Network simulation of the sewage treatment system in machine-building enterprises

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Abstract: The article examines the technological complex of wastewater treatment (WWS) of machine-building production. The wastewater treatment complex (WWS) of machine-building production has a complex multi-level structure; therefore, modern methods of system analysis, computer modeling, and the theory of Petri nets are used to study, model, and analyze such systems. The apparatus of the theory of Petri nets (SP) is selected from the main methods for modeling discrete-continuous chemical-technological systems (CTS) for modeling the process of SAL of engineering production. Petri nets are used, focused on modeling and analysis of discrete-continuous CTS, by including priority transitions, delay time of labels in positions and transitions. A model of a typical apparatus that implements the OSV technological process was synthesized in the form of a modified Petri net (SME). The software package for the OSV technological process control system was created using the TRACE MODE SCADA technology.

Keywords: modified Petri nets, wastewater treatment of machine-building production, simulated systems, chemical-technological system, computer simulation, emergency situations, technological process

1. Introduction
Engineering enterprises are a powerful source of environmental pollution. One of the main factors affecting the environment, flora and fauna, as well as humans, is the wastewater of these enterprises, containing mechanical impurities, petroleum products, motor oils, sand, coolant, surfactants, salts of heavy metals, various types of fuel. In this regard, wastewater with high toxicity must be treated before it enters open water. The treatment facilities of machine-building enterprises have a complex multi-level structure, they can be considered as complex cybernetic systems [1]. Therefore, wastewater with high toxicity cannot be discharged into open water without proper treatment. The effectiveness of the functioning of such systems can be achieved using new methods of information processing, using a system analysis of complex objects based on mathematical models of the technological process [2,3]. The industrial OSV installation is a chemical-technological system that includes a set of
interconnected material, heat and information flows of the apparatus. The wastewater treatment complex (WWS) can be divided into interconnected subsystems, with various management tasks at each level of the hierarchy. The overall objective is to treat wastewater to standard levels or to the level of recycled water supply. An information approach based on mathematical modeling of an object [4,5] is the main direction of the study of complex WWS systems. In order to create control systems, consider the behavior of an object in emergency situations, evaluate its structure and control laws, and also take into account the stochastic nature of disturbing influences [6,23], one can model and conduct computer experiments with a model - a substitute for the object. When modeling real objects, two approaches are distinguished. In the first of these, the object is represented as a dynamic system with a continuous variable. This approach is more often used in modeling chemical-technological systems with the continuous organization of the technological process, provided it is stationary and the physicochemical parameters are unchanged [7, 8]. In the second approach, the object is represented in the form of a dynamic system with discrete events (DSDS). These include production systems, assembly lines, computer networks, as well as discrete-continuous biochemical and technological systems. To solve the problems of organization of control of such discrete dynamic systems, special mathematical methods are required. Usually, methods of finite automata, logical-linguistic and simulation modeling, apparatus of the theory of graphs and networks, and SP are used [9]. We have chosen the apparatus of the theory of SP [9] as the main apparatus of mathematical modeling. Petri nets allow modeling discrete parallel asynchronous processes, obtaining a graphical representation of the network, describing systems at various levels of abstraction, representing the system hierarchy, and analyzing models using application software packages [10]. There are several definitions of a joint venture. We will use the terminology introduced in [11].

2. Methods
To analyze various modifications based on the theory of SP, a definition is formulated of a common Petri net - SP, on the structure of the behavioral properties of which there are no restrictions. This class of networks is central to many modifications of the joint venture.

Researchers studying and developing methods for analyzing Petri nets (methods based on the reachability tree, algorithmic methods based on matrix equations, decomposition methods for SPs) have come to the conclusion that, being a powerful tool for studying SPs, these methods turn out to be suitable for Petri nets with imposed restrictions.

Therefore, the following subclasses of SPs were distinguished, reflecting its behavioral (defined by labeling) and structural (defined by GSP topology) properties: ordinary SPs, non-reflexive SPs, simple SPs, live SPs, safe SPs, conflict-free SPs, stable SPs, automatic SPs, marked graphs, Free choice joint venture (CER), asymmetric choice networks (CAB) or correct joint ventures.

Using subclasses of SP in modeling, analysis and synthesis of real systems allows you to create objects with previously known properties (correct algorithms, microcircuits, parallel programs).

Modifications aimed at enhancing the modeling capabilities of Petri nets by introducing structural features (new types of transitions and positions, special transition functions, special arcs) are called extensions of the joint venture. There are a significant number of them, which is constantly growing, increasing the possibilities of modeling Petri nets of various classes of complex systems.

3. Results and discussion
The possibilities for modeling Petri nets of real systems are limited. This explains the appearance of a tendency to expand the model. Researchers using Petri nets developed their modifications of the joint venture for a narrow range of their tasks.

Stable SPs [12] - SPs are such that, for any two allowed transitions, starting one of them does not inhibit the operation of the other. In a stable network, any transition, having become allowed, retains this state until it works.

The concept of stability is useful in the study of parallel computing circuits and asynchronous circuits. Conflict-free SP [13] - there is SP for which either for each of its positions pi∈ P there is at most one outgoing arcO(pi)≦ 1, or for all tj∈ O(pi) performed tj∈ I(pi) (any position that is input for more than one transition is simultaneously output for each such transition).
Networks with an asymmetric choice (the correct joint ventures) are those networks in which each transition needs to have no more than one input position, which is shared with another transition and therefore serves to limit the possibility of conflicts. In solving problems of determining the correctness (correctness) of the algorithm and software of logical control systems, the correct Petri nets are widely used in ACS. Typically, the object of study is modeled by the joint venture, and the properties of the object are investigated in the analysis of the properties of the joint venture. The analysis of the joint venture can be omitted if we knowingly build the correct Petri nets. The technique for forming regular Petri nets is based on substituting a special kind of well-formed blocks into the original regular Petri net, the correctness of which was investigated on the basis of structural properties. This direction was developed in [14].

Networks with asymmetric choice (correct SPs) are those networks in which each transition needs to have no more than one input position, which is shared with another transition and therefore serves to limit the possibility of conflicts [14].

One of the extensions of the joint venture is the joint venture containing inhibitor arcs [15]. A more general case of the expansion of a joint venture introduced by Patil [16] is a joint venture with domains of restriction.

Another extension introduced in - joint venture with the transition "exclusive OR". The exclusive-OR transition can be triggered when only one of its inputs has labels, and all the others do not have them, and when it starts, it deletes the label only from the input with labels. A similar extension is a joint venture with switches. A switch is a transition with a special input called a switching and exactly two switching outputs. The allowed switching transition is triggered according to the following rule: the label is placed in the output marked with the e symbol if the switching input is empty, or in the output marked with the f symbol if the switching input is not empty.

Priority SPs are networks whose elements are partially ordered by some relation (less than or equal to), and priorities $np(t)$ are associated with each transition $t$ of the SP. Then we supplement the transition triggering rule by the following condition: the transition $t$ can work, if for any other transition $t_0$ of this network that can work according to the standard condition: $np(t) \leq np(t_0)$, that is, if several transitions are ready to work, then that whose priority is not less than the priorities of the remaining transitions ready for triggering. Control SPs can be used for algorithmic description of a wide range of tasks and modeling control algorithms in the construction of parallel programs and their parallel algorithms. Thus, we have described the main classes of Petri nets.

The range of Petri nets modifications is constantly supplemented and expanded. Each researcher introduces his extensions for his range of tasks.

The apparatus of the theory of Petri nets is the most convenient tool for modeling the structure and functioning of CTS. To simulate CTS, we decided to use temporary deterministic Petri nets that allow inhibitor arcs and priority transitions. It should be noted that these modifications were used by us for the convenience of modeling and software implementation of network models. The apparatus of classical Petri nets allows simulating the functioning of the CTS, but the SP - model will be cumbersome, beloved and large.

4. Summary

Figure 1 shows the control system of the sewage treatment plant of machine-building production (Fig. 1), in which a mathematical model based on the joint venture is used.
Fig. 1. The technological scheme of the installation of wastewater treatment engineering

Figure 1 shows: 1 - capacity; 2 - sand trap; 3 - hydrocyclone; 4 - coarse filter; 5 - fine filter; 6 - capacity of purified water; 7 - sludge collector; 8 - oil pan. SV - waste water; OV - purified water.

To describe the system, N – schemes are used, based on the mathematical apparatus of Petri nets, one of the advantages of which is the possibility of representing the network model both in analytical form, with the ability to automate the analysis process, and in graphical form, which allows you to visualize the model.

It is necessary to take into account the main limitation of the formalism of N-schemes, which consists in the fact that they do not take into account the temporal characteristics of the simulated systems, since the response time of the transition is assumed to be zero. Therefore, we proposed modified Petri nets. SME - Petri net of the form: $C<P,T,I,O,M,L,\tau_1,\tau_2>$, where $T=\{t_j\}$ a finite nonempty set of characters called transitions is estimated based on the number of conditional servings of products when continuously supplied to the apparatus of the technological scheme;

$P=\{p_i\}$ - a finite nonempty set of symbols called positions (in our case, this is a set of devices of the technological scheme);

$I: P \times T \rightarrow \{0, 1\}$ – input function, which for each transition $t_i$ defines a set of its positions $p_i \in I(t_i)$;

$O: P \times T \rightarrow \{0, 1\}$ - an output function that displays the transition to multiple output positions $p_i \in O(t_i)$;

$M: P \rightarrow \{1, 2, 3...\} - the function of marking (marking) the network, which associates with each position a non-negative integer equal to the number of labels in this position, which changes during the operation of the network;

$\tau_1: T \rightarrow N$ and $\tau_2 : P \rightarrow N$ functions that determine the delay time when the transition is triggered and the delay time in the position.

Thus, for each transition, you can define a set of input positions $I(t_j)$ and output positions $O(t_j)$ as:

$I(t_j) = \{p_i \in P / I(p_i, t_j) = 1\};$ $O(t_j) = \{p_i \in P / O(p_i, t_j) = 1\}$ (1)

The transition triggering instantly changes the markup $M(p) = (M(p_1), M(p_2), M(p_3)...M(p_n))$ to the markup $M'(p)$ according to the following rule:

$M'(p) = M(p) - I(t_j) + O(t_j)$ (2)

Writing equation (2) means that the transition $t_j$ removes one label from each of its input positions and adds one label to each of the output.

The dynamics of the implementation of SMEs is determined by the movement of labels simulating the balance of discrete flows of intermediates under the conditions of specified restrictions on the volume of the OSV apparatus.

The described modification of the joint venture allows an analysis of the functioning of the apparatus of the system in emergency situations, control switching at the network level, as well as technological schemes for discrete-continuous production to ensure a stable, stable state of the cleaning system.

A mathematical model of the technological scheme and its software implementation for controlling the WWS process have been developed. The implementation of the mathematical model of the WWS system developed in the form of SMEs made it possible to study the systemic relationships and laws of the operation of the installation as a whole. Models of the main apparatuses that implement the WWS
technological process were also constructed [17, 18, 19]. The model of the entire installation (Fig. 2) was synthesized from SP models of typical devices. The software package of the OSV technological module system simulating the operation of cleaning in virtual time was developed using the SP model. The software package of the OSV technological process control system [20, 21, 22] was modeled using the TRACE MODE SCADA technology. Using the process control system, you can perform supervisory control of the main elements of the control system, stop the WWS system and analyze its state to predict the development of emergency situations [4, 5, 17].

Fig. 2. The model of the technological module in the form of SMEs

Analytical description of the general Petri net:
15 Positions, 10 Transitions

O(t1)=\{ p1*1 \} \quad \text{I(t1)=\{ p2*1 \}}
O(t2)=\{ p2*1 p3*1 \} \quad \text{I(t2)=\{ p1*1 p4*1 \}}
O(t3)=\{ p4*1 p5*1 \} \quad \text{I(t3)=\{ p3*1 p6*1 \}}
O(t4)=\{ p7*1 \} \quad \text{I(t4)=\{ p3*1 \}}
O(t5)=\{ p6*1 p8*1 p11*1 \} \quad \text{I(t5)=\{ p5*1 p9*1 p11*1 \}}
O(t6)=\{ p10*1 \} \quad \text{I(t6)=\{ p5*1 \}}
O(t7)=\{ p7*1 \} \quad \text{I(t7)=\{ p5*1 \}}
O(t8)=\{ p9*1 p12*1 \} \quad \text{I(t8)=\{ p8*1 p13*1 \}}
O(t9)=\{ p13*1 p14*1 \} \quad \text{I(t9)=\{ p12*1 p15*1 \}}
O(t10)=\{ p15*1 \} \quad \text{I(t10)=\{ p14*1 \}}

5. Conclusions
The main limitation of the formalism of N-schemes, which consists in the absence of taking into account the temporal characteristics of the simulated systems, was revealed in the analysis of chemical-technological systems. Therefore, it is necessary to use the SP modification, focused on modeling and analysis of discrete-continuous CTS, by including priority transitions, as well as the delay time of labels in positions and transitions. The constructed mathematical model of the functioning of the treatment systems for technological effluents of machine-building production, implemented in the form of a modified Petri net, allows us to study the systemic relationships and laws of the operation of the installation as a whole. Using the created software package of the OSV system, it is possible to analyze the state of the OSV system as a whole and predict the development of emergency situations.

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