A system-inno-diversified approach to the development of technologies for the effective transformation of organizations of the agro-industrial complex into a digital economy

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Abstract. The paper examines the most important trends and concepts of the modern stage of digitalization and the end-to-end technologies offered by the “Digital Economy” program. The necessity of creating a technology of regulation by the agro-industrial complex as an important component of the modern digital economy is substantiated. The aim of the research is to develop technologies for the effective transformation of the organizations of the agro-industrial complex into a digital economy. According to the definition of the digital economy proposed in the work, it should be built as an in-diversified, self-developing system. The concept of technology for regulating the digital economy of the agro-industrial complex should be formed on the basis of a systematic approach and have a hierarchical 5-tier network structure. The possibility of implementing the structure using the mathematical apparatus of the theory of Petri nets is substantiated. It has been established that model design of technology is the most optimal, if not the only possible way to improve the structure of production systems and technological processes of organizations of the agro-industrial complex, as well as to manage its structures.

1. Introduction
The development of the state regulation practice of the agro-industrial complex occurs both under the influence of digitalization and as a result of the development of economic and mathematical theories and their influence on the national economy through the formulation of recommendations and proposals in the field of government regulation. Today, leading economists agree that the economic policy of the state was shaped by the development of economic and mathematical theories. However, there are disagreements about the scale, mechanisms and objectives of such an impact. Therefore, we need to consider the peculiarities of the formation of the main theoretical approaches to the problems of state regulation of the agro-industrial complex. Successful digital transformation requires organizations to consider a wide range of opportunities that will vary depending on the importance in the business context and the needs of the particular organization [1].

The concept of “digital economy” does not yet have an unambiguous, clear definition due to the large number of its diverse interpretations. Based on the definitions and concepts cited in various sources, we can formulate a generalized definition of the term “Digital economy”. We suggested using the following definition: “Digital economy is an environment that includes a combination of digital infrastructure and information and communication technologies for doing business” [2]. Intensive
Digitalization and the Internet of things penetrating into the agro-industrial complex, however, are able to transform it, to a lesser extent than other areas subject to greater influence of IT, into a high-tech business through accelerated increase in productivity and reduction of unproductive costs. The aim of the research is to develop technologies for the effective transformation of organizations of the agro-industrial complex into a digital economy. According to the proposed definition of the digital economy, it should be built on the basis of the innovation diversification model proposed by us [3] and should be a self-developing system. The term “innovation diversification” was introduced by us in 2016 [3] and describes the penetration of innovations in new areas.

2. Literature Review
In the work of A. Melnikov, V. Sidorenko, P. Mikhailushkin, O. Makarevich [4], the role of the state in the sustainable development of the agro-industrial complex of Russia is stressed. The need to develop a concept of a more advanced system of state regulation and support of the agricultural sector of the country’s economy, increasing the competitiveness of the industry and integration into the global agro-food system was noted. Studies have shown that the refusal of state planning, state order for produced agricultural products, unreasonable pricing policy in the industry, insufficient state support, unfounded privatization in some cases, especially enterprises processing and selling products, restrain the growth rate of the rural economy, led to a huge the debt of the Russian farmers.

There is no doubt that the strengthening of state regulation today is the basis of the agrarian policy and the shortest way of reviving the village. In the explanatory note of the direction “Digitization of agriculture” [5] the goal was set to provide the participants with the opportunity to use broadband, mobile, LPWAN communications, information technologies (small and big data, artificial intelligence, control platforms) of domestic instrument manufacture (tags, controllers, sensors, controls). Unfortunately, the program lacks a methodological substantiation and recommended platforms for achieving this goal. Therefore, to achieve this goal, it is necessary to provide a methodological substantiation for digitalization, in particular, state regulation of the agro-industrial complex, which we should begin with an analysis of the composition of the industry.

Many scientists, such as N. A. Volkova, O. A. Stolyarova, E. M. Kosterin [6], N. A. Popov [7] and a number of others propose to consider the agro-industrial complex on the basis of the systematic approach that unites the national economy sectors related to the production, procurement, processing and sale of food, as well as machines for agriculture. The agro-industrial complex is a 3-tier, interconnected and interdependent system consisting of three subsystems: production, agriculture and services. The leading place in this system belongs to agriculture, which is characterized by special conditions of influence on other subsystems and on the whole system as a whole. The spheres of production and services in the agro-industrial complex play, although an important, but still supporting role. G.M. Gritsenko [8] in addition to the 3 main subsystems proposes to include the 4th subsystem which represents scientific and educational institutions (SEI), information centers (IC) and monitoring services (MS). The authors agree that in the conditions of digitalization of the economy, the development of telecommunications means, it became necessary to increasingly introduce innovative ICTs in the production of the agro-industrial complex, to carry out personnel training of specialists who are able to work in the new conditions [5]. In our opinion, for the interaction and development of these subsystems and the system of the agro-industrial complex itself, it is necessary to include a regulatory subsystem (Figure 1).
Figure 1. The structure of the agro-industrial complex, as a system.

3. Research Methodology

Figure 1 shows that the methodological substantiation of the digitization of state regulation of the agro-industrial complex requires the use of the systematic approach. “The systematic approach is, first of all, the integrated approach, involving a comprehensive account of the specific characteristics of the selected object, determining its essence, structure and, therefore, organization” [9]. Accordingly, the methodological basis of the research in this work is the systematic approach to the theory of systems and system analysis [10] to the problems of developing the state regulation system of the agro-industrial complex and analyzing the resource potential of agricultural organizations, taking into account the conditions of transformation into digital economy and forming its own point of view on the processes taking place while studying the topic.

The difficulties of analyzing and synthesizing such complex objects as the organizations of the agro-industrial complex led to the need to develop special scientific tools. Such areas as systems analysis, cybernetics, synergetics act as a methodological toolkit for the study of complex systems. Their commonality lies in the fact that they are a tool for researching systems. However, there are differences between them, and they are significant enough which reflects their specificity and uniqueness (Figure 2) [11].

The system, being a multidimensional object, is the subject of research from the perspective of multidimensional statistical analysis. Methodologies for multivariate statistical analysis are based both on the basis of heuristic methods [10] and on the basis of analytical methods [12]. The toolkit of multivariate statistical analysis is more adequate in the study of multidimensional objects, such as the regulation of organizations of the agro-industrial complex, with a combination of heuristic and analytical methods of system analysis.
4. Results
The system-inno-diversified approach to the formation of a technology for efficiently transforming organizations of the agro-industrial complex into a digital economy should have a strict structure based on the theory of government regulation. The proposed version of such a structure is shown in Figure 3.

Figure 3. The structure of the platform for regulating the transformation of the digital economy of the agro-industrial complex.

The system-inno-diversified approach to the technological process of organizations of the agro-industrial complex is characterized by a complex dynamic system consisting of various units: equipment, control and management means, auxiliary and transportation equipment, processing tools or environments which are in continuous motion, interaction and change, production facilities, operators (people, robots, manipulators) carrying out processes and controlling them. Analysis of
complex technological processes involves the decomposition of the production system into subsystems and sub-subsystems of various depth levels. As a result of the decomposition of the system into subsystems, a hierarchy of the structure of the production system can be built which will allow to consider it at various levels of its detail.

Due to the high complexity and labor intensity of the design processes of agricultural technological processes and systems, it is advisable to use digital technologies.

Predicting the results of designing technological processes and systems using ICTs is best done using simulation modeling methods.

The objective function of the concept of in-diversification simulation modeling of processes and systems of the agro-industrial complex involves the design calculations of the characteristics of productivity and efficiency taking into account the analysis of various options for the structure of organizations, risk levels of the digital economy [10], as well as the impact of disturbing factors of the surrounding and internal spheres. To achieve this goal, it is necessary to solve the following problems of model design:

- predicting the main characteristics of production systems and technological processes;
- obtaining statistical indicators and other characteristics of technical and economic efficiency;
- using the obtained results of model design to find the best option for production systems or technological processes;
- studying the optimal variants of the structure of operations of the technological process using the tools of the digital economy model.

With the help of the model design tools it is possible, for example, to describe the work of an agricultural producer’s workplace, a farm, an agricultural holding or the industry as a whole. Model design of production systems or technological processes will allow reproducing parallel, sequential or parallel-sequential schemes of functioning, taking into account stochastic events and their influence on systems and processes [13]. Model design will allow a detailed analysis of the designed operating and route structures and the influence of various factors on productivity, load factor and other economic indicators necessary for making management decisions considering the unforeseen risks of the digital economy [10].

The algorithm for implementing the system-inno-diversified approach for regulating the systems of the agro-industrial complex is shown in Figure 4. In the algorithm, the system is understood as the structures of the platform for regulating the transformation of the digital economy of the agro-industrial complex shown in Figure 3.

![Figure 4. Algorithm for the implementation of the system-inno-diversified approach.](image-url)
Structures of any level are modeled using the Petri nets. Petri nets in the algorithm are considered as an element of the analysis. The classification of Petri nets [14] and their characteristics are shown in Figure 5. Each type of Petri nets has a number of advantages and disadvantages. Combined networks allow you to reduce or eliminate the disadvantages and enhance the benefits. Therefore, for greater efficiency, it is necessary to use a combination of all known networks and refer to such a network as an inno-diversified network (Figure 5).

| Highest priority | • Add to allowed transitions.  
|                  | • Allow to reduce non-determinism of operations by limiting the number of allowed transitions to the group of transitions with the highest priority. |
| Inhibitory       | • Characterized by the possibility of prohibitory (inhibitory) arcs.  
|                  | • The presence of a marker in the input position associated with the transition inhibitory arc means the prohibition of the transition. |
| Temporary        | • Characterized by adding delays when moving a marker.  
|                  | • Delays can be associated both with events and conditions. |
| Stochastic       | • Delays are stochastic values.  
|                  | • It is possible to introduce probabilities of triggering of excited transitions. |
| Ambiguous        | • Incorporating the description of ambiguity into various deterministic varieties and generalizations of networks.  
|                  | • The random nature of the occurrence of events. |
| Colored          | • Dynamic objects can be of several types, and for each type it is necessary to enter their own algorithms of behavior in the network.  
|                  | • In this case, each marker must have at least one parameter denoting the type of the marker (color). |
| Functional       | • Characterized by the functions of the argument system.  
|                  | • At each transition the process is associated with the data flow (priorities, queues, restrictions). |
| Hierarchical     | • Contain multilevel transitions in which other, possibly also hierarchical, networks are nested.  
|                  | • Processing of such transitions is characterized by the implementation of the full life cycle of the nested network. |
| WF-nets          | • Workflow networks, used to model workflows in business processes of organizations. |
| Combined         | • Different combinations of different types of networks. |
| Inno-diversified | • Combined Petri nets including all its known varieties in order to simulate the structures of organizations according to the system-inno-diversified approach to obtain a synergistic effect from regulatory influences. |

**Figure 5.** Characteristics of Petri nets.

5. Discussion of the results
Given that the methodology of the system-unique diversification approach is recommended to build the structures of organizations of the agro-industrial complex, it is better to use inno-diversified types of Petri nets for its implementation. At the first stage, the structure of the system or process is
constructed as a Petri net (Figure 6), then the structure model is analyzed using it. The process of designing structures and determining its characteristics is carried out in terms of Petri nets (Table 1). The challenge is to convert the Petri net visualization into a real working structure.

![Algorithm for constructing a Petri net](image)

**Figure 6.** Algorithm for constructing a Petri net.

| Name          | Notation | Presentation                                                                 | Remarks                                                                                           |
|---------------|----------|------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| C Petri net:  | C=P,T,I,O| Final set of networks: C=(C_{1,1}, C_{1,2}..., C_{i,j})                       | Understand networks, I will stay the hierarchies of regulation which are located at various levels representing or hierarchical network |
|               |          | where i is number of hierarchical levels, j - number of networks on i-volume level |                                                                                                   |
| T Event       |          | Finite set of transitions: T=(T_1, T_2, ..., T_i), where i is a number of transitions | Sowing, collection, processing, loading, unloading                                                |
| P Condition   |          | Finite set of positions: P=(P_1, P_2, ..., P_j), where j is a number of positions | Units, operators, accumulators, equipment                                                          |
| A Relations   |          | Finite set of relations: A=(A_1, A_2, ..., A_k) where k is a number of relations | Sequence of implementing a manufacturing process                                                  |
| M Tags (tokens) |        | Tag (token) in the condition means its execution | Marking of a set positions                                                                     |
| I Input function |        | P(A)→T Finite set of inputs: I(j,k)                                           | How many times the position P(j) is an input of the transition T(k)                               |
| O Output function |        | T→P(A) Finite set of outputs: O(j,k)                                           | How many times the position P(j) is an output of the transition T(k)                              |
| Z Actuation of transitions | | T(k)→P(j)×M(i)→A Transition is allowed when there are places for tags and if the number of tags is larger or equal to the number of relations |                                                                                                   |

The textual description of the system and/or process implies:
1. A description of the structure of a process or a structure includes a list of events that should occur during its implementation. For example, in a dairy farm in the workplace in the technological
process of milk production, at least two events are necessary: to begin the process of milking cows (T1) and to complete it (T2).

2. In order for the events to occur, it is necessary to create conditions. In order to start the milking process, at least cows (P1), equipment for this operation realization (P2) and milking operators (P3) are required. These conditions contribute to the process of starting the milking (T1) and creating the conditions for the implementation of the milking process itself (P4).

3. In order to complete the milking process (T2), it is necessary at least to have a completed state of the milking operation (P4) and operator (milker). These conditions contribute to the implementation of the milking completion process (T2) and the creation of conditions for the production of finished products (placing milk in a store of a certain capacity) (P5). As a result, operators and inventory are freed from participation in the technological process.

As all operations do not occur instantaneously, a delay duration in the same units of measurement is needed to be assigned to them.

The number of cows, sets of equipment and operators can be any, depending on the specific workplace. You can simulate both manual and machine milking processes. In the case of manual milking, the operator is not released after loading but accompanies the milking process and is released only after unloading. Not only humans can be used as operators but also robots or manipulators.

Constructing an abstract flowchart to display the logical structure of the system consists of a graphic illustration of the stages of the process (Figure 7). Simple flowcharts are easy to create in Microsoft Word, Excel, PowerPoint and easy to read because of the simplicity and clarity of the figures. Automatically create a simple flowchart based on data that is more efficiently designed using data visualizer in Visio which is an addition to the standard Microsoft application package. The "Simple flowchart" template in Visio contains figures that can be used to visually represent a variety of processes, including processes in organizations in the agro-industrial complex. The display of simple processes, such as the process of milking cows is shown in Figure 7.

![Figure 7. Flowcharts for displaying the logical structure of a cow milking process.](image)

In Petri nets events and conditions are designated by abstract symbols from two non-intersecting alphabets named accordingly as the transition set and the position set. There are several formal representations of Petri nets: set-theoretic; graphic – bichromatic (bipartite) graph; graphical; matrix [15]. The algorithm for constructing the Petri network graph is shown in Figure 8.

The simulation modeling is based on the structure of operations which clearly defines the order of carrying out: in which sequence which transitions in which position are implemented (table 1).

The construction of a Petri network graph is carried out in three steps.
At the first step of modeling design, a graphical model of modules (Figure 9), mathematical models in the form of a graph represented by a matrix of binary relations (table 2) and a set of two-component cortege are created:

\[ M_1 = \begin{pmatrix} (P_1, T_1), (P_2, T_1), (P_3, T_1), (T_1, P_4), & (P_4, T_2), (T_2, P_2), (P_3, T_2), (T_2, P_5) \end{pmatrix}. \]

At the second step, on the basis of the graphical model (Figure 9) a table for inputting the initial data is formed (table 2). Source data is processed using the “Simulator” application package [3].

**Figure 8.** Algorithm for constructing a Petri network graph.

**Figure 9.** Graphic model of modules.

**Table 2.** Binary Relation Matrix.

| T1 | T2 | P1 | P2 | P3 | P4 | P5 |
|----|----|----|----|----|----|----|
| T1 | 0  | 0  | 0  | 1  | 0  | 1  |
| T2 | 0  | 0  | 0  | 0  | 1  | 1  |
| P1 | 1  | 0  | 0  | 0  | 0  | 0  |
| P2 | 0  | 1  | 0  | 0  | 0  | 0  |
| P3 | 1  | 0  | 0  | 0  | 0  | 0  |
| P4 | 1  | 1  | 0  | 0  | 0  | 0  |
| P5 | 0  | 0  | 0  | 0  | 0  | 0  |
Petri nets consist of three components: the set of positions (places) P, the set of transitions T and the connections (incidence relations) A (table 1). The state of the system is characterized by chips or marks (tokens), which are indicated by black dots and placed in the positions of P. If large quantity of them, they can be replaced by numerical symbols.

At the third step, it is required to perform a simulation of a simulation model at a minimum of five points for a qualitative analysis of modeling design. The obtained results of the calculations are presented in a summary table, on the basis of which a graph is constructed for clarity (Figure 10).

![Figure 10. Efficiency of equipment and operations loading.](chart.png)

Analyzing the calculation results, based on the initial data, the module structure is optimized and management decisions are taken to modernize the production system or technological processes: reduce or increase equipment, operators, to change their technical and economic characteristics: increase or decrease performance indicators (duration of delays in work positions and in transitions), changes in storage capacity (delay arrows), etc.

6. Conclusion
In conclusion, it should be noted that as a result of the a priori research and analysis of various sources of information, the most rational, according to the authors of the theory, were identified: government regulation, risks, modeling, mathematical logic, sets, graphs, Petri nets and system-inno-diversified approaches; design-calculated, statistical-economic, economic-mathematical, sociological and other research methods can be involved as well. As a result, a new direction for the development of a system-inno-identified approach for simulation modeling of state regulation of the agro-industrial complex in a digital economy was formulated.

System-inno-diversified approach will allow to obtain the most accurate description of technological processes in organizations of the agro-industrial complex (field processing time or harvest, equipment utilization or loading coefficients, technical performance, operation delays, etc.). To effectively use the system-inno-diversified approach, preliminary development of algorithms for its implementation is necessary.

Given that system-inno-diversified approach is recommended to build the structures of organizations of the agro-industrial complex, it is more expedient to use a combined type of Petri nets for its implementation. The process of designing structures and determining its characteristics should be implemented in terms of Petri nets. The task is to transform the Petri nets visualization into a real working structure. Initially, the structure of the system or process is built in the form of a Petri net, and then, using the proposed algorithms, it is necessary to analyze the structure model for making decisions on regulatory influences.
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