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# Improving Fuzzy Network Models For the Analysis of Dynamic Interacting Processes in the State Space

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***Abstract*: Most promising approaches that deal with dynamics of interacting processes do not take into consideration the fuzzy properties of all components and the state space of the model, the set of parameters and features of the subject domain. This leads us to create integrated systematic approach to solve these problems as a sole task for developing new effective mathematical fuzzy models that take into account the advantages of existing models, formal criteria and approaches, modern technologies, methods and tools for solving theoretical and practical tasks.**

***The extended fuzzy Petri Networks and their further development are proposed with new capabilities to solve the analysis and adaptation problems depending on the peculiarities of the processes of the subjected area.***

***The proposed approach which is mainly based on some general provisions for the development of color Petri nets and fuzzy colored Petri dishes, tends to create a new class of fuzzy Petri nets to effectively solve complex tasks while reducing the dimension of the model and complexity. The implementation of the model is focused on the use of modern information technologies. Colored Petri nets can be considered an effective tool for determining the size of network models. Limitations on the homogeneity of logical operations are presented taking into account fragments of fuzzy network models. This can be done by practical use of the presented models..***

***Keywords*: fuzzy network models, Petri's network, positions, transitions, colored fuzzy Petri Networks, modeling, technology.**

## I. INTRODUCTION

Given that objects of special purpose function in a priori uncertainty, characterized by a fuzzy space of states, which requires new intellectual approaches to increase the reliability of the decisions that are adopted, characterized by functional and territorial distribution, a complex hierarchy of interacting processes [1]. It is necessary to predict certain requirements to the mathematical apparatus, methods of object-oriented modeling and analysis of interacting processes of a complex system, taking into consideration such systems may be different [2]–[4].

## II. PROBLEM STATEMENT

Mathematical models based on the apparatus of fuzzy sets, in general, reflecting relatively simple processes and procedures but not allow to explicitly taking into account the parallelism and dynamics in their interaction, as well as the set of parameters and features of the subject domain. Prospects are the solution based on mathematical fuzzy network models (FNM).

Existing solutions based on fuzzy Petri networks, as the most promising device for displaying the dynamics of interacting processes, do not provide for the consideration of the fuzzy properties for all components and the space of states of the model, as well as taking into account the set of parameters and features of the subject domain.

Thus, there is an urgent need to create integrated systematic approach to solve these problems as the sole task of developing new effective mathematical fuzzy models that take into account the advantages of existing models, formal criteria and approaches, modern technologies, methods and tools for solving theoretical and practical tasks.

## III. REVIEW OF THE LITERATURE

The tasks of comprehensive provision of adequate reflection of interacting dynamic fuzzy processes, as well as optimization of resources and the choice of alternatives to the development of fuzzy processes on the set of constraints, are important and at this time, there are no solutions that would find effective application in practical implementations. They often have an empirical, highly specialized character. An analysis of domestic and foreign sources has shown that studies in this area are not efficient enough and do not fully reflect the features of interacting dynamic fuzzy processes and systems. Existing approaches to analyzing, modeling and constructing complex data management and processing systems under these conditions [5]–[8] are ineffective because of their functional limitations. It should be noted that the promising apparatus for constructing complex systems is the use of fuzzy logic by Lotfi Zade, and for the analysis and modeling of interacting processes of complex systems.

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It is expedient to use the petri net system (PN) [9] and its extensions [10]–[14]. The aim of the study is to create effective models based on the ideas and principles of fuzzy logic, by integrating extended Petri net and the theory of fuzzy sets. The object of the study is the process of analyzing dynamic interacting processes in the state space.

The subject of the study is the apparatus of the theory of Petri Networks and their extensions.

## IV. MATERIALS AND METHODS

Given the significant limitations and assumptions, as well as the drawbacks of known models, new solutions and approaches to the further development of ideas for the construction of mathematical models are proposed. Classes of fuzzy network models (FNM) are considered which integrate the advantages of models based on PN and neuro-fuzzy networks (NFN).

Mathematical interpretation of FNM is given as:

$$\tilde{S}(f) = <\tilde{P}, \tilde{T}, \tilde{F}(f), \tilde{M}(f)_0, L>, \quad (1)$$

where:

- $\tilde{P} = \{\tilde{p}_j : \mu_{\tilde{p}_j}(k)\}$ – the finite set of fuzzy positions $\tilde{p}_j$.
- $\mu_{\tilde{p}_j}(k)$ – a function belonging to the j-th fuzzy set position $\tilde{P}$.
- k – some variable that defines the function argument $\mu_{\tilde{p}_j}(k)$, $j = \overline{1,m}$, $\tilde{P} \neq \varnothing$, $|\tilde{P}| = m$.
- $\tilde{T} = \{\tilde{t}_i : \mu_{\tilde{t}_i}(k)\}$ – the finite set of fuzzy transitions $\tilde{t}_i$, $i = \overline{1,n}$, $\tilde{T} \neq \varnothing$, $|\tilde{T}| = n$.
- $\mu_{\tilde{t}_i}(k)$ – a function belonging to the i-th fuzzy transition.

$$\tilde{F}(f) : (\tilde{P} \times \tilde{T}) \cup (\tilde{T} \times \tilde{P}) \rightarrow \{x_{ij}(k),\ y_{ij}(k)\}. \quad (2)$$

where:

- $\tilde{F}(f)$ – fuzzy function of incidence $\tilde{P}$ and $\tilde{T}$.
- $x_{ij}(k)$, $y_{ij}(k)$ – functionalities of incoming and outgoing incidents of some fuzzy positions $\tilde{p}_j \in \tilde{P}$ and fuzzy transitions $\tilde{t}_i \in \tilde{T}$.

It should be noted that the initial fuzzy space of states of model (1) is determined by the vector of fuzzy initial marking $\tilde{M}(f)_0$ of fuzzy model positions $\tilde{P}$:

$$\tilde{M}(f)_0 = \{\tilde{M}(\tilde{p}_j) : z_{\tilde{p}_j}(k), \quad (3)$$

where:

- $\tilde{M}(\tilde{p}_j) \rightarrow [0,1]$ – fuzzy marking of a fuzzy position $\tilde{p}_j \in \tilde{P}$ FNM.
- $z_{\tilde{p}_j}(k)$ – the function of the marking of the j-th fuzzy position $\tilde{p}_j \in \tilde{P}$.
- L – some predicate, which depends on the set of variables $\{x_u\}$, $u \in U$.

During the study, it was determined that with increasing the dimension of a complex system in FNM it is necessary to take into account $\{x_u\}$, $u \in U$ – a set of additional parameters, characteristics and conditions. It is established that an effective mechanism for reducing the dimension of FNM (1) can be considered colored fuzzy Petri networks (CFPN).

The concept of CFPN introduced in this way is introduced:

$$\tilde{S}_C(f) = <\tilde{P}, \tilde{T}, \tilde{F}_C(f), \tilde{M}_{0C}(f), \tilde{M}_C(f), L\{x_u\}, \tilde{C}, \tilde{V}, \tilde{K}>, (4)$$

where:

- $\tilde{P}$ – set of fuzzy positions.
- $\tilde{T}$ – set of fuzzy transitions.

$$\tilde{F}_C(f) = (\tilde{P} \times \tilde{T}) \cup (\tilde{T} \times \tilde{P}). \quad (5)$$

where:

- $\tilde{F}_C(f)$ – fuzzy function of network incidents $\tilde{S}_C(f)$.
- $\tilde{M}_{0C}(f)$ – vector of initial marking.
- $\tilde{M}_C(f)$ – vector of current marking.
- $L\{x_u\}$, $u \in U$ – a certain predicate, assigned to the set of positions, transitions, functions of incidence in the space of states of fuzzy interacting processes, which determines the additional conditions for the implementation of transitions.
- $\tilde{C}$ – a marker color function that defines the color of each marker $\tilde{M}(\tilde{p}_j)$ for the network position.
- $\tilde{V}$ – conditions for the operation of transitions depending on the color of the marker.
- $\tilde{K}$ – number of markers in positions with the account $\tilde{C}$.

Consequently, from (4), the network integrates the network (3) and the advantages of CFPN. In addition, the introduction of the predicate $L\{x_u\}$, $u \in U$ into model (4), as well as properties $\tilde{C}$, $\tilde{V}$, $\tilde{K}$ significantly increase the possibilities of the model compared with existing approaches.

Due to the introduction of color properties, the power of sets decreases substantially $|\tilde{P}|, |\tilde{T}|$, and the incidence of the incidence $\tilde{F}(f)$ and the incidence matrix is increased $\tilde{H}(f)$. The rarity of the incidence function $\tilde{F}(f)$ and the incidence matrix $\tilde{H}(f)$ can be given as:

$$1 - \frac{\sum_{i=1}^{n}\sum_{j=1}^{m}(x'_{ij}(k_0) + y'_{ij}(k_0))}{|\tilde{T}||\tilde{P}|}, \quad (6)$$

where:

$$x'_{ij}(k_0) = \begin{cases} 1, \text{ if } x_{ij}(k_0) \neq 0, \\ 0, \text{ if } x_{ij}(k_0) = 0, \end{cases}$$

$$y'_{ij}(k_0) = \begin{cases} 1, \text{ if } y_{ij}(k_0) \neq 0, \\ 0, \text{ if } y_{ij}(k_0) = 0. \end{cases}$$

Thus, it can be argued that (4) is a significant extension of FNM.

It should be noted that the important factor determining the efficiency of this model is the formalization and interpretation of dynamic interacting processes in terms of the model (4).

In addition, for the network (3) the following interpretation is proposed:

– the set of fuzzy transitions $\tilde{t}_i \in \tilde{T}$ of FNM $\tilde{S}(f)$ interprets a set of fuzzy actions $\{\tilde{d}_r\}$ of simulated fuzzy processes $\{\tilde{\Pi}_i\}$. In the general case:

$$\left|\{\tilde{d}_r\}\right| \neq \left|\{\tilde{t}_i\}\right|, \quad \text{if} \quad r \neq 1, i \neq 1;$$

– the set of fuzzy positions $\tilde{p}_j \in \tilde{P}$ of FNM $\tilde{S}(f)$ interprets a set of fuzzy conditions $\{\tilde{U}_l\}$ for the implementation of a set of fuzzy actions $\{\tilde{d}_r\}$. Moreover:

$$\left|\{\tilde{U}_l\}\right| \neq \left|\{\tilde{p}_j\}\right|, \quad \text{if} \quad l \neq 1, j \neq 1;$$

– the dynamics and state of the simulated processes are interpreted by moving the markers from the input positions $\{\tilde{p}_i(in)\}$ of the allowed transition $\tilde{t}_i \in \tilde{T}$ to the output positions $\{\tilde{p}_i(out)\}$ of the considered transition $\tilde{t}_i \in \tilde{T}$.

These rules are largely similar to the network $\tilde{S}_C(f)$. In addition, it is necessary to clarify the interpretation of markers and the space of states of the proposed model.

If a network is specified $\tilde{S}_C(f)$ and vectors are defined $\tilde{M}_{0C}(f)$, $\tilde{M}_C(f)$, then the mark $\tilde{M}_b(\tilde{p}_j) = 1$, $b$ of a color from $C_{bj} \in \{C_{bj}\}, b \in B, j \in J$ the marking of the position $\tilde{p}_j \in \tilde{P}$ determines the existence of some $b$ resource specified on the set of resources $R_b \in \{R_b\}, b \in B$ of the simulated domain processes. The fairness of the situation is based on the definition and essence of the dynamics of the development of processes when they are modeled on the networks of Petri.

If a network is specified $\tilde{S}_C(f)$, the value $C = \{C_\alpha\}, \alpha \in A$, where $\alpha$ – some color of $A$, and the volume $K$ of markers, according to the accepted interpretation of the space of states, are, for some position $\tilde{p}_j \in \tilde{P}$, related in the following way: $K_{\tilde{p}_j} = |C_{\alpha \tilde{p}_j}|$. The equivalence of the provision proceeds from the essence and interpretation $\tilde{M}_\alpha(\tilde{p}_j) = 1$ of the color marker $\alpha$. We also take into account that the function determines $C = \{C_\alpha\}, \alpha \in A$, besides the actual color, in this case also the volume of markers of each color in the positions $\tilde{p}_j \in \tilde{P}$ of the network $\tilde{S}_C(f)$.

The presence of some set of colored markers $|B|$ in the positions $\tilde{S}_C(f)$ of the network requires the definition of the conditions for the permissibility of its transitions.

Fuzzy transition $\tilde{t}_i \in \tilde{T}$ (3) is allowed $R_t$, if true:

$$\begin{aligned}
&((\tilde{t}_i \in \tilde{T} : \mu_{\tilde{t}_i}(k_0) \geq \mu_{\tilde{t}_i}(k_0)^*) \text{ and } ((\forall \tilde{p}_j \in \{\tilde{p}_i(in)\} \Big| \\
&\tilde{p}_j : \mu_{\tilde{p}_j}(k_0) \geq \mu_{\tilde{p}_j}(k_0)^*) \text{ and} \\
&\text{and } (\forall \tilde{M}(\tilde{p}_j) \in \tilde{M}(f) \big| (\tilde{M}(\tilde{p}_j) \geq 1) \text{ and} \\
&\text{and } (z_{\tilde{p}_j}(k_0) \geq z_{\tilde{p}_j}(k_0)^*)) \text{ and} \\
&\text{and} (x_{ij}(k_0) \geq x_{ij}(k_0)^*) \text{and } L = \text{true}),
\end{aligned} \tag{7}$$

where :

– $\mu_{\tilde{t}_i}(k_0)^*, \mu_{\tilde{p}_j}(k_0)^*, z_{\tilde{p}_i}(k_0)^*, z_{\tilde{p}_j}(k_0)^*, x_{ij}(k_0)^*$ – the restrictions on the value of the corresponding membership functions,

– $k_0$ – a certain value of a variable $k$ that defines a specific, based on expert estimates of the subject area, the value of the corresponding membership function.

Taking into account (4) and (7), we determine the conditions of the permissibility of network transitions $\tilde{S}_C(f)$.

Some $\tilde{t}_i \in \tilde{T}$ network $\tilde{S}_C(f)$ override is allowed if it is true:

$$\begin{aligned}
&R_t(\tilde{S}_C(f)) = \tilde{t}_i \in \tilde{T} \,|\, (\mu_{\tilde{t}_i}(k_0) \geq \mu_{\tilde{t}_i}(k_0)^*) \text{ and} \\
&\text{and} (\forall \tilde{p}_j \in \{\tilde{p}_i(in)\} \,|\, (\mu_{\tilde{p}_j}(k_0) \\
&\geq \mu_{\tilde{p}_j}(k_0)^*) \text{ and} \\
&\text{and} (\forall \tilde{M}_{C_\alpha}(\tilde{p}_j) \in \tilde{M}_C(f) \,|\, (\tilde{M}(\tilde{p}_j) > 1) \text{ and} \\
&\text{and } (z_{\tilde{p}_j}(k_0) \geq z_{\tilde{p}_j}(k_0)^*))) \text{ and} \\
&\text{and} (x_{ij}(k_0) \geq x_{ij}(k_0)^*) \text{ and } (L = \text{true}) \text{ and} \\
&\text{and} (\tilde{V} = \text{true}),
\end{aligned} \tag{8}$$

where:

– $\tilde{M}_{C\alpha}(\tilde{p}_j)$ – the mark (marker) of the color $\alpha$ in the position $\tilde{p}_j$.

– $V = V(K_{\tilde{p}_j \in \{\tilde{p}_i(in)\}}, C_{\alpha\, \tilde{p}_j \in \{\tilde{p}_i(in)\}})$ – the condition of the transition, depending on the color and volume of the markers.

Studies have shown that this approach is effective in practical implementation and reduces the dimensionality of the investigated processes.Analyze the test case, when the process can be run only if several conditions are fulfilled, and consider the additional capabilities of CFPN (4) as compared to the FNM (1). Let, for certainty, there is a process $\tilde{d}_r$, for which it is necessary to fulfill three conditions: $\tilde{U}_1, \tilde{U}_2, \tilde{U}_3$ from a plurality $\tilde{U}_l, l \in L$.

## V. EXPERIMENTS

Let's base the formalization and interpretation of dynamic interacting fuzzy processes on the basis of the apparatus (1) and (4).

Consider the mapping of interacting processes for cases where:

– the process is performed in the presence of exactly one input and even one output condition

$$\exists \tilde{t}_i \in \tilde{T} \,||\, \{\tilde{p}_i(in)\} | = | \{\tilde{p}_i(out) | = 1; \quad (9)$$

– the process is performed in the presence of several (not equal to one) input and even one source condition

$$\exists \tilde{t}_i \in \tilde{T} \,|\, (| \{\tilde{p}_i(in)\} | > 1) \text{ and } (| \{\tilde{p}_i(out) | = 1); \quad (10)$$

– the process is performed in the presence of exactly one input and several (not equal to one) output conditions

$$\exists \tilde{t}_i \in \tilde{T} \,|\, (| \{\tilde{p}_i(in) | = 1) \text{ and } (| \{\tilde{p}_i(out) | > 1); \quad (11)$$

– some condition of the process has several (not equal to one) input processes and exactly one output process

$$\exists \tilde{p}_j \in \tilde{P} \,|\, (| \{\tilde{t}_j(in)\} | > 1) \text{ and } (| \{\tilde{t}_j(out)\} | = 1); \quad (12)$$

– some condition of the process has exactly one input process and several (not equal to one) output processes

$$\exists \tilde{p}_j \in \tilde{P} \,|\, (| \{\tilde{t}_j(in)\} | = 1) \text{ and } (| \{\tilde{t}_j(out)\} | > 1); \quad (13)$$

– some condition has only exactly one output process

$$\exists \tilde{p}_j \in \tilde{P} \,|\, (| \{\tilde{t}_j(in)\} | = 0) \text{ and } (| \{\tilde{t}_j(out)\} | = 1); \quad (14)$$

– some condition has only exactly one input process

$$\exists \tilde{p}_j \in \tilde{P} \,|\, (| \{\tilde{t}_j(in)\} | = 1) \text{ and } (| \{\tilde{t}_j(out)\} | = 0); \quad (15)$$

– the process is performed in the presence of several (not equal to one) input and several (not equal to one) output conditions

$$\exists \tilde{t}_i \in \tilde{T} \,|\, (| \{\tilde{p}_i(in)\} | > 1) \text{ and } (| \{\tilde{p}_i(out) | > 1); \quad (16)$$

– some condition for the implementation of the process has several (not equal to one) input processes and several (not equal to one) output processes

$$\exists \tilde{p}_j \in \tilde{P} \,|\, (| \{\tilde{t}_j(in)\} | > 1) \text{ and } (| \{\tilde{t}_j(out)\} | > 1), \quad (17)$$

where:

- $\{\tilde{t}_j(in)\}$ – the set of entrance positions of the position $\tilde{p}_j$.
- $\{\tilde{t}_j(out)\}$ – the set of output positions of the position $\tilde{p}_j$.

It should be noted that the fragment (16) can be presented as a sequential combination of fragments (10) and (11). Fragment (17) can be represented as a sequential combination of fragments (12) and (13). In this regard, we exclude from further self-examination fragments (16) and (17), unless specifically stated.

For each of the fragments from (9)–(13) define the conditions for the permissibility of the transitions and the conditions for marking the positions of the models.

Taking into account that the considered fragments (9)–(11) differ only in the number of input $|\{\tilde{p}_i(in)\}|$ and (or) output positions $|\{\tilde{p}_i(out)\}|$ of the considered transition $\tilde{t}_i$, then the corresponding conditions (7) of the permissibility of the transitions for models are valid for them $\tilde{S}(f), \tilde{S}_C(f)$.

Given that the fragments (12)–(15) differ in the number of input $|\{\tilde{t}_j(in)\}|$ and / or output $|\{\tilde{t}_j(out)\}|$ transitions of the considered position $\tilde{p}_j$, the above conditions for their permissibility are also valid for the transitions $\{\tilde{t}_i\}$ included in the corresponding fragment from (12)–(15).

Interacting dynamic, fuzzy processes that represent fragments of knowledge, data, and complex procedures of their interaction can be formally presented, depending on their application, in different ways [1]. Without claiming to be complete in this regard, the most common formal representations of interacting processes in practical applications should be considered:

- analytical mappings.
- the logic of predicates containing logical, including fuzzy, operations – AND, OR, NO, their derivatives and logical functions.
- graphical representation, for example, in graphic diagrams of algorithms, including fuzzy rules of products based on if / then relationships.

Given that the analytical description and display of interacting dynamic fuzzy processes in practical applications can generally be presented by others, from the above formal descriptions, for example, in the form of a sequence of operations (algorithms), logical operations, etc. [5], then we exclude them from further consideration.

We construct a fragment of the model of interacting processes using fuzzy network models (1). The conditions of the three positions $p_1, p_2, p_3$ (Fig. 1) ensure the implementation of the transition $t_1$ (the process is carried out $\tilde{d}_r$).

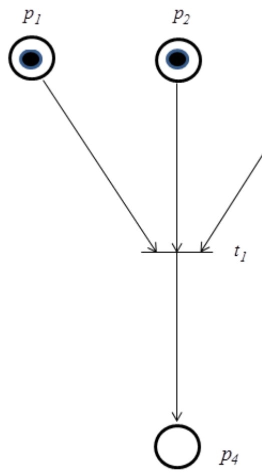


**Fig. 1. A model fragment constructed using a network (1).**

In Fig. 2 we will demonstrate this fragment of the model using painted fuzzy Petri nets (4). In Figure 2, the position $p_3$ is marked with three-color labels, which is conventionally shown as an additional marking of some conventional positions $p_1, p_2$.

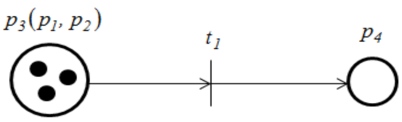


**Fig. 2. A model fragment constructed using a network (4).**

The analysis of the above figures showed that the latter version greatly simplifies resource costs. Therefore, the efficiency of CFPN will increase with increasing dimensionality of the model. This is especially true in distributed or hierarchical complex systems, which take into account, apart from objective and subjective factors, meteorological, geographic, physical and chemical. Most of these factors are poorly formalized, so their influence is realized on the basis of fuzzy expert assessments.

## VI. RESULT AND DISCUSSION

As follows from the above, it is necessary, at least, to provide fragmentation (1), (4), logical operations I, OR, NO, and the membership functions $\mu_{\tilde{\Pi}_i}, i \in I$ of the model component when describing interacting dynamic fuzzy processes presented by the logic of predicates.

We formulate the following provisions:

- The operation and $a_i, i \in I$ can be given by a fragment of the model (10).
- The fairness of the situation is based on the properties of the transition $\tilde{t}_i$ of the fragment (10) when marking all the input positions $\tilde{p}_j \in \{\tilde{p}_i(in)\}$ of the fragment.
- The operation or $a_i, i \in I$ can be represented by a fragment of the model (12).
- The fairness of the position is based on the property of marking the position $\tilde{p}_j$ of the fragment (12) when performing at least one transition $\tilde{t}_i \in \{\tilde{t}_j(in)\}$ of the position $\tilde{p}_j$ of the fragment.

It should be noted that in this interpretation, in fragment (12) there is a possibility of a conflict, and this should be taken into account in practical applications.

The operation NO can be given by inserting into the fragment (9) of the inhibitory arc and by modifying the permissibility of its transition $\tilde{t}_i$ in such a way that it will be resolved in the right way:

$$\begin{aligned}&\exists \tilde{t}_i \in \tilde{T} \mid (|\{\tilde{p}_i(in)\}| = |\{\tilde{p}_i(out)| = 1) \text{ and}\\ &\text{and}((\tilde{M}(\tilde{p}_j) = 0) \text{ or } (z_{\tilde{p}_j}(k_0) < z_{\tilde{p}_j}(k_0)^*))\end{aligned} \quad (18)$$

The fairness of the situation is based on the properties of the inhibitory arcs to control the permissibility of the transition, when the permissibility of the transition $\tilde{t}_i$ of the modified fragment (9) is possible without the marking of the entry $\tilde{p}_j \in \{\tilde{p}_i(in)\}$ of the fragment and (or) justice (18).

In the case of the submission of interacting dynamic fuzzy processes, complex procedures in the form of graphical representation of algorithms, it is necessary to select and describe fragments of fuzzy models of the least such fragments:

– development of processes for a logical condition;

– development of processes for the implementation of at least one of the previous ones.

– parallelization of processes.

– development of processes at the end of all previous.

– beginning of process development.

– obtaining the expected result.

The development of information technology has brought about significant changes regarding the mapping of the space of states of the interacting processes of complex systems, the integration of traditional approaches and geoinformatics has greatly influenced.

The tool for realizing the provisions of geoinformatics is geographic information systems (GIS) that allow the use of modern object-oriented information technology and remote sensing technology for describing spatially distributed objects.

For research and modeling of specific spatial objects, models are used: digital spatial model of geospatial data, information model, and mathematical model of the image.

It should be noted that methods of geographic modeling of a complex geosystem and its components include modeling of structure, dynamics, interconnection, and also functioning of the system in space and time. The main component of the simulation is the digital model of the terrain, which can be obtained using modern technology. The condition of perception of a digital map is the visualization of a cartographic image encoded on it by displaying its contents on the monitor screen.

In addition, distinguish the following types of information models: information descriptive, information resources, intellectual. The information descriptive (descriptive) class includes models that are constructed as a description of a process, phenomenon or object, for example, a file, a text document.

Information resource model is able to accumulate data for its improvement and optimization (database model). An intellectual model is capable of accumulation of information, self-improvement and implementation of actions based on knowledge-oriented technologies, the use of fuzzy logic, pattern recognition.

Information models are based on mathematical models of the image.

The problem of fuzzy spatial data modeling of complex spatially distributed objects is quite complex and multifaceted. The study suggests the creation of meteorological data based on applications of intellectual approaches that combine object-oriented databases and knowledge for modeling and queries of spatially distributed objects. The analysis of these works showed the importance and promise of research based on models that use fuzzy logic and knowledge-oriented technologies.

In the future, there are perspective studies based on the models of spatial analysis of the states of interacting processes of complex systems using fuzzy logic and knowledge-oriented technologies of geoinformatics.

## VII. CONCLUSION

We formulate some provisions that define the interpretation of fragments of the model:

– the computational process, the process of management, decision-making $\tilde{\Pi}_i$ can be presented on the model by fragment (9).

– the development of fuzzy processes in the implementation of the logical condition on the model can be implemented by fragment (14).

– the development of processes in the performance of at least one of the previous on the model can be implemented by fragment (15).

– the procedure for parallelizing the processes $\{\tilde{\Pi}_i\}$ can be given by the fragments of model (11).

– the procedure for the development of processes $\{\tilde{\Pi}_i\}$ at the end of all preceding can be given by model (10).

– procedures for initiating the development of processes and obtaining the desired result can be presented in accordance with the fragments (14) and (15) of the model.

An important area of creating data management and processing systems is the design and implementation of knowledge-bases based on production systems, as well as their modeling and research tools. In this regard, it is advisable to propose the procedures for displaying the rules of products of the appearance if / then of the model fragments (9)–(15). Without loss of generality, consider the case when the rules of products present logical operations of one type.

If the fragments of the knowledge-base are given by the rules of the products of the species if / then, then it is obvious that the rules of products can be represented by fragments of fuzzy network models $\tilde{S}(f), \tilde{S}_C(f)$, similarly to the representation of interacting processes with predicates, logical functions and operations.

Considering the structure of the product rules in a clear representation:

$$\text{if } A \text{ and } B \text{ and } C \text{ then } D. \tag{19}$$

In the verbal presentation (19) can be represented as follows: if true $A$ and $B$ and $C$, then perform action $D$, or in the language of Boolean logic:

$$D = \text{true} \mid (A \text{ and } B \text{ and } C) = \text{true}. \tag{20}$$

For a type expression (20), a solution is already described on the basis of the display of logical operations with the corresponding fragments of fuzzy network models $\tilde{S}(f), \tilde{S}_C(f)$, which allows obtaining the expected result. Similarly (19) and (20) we can show the validity of the corresponding solutions of products containing operations OR, NO and their derivatives.

We note that the properties of fuzziness as components of predicates, as well as graphic representation of algorithms, as well as rules of products are completely determined by the corresponding membership functions. Similarly (19) and (20) in the fuzzy mapping for:

$$\begin{aligned}&\text{if } \tilde{A} \text{ is } \mu_{\tilde{A}}(k) \text{ and } \tilde{B} \text{ is } \mu_{\tilde{B}}(k) \text{ and}\\ &\text{and } \tilde{C} \text{ is } \mu_{\tilde{C}}(k) \text{ then } D \text{ is } \mu_{\tilde{D}}(k)\end{aligned} \tag{21}$$

can be defined as follows:

$$\begin{aligned}&\tilde{D} = \text{true} \mid ((\tilde{A} \text{ and } \tilde{B} \text{ and } \tilde{C}) = \text{true}) \text{ and}\\ &\text{and}(\mu_{\tilde{A}}(k_0) \geq \mu_{\tilde{A}}(k_0)^*) \text{ and}\\ &\text{and } (\mu_{\tilde{B}}(k_0) \geq \mu_{\tilde{B}}(k_0)^* \text{ and}\\ &\text{and}(\mu_{\tilde{C}}(k_0) \geq \mu_{\tilde{C}}(k_0)^*) \text{ and } (\mu_{\tilde{D}}(k_0) \geq \mu_{\tilde{D}}(k_0)^*,\end{aligned} \tag{22}$$

where:

– $\mu_{\tilde{A}}(k_0)^*, \mu_{\tilde{B}}(k_0)^*, \mu_{\tilde{C}}(k_0)^*, \mu_{\tilde{D}}(k_0)^*$ – the boundary values of the corresponding functions of belongings.

The functions $\{\mu_{\tilde{\Pi}_i}(k)\}$ of the plurality of processes $\{\tilde{\Pi}_i\}$ that determine the conditions and actions of the subject domain are reflected in the set of fuzzy positions $\{\tilde{p}_j\}$ and fuzzy transitions $\{\tilde{t}_i\}$ in the space of states of models $\tilde{S}(f), \tilde{S}_C(f)$.

The fairness of the situation is obvious, given that fuzzy models $\tilde{S}(f), \tilde{S}_C(f)$ reflect fuzzy processes in the subject area.

For example, to give a fragment of some fuzzy knowledge to the product rule, which includes fuzzy conditions and fuzzy actions, we can write it in the form (21).

The above is a restriction on the use of only one type of logical operations in the mapping of domain processes. In general, this strong restriction is not mandatory. Let's show it on an example. Using the obtained results, for example, we consider the product rule, which is a modification of the rule (21):

$$\begin{aligned}&\text{if } \tilde{A} \text{ is } \mu_{\tilde{A}}(k) \text{ and not} \tilde{B} \text{ is } \mu_{\tilde{B}}(k) \text{ or}\\ &\text{or} \tilde{C} \text{ is } \mu_{\tilde{C}}(k) \text{ then } \tilde{D} \text{ is } \mu_{\tilde{D}}(k)\end{aligned} \quad . \tag{23}$$

Using the results of the above provisions, as well as distributing the results obtained above to the fragment (23), we obtain a fragment of the model $\tilde{S}(f)$, which includes a sequentially connected modified fragment (10), a fragment (12) and a fragment (10). For the corresponding fuzzy positions and fuzzy transitions of the obtained fragment of the model $\tilde{S}(f)$, functions of belongings $\mu_{\tilde{p}_j}(k), \mu_{\tilde{t}_i}(k)$ are defined in full accordance with the functions $\mu_{\tilde{A}}(k), \mu_{\tilde{B}}(k), \mu_{\tilde{C}}(k), \mu_{\tilde{D}}(k)$. In case of using the model $\tilde{S}_C(f)$, instead of the modified fragment (10), the modified fragment (9) should be used.

Thus, in the practical applications, the above limitations on the homogeneity of logical operations in the rules of products when they are represented by fragments of FNM are removed.

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