New York: McGraw-Hill Book Co)

[9]   Burlov V G, Grachev M I 2019 *T-Comm: Telecommunications and transport* **13** 27–34 doi: 10.24411/2072-8735-2018-10314.
[10]   Burlov V G, Grachev M I 2017 *Technical and technological problems of service* 34–38.
[11]   Anokhin P K 1979 *Systemic mechanisms of higher nervous activity. Systemic mechanisms of higher nervous activity* (Moscow: Nauka)
[12]   Dorrer A G, Dorrer G A, Rudakova G M 2005 *Information technologies* 63–69
[13]   Khvostov A A 2019 *FGBOU VO "VSTU"* 30–35
[14]   Mesarovic M, Takahara Y 1975 *General Systems Theory: Mathematical Foundations (Mathematics in Science and Engineering)* (New York: Elsevier)
[15]   Moiseev N N 1981 *Mathematical problems of system analysis.* (Moscow: Nauka)
[16]   Simpson III V P, Patterson J H 1996 *European Journal of Operational Research* **89** 525–542
[17]   Burlow V G, Grachev M I, Shlygina N S 2017 *Proceedings of 2017 XX IEEE International conference on soft computing and measurements* 107–108 doi: 10.1109/scm.2017.7970510
[18]   Burlov V G, Grachev M I 2017 *Transportation Research Procedia* **20** 100–106 doi: 10.1016/j.trpro.2017.01.023
[19]   Andreev A V, Burlov V G, Grachev M I 2019 *Proceeding of International Science and Technology Conference "EastConf"* 8725428 doi: 10.1109/EastConf.2019.8725428