# Management of Industrial and Technological Processes of Complex Systems Based on Modified Neuro-Fuzzy Petri Nets

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**Abstract**

For the effective functioning within a complex system, industrial and technological processes are supported by appropriate information-analytical processes that ensure the collection and analysis of information, as well as modeling and making control decisions for the industrial and technological process.

A variety of neuro-fuzzy Petri nets with temporal fuzzy neurons is proposed.

An example of constructing a model of an industrial and technological process and the corresponding information-analytical processes is considered.

The developed specialized software for modeling of industrial and technological processes and the implementation of information-analytical processes is considered.

**Keywords**

complex systems, neuro-fuzzy Petri nets, temporal logic

## 1. Introduction

The organization of the control process in modern complex technical systems is an urgent task, the solution of which is significantly hampered with an increase of information flows intensity and diversity in such systems. Often, specialists are simply unable to cover all the events and phenomena occurring within the system, affecting the system from the outside, as well as their combinations. There is a steady growth in the volume of information of different quality coming from different sources, which is necessary for the analysis and development of control decisions in the course of the system's performance of the assigned tasks.

A possible solution is the management of complex systems and production and technological processes based on modeling [7]. As a basis for modeling, it is proposed to use a neuro-fuzzy variety of Petri nets, which have established themselves as a convenient, visual, and at the same time mathematically rigorous formalism for modeling and analyzing complex systems and their inherent processes. They allow to model processes, interaction protocols, and control processes with a sufficient degree of detail and visualization. Petri nets allow to naturally describe synchronization, parallelism, conflict and causation, as well as to visualize the structure and functioning of complex systems.

## 2. Complex systems and their production and technological processes

As examples of complex systems, one can cite enterprises in the oil and gas industry, enterprises in the fuel and energy complex, energy supply systems (electricity, heat and water supply), systems for

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managing energy consumption and energy conservation of end consumers, as well as enterprises in the nitrogen industry.

The features of such complex systems are:

- the complexity of the structure, multicomponent, the presence of functional subsystems that solve various target tasks, a large number of parameters characterizing the production and technological processes of the system [2];
- dynamic changes in the structure and parameters of the system;
- incomplete information about the functioning and state of the system;
- variety of external and anthropogenic impacts on the system;
- the presence of complex nonlinear relationships between parameters;
- the complexity of making management decisions to improve the efficiency of the system;
- limited opportunities for experimental studies of the system and ongoing processes;
- the impossibility of using a unified approach to the creation of models of industrial and technological and information-analytical processes taking place in such systems.

The features of production and technological processes in complex systems include the following:

- most production and technological processes are characterized by a continuous cycle;
- functional subsystems and their elements are interdependent, in addition, elements of one subsystem can be simultaneously elements of another subsystem;
- production and technological processes are energy and resource intensive;
- a number of production and technological processes are classified as harmful and hazardous (from the point of view of man-made disturbances and emergencies);
- production and technological processes are highly complex, which increases as the requirements for operational efficiency increase;
- models of production and technological processes are poorly focused on solving management problems [4];
- production and technological processes are closely related to information-analytical processes.

## 3. Information-analytical processes in complex systems

Information-analytical processes are closely related to production and technological processes and are necessary to ensure the functioning of complex systems. Information-analytical processes include the processes of collecting, processing, generalizing, assessing and predicting the state of the system, developing informed management decisions, assessing their feasibility, efficiency and resource conservation.

They are characterized by:

- the need to process large volumes of heterogeneous semi-structured information;
- the need to take into account the specifics of the system of nonlinearly dependent generalized and partial indicators;
- high dynamics of changes in systemic and external factors affecting management efficiency.

In complex systems, a large number of information-analytical processes are carried out in parallel, differing not only in the direction of the data flow (input and output of information), but in orientation to various, both overlapping and independent subject areas within the framework of a common complex system.

In most complex systems, the number of processes is measured in hundreds or thousands, and their design is carried out by experts in various fields.

Various approaches are used to describe and design information-analytical processes in complex systems. The faster and more accurately the information-analytical process is developed and modified, and the information-analytical processes that require adjustment are identified, the less time a complex system will spend on adapting to changed conditions [5].

## 4. Models and methods for analysis and control of complex systems

To reduce the time and material costs associated with the development or modification of information-analytical processes caused by changes in the parameters of the system, the external environment or changes in the parameters of information-analytical or production and technological processes, it is advisable to use an approach that involves modeling such processes. Modeling provides tools for in-depth analysis of the processes running in the system, as well as the ability to assess the impact on the system or its environment of changes in one or another information-analytical process.

Process modeling is also an important step for analyzing and managing the developed process. The use of modeling helps to detect defects in the process, its bottlenecks, to clarify the complexity of the process [9].

Existing models designed for the analysis and management of complex technical systems are usually cumbersome and difficult to analyze, or their analysis takes a long time. Most of these models do not have sufficient flexibility and adaptability to changing conditions, and also do not take into account the influence of environmental factors. Typical neuro-fuzzy models, as a rule, are not focused on analyzing the states of the analyzed processes and are not focused on adapting to constantly changing production and technological processes [8].

In most cases, the problems of modeling and control of such systems are solved separately from each other, namely, the existing models are not focused on analysis, reasonable choice and implementation of control actions (measures) in the course of production and technological processes.

It is possible to formulate requirements for models and methods of analysis and management of complex systems:

- taking into account the hierarchical nesting of processes;
- taking into account the state of processes and their development in time;
- flexible assignment and change of conditions (including temporary ones) of process control;
- taking into account the limitations and risks (economic, man-made and others) of disruption of production and technological processes;
- taking into account the influence of uncertainty of systemic and external factors;
- taking into account the close interdependence of industrial and technological and information-analytical processes;
- the ability to quickly change the structure and parameters of the model when changing production and technological and/or information-analytical processes [6].

## 5. Using a Petri net for modeling processes in a complex system

One of the main advantages of the Petri nets apparatus is that they can be presented both in graphical form (this provides clarity) and in analytical form (this allows you to automate the process of their analysis). In graphic interpretation, a Petri net is a graph of a special kind, consisting of two types of vertices: positions and transitions connected by oriented arcs (branches), and each branch can connect only different types of vertices (position with transition or transition with position) [3].

Within the framework of the approach for modeling and developing processes in a complex system, it is proposed to use varieties of Petri nets, including the temporal neuro-fuzzy neurons of Kwan and Kei.

A classic fuzzy neuron can have several outputs, the output values form the degree of membership in some fuzzy sets (Fig. 1) [1].

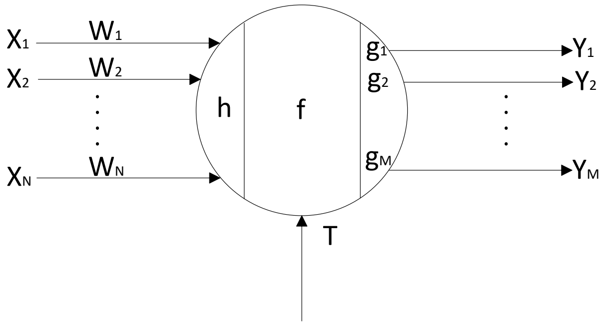


**Figure 1**: An example of a fuzzy neuron

To take into account the state of processes and their development in time, a temporal modification of the Kwan and Kei neuron is proposed (Fig. 2).

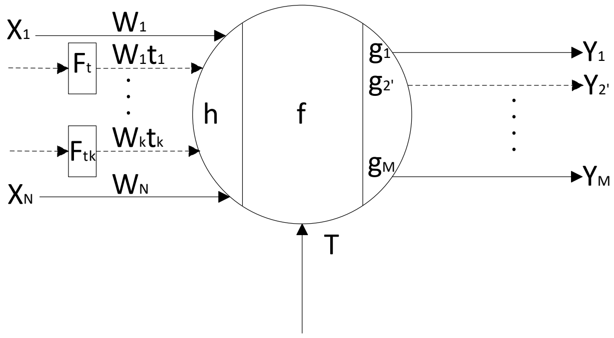


**Figure 2**: Fuzzy neuron with temporal inputs

## 6. Example of simulation of production and technological process in a complex system

Let's consider the control scheme of the oil refining process (Fig. 3).

The operating process of an oil refinery is largely dependent on the type of oil that is supplied. Oil is made up of a wide variety of hydrocarbons. Their molecules differ in mass, which, in turn, is determined by the number of carbon and hydrogen atoms that make up them. To obtain one or another petroleum product, substances with very specific characteristics are needed. Each batch of oil that enters the refinery is different in its chemical composition.

The existing scheme of the production and technological process consists of two main parts:

- Technological equipment (lower part of the figure) on which the technological process of oil refining takes place. The incoming raw materials are treated through a desalting unit, then heated and fed to the atmospheric distillation unit for separating oil into fractions, by repeated evaporation and condensation of vapors, carried out at normal (atmospheric) pressure. After that, each fraction is processed in accordance with its technological and production process.
- Control system (upper part of the figure), which consists of a block for filtering input data, as well as blocks for automatic and manual process control. In this diagram, a model of the system is introduced into the control loop (including a model of production and technological processes in the system closely interacting through the data bus and a corresponding model of information-analytical processes used to analyze and control the system). The scheme also includes a control decision support system connected to the model outputs and forming decision options for the operator.

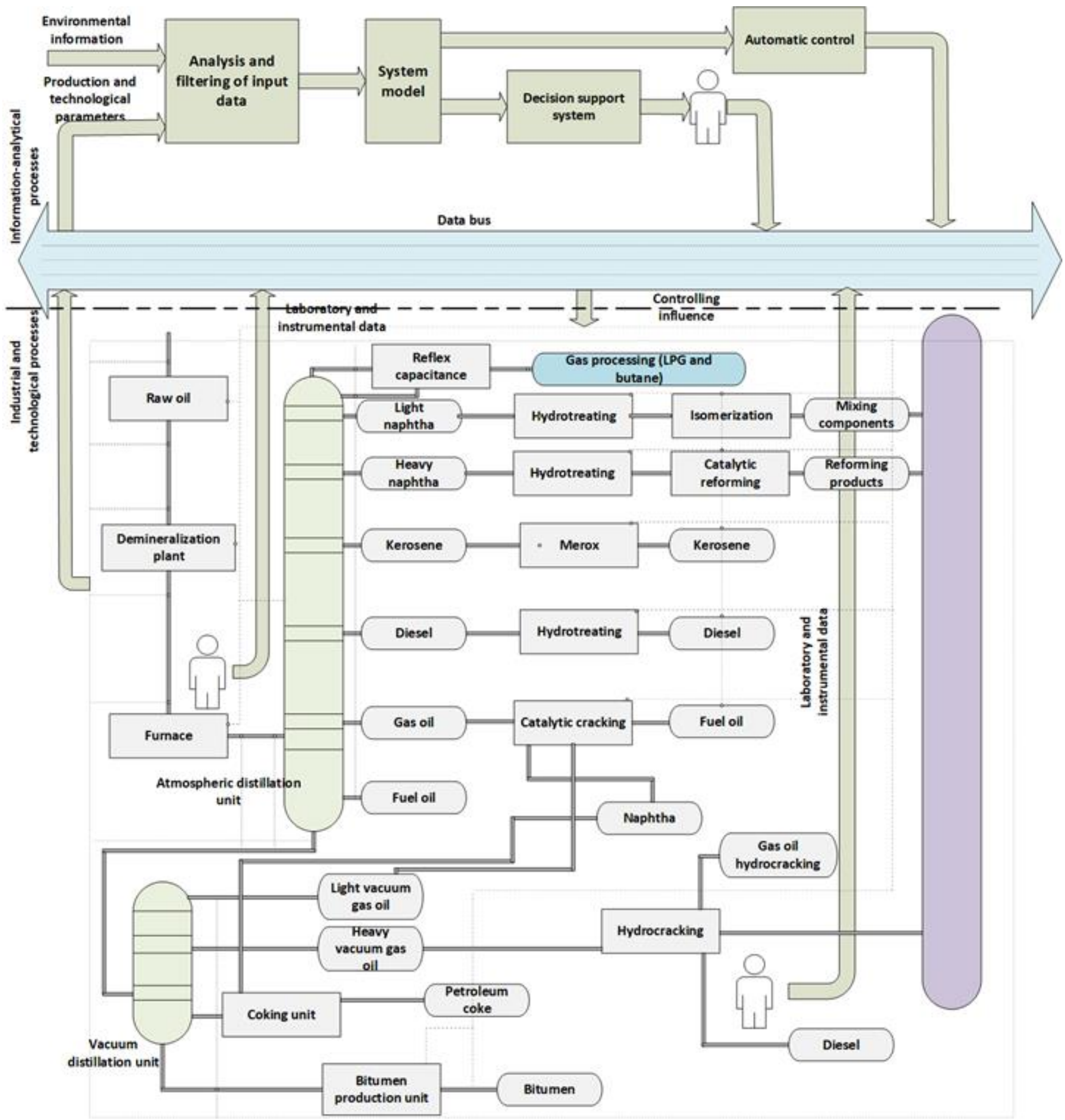


**Figure 3**: Scheme of the industrial and technological process of oil refining

Neuro-fuzzy Petri net can be represented as follows:

$$NPN = (P, T, I, O, A, PR, FP, f, \alpha, m\_0, n, \mu),$$

- $P = \{p1, p2, \dots, pn\}$ is a finite non-empty set of Petri net positions;
- $T = \{t1, t2, \dots, tm\}$ is a finite non-empty set of Petri net transitions;
- $I$ - input transition function;
- $O$- output function of transitions;
- $A$ is a finite set of arcs;
- $PR$ is a finite set of priorities that determine the order of firing transitions in the case of several active transitions;
- $FP$ - a function that assigns the $FT$ triggering priority to each transition: $T$-> $PR$;
- $f = \{f1, f2, \dots, fn\}$ is the vector of values of the fuzzy transition function;
- $\alpha = \{\alpha1, \alpha2, \dots, \alpha n\}$ is the vector of transition firing values;
- $m\_0$ is the vector of the initial marking, each component of which is determined by the value of the membership function of the fuzzy presence of one marker in the corresponding position.

- $M^{\ddot{}} \cong \{m : m : P \rightarrow (U^{((+))} \cup \{\emptyset\}) \times R\}$;
- $n = \{n1, n2, \ldots, pm\}$ - a finite set of integer values of labels, which is necessary for the transition to be triggered;
- $\mu = (\mu 1, \mu 2, \ldots, \mu n)$ is the vector of network marking.

The model of production-technological and information-analytical processes based on neuro-fuzzy Petri net can be represented as follows (Fig. 4)

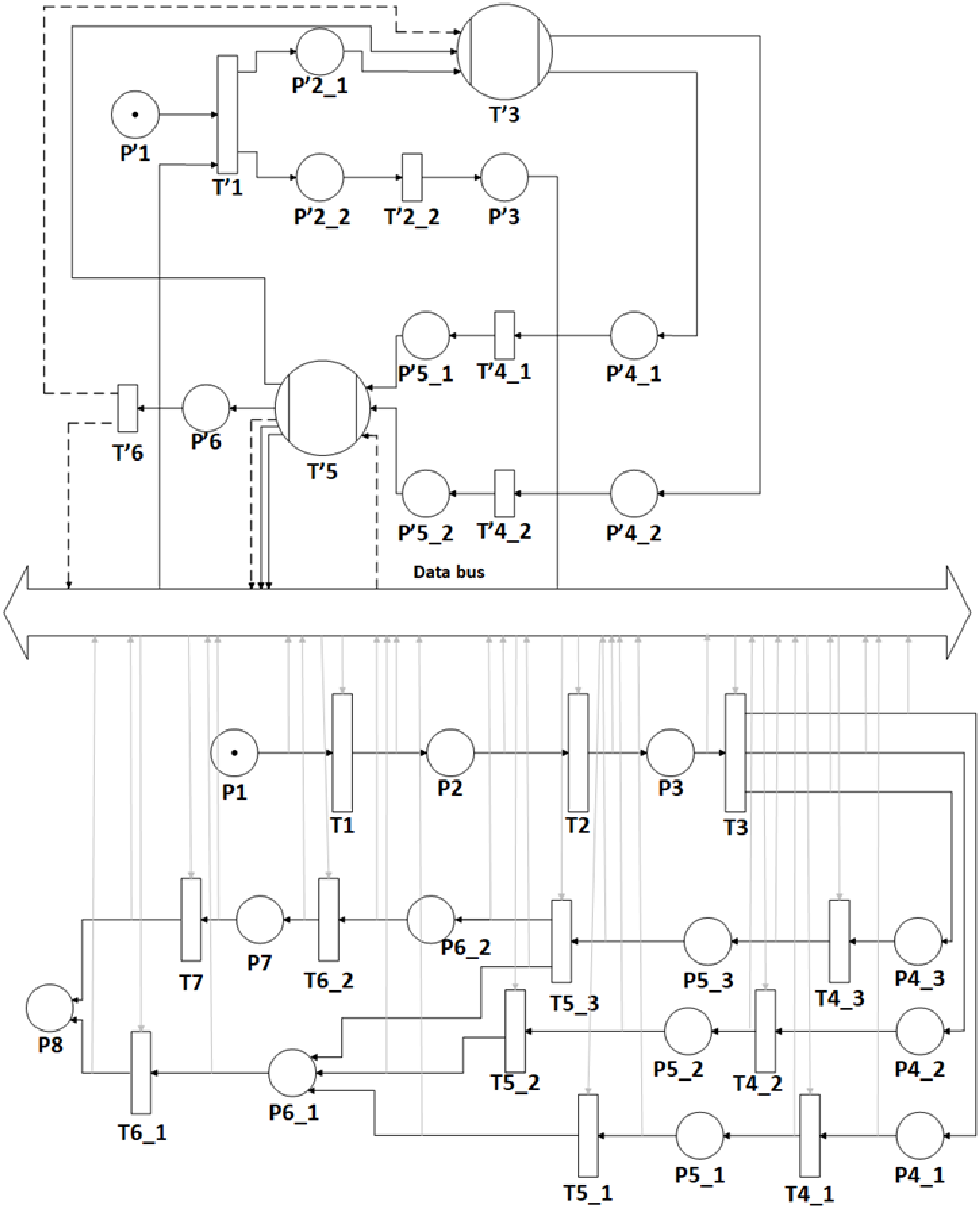


**Figure 4**: Model of industrial and technological and information-analytical processes based on neuro-fuzzy Petri net

## 7. Specialized software

Specialized software has been developed within which it is possible to simulate production and technological processes and implement information-analytical processes of a complex system with the following capabilities:

- formation of an ontological model of a complex system, including classes of information entities and quasi-hierarchical connections between them;
- input and storage of user data and data obtained from external sources;
- using a neural network supervisor to validate external and analytical data;
- building an information-analytical process using the mechanisms of constructors based on neuro-fuzzy Petri nets;
- flexible adjustment of priority management of information-analytical processes competing for resources based on the apparatus of neuro-fuzzy Petri nets.

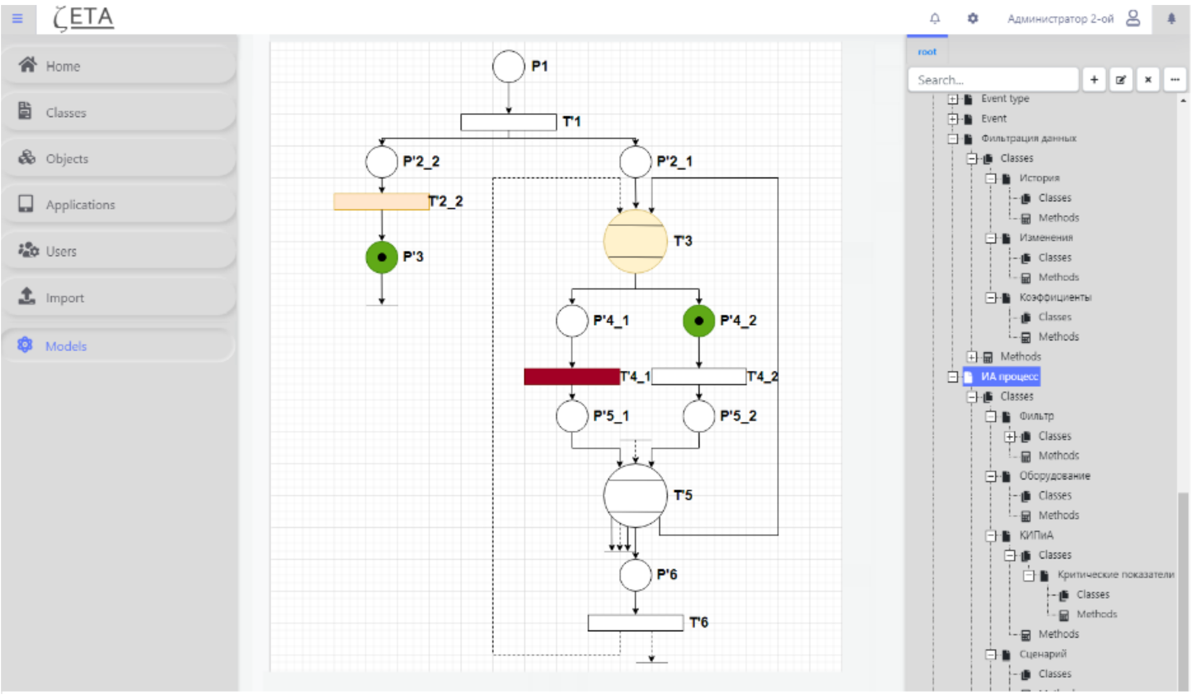


**Figure 5**: Screen form of specialized software for modeling production and technological processes

## 8. Conclusion

For effective functioning within the framework of a complex system, production and technological processes are supported by appropriate information-analytical processes that ensure the collection and analysis of information, as well as modeling and making control decisions for the production and technological process.

A variety of neuro-fuzzy Petri nets with temporal fuzzy neurons is proposed.

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