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AN APPLICATION OF PETRI NETS IN TECHNOLOGICAL PROCESS SYNTHESIS ISSUES ON AGRICULTURE

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ABSTRACT

Modern agriculture aims at product quantity and quality increase, with cost reduction, achievable through technology development, machinery, and creation of modern intelligent decision support systems aimed at technological process synthesis based on the economic, human, technical and technological resources. The development of new models and methods capable of solving the problems of structural and parametric synthesis will increase the speed without resorting to significant economic costs associated with computing device productive capacity increase. This paper uses three modern trends: simulation modeling, evolutionary methods and Petri net theory (allowing combining all trends by one mathematical apparatus that supports both software and hardware implementations). The genetic algorithm is adapted using embedded Petri nets and expert knowledge. To synthesize technological process for winter wheat cultivation, it proposes to use the common IDEF3 methodology, making it possible to identify the branch points. This study creates a unified model that greatly simplifies the process of software and hardware implementation of an intelligent decision support system. The simulation of technological process models is obtained as a result of intellectual synthesis using PIPE4 open software. After the computational experiment, the obtained models for winter wheat growing correspond to a given criterion of economic benefits for conventional agricultural enterprises.

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1. INTRODUCTION

One of the areas of modern science is the development of intelligent methods for decision support systems [1,2]. A lot of research is being conducted in this area by domestic and foreign scientists.

One of the objectives of this trend is the development of intelligent structural synthesis methods of large or complex discrete systems, which include technological processes in various subject areas. The total research in this subject area allows to identify two leading directions.

In the first direction, the task of structural synthesis is solved at the subject level, without going beyond a specific type, in rare cases beyond the class of technical objects. The bulk of the work in this paradigm is performed by circuit design experts in the field of digital, computer engineering and information systems.

The second trend is the development of universal methods of structural synthesis, applicable for various technical objects and independent of industry specifics.

The main trends of structural synthesis problem solution are the following ones:

- Formal synthesis;
- Specialized synthesis methods;
- Computer synthesis;
- Heuristic synthesis;
- Combinatorial and logical methods of synthesis;
- Intelligent synthesis methods.

The most common mathematical apparatus for synthesis procedure description is graph theory (graphic-analytical method). For example, it is accepted to solve the synthesis problem using the following methods within combinatorial and logical methods:

- Morphological synthesis;
- "Forward" synthesis;
- The synthesis by A-trees;
- The synthesis by multi-partition graphs;
- The synthesis by oriented hypergraphs;
- Logical synthesis systems.

Proceeding from the mentioned above, we can conclude that the creation of a new structural synthesis approach based on the combination of intellectual method and graph theory is promising.

2. METHODOLOGY

As the main tool for the solution, it is proposed to use genetic algorithms adapted to the problem of technological process structural synthesis in agriculture using the theory of Petri nets.

2.1 GENETIC ALGORITHM (GA)

The genetic algorithm selected as an instrumental, structural synthesis, implementing the process, reflects the principles of natural selection, that is, the survival of the most promising individuals, inheritance and mutations. This tool needs to be pre-configured, that is, to determine the setting of operator functioning and the objective function development, which makes it possible to influence the speed of model synthesis that meets the search criteria [3-6].

The main differences of genetic algorithms from traditional methods are the following ones:

1. Within the genetic algorithm, solutions are presented in the form of a code string, while the conversion of these codes is made without any connection with their semantics [4-10].

2. The genetic algorithm uses the property of parallelism, that is, several points of the spatial solution are used during the stage of the search, which makes it possible to avoid undesirable falling into a local extremum of the objective function that is not unimodal.

3. With proper coding, the genetic algorithm will use only valid values of the structures and parameters, which will give the opportunity to increase the speed of structural-parametric synthesis process significantly.

4. During the synthesis of new points in the solution space, the genetic algorithm uses probabilistic rules, and during the transition from one point to another, they use deterministic rules. The combination of these two rules is more efficient than their separate use.

2.2 PETRI NET THEORY

The developed models of the genetic algorithm, the elements of the technological process and the technological process itself can be represented as Petri nets.

When they implement a genetic algorithm with Petri nets, one should take into account the fact that more than one network level is required. The upper level should describe the work of the genetic algorithm itself, and the lower level should contain the models of synthesized technological processes. Therefore, from the variety of extensions of Petri nets one should choose the one that will support:

- The subject area independence;

- Concurrency;

- Probability and determinism;

- Structural nature;

- Multi-level nature.

This extension is nested Petri nets. In this expansion, the marks of each level can be represented by Petri net, which allows to describe the elements of technological processes and the technological processes themselves by different nesting models, which will simplify both the process of structural synthesis and the element base description.

3. PROBLEM SOLUTION

3.1 STRUCTURAL SYNTHESIS PROBLEM STATEMENT OF THE TECHNOLOGICAL PROCESS

It is required to develop the model of genetic algorithm that will perform the synthesis of a process model capable of processing a given input vector into a desired output at the condition of compliance with an economic indicator, based on the set of models available in the element base, according to a predetermined structure in the form of IDEF3 diagram.

3.2 STRUCTURAL SYNTHESIS FOR TECHNOLOGICAL PROCESS

The task of technological process structural synthesis in agriculture can be represented as follows.

Given:

$$S = \langle K, E \rangle \quad (1),$$

where *S* is the technological process whose intellectual synthesis should be carried out; *K* - the process structure, and *E* - its composition.

The process *S* may consist of many elements

$$E = (E_1, \ldots, E_R) \quad (2),$$

where *Ei* is the *i*-th component of the technological process, and *R* is the total number of elements that are included in the process.

Each component of the process corresponds to a specific instance, that is, you can put a certain number of analogues that perform the same function in place of each component within the synthesized process. Mathematically, this can be written as

$$E_i = \{ E_{ij} \}_{j=1}^{M_i} \quad (3),$$

where *Eij* is the j-instance for the *i*-th component, the total number of copies is *M*.

Assume that the synthesized process must have some set of properties,

$$U = \{ U_k \}_{k=1}^{L} \quad (4).$$

Then, during the synthesis of the technological process *S*, it is necessary to choose such a configuration of the components $E_{ij(k_0)}$, so that the combination of their properties gives the desired result during the operation of *S*.

Since the mathematical toolkit of the Petri net was chosen as the mathematical tool to describe the process *S* itself and the means of intelligent synthesis, therefore, it is required to present this system in the appropriate form.

Each component $E_{ij(k_0)}$, with a given property will be presented by a simulation model based on PNij Petri net. The structure can be the relationship between the outputs of the previous component

OUTi (the *i*-th output position) and the inputs of the next INi (the i-th input position) connected by an arc through the transition T, i.e.

$$F : T \rightarrow \underset{i=1}{\overset{R}{\mathrm{Y}}} (IN_i \ \mathrm{Y} \ OUT_i) \qquad (4).$$

Such correspondence completely determines the structure of the synthesized technological process using Petri nets. [3. - p. 207]

Thus, the synthesized technological process can be represented as

$$PN = \langle PN1, \ldots, PNi, \ldots, PNR, T, F \rangle \qquad (5).$$

Since the main indicator in this work is the economic cost of work in the synthesized technological process, we will compare the tag weight (initial value is 0) to determine the cost of the technological process, which is incremented in accordance with the cost of a particular operation during the simulation modeling resulting from PNi synthesis. In the future, let's compare this value with the given one, the difference between the endogenous variable and the reference value will be the value of the fitness function.

The smaller the modulus of the function value, the closer the model of the technological process obtained as the result of intelligent synthesis to the desired one.

In this study, the structure of the synthesized technological system remains fixed, but it should be created.

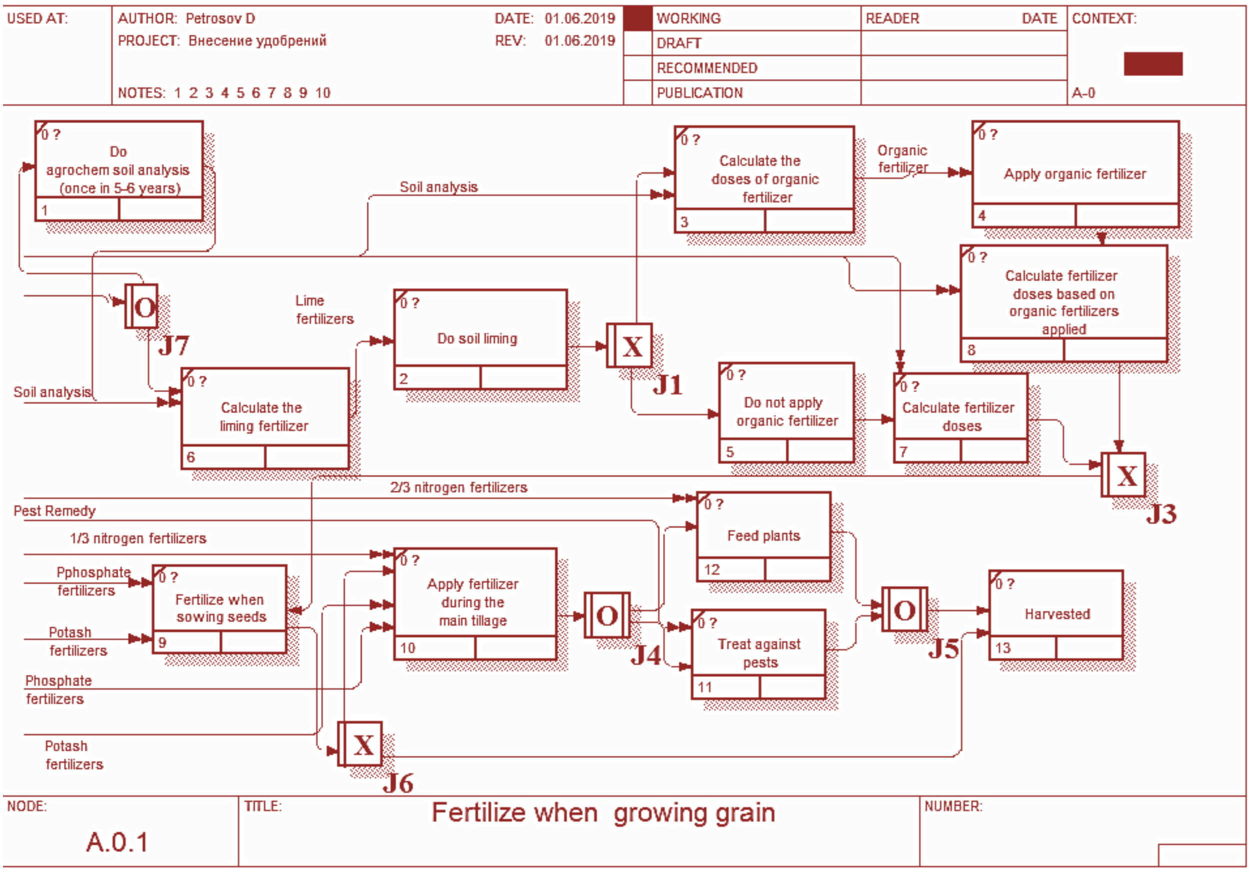

Figure 1: The example of fertilizer application technological process during winter wheat cultivation.

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For this, we will use IDEF3 methodology, allowing us to describe the technological process. Figure 1 shows the example of fertilizer application technological process for winter wheat growing (a simplified model of the process was developed with the involvement of leading experts in the field of agronomy and agrochemistry from Belgorod State Agrarian University named after V.Ya. Gorin).

According to agronomists, the technological process of winter wheat cultivation is well-established, taking into account regional peculiarities, but there are branches in it that can significantly affect the crop quality and quantity. These points must be subject to synthesis. In this paper, the possibility of technological process synthesizing is considered in accordance with economic requirements, therefore, for each process, the cost of its implementation will be assigned and synthesis will be carried out on all components.

On this branching diagram of the technological process, the connections between the elements are indicated by intersections. The changes in these parts of the process can affect endogenous system variables. The relationship of the remaining elements of the system remains unchanged.

The modeling of components and their interrelation in the proposed model of intellectual structural synthesis is carried out using the theory of Petri nets. Therefore, it is required to create an element base of models on the chosen mathematical apparatus.

It is necessary to create the models of intersections based on Petri nets for the full functioning of the structure, which will not be subject to change:

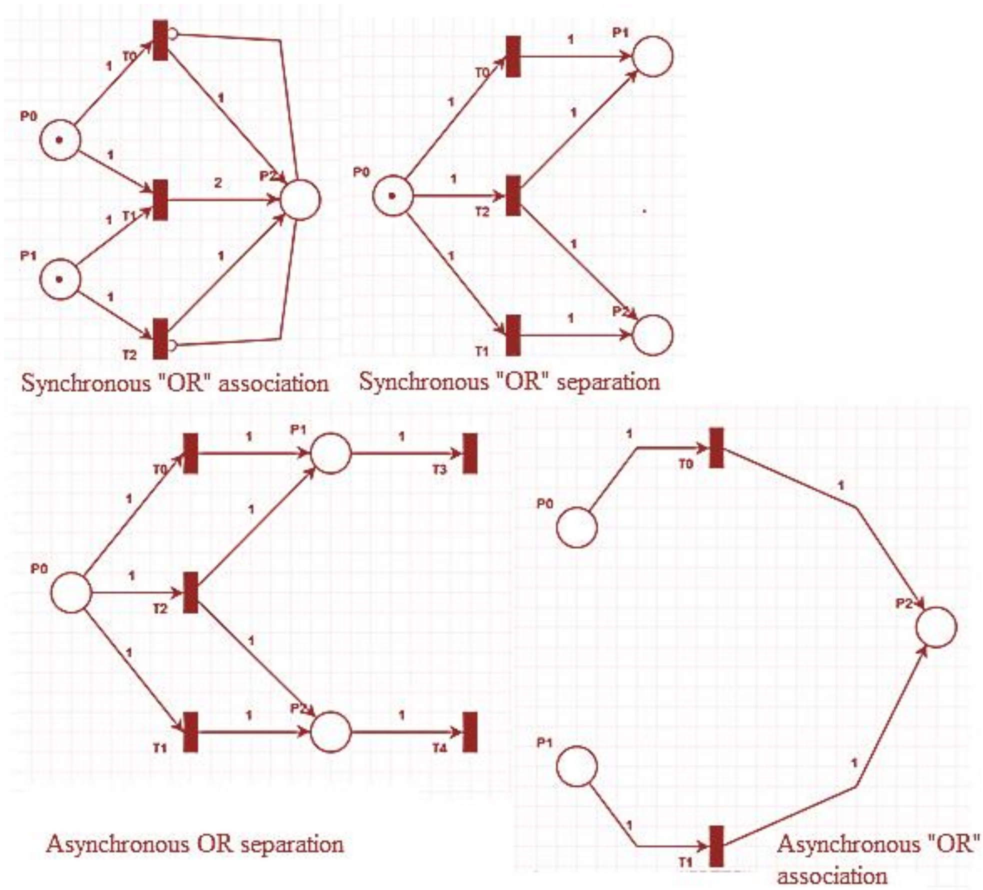

Figure 2: Patterns of "OR" intersection based on Petri nets

- Synchronous "OR", "AND";

- Asynchronous "OR", "AND", "Exclusive OR".

Besides, it should be noted that these intersections can be both branching (J4) and unifying (J5).

Figure 2: shows the models developed for "OR" intersection.

Since the logical intersection of this type in IDEF3 methodology can function in synchronous and asynchronous mode, and can also perform the functions of combination and branching processes, it is required to develop four models. The work of the synchronous “OR” intersection for joining implies that one or several processes (included in the intersection) must be completed simultaneously, the asynchronous “OR” does not set the task of process simultaneous termination. During branching (the exit of the connecting arcs from the intersection) with the synchronous "OR", one or several processes are started simultaneously, and in the case of the asynchronous presentation, one or several processes are started, but not necessarily simultaneously.

Figure 3 shows the developed models of “AND” intersection based on Petri nets.

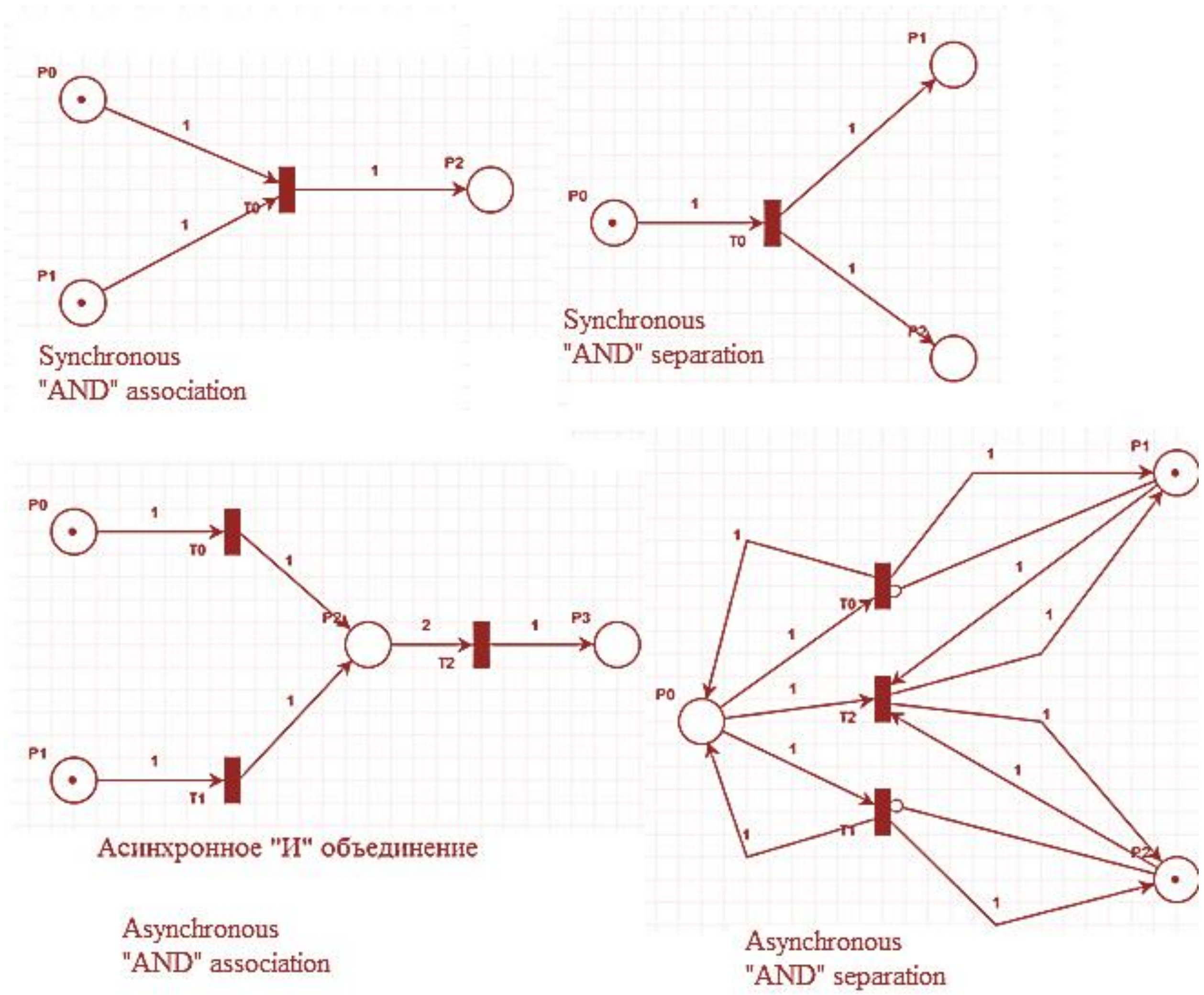

Figure 3: “AND” intersection models based on Petri nets

The logical "AND" intersection is also represented by four models. The difference between the logical "AND" and "OR" is that all processes must be executed or started. In the synchronous presentation, the processes begin or end at the same time, and in the case of asynchronous presentation, the simultaneous start of the processes is not necessary.

Figure 4 shows "Exclusive OR" intersection model. Exclusive "OR" works only in asynchronous mode, since it is possible to start or end only one process. Therefore, two models have been developed for this type of logical intersection, based on the mathematical apparatus of Petri nets.

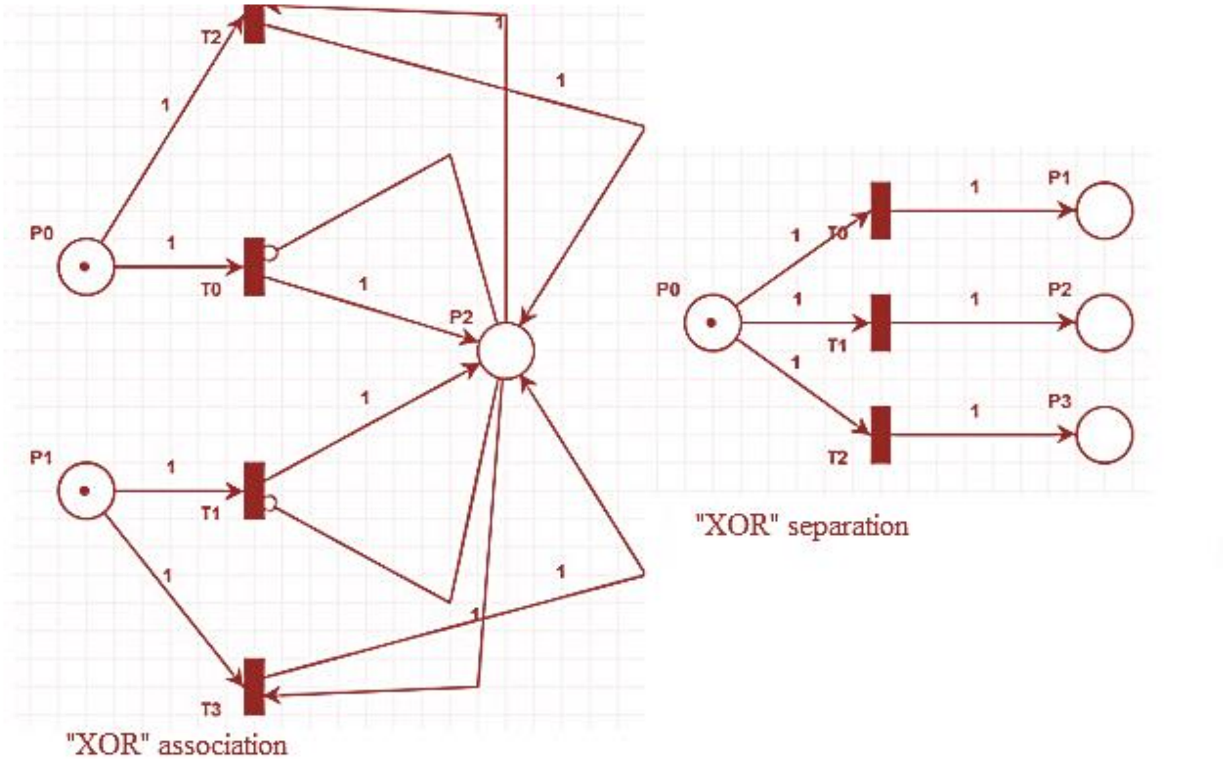

Figure 4: "Exclusive OR" intersection models based on Petri nets

In addition to logical intersections, process modeling is required. Depending on the problem being solved, the process models may differ. Since this work requires to synthesize a technological system that will meet the costs of an agricultural enterprise for winter wheat cultivation, the process model can be represented as follows (see Fig. 5). The intersection T0 changes the previous weight of the H mark (at the beginning of the computational experiment, the value is 0), incrementing it by operation cost.

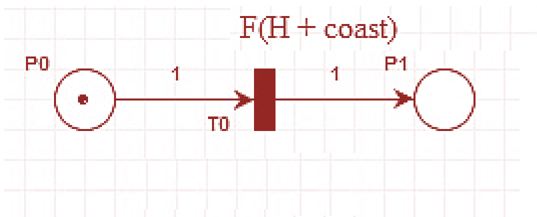

Figure 5: Simplified process model that solves the problem of operation cost calculation

After the element base creation, they should develop a model that will reflect the work of the genetic algorithm. To describe the work of the genetic algorithm, it is proposed to use such an extension of Petri nets as nested nets. In this view, the first level mark is a network. They proposed to use this property. Each first level macro mark of the developed model will be a Petri net, which models the work of the synthesized technological system and is the population genotype.

Figure 6 shows the genetic algorithm model based on nested Petri nets.

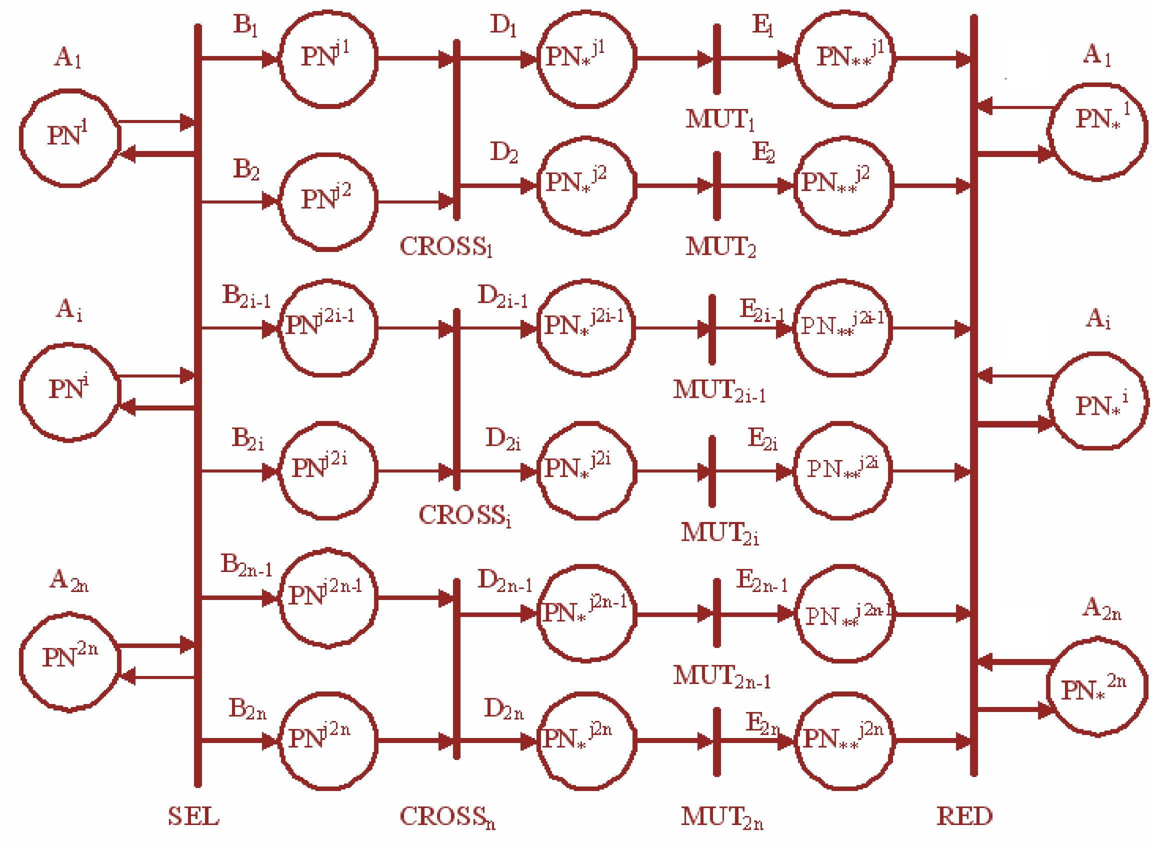

Figure 6: The model of genetic algorithm based on nested Petri nets

3.3 GENETIC ALGORITHM OPERATORS

The role of genetic algorithm operators is performed by network top level transitions: SEL transition (selection operator), CROSSi transitions (crossing operator), MUTi transitions (mutation operator) and RED transition (reduction operator).

The work of the genetic algorithm operators is the following one:

1. SEL (Select) operator prepares the initial population (calculates the fitness function, the value less or equal to a given amount of money equivalent that an agrarian enterprise is willing to spend on the execution of the technological process), evaluates randomly generated individuals and prepares the pairs for crossing (for example, the best with the best) [7-10].

2. CROSS operator performs the exchange with the part of the main technological system elements, thereby generating the so-called descendants.

3. MUT operator performs the replacement of the technological system element to any possible.

4. RED (Reduction) operator evaluates the resulting generation by calculating the fitness function, the individuals with the worst value of the function are destroyed by the operator, only individuals with the best fitness function remain in the population.

The work of the proposed model continues with the remaining individuals until the stopping requirements are met:

1. The solution is found;

2. The time for solution is over;

3. A certain number of populations were processed.

Thus, they developed the simulation model of a genetic algorithm that is capable to perform the synthesis of technological process model to process a given input vector to the desired output taking into account the condition of compliance with an economic indicator, based on the set of models available in the element base, according to a predetermined structure in the form of IDEF3 diagram.

3.4 RESULT

Table 1 presents the cost options of each process, taking into account the work of machinery, wages and the cost of materials that arise during winter wheat growing (the work cost performed by the agronomist of the farm is assumed to be 0 rubles).

Table 1: cost options for each operation.

№	Operation name	Designation	Cost for a 50 ha field, Thousand Rubles.
1.	Agrochemical soil analysis	ААХП250	250
		ААХП0	0
		ААХП350	350
2	Soil liming	ВИП1500	1500
		ВИП2000	2000
		ВИП2500	2500
3	Apply organic fertilizer	ВОУ2000	2000
		ВОУ 0	0
		ВОУ 1500	1500
4	Fertilize during sowing	ВУП1000	1000
		ВУП1500	1500
		ВУП0	0
5	Fertilize during primary processing	ВУОО1500	1500
		ВУОО 1600	1600
		ВУОО0	0
6	Plant feeding	ВПР1200	1200
		ВПР 1300	1300
		ВПР 0	0
7	Process from pests	ОВ1000	1000
		ОВ1050	1050
		ОВ0	0
8	Harvesting	СУ1000	1000
		СУ1400	1400
		СУ2000	2000

Thus, based on the presented components and instances, the initial population will be formed according to the following structure:

$$< OR, \text{ААХП}i, \text{ВИП}i, \text{X}, \text{ВОУ}i, X, \text{ВУП}i, \text{X}, \text{ВУО}i\ , \text{ВПР}i, \text{ОВ}i, \text{СУ}i >$$

where X and OR is the type of intersection (not affected by the genetic algorithm operators, therefore, they may not participate in the procedure of intelligent synthesis).

The example of population individual:

ААХП250,ВИП1500,ВОУ2000,ВУП1000,ВУО1500,ВПР1200,ОВ1000,СУ1000

The macro mark in the form of Petri net corresponding to the represented individual is shown on Figure 7.

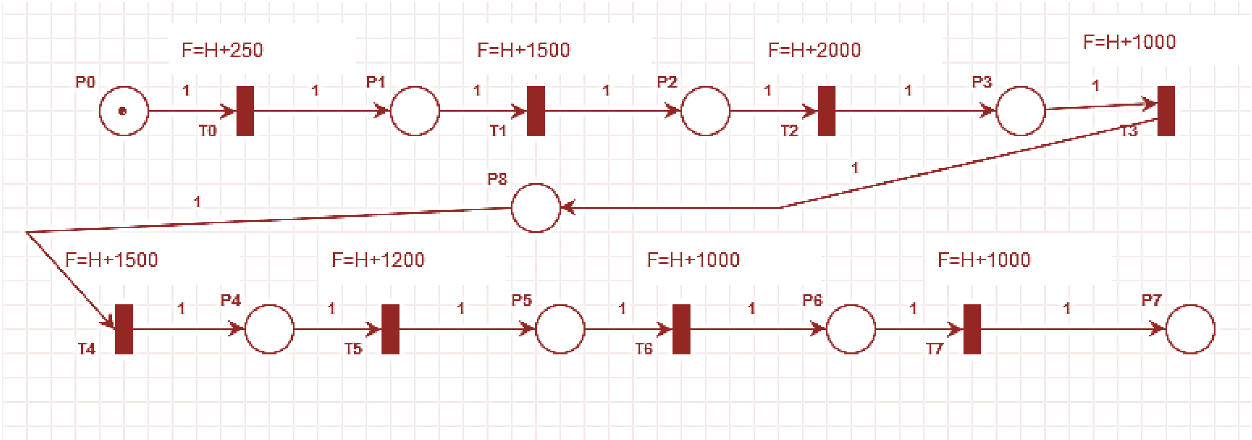

Figure 7: Population individual example based on Petri nets

The search for a solution was implemented at the request of the cultivation budget which made 7300 thousand rubles.

A number of satisfying solutions were obtained in 7 seconds after the simulation:

ААХП0,ВИП1500,ВОУ0,ВУП1000,ВУО1500,ВПР1200,ОВ1000,СУ1000 = 7200 thous. rub.

ААХП0,ВИП1500,ВОУ0,ВУП1000,ВУО1500,ВПР1200,ОВ1000,СУ1400 = 7400 thous. rub.

ААХП0,ВИП1500,ВОУ0,ВУП1000,ВУО1500,ВПР1200,ОВ0,СУ1000= 6200 thous. rub.

*ААХП250,ВИП1500,ВОУ0,ВУП1000,ВУО1500,ВПР1200,ОВ0,СУ1000= 6450 thous. rub.*r

4. RESULT AND DISCUSSION

This paper proposes the approach to create a new method for technological process synthesizing, which is based on three modern theories: simulation modeling, the theory of Petri nets, and evolutionary methods. The resulting models are a universal tool for the synthesis of discrete systems, which have the property of parallelism and can be used both in software and in hardware implementation. The article presents the example of the proposed operation models and methods during the technological process selection on the basis of fertilizer application cost when winter wheat is cultivated. However, it is possible to evaluate such indicators as environmental friendliness, manufacturability, etc. For this, it is required to develop the library of element models in the required subject area. Previously, this method was applied to the problems of workflow system synthesis [3], the synthesis of computing technology based on trigger elements [4].

5. CONCLUSION

The proposed models make it possible to manage the process of finding solutions by transition functioning reconfiguration that simulate the work of genetic algorithm operators in the process of work [5, 6], which can significantly reduce the search time for solutions. Parallelism, inherent in the essence of the proposed method due to the applied mathematical tools, can be used in conjunction with the GPGPU (General-purpose computing on graphics processing units) technology, which will increase the speed of the intelligent decision support system during software implementation.

6. AVAILABILITY OF DATA AND MATERIAL

Used or generated data already present in this study.

7. ACKNOWLEDGEMENT

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