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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

DEVELOPMENT OF MODELS AND ALGORITHMS FOR CONTROL COMPLEX SYSTEMS USING FUZZY TIMED PETRI NETS

Speciality: 1203.01- Computer sciences
Field of science: Technical sciences

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GENERAL DESCRIPTION OF THE DISSERTATION

Relevance of the topic and the degree of processing. As a modeling apparatus, the Petri net(PN) and its various modifications are able to adequately describe the structure of complex distributed systems, and the logical-temporal characteristics of the processes of their functioning. Various modifications of the PN are mathematical models that describe the analysis of the structure and dynamics of the system in a "state-event" environment. PN models allow us to study the functioning of simulated systems, the optimality of their structure, the efficiency of the functioning process, as well as the possibility of studying the achievement of certain situations in the process of functioning. PN and its generalizations are an effective modeling apparatus for modeling asynchronous, parallel distributed and non-deterministic processes that clearly describe the dynamics of the system and its constituent elements. There are various types and extensions of PN, including temporary, color, algebraic and other modifications of PN. Features of hierarchical applications of PN allow us to consider models with varying degrees of detail, providing the necessary decomposition of complex systems and processes.

Models of this class make it possible to describe the structure and dynamics of simulated systems without the influence of certain uncertainty factors. Such an approach to structural relations and the dynamics of the functioning of the PN limits the practical application of models of these classes and cannot adequately describe some aspects of domain knowledge. The inclusion of a description of uncertainty in various deterministic types and generalizations of PN can be implemented in different ways for each key component of the initial formalism of the corresponding classes of PN. In this case, one can look at various forms of uncertainty (stochastic, fuzzy, combined), and, continuing in this way, one can obtain several extended versions of the corresponding PN uncertainty formalism. Although the application of fuzzy PN(FPN) in the research, modeling and management of uncertain, knowledge-based fuzzy systems is considered successful, there are a number of problems in her theoretical studies. For further research, the basic dynamic interacting properties of FPN are investigated. First, a comparison is made between the elementary network and the FPN extension using the counter-adaptation method, confirming that the FPN is an extended PN formalism. Then, the current results of dynamic properties are used in the analysis of FPN models. The results show that FPN models for analyzing the properties of restriction, security, reachability, etc., make it necessary to conduct theoretical research in the development of interconnected division algorithms. In this regard, the development of computational and information technologies requires the improvement of existing modeling methods and mathematical apparatus. Modified extensions of the PN using the theory of fuzzy sets are used in the construction of models with a complex structure and logical behavior, and control based on production rules. This actualizes the creation and application of various extensions of the FPN to simulate complex asynchronously parallel distributed processes in real time.

The goals and objectives of the study. The purpose of the dissertation is the study, modeling, development of models and control algorithms for complex systems using timed, colored timed, triangular fuzzy timed, trapezoidal fuzzy timed, fuzzy timed Petri nets of type V_f.

Research Methods. To solve the problems, we used the mathematical apparatus of the PN theory, matrix theory, graph theory, fuzzy set theory, theory of formal languages, modern concepts and methods of artificial intelligence.

The main tasks to be defended are:

- classification and systematization of the modeling apparatus for the study and control of dynamically interacting parallel processes in real time;
- algorithms for the functioning, analysis and calculation of structural elements timed PN(TPN) and coloured timed PN(CTPN);
- algorithms for the functioning, analysis and calculation of structural elements of the triangular and trapezoidal fuzzy

timed PN(FTPN);

- algorithms for the functioning, analysis and calculation of structural elements of FPN type V_f and FTPN type V_f;
- The control model of processing devices in the production system of machining in the form of TPN; Control models of processing devices and a transport manipulator in a machining center in the form of CTPN; The synchronization model of the functioning of transport manipulators in the machining center in the form of CTPN;
- The control model of parallel-functioning processing devices in the manufacturing machining system in the form of FPN type V_f and FTPN type V_f;
- Decision-making models based on production rules for the functioning of CTPN and FTPN of type V_f;
- System software for modeling complex systems using FTPN.

The scientific novelty of the study. The scientific novelty of the dissertation is as follows:

- Algorithms for the functioning, analysis and calculation of structural elements TPN, CTPN are proposed and developed.
- A control model for processing devices in the production system of machining in the form of TPN is developed. The control models of processing devices and the transport manipulator, the synchronization model of the operation of transport manipulators in the machining center are developed in the form of CTPN.
- Algorithms for the functioning, analysis and calculation of the structural elements of the triangular and trapezoidal FTPN are proposed and developed.
- The control model of the cyclical action robotic complex was developed in the form of a triangular FTPN, the control model of parallel processing devices in the machining system was developed in the form of a trapezoidal FTPN.
- Algorithms for the functioning, analysis and calculation of structural elements of FPN type V_f and FTPN type V_f with fuzzy marking in positions are proposed and developed.
- The control model of parallel-functioning processing devices in

the production machining system is developed in the form of FPN type V_f and FTPN type V_f.

- Decision-making models based on production rules for the functioning of CTPN and FTPN of type V_f have been developed.

Theoretical and practical significance of the research. The practical significance of the thesis lies in the fact that the obtained scientific and practical results, the proposed approaches and algorithms can be used in the design of flexible production systems, in artificial intelligence technology, in control, in theoretical programming, in modeling and research of dynamically interconnected parallel processes operating in difficult and fuzzy conditions.

Approbation and implementation of the results. The main results of the dissertation were discussed at the following national and international scientific and technical conferences: The Third International Conference “Problems of Cybernetics and Informatics” (Baku, September 6-8, 2010);

Republican scientific-technical conference "Actual problems of automation and control" (Baku, December 27, 2012); III Republican scientific conference "Tasks of applied mathematics and new information technologies" (Sumgayit, December 15-16, 2016); I Republican Conference "Actual scientific and practical problems of software engineering" (Baku, May 17, 2017); International scientific conference "Theoretical and applied problems of mathematics" (Sumgayit, May 25-26, 2017); XII International Conference "Fundamental and Applied Problems of Mathematics and Informatics" (Makhachkala, September 19-22, 2017); XXI Republican Scientific Conference of Doctoral Students and Young Researchers (Baku, October 24-25, 2017); IV scientific-practical international conference of young scientists "Applied Mathematics and Informatics: modern research in the field of natural and technical sciences" (Togliatti, April 23-25, 2018); International Scientific Conference "Information Systems and Technologies: Achievements and Prospects" (Sumgait, November 15-16, 2018); International scientific-practical conference on the possibilities and prospects of information technology and systems in construction (Baku, July 05-06, 2018); II All-Russian Scientific Conference "Information Technologies in Modeling and Management: Approaches, Methods, Solutions" with international participation (Togliatti, April 22-24, 2019); V International Scientific-Practical Conference of Young Scientists "Applied Mathematics and Informatics: Modern Studies in the Field of Natural and Technical Sciences" (Togliatti, April 22-24, 2019); 21th International Conference on Computational Mechanics and Modern Applied Software Systems (Alushta, May 24-31, 2019); 14th International Conference on Pattern Recognition and Information Processing (PRIP'2019) (Minsk, May 21-23, 2019); XXXII International Scientific Conference on Mathematical Methods in Engineering and Technology (MMTT-32) (St. Petersburg, June 3-7, 2019); XIII International Conference "Fundamental and Applied Problems of Mathematics and Informatics" (Makhachkala, September 16-20, 2019); Proceedings of the 7th International Conference on Control and Optimization with Industrial Applications (COIA 2020)(Baku, 26-28 august,2020).

The name of the organization in which the dissertation was completed. The dissertation work was performed at the Department of “Informatics” of Sumgait State University.

Volume and structure of the dissertation. The dissertation consists of introduction, four chapters, conclusion, list of references and applications. The main content of the work consists of 129 pages, 25 figures and 3 tables. The bibliography lists 105 sources. The volume of general and structural sections of the dissertation is approximately distributed as follows:

- Total - 211000 characters
- Introduction - 16000 characters
- Chapter One - 42000 characters
- Second chapter - 58000 characters
- Chapter Three - 78000 characters
- Chapter Four - 15000 characters
- Conclusions - 2200 characters

THE CONTENT OF THE DISSERTATION

The introduction substantiates the relevance of the dissertation, defines the purpose and directions of research, identifies the main problems that need to be addressed, gives basic provisions for protection, demonstrates scientific innovations and the practical significance of the results.

The first chapter are considered literature sources with the aim of analyzing the current state of research and modeling complex parallel distributed processes. It is shown that research, modeling and management of complex systems require the improvement of existing modeling methods, the creation of mathematical modeling based on modern computing technologies. The study revealed a number of unresolved issues of theoretical and practical importance: the lack of a unified approach to the classification and systematization of asynchronous real-time processes, the inclusion and description of time parameters in the structure of the model; a description of the cause-effect relationships of events with complex logical expressions as their basis in the system and their fuzzy nature; the difficulty or impossibility of describing the initial moments of events, intervals of execution, parameters of the reference moments in exact numerical quantities. The results of analysis and research show that to assess various characteristics of objects associated with uncertainty, fuzziness, time, resource, value and other constraints, to solve data analysis problems in the form of "cause-and-effect" relationships, to eliminate logical inconsistencies in dynamic parallel processes , a promising direction is the creation and application of new modifications by combining the structural elements of various PN extensions as an apparatus for mathematical modeling. The choice of the modeling apparatus as timed, colored timed, triangular fuzzy timed, trapezoidal fuzzy timed, fuzzy type V_f and fuzzy timed type V_f extension PN is justified.

The second chapter is devoted to modeling complex parallel distributed systems using TPN extensions. It was shown that the inserted restrictions for real-time systems modeled using TPN correspond to the conditions for time delays of positions and network transitions. It is noted that the impossibility of modeling priority events, a significant increase in the number of positions and transitions for describing parallel distributed processes and the inability to describe time parameters in an explicit form limit the possibilities of PN modeling. Overcoming these shortcomings is possible with the use of CTPN, one of the universal extensions of PN. CTPN describes the sequence of events, monitors and regulates the sequence of transitions, reflects the interaction of parallel processes, simulates several parallel events simultaneously during the operation of complex systems, types data on the basis of many colors, significantly reduces the number of network positions and transitions, simplifies and accelerates the modeling process. To this end, rules are presented for the o functioning, transitions, and marker distribution at CTPN positions. In accordance with the above rules, algorithms were proposed and developed for the functioning, analysis and calculation of structural elements of TPN, CTPN. Using the proposed algorithms, a model for controlling the manufacturing module of a processing center in a mechanical processing system in the form of TPN and CTPN, a model for controlling a transport manipulator and synchronization of transport manipulators in a mechanical processing center, and a decision-making model based on production rules were developed. Based on the presented rules, algorithms for the functioning, analysis and calculation of TPN, CTPN structural elements are proposed and developed. Using the proposed algorithms developed a control model for the production module of the processing center in the machining system in the form of TPN and CTPN, a control model for the transport manipulator and synchronization of the functioning of transport manipulators in the machining center in the form of CTPN, as well as a decision-making model based on production rules for the functioning of CTPN.

➢ **Algorithm for the functioning, analysis and calculation of structural elements TPN**

The beginning of the algorithm

Step 1. Creation of an input incidence matrix of transition sets with dimension $n \times m$:

$$c^{-}_{i,j} = \begin{cases} w(p_i, t_j), & \text{if} \quad \forall p_i \in I(t_j); \\ 0, & \text{if} \quad \forall p_i \notin I(t_j), \end{cases}$$

where, $i = \overline{1,n}$, $j = \overline{1,m}$.

Step 2. Creating a matrix of output incidence of sets of transitions with dimension $m \times n$:

$$c^{+}_{i,j} = \begin{cases} w(t_j, p_i), & \text{if} \quad \forall p_i \in O(t_j); \\ 0, & \text{if} \quad \forall p_i \notin O(t_j), \end{cases}$$

where, $i = \overline{1,n}$, $j = \overline{1,m}$.

Step 3. Creation of the initial marking vector μ^0:

$$\mu_i^0 = \mu^0(p_i), (i = \overline{1,n}) .$$

Step 4. Creation of a vector of marker delays at positions:

$$z = (z_1, z_2, ..., z_n) .$$

Step 5. Creating a response time vector of allowed transitions:

$$s = (s_1, s_2, ..., s_m) .$$

Step 6. İnitial marking of the time instant of the network $\tau = 0$.

Step 7. Creation of the current network marking, where $\mu_{\tau i} = \mu_i^0$, $i = \overline{1,n}$.

Step 8. Search for an allowed transition: For each transition $t_j, j = \overline{1,m}$, the following triggering conditions are checked:

8.1. If for all input positions for which $c^{-}_{ij} \neq 0$ the condition $\mu_{\tau i} \geq c^{-}_{ij}$, $i = \overline{1,n}$ is satisfied, then the transition t_j is triggered and proceeds to step 9, otherwise the value j of increases by one j=j+1.

8.2. If $j \leq m$, then proceeds to step 8, otherwise messages about the deadlock state are announced and a transition to the end of the algorithm.

Step 9. Finding the maximum time for blocking markers of input transition positions t_j:

9.1. $z_{max} = 0$;

9.2. if for all positions $p_i \in I(t_j)$, the condition $z_i > z_{max}$ is satisfied, then assigned $z_{max} = z_i$.

Step10. Calculated response time of transition t_j: $\tau = \tau + z_{max} + s_j$;

Step11. Creating a new marking vector:

$$\mu'_{\tau i} = \mu_{\tau i} - c^{-}_{ij},\ \forall p_i \in I(t_j)$$

$$\mu'_{\tau i} = \mu_{\tau i} + c^{+}_{ij},\ \forall p_i \in O(t_j).$$

Step12. The new marking is taken as the current one: $\mu_{\tau i} = \mu'_{\tau i}$, $i = \overline{1,n}$; and proceeds to step 8.

The end of the algorithm.

➢ **Control model in the form of timed PN of processing devices in the machining production system**

The machining center(MC) consists of one personal input drive for unprocessed parts; from device1 and device2, performing two different operations on the part; from a robot manipulator(RM) that performs loading and unloading of device1 and device2, respectively, and from a personal output drive for machined parts. The connection of the module with the previous and subsequent modules occurs, respectively, using the above drives.

The module works as follows: the parts arrive at the input drive and await processing; if there are parts on the input drive, the robotic arm loads the device1, after processing the parts are unloaded, then the device2 is loaded, after processing the part, the device2 is unloaded and the cycle repeats.

In the presented model, compiled using TPN(Fig.1), the state of the processing center module is described by the following positions:

p_1 and p_2 – respectively, maintenance of device1 and device2; p_3 – input drive raw parts; p_4 and p_8 – respectively loading of device1 and device2; p_5 and p_{10} – respectively, readiness to perform operations with one part of device1 and device2; p_6 and p_9 –

completing processing on a part of device1 and device2; p_7 and p_{11} – respectively, unloading device1 and device2; p_{12}–machined parts output drive.

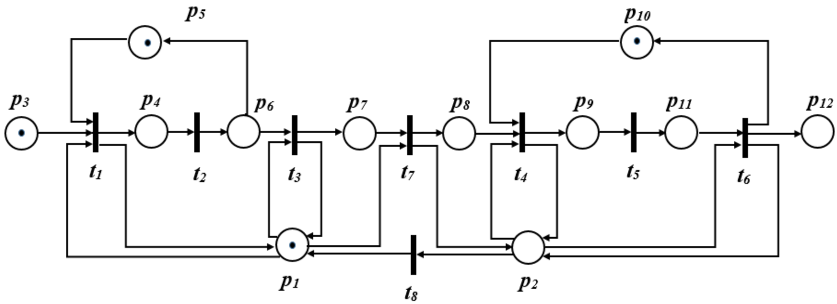

Figure 1. Graph model "machining center" module in a machining system

Possible events in the MC module are described by the following transitions:

t_1 and t_4 – accordingly, loading of device1 and device2; t_2 and t_5 – accordingly, processing the details of device1 and device2; t_3 and t_6 – accordingly, unloading device1 and device2; t_7 – transportation of the part from the output of device1 to the input of device2; t_8 – moving the robot manipulator from device2 to device1.

The initial marking is represented by a vector: $\mu_0 = (1,0,1,0,1,0,0,0,0,1,0,0)$.

Based on the developed algorithm, the structure of TPN was determined. As a result of a computer experiment, a sequence of transitions $\sigma = (t_1 t_2 t_3 t_7 t_4 t_5 t_6 t_8)$ f rom the initial markup was obtained:

transition t_1 is triggered, execution time of transition $\tau = 8$, the vector new marking: $\mu_1 = (1,0,0,1,0,0,0,0,0,1,0,0)$;

transition t_2 is triggered, execution time of transition $\tau = 11$, the vector new marking: $\mu_2 = (1,0,0,0,0,1,0,0,0,1,0,0)$;

transition t_3 is triggered, execution time of transition $\tau = 18$, the vector new marking: $\mu_3 = (1,0,0,0,1,0,1,0,0,1,0,0)$;

transition t_7 is triggered, execution time of transition $\tau = 25$, the vector new marking: $\mu_4 = (0,1,0,0,1,0,0,1,0,1,0,0)$;

transition t_4 is triggered, execution time of transition $\tau = 34$, the vector new marking: $\mu_5 = (0,1,0,0,1,0,0,0,1,0,0,0)$;

transition t_5 is triggered, execution time of transition $\tau = 38$, the vector new marking: $\mu_7 = (0,1,0,0,1,0,0,0,0,1,0,1)$;

transition t_6 is triggered, execution time of transition $\tau = 47$, the vector new marking: $\mu_1 = (1,0,0,1,0,0,0,0,0,1,0,0)$;

transition t_8 is triggered, execution time of transition $\tau = 52$, the vector new marking: $\mu_8 = (1,0,0,0,1,0,0,0,0,1,0,1)$.

Thus, the presented rules for triggering transitions completely describe the process functioning of TPN.

➢ **Algorithms for the functioning, analysis and calculation of structural elements CTPN**

The beginning of the algorithm

Step1. Create a matrix $D^- = [d_{ij}^-]$ of input incidents, where $i = \overline{1,n},\ j = \overline{1,m}$ (n– is the number of positions; m– is the number of transitions). The element d_{ij}^- is equal to the number of arcs from the i – th position to the j – th transition:

$$d_{ij}^- = \begin{cases} 1, & \text{if} \quad p_i \in I(t_j); \\ 0, & \text{if} \quad p_i \notin I(t_j). \end{cases}$$

Step2. Creating a matrix $D^+ = [d_{ij}^+]$ of output incidents, where $j = \overline{1,m},\ i = \overline{1,n}$. The element d_{ij}^+ is equal to the number of arcs from the j-th transition to the i-th position:

$$d_{ij}^{+}=\begin{cases}1, & \text{if} \quad p_i \in O(t_j);\\ 0, & \text{if} \quad p_i \notin O(t_j).\end{cases}$$

Step3. Create an initial marking matrix $M=[\mu_{il}]$, where $i=\overline{1,n},\ l=\overline{1,k}$ (k is the number of colors). An element μ_{il} is equal to the number markers of color r_l in a position p_i.

Step4. Creating a matrix for the distribution of colors by positions $\Lambda=[\lambda_{il}]$, where $i=\overline{1,n},\ l=\overline{1,k}$:

$$\lambda_{il}=\begin{cases}1, & \text{if } (p_i \cdot r_l) \in R;\\ 0, & \text{otherwise.}\end{cases}$$

Step5. Creating a matrix for the distribution of marker colors at the input positions of transitions $\Phi=[\varphi_{jl}]$, where $j=\overline{1,m},\ l=\overline{1,k}$

$$\varphi_{jl}=\begin{cases}1, & \text{if} \quad (p_j, t_l)=r_l;\\ 0, & \text{otherwise}\end{cases}$$

Step6. Creating a matrix for the distribution of marker colors at the output positions of transitions $\Psi=[\psi_{jl}]$, where $j=\overline{1,m},\ l=\overline{1,k}$:

$$\psi_{jl}=\begin{cases}1, & \text{if} \quad (t_l, p_j)=r_l;\\ 0, & \text{otherwise.}\end{cases}$$

Step7. Creating a vector of marker delays at positions: $z=(z_1, z_2, \ldots, z_n)$.

Step8. Creating a response time vector of allowed transitions: $s=(s_1, s_2, \ldots, s_m)$.

Step9. The initial network functioning time $\tau=0$. The network functioning time is T.

Step10. Search for the allowed transition: for each transition $t_j, j=\overline{1,m}$, the triggering condition is checked:

10.1. From the matrix $D^{-}=[d_{ij}^{-}]$, determined all input positions transition $t_j: p_{i_1}, p_{i_2}, \ldots, p_{i_q}$, $q=\left|I(t_j)\right|$;

10.2. From the matrix Φ, all available color distributions for input positions of transition t_j are determined: $r_{l_1}, r_{l_2}, \dots, r_{l_i}$, $i \in [1,k]$;

10.3. From the matrix M, selected the numbers of the set markers color at all defined input positions of transition t_j:

$$\mu_{i_q l_v} = (p_{i_q}, r_{l_v}),\ q = \overline{1, |I(t_j)|},\ \ v = \overline{1,k};$$

10.4. If for $\forall i_q$ exists $\exists l_v$, at the same time $\mu_{i_q l_v} \ge d^-_{i_q j}$, then the transition t_j is allowed, and proceeds to step 12.

Step 11. If the trigger condition is not satisfied for the transition t_j, then the index j increases by one: j = j + 1. If $j \le m$, then the transition to paragraph 10.1 is carried out, otherwise a deadlock state is reported and the transition to the end of the algorithm is performed.

Step 12. Finding the maximum blocking time for markers at input positions of transition t_j:

12.1. $z_{max} = 0$;

12.2. if for all $p_i \in I(t_j)$ the condition $z_i > z_{max}$ is met, then it is assumed $z_{max} = z_i$.

Step13. The transition response time is calculated: $\tau = \tau + z_{max} + s_j$.

Step14. If $\tau < T$, then proceeds to step 15, otherwise the network operation time ends and the transition to the end of the algorithm proceeds.

Step15. Calculation of matrix elements of the new marking M':

$$\mu'_{i_q l} = \mu_{i_q l_v} - \varphi_{j l_v} d^-_{i_q l_v},\ \ q = \overline{1, |I(t_j)|},\ \ v = \overline{1,k};$$

$$\mu'_{i_q l_v} = \mu_{i_q l_v} + \psi_{j l_v} d^+_{j i_q},\ \ q = \overline{1, |O(t_j)|},\ \ v = \overline{1,k}.$$

Step16. Go to step 10.

The end of algorithm.

➢ **Model of functioning of the transport manipulator in the form of CTPN in the center of mechanical processing**

İn the graph of the model compiled using the CTPN, the functioning of the transport manipulator(TM) in a flexible production system for machining its states are described by the following positions:

p_1 – transport manipulator performing loading – unloading of MC1, MC2, MC3; p_2, p_3, p_4 – respectively, input drives of raw parts MC1, MC2, MC; p_5, p_6, p_7 – accordingly, the end of the load, the beginning of the processing of parts MC1, MC2, MC3; p_8, p_9, p_{10} – accordingly, the end of the processing of parts, the beginning of unloading MC1, MC2, MC3; p_{11}, p_{12}, p_{13} – accordingly, the locks excluding loading not unloaded MC1, MC2, MC3; p_{14}, p_{15}, p_{16} – respectively, the output drives of the machined parts MC1, MC2, MC3.

Possible events during the operation of the TM are described by the following transitions:

t_1, t_2, t_3 –respectively, loading operations MC1, MC2, MC3; t_4, t_5, t_6 – respectively, the processing of parts MC1, MC2, MC3; t_7, t_8, t_9 – accordingly, the unloading operations MC1, MC2, MC3.

Elements of the vector of parameters of time delays of markers in positions:

$$Z = (3,3,1,1,2,1,3,4,2,2,4,3,6,3,4,7).$$

Elements of the vector of parameters of the response times of allowed transitions:

$$S = (5,2,4,5,2,5,4,2,6).$$

As a result of a computer experiment, a sequence of triggering transitions $\sigma = (t_1, t_2, t_3, t_4, t_5, t_6, t_7, t_8, t_9)$ from the initial marking was obtained.

In the developed model, many colors associated with the marks and arcs of the network are described with a vector $R = (r_1, r_2, \ldots, r_9)$. The network has a colored mark imitating the functioning of processing centers and arcs of the trajectory of the route of the transport manipulator. The initial color of the mark at the position p_1 is equal r_1 and the arc (p_1, t_1) is painted with color r_1. After triggering the transition t_1, the mark returns to the position p_1, having color r_2, since the arc (t_1, p_1) is painted in color r_2. In this case, the transition t_2 is triggered, since the arc (p_1, t_2) is painted in color r_2. After the transition t_2 is triggered, in position p_1, the mark returns with color r_3. The transition t_3 is excited, since the arc (p_1, t_3) is painted in color r_3, after the transition t_3 is triggered to the position, the mark returns having color r_4, since the arc (t_3, p_1) is painted in color r_4. In any state of the system colorization of arcs provides excitation of only one of the transitions following p_1. With this coloring, the route of the transport manipulator is represented by a sequence of triggered transitions $t_1, t_2, t_3, t_7, t_8, t_9$, i.e. MC1 is loaded, then MC2, MC3. After loading MC3 their unloading follows and the cycle repeats.

The third chapter is devoted to the study, modeling and control of parallel distributed processes operating in an uncertain environment using FTPN. It is shown that the functional and structural relationships between the elements of an object, characterized by uncertain parameters, a description of these relationships with complex cause-effect relationships, asynchronous processes of a non-deterministic nature, necessitate the use of various extensions of fuzzy PN. The proposed approach offers various extensions for modeling and analysis of complex parallel distributed systems based on the mathematical apparatus FTPN, which is a generalized TPN that combines determinative and non-determinate properties. It is noted that the FTPN apparatus plays an important role in the study of dynamically interconnected parallel distributed processes with a complex structure in a variety of fuzzy conditions and situations characterized by various features and time parameters. The advantages of this mathematical apparatus are its ability to be well formalized and interpreted, the modification of models and processes, as well as the possibility of a detailed study of many model situations. In this chapter, algorithms for the functioning, analysis and calculation of structural elements of a triangular, trapezoidal FTPN, FPN of type V_f and FTPN of type V_f are proposed and developed. The control model of parallel-functioning processing devices in the production machining module is made in the form of a trapezoidal FTPN, a control model of a robot-technological complex with cyclic action in the form of a triangular FTPN, a control model of parallel-functioning processing devices in the production system of machining in the form of FPN of type V_f and FTPN of type V_f.

➢ **Algorithm for the functioning, analysis and calculation structural elements of trapezoidal FTPN**

Beginning of the algorithm

Step 1. Creation of input and output matrices representing the input and output functions of the FTPN in dimension $m \times n : d^{-}_{ij}, d^{+}_{ij}\ (i = \overline{1,n}; j = \overline{1,m})$.

Step 2. Determination of dimension and input of structural elements of FTPN: $\mu_{ij}, z_{ij} (i = \overline{1,k}; j = \overline{1,n});\ s_{ij}\ (i = \overline{1,k}; j = \overline{1,m})$.

Step 3. Believed: $k = 1$.

Step 4. Believed: $j = 1; q = 1; i = 0$.

Step 5. The index i is increased by one: i=i+1.

Step 6. If performed condition $i \le n$, then is carried out to step 7, otherwise, to step 15.

Step 7. Creating an intermediate matrix μ^1_{li}: $\mu^1_{li} = \mu_{li}; (l = \overline{1,4})$.

Step 8. If performed condition $(\mu^1_{1i} = 0) \wedge (\mu^1_{2i} = 0) \wedge (\mu^1_{3i} = 0) \wedge \wedge (\mu^1_{4i} = 0)$, then is carried out to step 5, otherwise, to step 9.

Step 9. The elements of the matrix μ^1_{il} are calculated: $\mu^1_{li} = \mu_{li} + z_{li}; (l = \overline{1,4})$.

Step 10. If performed condition $i = d^{-}_{kj}$, then is carried out to step 11, otherwise, to step 5.

Step 11. If j=1, then believed: $\max_a = \mu^1_{i1}$; $\max_b = \mu^1_{i2}$; $\max_\alpha = \mu^1_{i3}$; $\max_\beta = \mu^1_{i4}$ and is carried out to step 12, otherwise, to step 13.

Step 12. Zeroing elements of the matrix μ^1_{li}: $\mu^1_{li} = 0 (l = \overline{1,4})$; the index j is increased by one: j=j+1 and is carried out to step 5.

Step 13. Believed: $a_1 = \max_a$; $a_2 = \mu^1_{1i}$.

Step 14. If performed condition $a_1 \geq a_2$, then $\max'_a = a_1$, otherwise $\max'_a = a_2$;

14.1 Believed: $b_1 = \max_b$; $b_2 = \mu^1_{2i}$;

14.2 If performed condition $b_1 \geq b_2$, then $\max'_b = b_1$, otherwise $\max'_b = b_2$;

14.3 Believed: $\alpha_1 = \max_\alpha$; $\alpha_2 = \mu^1_{3i}$; $\beta_1 = \max_\beta$; $\beta_2 = \mu^1_{4i}$; Calculate: $\alpha'_1 = a_1 - \alpha_1$; $\alpha'_2 = a_2 - \alpha_2$;

14.4 If performed condition $\alpha'_1 \geq \alpha'_2$, then $\max'_\alpha = \alpha'_1$, otherwise $\max'_\alpha = \alpha'_2$;

14.5 Calculate: $\max_\alpha = \max'_a - \max'_\alpha$; $\beta'_1 = b_1 + \beta_1$; $\beta'_2 = b_2 + \beta_2$;

14.6 If performed condition $\beta'_1 \geq \beta'_2$, then $\max'_\beta = \beta'_1$, otherwise $\max'_\beta = \beta'_2$;

14.7 Calculate: $\max_\beta = \max'_\beta - \max'_b$; is carried out to step 12.

Step 15. Believed : i=1.

Step 16. If performed condition $i \leq n$, then is carried out to step 17, otherwise go to step 25.

Step 17. If performed condition $i = d^+_{kq}$, then is carried out to step 18, otherwise the index i is increased by one: i=i+1 and is carried out to step 16.

Step 18. Creating an intermediate matrix μ^2_{li}: Calculate:

$$\mu^2_{i1} = \max_a + s_{k1}; \mu^2_{i2} = \max_b + s_{k2};$$

$$\mu^2_{i3} = \max_\alpha + s_{k3}; \mu^2_{i4} = \max_\beta + s_{k4}.$$

Step 19. If performed condition $(\mu^1_{1i} = 0) \wedge (\mu^1_{2i} = 0) \wedge (\mu^1_{3i} = 0) \wedge$

$\wedge (\mu_{4i}^{1} = 0)$, then is carried out to step 20, otherwise, to step 21.

Step 20. Believed: $\mu_{li}^{1} = \mu_{li}^{2}; (l = \overline{1,4})$; the index i is increased by one: i=i+1 and is carried out to step 16.

Step 21. If performed condition q=1 , then вelieved: $\left\{ \min_{a} = \mu_{1i}^{2}; \min_{b} = \mu_{2i}^{2}; \min_{\alpha} = \mu_{3i}^{2}; \max_{\beta} = \mu_{4i}^{2}; \right\}$ and is carried out to step 22, otherwise, to step 23.

Step 22. Believed $\mu_{1i}^{1} = \min_{a}; \mu_{2i}^{1} = \min_{b}; \mu_{3i}^{1} = \min_{\alpha}; \mu_{4i}^{1} = \min_{\beta}$; the index q is increased by one: q=q+1 and is carried out to step 17.

Step 23. Believed : $a_1 = \min_a;\ a_2 = \mu_{1i}^{2}$.

Step 24. If performed condition $a_1 \le a_2$, then $\min_a' = a_1$, otherwise $\min_a' = a_2$;

24.1 Believed : $b_1 = \min_b;\ b_2 = \mu_{2i}^{2}$;

24.2 If performed condition $b_1 \le b_2$, then $\min_b' = b_1$, otherwise $\min_b' = b_2$;

24.3 Believed: $\alpha_1 = \min_\alpha;\ \alpha_2 = \mu_{3i}^{2}$; $\beta_1 = \min_\beta;\ \beta_2 = \mu_{4i}^{2}$; calculate: $\alpha_1' = a_1 - \alpha_1;\ \alpha_2' = a_2 - \alpha_2$;

24.4 If performed condition $\alpha_1' \le \alpha_2'$, then $\min_\alpha' = \alpha_1'$, otherwise $\min_\alpha' = \alpha_2'$;

24.5 Calculate: $\min_\alpha = \min_a' - \min_\alpha'$; $\beta_1' = b_1 + \beta_1;\ \beta_2' = b_2 + \beta_2$;

24.6 If performed condition $\beta_1' \le \beta_2'$, then $\min_\beta' = \beta_1'$, otherwise $\min_\beta' = \beta_2'$;

24.7 Calculate: $\min_\beta = \min_\beta' - \min_b'$ is carried out to step 22.

Step 25. The new marking is adopted for the current: $\mu_{lr} = \mu_{lr}^{1}; (l = \overline{1,4};\ r = \overline{1,n})$.

Step 26. The value k is increased by one: k=k+1. If $k \le m$, then is carried out to step 4.

End of algorithm

➢ **Model of parallel processing devices in the manufacturing**

module of machining

The manufacturing module for machining consists of one industrial robot, one transport manipulator, one personal input drive, two devices of the same type to perform the same operation on batches of the same details, and from one personal output drive. The connection of the module with the previous and subsequent modules occurs, respectively, using the above drives. The module processes one type of detail. Details are sent to a personal input drive and are awaiting processing. Free device1 or device2 captures details from the input drive. The processed details are sent to the output drive and are waiting to be sent to the subsequent module.The model of the module states compiled by structural elements of the FTPN module of parallel-functioning processing devices is described by the following positions and transitions:

p_1 and p_2 – respectively, the processing of the workpiece on the device1 and on the device2; p_3 and p_4 – respectively, device1 and device2 are free; p_5 and p_6 – respectively, a workpiece is delivered to the input of device1 and to the input of device2; p_7 and p_8 – respectively, device1 and device2 have submitted a service request; p_9 – the transport manipulator fulfills the application of the device1 and device2; p_{10} –the robot is free; t_1 and t_2 –respectively, processing on the blank of device1 and device2; t_3 and t_4 – respectively, discharge the output drive of device1 and device2; t_5 and t_6 – respectively, loading the input drive of device1 and device2; t_7 and t_8 – accordingly, the execution of the application of the device1 and device2; z_1 and z_2 – respectively, the processing time of the workpiece on the device1 and on the device2; z_3 and z_4 – accordingly, the loading time of the transport manipulator at the output of device1 and at the output of device2 and movement from device1 and from device2 to the output drive; z_5 and z_6 – respectively, the waiting time of the transport manipulator and the execution of the application of the device1 and device2; z_7 and z_8– accordingly, the travel time of the transport manipulator from the output drive to the device1 and to the device2; z_9 – time to configure the transport manipulator to complete the next task; z_{10} – time to configure the robot to complete the next task.

Elements of the initial marking vector:

$$\mu_1^0 = \mu_2^0 = \langle 1, 2, 1, 1 \rangle,\ \mu_3^0 = \mu_4^0 = \mu_5^0 = \mu_6^0 = \mu_7^0 = \mu_8^0 = \langle 0,0,0,0 \rangle,$$
$$\mu_9^0 = \langle 2, 3, 1, 1 \rangle,\quad \mu_{10}^0 = \langle 1, 2, 1, 0 \rangle.$$

Elements of the vector of parameters of time delays of markers in positions:

$$z_1 = z_2 = \langle 2,3,1,1 \rangle, z_3 = z_4 = \langle 1,2,1,1 \rangle, z_5 = z_6 = \langle 2,3,0,1 \rangle,$$
$$z_7 = z_8 = \langle 1,2,0,1 \rangle, z_9 = \langle 1,2,1,0 \rangle,\ z_{10} = \langle 1, 2, 0, 1 \rangle.$$

Elements of the vector of parameters of the response times of allowed transitions:

$$s_1 = s_2 = \langle 2,3,1,1 \rangle, s_3 = s_4 = \langle 1,2,1,1 \rangle, s_5 = s_6 = \langle 1,2,0,1 \rangle, s_7 = s_8 = \langle 2,3,1,0 \rangle$$

Based on the developed algorithm, the structural elements of the FTPN are calculated[1]. As a result of a computer experiment, a sequence of triggering transitions was obtained $\sigma = (t_3 t_5 t_7 t_1 t_4 t_6 t_8 t_2)$ from initial marking μ':

1. the transition t_3 is triggered, the resulting marking has the form:

$$\mu_1^1 = \mu_4^1 = \mu_5^1 = \mu_6^1 = \mu_7^1 = \mu_8^1 = \mu_9^1 = \langle 0,0,0,0 \rangle,\ \mu_2^1 = \langle 3,5,2,2 \rangle,$$
$$\mu_3^1 = \langle 5,8,3,3 \rangle,\ \mu_{10}^0 = \langle 2,4,1,1 \rangle;$$

2. the transition t_5 is triggered, the resulting marking has the form:

[1] Мустафаев, В.А., Салманова, М.Н. Разработка модели функциониро¬вания обрабатывающего центра с применением нечетких временных сетей Петри // – Воронеж: Вестник Воронежского государственного технического университета, –2018. Т.14, №3, – с.13-19.

$\mu_1^2 = \langle 0,0,0,0 \rangle$, $\mu_2^2 = \langle 5,8,3,3 \rangle$, $\mu_3^2 = \mu_4^2 = \langle 0,0,0,0 \rangle$,
$\mu_5^2 = \langle 8,13,5,5 \rangle$, $\mu_6^2 = \mu_7^2 = \mu_8^2 = \mu_9^2 = \mu_{10}^2 = \langle 0,0,0,0 \rangle$;

3. the transition t_7 is triggered, the resulting marking has the form:
$\mu_1^3 = \langle 0,0,0,0 \rangle$, $\mu_2^3 = \langle 7,11,4,4 \rangle$, $\mu_3^3 = \mu_4^3 = \mu_5^3 = \langle 0,0,0,0 \rangle$,
$\mu_6^3 = \mu_8^3 = \mu_9^3 = \langle 0,0,0,0 \rangle$, $\mu_7^3 = \langle 11,18,6,7 \rangle$, $\mu_{10}^3 = \langle 11,18,6,7 \rangle$;
4. the transition t_1, is triggered, the resulting marking has the form:
$\mu_1^4 = \langle 13,22,7,9 \rangle$, $\mu_2^4 = \langle 9,14,5,5 \rangle$, $\mu_3^4 = \mu_4^4 = \mu_5^4 = \langle 0,0,0,0 \rangle$,
$\mu_9^4 = \langle 13,22,7,9 \rangle$, $\mu_{10}^4 = \langle 12,20,6,8 \rangle$, $\mu_6^4 = \mu_7^4 = \mu_8^4 = \langle 0,0,0,0 \rangle$.

The process continues until the desired marking is obtained.

➢ **Algorithm for the functioning and calculation of the structural elements of FTPN of type Vf.**

Beginning of the algorithm

Step 1. Creating an input incident matrix $D^- = [d_{ij}^-]$, where $i = \overline{1,n}$, $j = \overline{1,m}$ (n is the number of positions; m– is the number of transitions). The element d_{ij}^- is equal to the number of arcs from the *i* – th position to the j – th transition:

$$d_{ij}^- = \begin{cases} 1, & \text{if} \quad p_i \in I(t_j); \\ 0, & \text{if} \quad p_i \notin I(t_j). \end{cases}$$

Step 2. Creating a matrix of output incidents $D^+ = [d_{ij}^+]$, where $j = \overline{1,m}$, $i = \overline{1,n}$. The element d_{ij}^+ is equal to the number of arcs from the *j* – th transition to the i – th position:

$$d_{ij}^+ = \begin{cases} 1, & \text{if} \quad p_i \in O(t_j); \\ 0, & \text{if} \quad p_i \notin O(t_j). \end{cases}$$

where $1 \in N_0$.

Step 3. Determining the number of columns d of the initial marking matrix M_0:

3.1 It is believed max=d_{11}^{-};

3.2 If $d_{ij}^{-} > \max$, then is assigned max=d_{ij}^{-}, where $j=\overline{1,m},\ i=\overline{1,n}$;

3.3 Iit is believed d= max.

Step 4. Creating a matrix of initial marking $M_0=[\mu_{ij}]$, where $i=\overline{1,n},\ j=\overline{1,d+1}$.

Step 5. Determination and input elements of the vector parameters of the markers time delays in the positions: $z=(z_1,z_2,...,z_n)$.

Step 6. Determination and input the elements of the vector parameters of the triggering time transitions: $s=(s_1,s_2,...,s_m)$.

Step 7. The initial time the functioning of the network is taken: k=0 and $\tau_{ki}=0$, $i=\overline{1,4}$.

Step 8. Calculation elements of the vector ∂:

8.1 Iit is set as: $i=1$;

8.2 It is set as: $r=0$;

8.3 if the condition $\mu_{ij}\neq 0$, then assigned $r=j$, for all $j=\overline{1,d+1}$;

8.4 is assigned $\partial_i=r-1$ and the index i is increased by one: i=i+1. If $i\leq n$, then the transition to step 8.2 takes place, otherwise go to step 9.

Step 9. Search for allowed transition: for each transition $t_j, j=\overline{1,m}$, the trigger condition is checked: If the condition $\partial_i \geq d_{ij}^{-}$ $(i=\overline{1,n})$ is satisfied for all input positions of the t_j transition, then the transition t_j is allowed, and is performed the transition to step 12.

Step 10. If the trigger condition is not met for the $t_j$transition, then the index j is increased by one: j = j + 1 and are accepted k=k+1 . If $j\leq m$, then the transition is carried out in step 8, otherwise is reported a deadlock condition and is performed a transition to the end of algorithm.

Step 11. Calculation of the maximum time for blocking markers at the input positions of transitions t_j:

11.1. it is set as $z_{max_i} = 0$, for all $i = \overline{1,4}$;

11.2. For all $d^-_{ij} \neq 0, (i = \overline{1,n})$ is calculated :

11.3. If the condition $z_{i1} > z_{max_1}$ is satisfied, then $z_{max_1} = z_{i1}$ is accepted;

11.4. If the condition $z_{i2} > z_{max_2}$ is satisfied, then $z_{max_2} = z_{i2}$ is accepted;

11.5. If the condition $z_{i1} - z_{i3} > z_{max_3}$ is satisfied, then $z_{max_3} = z_{i1} - z_{i3}$ is calculated;

11.6. If the condition $z_{i2} + z_{i4} > z_{max_4}$ is satisfied, then $z_{max_4} = z_{i2} + z_{i4}$ is calculated;

Step 12. Calculated: $z_{max_3} = z_{max_1} - z_{max_3}$; $z_{max_4} = z_{max_4} - z_{max_2}$.

Step 13. Calculation of the degree of belonging q_j of a fuzzy triggering transition t_j:

13.1 if $d^-_{ij} \neq 0, (i = \overline{1,n})$, then believe $q_j = const > 1$; $max = 0$ and the transition to item 14.2 is carried out;

13.2 if $\mu_{ir} > max$, then is assigned $max = \mu_{ir}$, $(r = \overline{d^-_{ij} + 1, d + 1})$;

13.3 if $(max < q_j) \wedge (max > 0)$, then believe $q_j = max$, where $\wedge$ –is the operation of the logical minimum;

Step 14. Calculation of the time τ fuzzy performance of the transition t_j:

Step 15. Calculation elements of the matrix of new marking M' :

15.1 For all $d^-_{ij} \neq 0, (i = \overline{1,n})$ is calculated:

15.1.1 It is set as : $max = \mu_{i1}$; if $\mu_{ir} > max$, then it is assigned $max = \mu_{ir}$, $(r = \overline{1, d^-_{ij} + 1})$;

15.1.2 Assigned $\mu'_{i1} = \max$;

15.1.3 Assigned $\mu'_{ir} = \mu_{i,r+d^-_{ij}}$, $r = \overline{2, d+1}$;

15.2 For all $d^+_{ij} \neq 0, (i = \overline{1,n})$ is calculated:

15.2.1 if the condition $\mu_{ir} < 1 - q_j$ is satisfied, then $\mu'_{ir} = \mu_{ir}$, otherwise $\mu'_{ir} = 1 - q_j$, $(r = \overline{1, d^+_{ij}})$;

15.2.2 if $\mu_{ir} < 1 - q_j$, then $\min 1 = \mu_{ir}$, otherwise $\min 1 = 1 - q_j$; if $\mu_{i,r-d^+_{ij}} < q_j$, then $\min 2 = \mu_{i,r-d^+_{ij}}$, otherwise $\min 2 = q_j$; if $\min 1 > \min 2$, then $\mu'_{ir} = \min 1$, otherwise $\mu'_{ir} = \min 2$, for all $r = \overline{d^+_{ij} + 1, d+1}$.

Step 16. The new marking is taken as current: $\mu_{ir} = \mu'_{ir}$; $(1 = \overline{1,n};\ r = \overline{1, d+1})$ and the transition to step 8 is made.

End of algorithm.

➢ **Control model the module of parallel functioning machining devices in the mechanical processing system in the form FTPN type V_f**

Consider a typical machining center of mechanical processing consisting of three personal input drives, three parallel processing devices(PD) of the same type to perform the same operation on different types of workpiece and three personal output drives. The module handles parts of the same type. Workpiece arrive at personal input drives and are waiting processing. One free device (there are three such devices in total) captures the workpiece from the left or right input drive. If all devices are free, then there is a conflict situation. The conflict is resolved by random selection of the fuzzy laws of composition. The machined details arrive at the output drives and are waiting sending.The model of control of parallel processing devices in a flexible production system of mechanical processing is described in the form of FTPN. In the developed graph-models the state of the network is described by the following positions[2]:

p_1, p_5, p_8 – respectively, PD1, PD2, PD3 in the initial state and in the standby mode; p_3, p_4, p_6 – respectively, the presence of the workpiece in the input drives and the input drives are free; p_2, p_7, p_9 – respectively, PD1, PD2, PD3 in the final state and on the output drives there is a processed detail.

Possible events in the module are described by the following transitions: t_1, t_3, t_5 – processing of the workpiece starts at PD1, PD2, PD3, respectively; t_2, t_4, t_6 – ends processing of the workpiece in PD1, PD2, PD3, respectively.

The initial marking matrix of the control model developed in the form of FTPN type V_f is given as follows:

$$\mu^0(9,4) = \begin{Vmatrix} 0.30 & 0.80 & 0.00 & 0.00 \\ 0.10 & 0.20 & 0.60 & 0.90 \\ 0.50 & 0.70 & 0.00 & 0.00 \\ 0.40 & 0,80 & 0.00 & 0.00 \\ 0.60 & 0.70 & 0.00 & 0.00 \\ 0.30 & 0.90 & 0.00 & 0.00 \\ 0.10 & 0.20 & 0.60 & 0.90 \\ 0.70 & 0.80 & 0.00 & 0.00 \\ 0.10 & 0.20 & 0.60 & 0.90 \end{Vmatrix}$$

Elements of the vector of parameters of time delays of markers in positions:

$$z_1 = \langle 1, 2, 0, 1 \rangle, \quad z_2 = \langle 2, 3, 1, 1 \rangle, \quad z_3 = \langle 3, 4, 1, 1 \rangle,$$
$$z_4 = \langle 2, 3, 1, 0 \rangle, \quad z_5 = \langle 2, 4, 1, 1 \rangle, \quad z_6 = \langle 1, 4, 0, 3 \rangle,$$
$$z_7 = \langle 3, 5, 1, 1 \rangle, \quad z_8 = \langle 2, 3, 0, 1 \rangle, \quad z_9 = \langle 4, 5, 0, 1 \rangle.$$

Elements of the vector of parameters of the response times of

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[2] Мустафаев, В.А., Салманова, М.Н. Моделирование динамических взаимодействующих процессов с применением нечетких временных сетей Петри типа V_f //–Москва: Вестник компьютерных и информационных технологий, – 2019. № 9(183), – с.19-26.

allowed transitions:

$$s_1 = \langle 0,1,0,1 \rangle,\ s_2 = \langle 1,2,0,1 \rangle,\ s_3 = \langle 2,3,0,1 \rangle,$$
$$s_4 = \langle 3,4,0,1 \rangle\ s_5 = \langle 2,3,0,1 \rangle,\ s_6 = \langle 1,2,1,0 \rangle.$$

Based on the initial data, a computer experiment was conducted and the sequence of transitions triggering $\sigma = (t_1, t_2, t_3, t_4, t_5, t_6)$ was obtained from the initial marking and fuzzy time intervals for the appropriate transitions:

τ_1 =<3,5,1,2>, τ_2=<6,10,2,4>, τ_3 =<11,17,3,8>,
τ_4 =<17,26,4,10>, τ_5 =<21,33,4,14>, τ_6 =<26,40,5,15>.

The fourth chapter is devoted to the development of software for modeling complex systems using FTPN. A classification scheme of PN extensions used in the modeling and control of dynamic interacting parallel processes in real time is given. A block diagram of computer modeling of research and installation of the model with the appropriate software is developed, the stages of the software development process are shown.

Software for modeling dynamically interacting processes using FTPN was developed as a two-level system of semantic control: system programs (level I), application program management (level II). System software includes: management, service programs, design, instrumental programming systems, user interface creation and program code, testing, analysis of results and documentation. Management applications consist of the following software modules: operation and analysis of TPN, operation and analysis of CTPN, operation and analysis of triangular FTPN, operation and analysis of trapezoidal FTPN, operation and analysis of FPN type V_f, and operation and analysis of FTPN type V_f Each of these modules includes many software modules, procedures and routines.

The main aspects of the operation of control applications developed in the visual programming environment Delphi 7.0 are shown. Tools and applications for modeling parallel distributed systems using FTPN are released in MATLAB using the Fuzzy Logic Toolbox fuzzy simulation extension package.

MAIN RESULTS OF THE DISSERTATION

1. For the study and control of parallel asynchronous processes characterized by uncertainty, fuzzy properties, the choice of temporary, colored temporary triangular fuzzy time, trapezoidal fuzzy time, fuzzy type V_f and fuzzy time type V_f extensions PN in real time is justified as a modeling apparatus.

2. An approach based on fuzzy sets and the theory matrices of PN is proposed, which transforms data into a form used in the modeling environment, describes the structure, dynamics, set of situations, a sequence of transitions in the form of a set of vectors and matrices, which forms generalized modifications of PN with time parameters, eliminating conflicts. accelerating the modeling process.

3. Proposed and developed algorithms for the functioning, analysis and calculation of structural elements TPN and CTPN. In the production system machining a model control of processing devices in the form of TPN and CTPN, a model synchronization the operation of transport manipulators and a model control of a transport manipulator in the form of CTPN have been developed.

4. Algorithms for the functioning, analysis and calculation of the structural elements of the triangular and trapezoidal FTPN are proposed and developed. The control model of a robotic complex with cyclic action was developed in the form of a triangular FTPN, the control model of parallel-functioning processing devices in the machining system was developed in the form of a trapezoidal FTPN.

5. Algorithms for the functioning, analysis and calculation of structural elements FPN of type V_f and FTPN of type V_f with fuzzy marking in positions are proposed and developed. The control model of parallel-functioning processing devices in the machining system was developed in the form FPN of type V_f and FTPN of type V_f.

6. Developed decision-making models based on production rules for the functioning of CTPN and FTPN of type V_f.

7.Delphi 7.0 system has developed software for modeling complex systems using FTPN. Using software, control models using the Fuzzy Logic Toolbox in MATLAB were investigated.

THE MAIN PROVISIONS OF THE DISSERTATION ARE PUBLISHED IN THE FOLLOWING SCIENTIFIC PAPERS:

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6. Мустафаев, В.А., Салманова, М.Н. Алгоритм вычисления структурных элементов модели нечеткого управления // **Материалы международной научной конференции «Теоретические и прикладные проблемы математики»**, −

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