Modeling of process of regulating production, processing and marketing of milk and milk products

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Abstract. The article is devoted to the investigation of problems of regulating processes in dairy industry. One of such problems is the absence of effective informative technological technology of simulating these processes. To achieve the goal set, it has been supposed to apply the simulation based on the theory of Petri nets. Methodological base of the investigation includes the formal theory of Petri nets as well as the theory of its practical application. The work has demonstrated main stages of evolution of Petri nets from simple to innodiversification ones, the latter being suggested for simulating technological processes and systems of organizations of dairy industry. Specific feature of innodiversification Petri nets is the conjunction of combinations of all known kinds of Petri nets and the application of their advantages to solve particular tasks. It has been found that the instruments of innodiversification Petri nets may be effectively applied to simulate organizations of dairy industry of any level.

1. Introduction

Dairy industry develops under digitalization influence as well as due to development of economic and mathematical theories, and their impact on the national economy by means of formulating recommendations and suggestions in the field of public administration. Today, leading economists agree that state economic policy has been formed under the influence of developing economic and mathematical theories. However, there are disagreements concerning scales, mechanisms and goals of such influence. In this connection, there occurs a task to consider characteristics of forming main theoretical approaches to the problems of public administration, taking the dairy industry as an example.

State regulation of economy in terms of digitalization leads to modification of the system of measurements of legislative, executive and controlling character which must be implemented by authorized government agencies and community organizations in order to adapt economic and social systems to the conditions of digital economy. Today, the main driving forces of digital transformation are new products and services, new information and management technologies, innovative business-models. The key drivers of digital transformation are industry digital platforms, including the dairy industry.
2. Research Methods and Approaches

Dairy industry is characterized by net structure of its organizations. Mathematical apparatus for the systems of net structure has been theoretically developed and can be implemented for this field organizations as a simulation model. According to the authors, such structure may be implemented based on the Petri net theory.

According to the authors, it is the further development of Petri nets that allows to apply them to simulate the work of organizations taking impacting decisions of the subsystem of regulating the dairy industry. In the research field, a subregulator may be considered indirectly, by means of a model. By manipulating the subregulator model of the dairy industry, it will be possible to get new information about organizations, avoid dangers, expensiveness, or discomfort of analyzing the real system itself. As a rule, models are based mathematically. Today, further development of the Petri net theory has the following main directions:

- development of main means, methods, and notions which are necessary in order to further develop the formal Petri net theory;
- application research of the Petri net theory in the field of modeling systems, analyzing them, and achieving results of deep penetration into processes and systems being modeled.

Innovative approach to technological process of organizations of the dairy industry is characterized by complex dynamic system, including various units, such as equipment, control and management means, auxiliary and transport devices, processing instruments or media which constantly move, interact and change, production objects, operators (people, robots, manipulators) performing processes and managing them. Analyzing complex technological processes suggests decomposition of the production system into subsystems and subsubsystems of different level of depth. Due to the decomposition of the system into subsystems, hierarchy of the production system structure may be made, this allows to consider it at different levels of detailing.

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

In order to forecast results of projecting technological processes and systems, to use information and communication technologies (ICT) is advisable with the help of simulation modeling methods.

The goal function of conception of innovative simulation modeling of processes and systems in the dairy industry is to make project calculations of productivity and efficiency characteristics, considering the analysis of different structural variants of organizations, degrees of risks of digital economy [2], as well as the impact of disturbing factors of surrounding and inner spheres. To achieve the goal set, it is necessary to solve the following tasks of designing a model:

- forecasting main characteristics of production systems and technological processes;
- obtaining statistic data and other characteristics of technical and economic efficacy;
- using the obtained results of projecting a model to search for the best variant of production systems, or technological processes;
- studying optimal variants of structure of technological process operations with the help of the instruments of digital economy model.

Thanks to the instruments of projecting a model, it is possible, for example, to describe a workstation (WKS), a dairy farm, agricultural holding, or the whole industry. The model projecting of production systems or technological processes allows to reproduce parallel, successive, or parallel and successive schemes of functioning, considering stochastic events and their impact on systems and processes. The model projecting allows to make the detailed analysis of projected variants of operative and route structures, and of influence of various factors on productivity, loading factor, and other economic parameters which are necessary to manage, considering technological risks of digital economy [2].

3. Research Results

One of the directions of digitalization of dairy organizations is to make workstations. In this connection, due to control response (leasing, subsidies, loans, investments, allowances, etc.) business
process changes and transition from manual labor to automated one are stimulated. For example, to automate the universal technological process of milk production (figure 1a), milking machines are installed. As a result of such control response, the following transformation of workplace will occur (see figure 1b).

![Figure 1. Petri net graph of universal (a) and automated (b) workstation.](image)

Figure 1 presents the technological operations of starting (T₁) and completion (T₂) of milk production processes in manual (a) and automated (b) work regimes. To start the operation (T₁), cows (P₁), implements (P₂), and operators (P₃) must be present, i.e. there must be tags in these positions (P₁>0, P₂>0, P₃>0). For the operation (T₂) it is required to complete the milk production (P₄), and for the automated regime there must be free operators in the position (P₃). After completing the operation (T₂), ready products are placed into the accumulator (P₅).

Due to automation (figure 1b), the operator does not follow the technological process of milk production, but just installs a milking unit before milking and removes it after milking, this allows to reduce significantly the labor effort and halve the personnel of the given workplace (the number of tags in the position P₃). Besides, machine milking is more productive than manual one. The disadvantages include increased social risks of digital economy [2], particularly, unemployment which may influence negatively and requires to be regulated socially. First of all, there are social and psychological risks related to labor income and especially unemployment. And besides, risks related to labor income in digital economy tend to change rapidly and dynamically [3].

However, the world practice has shown that automation and robotization contribute to labor productivity growth and effective work of enterprises, including dairy industry ones. Particularly, during machine milking the operator can perform other operations, or, together with the automated operation, perform the technological operation of milk production in manual regime (figure 2a).

![Figure 2. Graph of Petri net of combined workplace for parallel (a) and sequential (b) scheme.](image)

Figure 2a presents the combination of operations: P₄ – automated cow milking and P₆ – manual cow milking, as well as starting (T₁) and completion (T₂) of technological processes of automated milk production, starting (T₃) and completion (T₄) of manual milking processes.

An example of other kind of work is to place the product (milk) in transporting means (figure 2b).
Figure 2a also includes positions: $P_6$ – capacity for products to transport in the standby mode, $P_7$ – transportation capacities in the filling mode, $P_9$ – capacities ready for transportation, as well as starting ($T_3$) and completion ($T_4$) of the process of preparing capacities for transportation.

The analysis of figure 2 has shown that a situation may arise when the process does not proceed rationally, as it is possible to start the transition of manual milking $T_3$ (figure 2) earlier than that of automated one $T_1$. In this case, following the manual milking, the operator may not start the process of automated milk production. To exclude such development of events, it is necessary to correct the initial Petri net and add priorities of transitions. Priority Petri Net is a standard Petri net, with each transition $T$ being matched by a certain number $P_{rt}$ called the priority of the given transition. The priority is used to solve conflicts. For example, of two transitions $T_1$ and $T_3$ which clash due to a certain common resource in position $P_3$, advantage is given to that of them which has higher priority. Particularly, if all transitions of the given net have different priorities, then there will not be any conflicts in such a net. It is possible to determine priorities for potentially conflict transitions only. Let us determine the following priority rules:

- automated operations must have higher priority than universal (manual) ones;
- unloading (final) operations must have higher priority than loading (initial) ones.

Considering these rules, it is possible to avoid conflicts in the net by the way of setting transition priorities (numbers in round brackets) (figure 3).

Figure 3 shows that, of all possible transitions, the transition $T_2$ will be made in the first turn at the moment of starting transitions, since it is of the highest priority. Priority may not be assigned to the transition $T_4$, as it will be always performed in order to free the operator, without the latter it is impossible to run other transitions.

Besides, it should be noted that in real organizations there are some limitations for certain processes. For example, product storages have a certain capacity size. To introduce such limitations in Petri nets, delay (inhibiting) arrows may be applied (figure 3). In inhibitory Petri nets, a special kind of inhibitory (delaying) arrows is added to standard relations leading from positions to transitions. Such an arrow hinders activation of the corresponding transition, provided there are tags in the corresponding position more than the given in the limitation. So, such transition will be activated only when in the given position the number of tags is fewer than it is given in the limitation. Thus, delay arrows allow to check evidently the number of tags in the given position.

The analysis of figures 1–3 has also demonstrated that the storage of ready products (the capacity of milk obtained) $P_5$ is not limitless, and it is suggested to be limited by the volume of the milk obtained from 4 cows. As it is necessary to empty the storage for subsequent milk parties, or install the next one, it is required to limit the transition $T_2$ with a delay arrow from the position $P_5$, as it is shown in figure 3.

In figure 3 the delay arrows are shown by point vectors with the limitation values in braces.

Organizations function dynamically, so it is advisable to introduce temporary delays in the apparatus of Petri nets (figures 1–3), which may be made by means of considering temporary delays of the markers in the positions and time of deploying the transitions permitted. Such delays allow to represent the dynamic character of changing conditions and procedural aspect of using resources in the
functioning of systems being simulated» [1]. Duration of operations (delays) is of stochastic character (figures 1–3), i.e. delays are random variables. As all random variables, they are evaluated by mathematical expectation and mean square deviation.

Besides, like the duration, the events themselves are of stochastic character of indistinctness (figures 1–3), i.e. they are random variables which may or may not occur. For example, there is a probability for machines or operators to fail, disturbing the normal functioning of processes as well as of the whole organization. It is possible to introduce probabilities of failing implements and operators in stochastic Petri nets. Delays for restoring the system’s performance and its processes are of random character as well.

In Petri nets, delays may be defined as some-variable functions. The number of tags in positions, the state of transitions, limitations, priorities, turns, etc. are used as arguments. In simulating technological processes in dairy industry organizations, many dynamic objects of different types are used, and it is necessary to use original algorithms of behaving in the net for each of them. To solve this problem, it is advisable for each tag to have at least one parameter designating the type of a marker. Such parameters are usually distinguished by colors. Colors of tags can be used as an argument in functional nets. Such functional net is assumed to be called a colored one [4].

The analysis of figure 3 has shown that in the positions $P_1$ (the number of cows), $P_5$ (amount of ready products – milk), $P_8$ (packed products – milk poured in cans) there are different objects with different units of measuring production which should be purposefully marked by different colors. Colored Petri nets (figure 3) allow to assign individual meanings (colors) to tags, this making possible to distinguish them. Tag meanings may be simple, or arbitrary complex. Transition in colored Petri nets (figure 4) defines correlations between the values of input tags and those of output tags. For example, yields from 4 cows will be enough to fill a milk can with capacity 25 liters. Using the property of graph multiplicity, this can be presented as 4 input connections from the position $P_5$ and one leaving for the position $P_7$ to transit $T_3$ (figure 4).

![Figure 4. Hierarchical 3-level simulation model of the organization for the production, processing and sale of milk.](image)
As figure 4 shows, the precondition, which defines how many tags are absorbed by the given transition and what are the meanings of the tags, is assigned to the input connections of the transition $T_3$. Output connection of the transition $T_3$ defines (with the help of expressions) the number of tags which will be placed in corresponding positions. With the help of colored tags, the graph in figure 4 allows to simulate the process of transforming provisions (cows) into semi-finished products (milk) as a result of the first technological operation (milking), and then, as a result of the second technological operation (filling cans with milk), into products (cans filled with milk).

The process is not completed with these operations. Preliminary maintenance operation (care for cows and placement) and sales of finished products (the milk poured in cans) are still necessary. Preliminary maintenance operation suggests the time expenses of the operator to maintain the placement according to sanitary norms, as well as feeding of animals. Sales of finished products may have some different options: sales of milk to suppliers, converters, delivery to retail outlets, or independent sales in the market or other places. Besides, some farms can independently process milk into dairy products (sour cream, cottage cheese, butter, yogurt and others) with subsequent sales of more technological and, as a result, more expensive products. These procedures increase a variety of tag colors in the Petri net. Considering the above mentioned, the graph can be transformed into a simulation model of personal subsidiary farm (PSF) for production and sale of dairy products (figure 4).

Figure 4 shows the implements necessary to maintain the placement according to sanitary norms, as well as to feed animals, in the positions $P_9$ – a standby mode, $P_{10}$ – an operating mode. Position $P_{11}$ is a capacity (storage, placement) with feed for cows. Transitions characterize the operations of starting ($T_6$) and completion ($T_5$) of the technological operation for maintaining the placement according to sanitary norms and feeding animals.

Sales of finished products is implemented in outlets (suppliers, trade organizations, markets, etc.) in the positions $P_{13}$ – a standby mode, $P_{14}$ – an operating mode. Transitions characterize the operations of starting ($T_8$) and completion ($T_7$) of the technological operations for sales of finished products. Results in the form of incomes (cash and non-cash) from the operation for sales of products are placed in the accumulator (account, wallet), position $P_{12}$.

Independent processing of milk into dairy products is implemented with the help of special equipment and instruments in positions $P_{16}$ – a standby mode, $P_{17}$ – an operating mode. Transitions characterize the operations of starting ($T_9$) and completion ($T_{10}$) of the technological operation for processing milk into dairy products. Finished products (sour cream, cottage cheese, butter, yogurt and others) are placed into the accumulator (product packaging), position $P_{15}$. If a farm does not process milk into dairy products, then the positions $P_{16}$, $P_{17}$, transitions $T_9$ and completions $T_{10}$ shown in figure 4 are excluded from the simulation model.

The simulation models given in figures 1–4 present modules (bricks) which may be used to construct a simulation model of dairy industry organizations of any complexity level, and which may be composed of just one module (figures 1–3). However, if a farm has more than one operator (people, robots, manipulators) and each of them has its own specialization, then there may be several modules, e.g. 4, as it is shown in figure 4.

Figure 5 shows a 2-level simulation model as the component of 3-level one for milk production and sales. Its upper level includes 4 modules of the lower level, which implement the technological operations:

- $C_{01}$ – for maintaining the placement according to sanitary norms and feeding animals, serviced by the operator $P_{16}$.
- $C_{02}$ – of cow milking, serviced by the operator $P_3$.
- $C_{03}$ – of preparing capacities for transportation $P_{18}$.
- $C_{04}$ – of selling products $P_{17}$.

Figure 5 shows that the two-level structure including 4 nets of the lower level is reflected in the hierarchical net. In this case, the lower level nets can be considered as predetermined processes.
(subsystems), and then the process of simulating of different multi-level (hierarchical) systems of any depth of nesting can be implemented.

The main characteristic of hierarchical Petri nets that differs them from other ones is that they are characterized by two transition types: simple and composite. Simple transition is similar to those examined earlier, and composite transition includes Petri nets of lower levels.

4. Results Discussion

Synthesis of Petri nets of higher level is implemented due to including modules and nets of lower level. Agricultural cooperation (AGC) combining several personal subsidiary farms (PSF) on a voluntary basis may be taken as an example. The example of such cooperation of PSF composed of a module and PSF as an hierarchical net including 4 modules is shown in figure 4.

In most cases, cooperatives are composed of a great number of members (n), so their simulation models are advisable to construct, using the property of nesting. Figure 5 shows the hierarchical simulation model AGC composed of parallel functioning n of modules PSF, each of them can present a simple or composite hierarchical Petri net of any nesting degree.

![Hierarchical simulation model of AGC with the help of WF-networks of milk production, processing and sales organization.](image)

Figure 5 shows «that the transition process to hierarchical Petri nets is based on the rule that any positions and transitions can include Petri nets» [4] simulating the routes of technological processes functioning at enterprises, including the simplest models located in the corresponding net top. The common kind of activities for PSFs forming an AGC can be, for example, launching a production line for bottling milk in containers, as this is more technological product with greater value. Simulating of operating flows in WorkFlow-systems with the help of WF-Petri nets, called also the nets of operating flows, is given in Figure 5 (the positions from P22 to P26).

Main properties of WF-Petri nets given in Figure 6 are applied to check the operating flow nets for zero defects. Zero defects mean the absence of structural conflicts such as deadlocks and lacks of synchronization [5].

Classification of frequently applied combined nets which are dependent on preceding nets they inherit are given in figure 7.
### Limitation
- There is only one initial position $P_{22}$ of WF-nets in which there are no transitions entering $P_{22}$
- There is only one final position 0, in which there are no transitions leaving $P_{26}$
- Each node of the given net is located on the way from $P_{22}$ to $P_{26}$.

### Zero Defects
- For any marking reached from initial condition there is a succession of operations which converts the marking into final condition.
- Condition is the only one that is reachable from the condition and contains at least one tag in the position.
- WF-net does not have any deadlock transitions, i.e. those that never operate.

**Figure 6.** A list of main properties of WF-nets.

| Property               | Description                                                                 |
|------------------------|-----------------------------------------------------------------------------|
| Temporary colored      | when it is necessary to simulate the change in time of condition of the object which possesses a number of characteristics that are not discrete variables. |
| Hierarchical colored   | when the simulated system is composed of a large number of parts subordinated to each other. |
| Hierarchical temporary colored | allow to simulate any arbitrary object or system of any complexity, this being their main advantage. |
| Indistinct hierarchical temporary colored | to simulate any arbitrary object but they are much more effective than the previous kind, when operating with objects which do not succumb to strict formalization. |
| Inno-diversification   | to simulate any arbitrary object in any sphere including: temporary stochastic indistinct colored functional hierarchical nets; with additions of priority inhibitory WF-nets. |

**Figure 7.** The purpose of combined networks.

Extension of interpreted indistinct hierarchical temporary colored Petri nets [6] combined with stochastic functional and of some addition priority inhibitory WF-nets, which we call inno-diversification nets, is especially interesting for simulation modeling of functioning dairy industry organizations.

Inno-diversification nets possess the following advantages:
- Simplicity of describing the functioning of upper level organizations by means of Petri nets.
- Simplicity of construction of modeling technological processes which proceed in lower level organizations, or their structural divisions, by means of Petri nets.
- Possibilities of increasing the efficacy of functioning inno-diversification nets due to applying properties of multi-level organizations and their structural divisions.
- Tags of inno-diversification nets include transferred and transformed data of different types.
- Movements of tags over the inno-diversification net simulate data transferring over technological processes proceeding in organizations, and their transformation. Assignment of information about technological processes proceeding in organizations to tags allows to make multi-
level nets capable to simulate the work of any organization regardless to its level and with reference to various kinds of limitations, making them closer to real conditions of functioning.

Technique of projecting by system-innodiversification approach is implemented by assignment of higher level of nested Petri nets of lower levels which describe actions implemented with the help of matching elements to positions and transitions [7]. Figure 5 shows simulation models of PSF as hierarchical Petri nets composed of three levels. It should be especially emphasized that the number of levels of hierarchical Petri nets may increase in transition to organizations of higher level. Growth of the number of levels of Petri nets increases adequacy of modeling and accuracy of models.

Application of innodiversification Petri nets allow to overcome the disadvantages of other kinds of Petri nets [7].

5. Conclusions
Based on the foregoing, it should be noted that the instruments of innodiversification Petri nets may be effectively applied to simulate organizations of dairy industries of any level. The task of defining parameters of dairy industry organizations, considering various priorities, can be obtained, using simulation modeling based on innodiversification Petri nets. The possibility of making simulation models for higher levels of hierarchy should be considered.

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