The System of Fuzzy Cognitive Analysis and Modeling of System Dynamics

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Abstract. The article considers the developed software system of fuzzy cognitive analysis and modeling of the system dynamics of complex processes. The system is intended: firstly, to analyze the direct and indirect interaction of systemic and external systemic factors in the study of complex problem situations which occur in urban areas; secondly, to model the system dynamics of complex processes occurring within these problem situations; thirdly, to predict the state of objects of urban areas; fourth, to justify a set of measures to improve the sustainability of the functioning and development of urban facilities, taking into account the non-linear nature of the links between the socio-economic development of the city, the environment and climate.

The software system is based on a set of intelligent models, methods and technologies (including original ones) focused on intellectual analysis and modeling of complex systems and processes under conditions of various types of uncertainty, including: fuzzy cognitive models, fuzzy evaluation models, fuzzy logic models, neuro-fuzzy classifiers, models of system dynamics. The approbation of the developed software system is carried out on the example of an integrated assessment of the influence of climatic phenomena on objects of the urban areas of Moscow in various scenario climatic conditions.

Models and methods of their usage created with the help of the software system are an effective tool for substantiating medium and long-term programs for the development of cities in the Russian Federation.

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1 Introduction

Nowadays there have been a lot of software tools that let make the analysis of system dynamic of fuzzy cognitive models [1]. Software tools for specialists of program area are created by IT-specialists, that can appreciably complicate the elaboration for badly formalizable objective fields, and accompaniment and service maintenance of such software tools because of insufficient understanding between specialists of program areas leads to emergence of unguided architecture. [2]. The preconditions to creating the system under consideration have developed in process of researching the common regularities and the qualities of developing of urban power systems in various socio-economic and natural-climatic conditions.

Currently economic, political and cultural life in the whole world is concentrated in cities. One of the major problems of the global community during the last twenty years has been the issue of stable development of cities. The problems related to high level of technogenic load on environment are typical not only for Russian cities, but also for the rest ones.

The development of cities, beginning with the industrial revolution, is inseparably connected with power development. Right till present time the city impact on the environment is significantly determined by the work of its power supply system working. It's known, that this impact can result in considerable ecological and climate changes that in its turn is inevitably detrimental to the city development.

The non-linear nature of the feedbacks between the socio-economic development of the city, the environment and climate define the difficulties of the problems that arise during the analysis of the need in thermal and electric energy and power of cities and urban settlements. Besides, the energy system of each region functions in wide range of demographic, political, economic and social factors, that are always evaluated with some uncertainty, what makes the additional serious difficulties for elaboration of predication grades of the urban electrical consumption.

The necessity of taking in the account the manifold input parameters of the model that have complicated structure of interrelations and also characterized by properties of imperfection and nebulosity is the reason for practice and development of original author methods, that are basing on the apparatus of fuzzy analysis and modeling of complicated systems and processes including fuzzy cognitive modeling and fuzzy logic models.

The problems of analysis and modeling the influence of outer factors, to which, above all, relate climate phenomena, on functioning and development of urban objects, including power supply systems of cities and urban settlements, (from point of view of the impact on vulnerabilities of these objects) rely to the hardly formalizable issues, what is detected in:

- information of different quality about the climate phenomena themselves as well as about their influence;
- data insufficiency and difficulties of determination the dependence of the influence of various climate phenomena on vulnerabilities of urban objects;
- complexity of construction and usage of the traditional models and methods for solving these problems.

In these conditions for evaluation of impact of climate phenomena on urban objects the use of intellectual methods, models, technologies, based on fuzzy logic and neuro-fuzzy approaches is rational. Their advantages are:

- possibility of solving private and complex problems of modeling and evaluating the impact of various climate phenomena on vulnerabilities of all urban objects on the whole within the framework of the unified approach;
- possibility of describing the regularities and dependences of influence of various climate phenomena on vulnerabilities of all urban objects in the form of fuzzy rules "if-then" and relations;
- adequate handling of uncertain information, considering the data representation in quantitative and qualitative form;
- larger «transparency» because of the linguistic interpretation of fuzzy production rules;
- approximation with the given accuracy of complicated non-linear dependences between the parameters of climate phenomena impact and vulnerability of urban objects;
- good possibilities for adaptation and education of such models when changing the parameters of analyzed problems;
- typed approach to solving various evaluative and analytical tasks through equable representation of in- and output indexes of models and also the use of well-developed use of fuzzy logic apparatus.

2 The structure of software tools of cognitive analysis and modeling of the system dynamic

The elaborated software tools of fuzzy cognitive modeling of the system dynamic give an opportunity to research the work of fuzzy cognitive map, using various models of events (outer influences), noting the necessary indicators (sensors or receptors), and to make models too, using various scale of temporal interval [3]. The decision is based on the model of software tools that is characterized by modularity according to the following stages of work.

Stage 1. Making the fuzzy cognitive map according to an automatic setting or expert report.

Stage 2. Making systems of fuzzy conclusion for assessment of subsystems.

Stage 3. Making a system of fuzzy conclusion for assessment of the system.

Stage 4. Event setting (outer influences) of the system in process of modeling the fuzzy cognitive map.

Stage 5. Indicators setting (receptors or sensors) for monitoring the intermediate, important or critical events in process of modeling the fuzzy cognitive map.

Stage 6. Making a report about modeling of cognitive dynamics in form of table or graphically.

The structure of software tools in compliance with the steps of fuzzy cognitive modeling of system dynamics written above is shown in figure 1.

Data source can be a database, data tables, specialized data files of different formats, etc. Data is loaded by software tools and transforms into fuzzy cognitive

map, fuzzy cognitive models of output the assessment of systems and subsystems [4]. If a data source contains standard values of indexes of modeling the system dynamic of fuzzy cognitive map, then the educational sample for evaluation of indexes of subsystems and the whole system is formed.

The module of setting the fuzzy cognitive map provides setting concepts and their values and also, if needed, delimitation of frontiers of value changes of concepts that can be changed in process of modeling the dynamic process. The connection between the concepts is supplied by the arcs, weights of which are given over the range [-1, 1]. The problem of processing the negative impacts is solved with the help of doubling the power of concept multiplicity and separate processing of positive and negative influences. Fuzzy values of concepts are calculated with the help of T-norms or S-norms above the fuzzy values of concepts and weights of impacts [5,6].

The module of setting systems of fuzzy output for evaluation of subsystems provides setting models of fuzzy output for assessment of subsystems impacts of the dynamic process under investigation in process of modeling. As the input parameters of fuzzy output model are taken the concepts of the fuzzy cognitive map, values of which change in process of dynamic modeling. Output values of fuzzy output of subsystems value can be separate indexes, as well as input data for evaluation of the whole dynamic system.

Setting the impact model for subsystems contains 3 stages.

At first stage the linguistic terms, which can be triangular, bell-shaped, trapezoidal and compound are set in accordance to the chosen concepts.

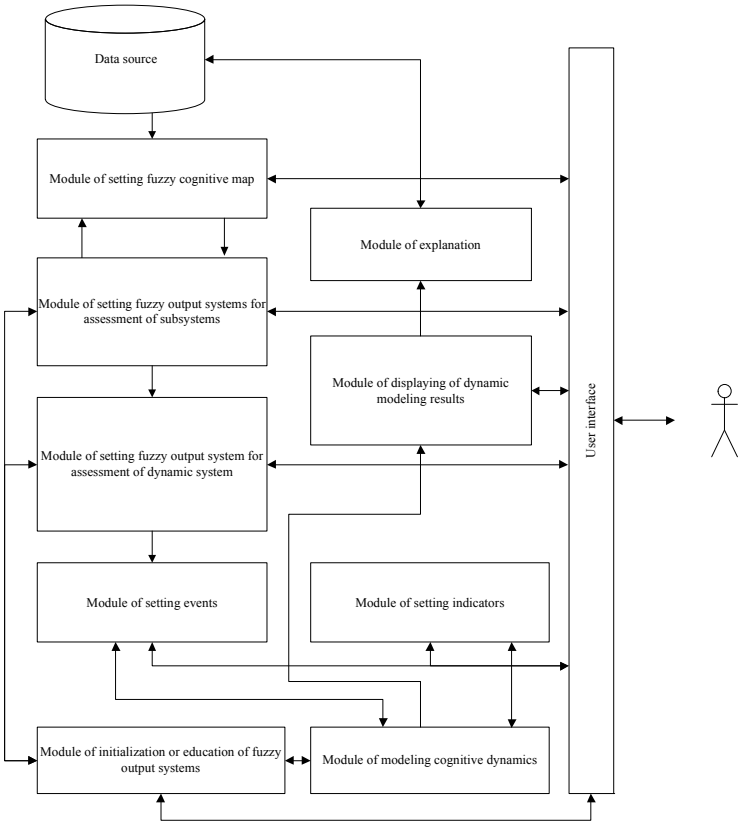


Figure 1. Structure of software tools of fuzzy cognitive model of the dynamic system

In the second stage the linguistic terms for output variable of fuzzy model of subsystem's assessment are marked. The linguistic terms are indicated depending on the type of the fuzzy output system chosen.

In the third stage the base of fuzzy rules is formed. The algorithm of «mountain» clustering is used by automatic setting [7], the input parameters of which are the input temporal series of educational sample of predictive model and parameters of clustering.

In order to set parameters of training the predictive model it's necessary to indicate the coefficient of education and its changes at each stage of training, and also the methods of intersection and merging of fuzzy multiplicities of fuzzy variables. The correction of linguistic terms of fuzzy variables and base of fuzzy rules is available after training the predictive model.

The module of setting the fuzzy output system for the assessment of the dynamic system determines the model of the fuzzy output for assessment of the whole cognitive dynamics. The adjustment of the model is realized by the algorithm, which is the same for customization of fuzzy output systems for subsystems' assessment.

The module of setting events is used in order to set the output impacts on fuzzy cognitive maps. Each event model contains loads of concepts of fuzzy cognitive maps changes or weights of impacts that are used in the shown step by dynamic modeling of the system.

The module of setting the indicators is used in order to set the indicators that activate by fulfilling the action conditions. The informative, important or critical events, which appear by modeling of cognitive dynamics, can be shown in the form of indication.

The module of initialization or training the systems of fuzzy output provides checking the system integrity in advance and, if needed, customization by modeling of cognitive dynamics. In case of impossibility of modeling, the module will indicate the inaccuracies of setting the initial modeling conditions.

The module of modeling the cognitive dynamics provides the direct modeling of dynamic process of the fuzzy cognitive map, calculates the indicators of subsystems and the whole system. The results of modeling in real-time are shown to users for on-line interaction with the help of the display module of the results of dynamic modeling.

The module of explanation provides forming the results of the dynamic modeling in understandable for people shape.

3 The approbation of the elaborated software tools of the analysis and modeling of the system dynamics

The software tools are based on the complex of intellectual models, methods and technologies (including the original ones), oriented on the intellectual analysis and modeling of complicated systems and processes under uncertainty of various types, including: fuzzy cognitive models, fussy evaluation models, fuzzy logic models, neuro-fuzzy classifiers, models of system dynamics. The approbation of the elaborated software system is lead using the example of complex assessment of influence of climate phenomena on urban objects of Moscow in various script climate conditions. The evaluation was realized using the cognitive map shown in figure 2.

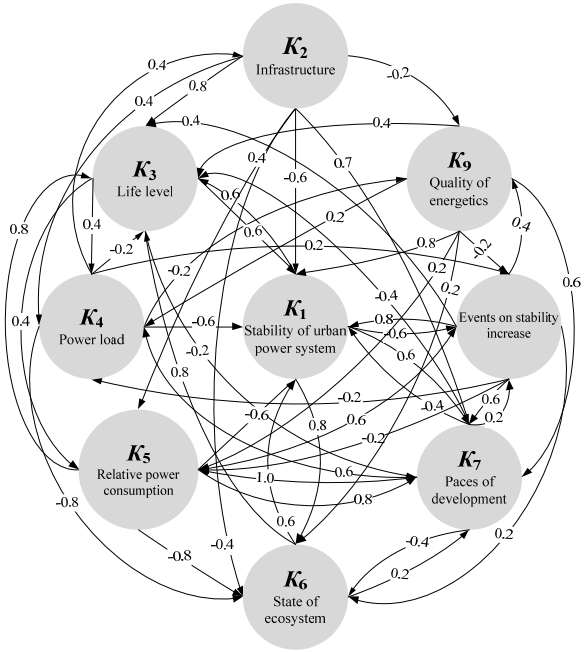


Figure 2. Structure of fuzzy cognitive map for evaluation of impacts of the events on indexes and power supply subsystem

The cognitive map is the multiplicity of peaks $C = \{c_1, ..., c_N\}$, which are connected with each other by arcs, values of which can be represented by matrix:

$$W = \begin{pmatrix} w_{11} & ... & w_{1N} \\ ... & ... & ... \\ w_{N1} & ... & w_{NN} \end{pmatrix},$$

with W – matrix of concepts' rations; w_{ij} – value between i and j concepts. If arcs are not given then $w_{ij} = 0$.

The mathematical apparatus of impulse processes is used for analyzing the dynamics of the development of cognitive maps [8]. The calculation of the dynamic process of a cognitive map is an iterative process. Each peak of the cognitive map takes value $K_i(t)$ in discrete times $t = 0, 1, 2, ..., n$, with n – the amount of the set iterations. The values of concepts in each next iteration are calculated by certain rule.

The feature of the realized mathematical apparatus of modeling is the property of calculation all the concepts concurrently. This feature defines notably specific assumptions of influence of a concept variation on parameters of other concepts. These assumptions are defined as the choice of the rule of changing the values of concepts depending on other concept values and relations between the corresponding concepts.

The choice of the rule is very important. If it is assumed that the original data is known with some precision, then the final conclusions based on the certain rule of

changing the values of concepts will also always be imprecise. Each of the results of the dynamic modeling should be considered preliminary. It's necessary to put this result to expert analysis. The expert analysis can include the additional second modeling with changed parameters (original data) and probably the choice of other rules of changing the values of concepts.

There are many possible options in determining the rules of a concept [9]. In this work the modeling is realized using the following rules:

$$K_i(t+1) = K_i(t) + \sum_{j=1}^{n} w_{j,i} \cdot K_j(t),$$

$$K_i(t+1) = K_i(t) + sigmoid\left(\sum_{j=1}^{n} w_{j,i} \cdot K_j(t) \right),$$

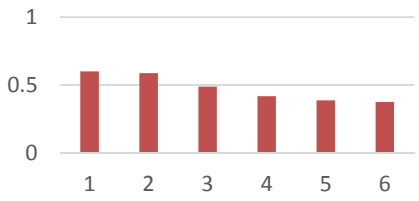
$$K_i(t+1) = sigmoid\left(K_i(t) + \sum_{j=1}^{n} w_{j,i} \cdot K_j(t) \right),$$

with $K_i(t+1)$ – value of i concept in the next calculation stage; $K_i(t)$ – value of i concept in the present calculation stage; $w_{j,i}$ – value of the arc outgoing from j to i concept; $sigmoid$ – sigmoid function that smoothly limits the calculation values.

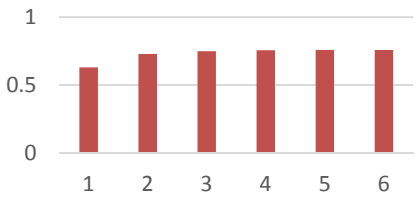
The definition of the primary values of concepts is realized by averaging of values rated from 0 to 1 of the certain indexes that are a part of the concept [10].

The modeling of the system dynamics of the cognitive map was fulfilled by the following sequence:

- setting the original index values;
- setting the function of the concept change;
- modeling the system dynamics;
- expert analysis of the result of modeling;
- changing the function, if needed, or customizing the parameters of concept change function;
- fixation of the output rule, that provides convergence with expert opinion, and its parameters.



a)



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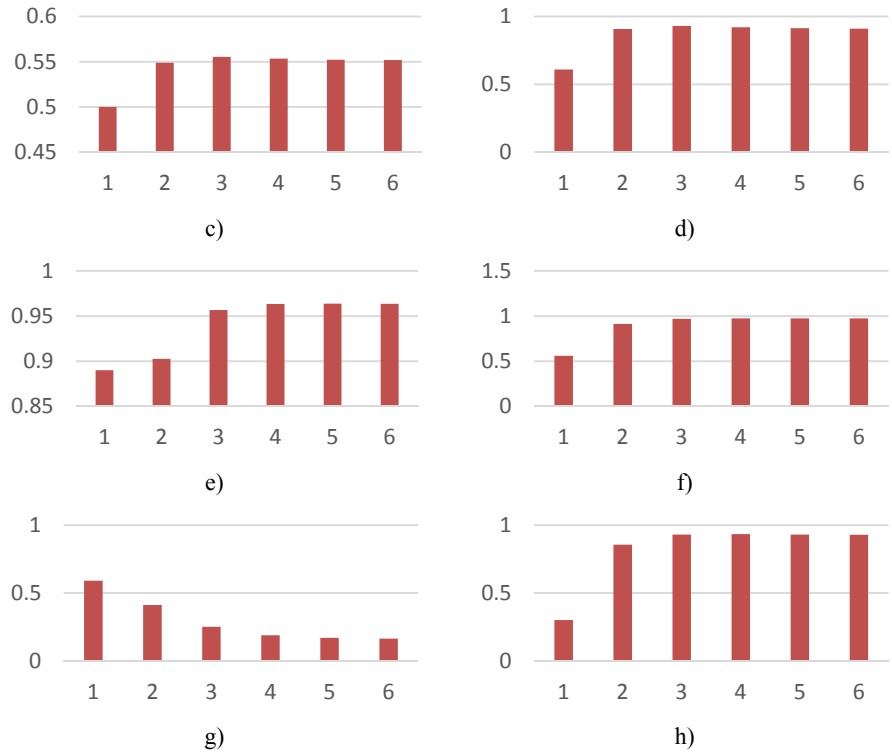

Figure 3. Illustration the behavior of the concepts in 5 model steps: a) stability; b) infrastructure; c) quality of energetics; d) life level; e) power load; f) relative power consumption; g) state of ecosystem; h) paces of development

When the intended behavior of the cognitive map in the dynamics is achieved, it's possible to research the effectiveness of using the events, which are set by an expert or a group of experts in process of the dynamic modeling of fuzzy cognitive map. An event is a one-time or long-term change of arch weights or concept value – appending, subtraction or reappropriation the established value, which imitates the impact of the real events that change the branch condition.

Figure 3 shows graphs that illustrate the behavior of the concepts in 5 model steps (counting 1 – the initial state, counting 2-6 – the results of modeling the system dynamics).

4 Conclusion

In order to realize the system discussed above was designed the methodical ensuring and were realized software tools of modeling the system dynamics of power system of cities and urban settlements paying attention to the main factors, which influence the stability of power system development. Customization of the model of

the system dynamic was lead along with engagement of the experts of separate urban branches. The approach to setting the initial conditions and verification of the modeling results with the use of information from the data base «GEPL Urban Energy & Environment» was determined.

With the use of elaborated software the indexes of Moscow power supply system functioning for the period up to 2050 are calculated in new script climate conditions.

The elaborated system is the first step to creating an integrated info-analytical platform of intellectual analysis, modeling and prognosis of the state of complex socio-technical systems considering the policy of socio-economic development and the dynamics of extreme weather phenomena.

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