DYNAMIC COGNITIVE MAPS FOR THE SUBSTANTIATION OF STRATEGIC DECISIONS ON MANAGEMENT OF ENERGY SECTOR DEVELOPMENT

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Abstract[1]: *This article describes the tools of intelligent decision-making support in the research of energy security problems using the cognitive approach. The application of dynamic cognitive modeling and the notion of dynamic cognitive modeling are described. The author proposes the future directions of this approach developmen.*

Introduction

The task of situational analysis is to identify the parameters and significant factors, or circumstances that determine the situation, the relationship between the factors and the character of their mutual influence. A situation is understood as a set of circumstances that determine the internal state of an object or system, and the circumstances that determine the state of the environment in relation to a given object or system. The first are described by parameters characterizing the state of the system, the second - the environmental conditions or significant factors affecting on the development of the system [1,2]. Situational analysis includes: analysis of problem situations (for example, emergency situations in power engineering); identification of ways to resolve problem situations (alternatives); the definition of criteria for the evaluating alternatives (for example, economic); analysis of alternatives; choice and implementation of the best alternative [3,4]. Given that the presence of uncertainties complicates the adequate state assessment of the object and environment, the author suggested to use the semantic technologies of situational analysis, which include ontological, cognitive and event modeling, and probabilistic simulations using Bayesian networks of trust.

Cognitive modeling is the construction of cognitive models, or, in other words, cognitive maps (oriented graphs) in which vertices correspond to factors (concepts), and arcs describe the relationships between factors (positive or negative), depending from the nature of the cause-effect relationship. The mathematical apparatus for constructing of cognitive models is the graphs theory.

The foundations of cognitive modeling were developed in due time by Wang Hao (1956), Axelrod (1976), D.A. Pospelov (1981), this work was continued by E.A. Trakhtengerts [5], and is actively developing in the Institute of Control Problems of the Russian Academy of Sciences (Abramova N.A., Maksimov V.I., etc.) for describing of weakly structured situations and for effect analysis in weakly structured situations management. Ideas of development and application of fuzzy cognitive maps are actively developing in Greece (Groumpos P.P., etc.) [6-8]

It should be noted the relevance of the new direction related to 3D-visualization, called "Situational Awareness". The concept of Situational Awareness was formed at the turn of the 1990s and is associated primarily with the pioneering work of Mica R. Endsley [9]. It is proposed to joint semantic modeling tools and situational awareness within the OODA cycle (proposed by D. Boyd) [10] for the purposes of situational management.

MESI SB RAS has traditionally conducted research on energy security (ES) problems. Currently, the research uses primarily a quantitative approach to assessing the ES level, supported by the traditional software systems. The use of these software systems, as a rule, requires a lot of time for the preparation of information, the formation and updating of information models, the determination of emergency situations (EmS) and the choice of computational experiments strategy.

To reduce expert burden, the team in which the author works offers a two-level technology of research, supported by an intelligent IT environment in which qualitative analysis is performed at the first level using ontological, cognitive and event modeling [11,12]. Based on the results of qualitative analysis, decision-makers select variants requiring a detailed justification, these variants are calculated at the second level.

This approach is currently being applied in MESI SB RAS to substantiate strategic decisions on energy development management. One such work was carried out at the request of the Russian Energy Agency to solve the problem of logical modeling of the improvement / deterioration of the situations with ensuring of the country's energy security at the federal level. In the course of the work, some shortcomings of cognitive modeling in the classical sense were noted, which can be eliminated using the author's proposed dynamic cognitive maps.

1. Intelligent IT-environment

The concept of an intelligent IT-environment supporting a two-level technology for research into the directions of the development of the fuel and energy complex, taking into account the requirements of the ES [13], is proposed. The intelligent IT environment is defined as

$V_{IT} = \{O, E, M_C, M_S\} \cup T_V$, where $\{O\}$ - the set of ontologies, $\{E\}$ - the set of emergency precedents descriptions, $\{M_C\}$ - the set of cognitive models, $\{M_S\}$ - the set of event models, T_V - the tools for supporting the IT-environment, including the description of knowledge presented

in the form of ontologies, descriptions of emergency precedents, cognitive and event models and manipulating tools of them.

Thus, the intelligent IT environment includes a knowledge space that integrates: ontological models of knowledge in the field of ES research, the knowledge base of emergencies precedents in energy sector and knowledge bases containing cognitive models of ES strategic threats and event models of the development and consequences of emergencies in energy, and tools for describing knowledge and manipulating them (Figure 1). The joint use of ontological, cognitive and event modeling gives the expert a more complete representation of the extreme situation in the energy sector.

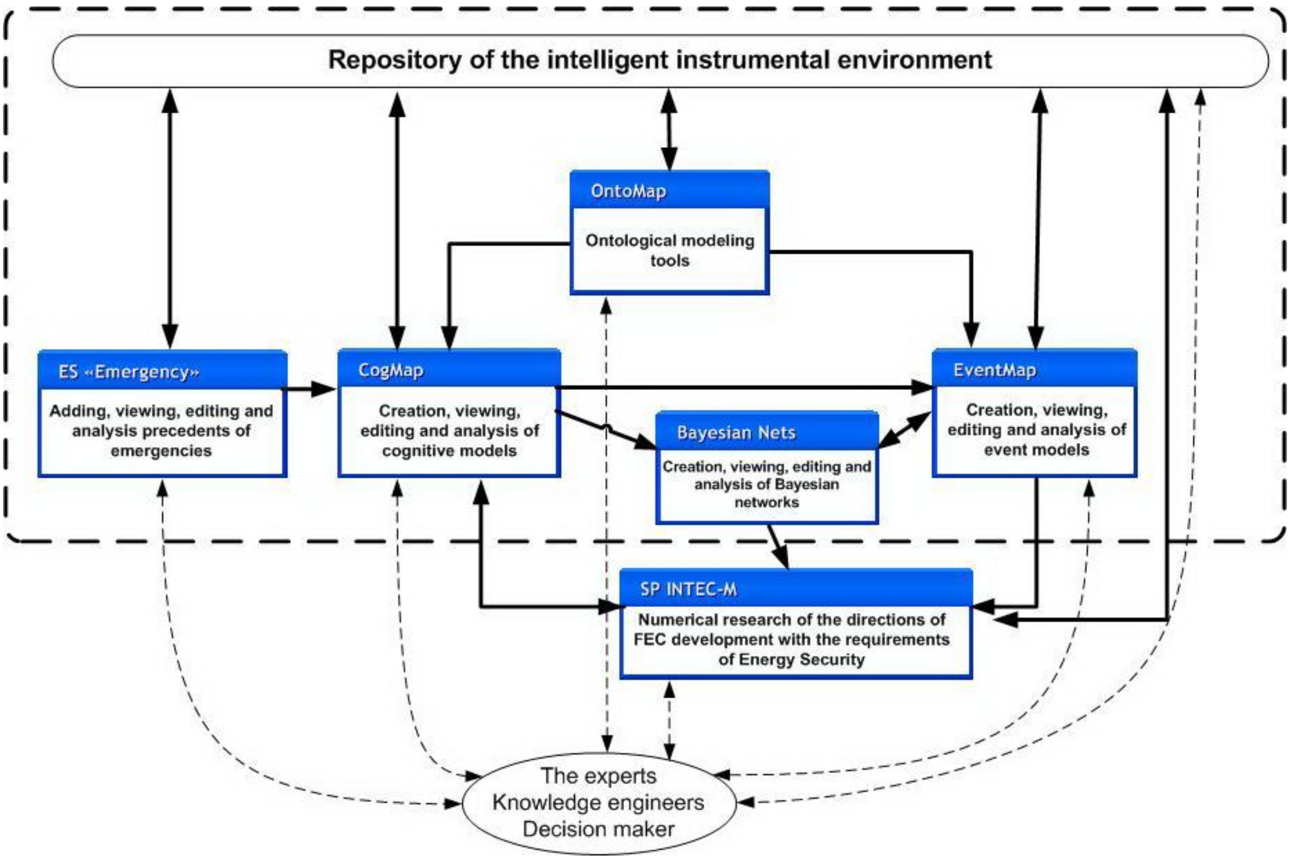

Figure 1 - Interconnection of the tools in the intelligent IT-environment

2. Cognitive approach to research on ES problems.

Cognitive modeling is the construction of cognitive models, or, in other words, cognitive maps (oriented graphs) in which vertices correspond to factors (concepts), and arcs describe the relationships between factors (positive or negative), depending from the nature of the cause-effect relationship. The mathematical apparatus for constructing of cognitive models is the graphs theory. Most often, fuzzy cognitive maps are used, and in the simplest case, the connection weight is defined as +1 or -1.

Cognitive modeling is considered, in particular, in [13, 14] and is used primarily for the analysis of socio-economic situations. The author proposed to use the cognitive approach in research of ES problems [15]. This approach makes it possible to obtain scenarios for the sustainable and crisis development of the energy sector in the region, to identify factors that affect on the scenarios of the energy system development, and to develop plans of counteract to the ES threats. Scenario programming was chosen as a methodology for modeling the region's energy system, from a mathematical point of view it is a logical and probabilistic extension of the cognitive map system [15].

We illustrate cognitive modeling on the example of the natural ES threat, namely the threat of "Coldness" (Fig. 2).

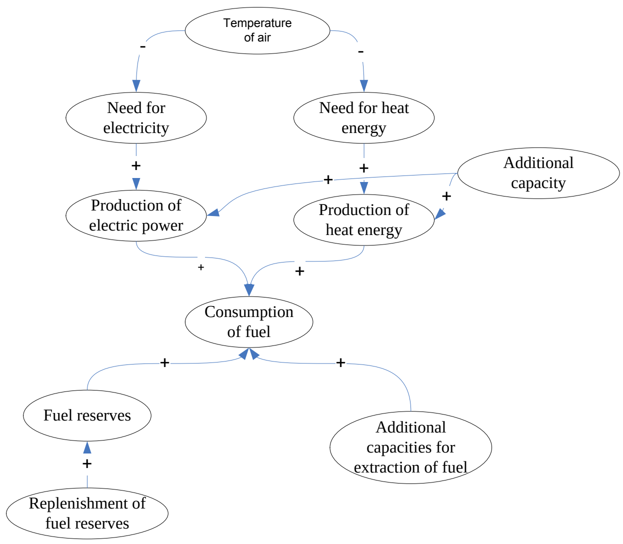

Figure 2 - Cognitive map of the natural threat "Coldness"

On the cognitive map of the natural threat "Coldness", the main factors influencing the decision-making of the decision maker are revealed, factors – threats and factors – events are identified. This map shows the cause-effect relationship between the factors. The weight coefficients of the connections are assigned by experts, by default the weight coefficients are +1 or -1.

Cognitive maps, in turn, can not always give a complete, and most importantly unambiguously interpreted, view of the situation to the expert. To eliminate this shortcoming, the author proposes introducing the concept of dynamic cognitive maps.

3. Dynamic cognitive maps

The cognitive map is inherently static and at the same time reflects only the nature of the factors interconnection, and in the modeling of extreme situations in the energy sector, a dynamic representation is desirable. The author proposes to use dynamic cognitive maps for this goal.

In contrast to event modeling, aimed at analyzing the development and consequences of emergencies, dynamic cognitive maps retain the ability to identify the cause-effect relationships of concepts aimed at analyzing ES threats, described in conventional cognitive maps (CM). The difference from the fuzzy cognitive maps used in ES research earlier is that the expert will be able to see and evaluate the influence of connections relative to the time scale, and most importantly, in modeling, he can confine himself to considering individual factors of influence.

The dynamic cognitive map (DCM) differs from the conventional cognitive map in that it is a set of cognitive maps presented at different times, ie:

$\{D\} = \{D_{t_0}, D_{t_1} ... D_{t_n}\}$, where $\{D\}$ - a set of dynamic cognitive maps; $\{D_{t_0}\}, \{D_{t_1}\}, \{D_{t_n}\}$ - sets of cognitive maps at time instants t0, t1, t_n.

As a result, it becomes necessary to include in the DCC the weights of the relationships that would reflect the influence of factors (and / or objects) on each other as a function of time.

Then we can represent the bond weight as some function W (t). In most cases, the connection weights in DCM can be represented by simple functions.

Analyzing the existing knowledge base of cognitive models, in accordance with the methodology of cognitive modeling of ES threats [16], we distinguish several basic classes of factors for which we can determine the simplest cases of interaction: 1) the class of ES threats; 2) a class of events (preventive, operational and liquidation); 3) the class of energy objects.

Consider the simplest case, typical for a class of ES threats: the occurrence of an event. It can be represented in the form of a single impulse. This dependence is characterized by the fact that the period of occurrence and action of the event is much less or equal to the chosen time step.

The next type of connections and their weights is more complex, since the degree of its impact can continue for several steps, and for the simplest connections, the weight functions W(t) will have a linear form.

One of the problems in constructing DCM is the mapping of the mutual influence of various connections on the same concepts (factors). To determine the degree of interference, it is necessary to introduce for the factors a set of parameters (characteristics of factors) that can be influenced by links with other factors (for example, see the concept "Fuel Consumption" in Figure 2). Due to the fact that different factors can be included at different time periods, it becomes necessary to display implicit relationships.

An example of such implicit connections is the presence in the cognitive map of a preventive action and a threat that at the moment *t* develops into an EmS. The effective implementation of preventive measures can prevent the outbreak of the ES threat in EmS.

4. Fuzzy DCM (FDSM)

Based on the proposed approach, within the framework of two-level technology it is supposed to use cognitive maps for qualitative analysis of ES problems. In this case, for using of DCM the expert have to determine the weight of the connection and the speed of its influence on other factors in the CM. Therefore it is proposed to introduce a linguistic scale similar to used in fuzzy CM, with the difference that the introduced gradation will display the speed of weight changes and its effect on the selected factor.

If in a fuzzy cognitive map it is possible to determine the weight in the range "weakly-strong", then in FDCM communication can be determined in the "long-fast" range.

In other words, if we take t_n as the time of the final step, then the event that lasts the time interval $T \geq t_n / 2$, is a long event.

The next stage in the development of methods for constructing FDCM is their integration with various mathematical models. MESI SB RAS uses the software package INTEK-M [17], which is designed to support the computational experiment of research into the directions of the development of the fuel and energy complex, taking into account the requirements of energy security. These studies are considered as the basis for justifying of strategic decisions on energy development.

This software package INTEK-M uses the traditional TRV model (Figure 3), where:

T is a technology, R is a district and V is a vector that denotes different modes of operation for different objects.

After the construction, in accordance with the proposed methodology, of cognitive models, the user is given the opportunity to specify characteristics of factors (basic concepts) of the cognitive model. Further, these characteristics will be transformed into corrections of the mathematical model, which are transmitted to the INTEK-M in the form of a special file.

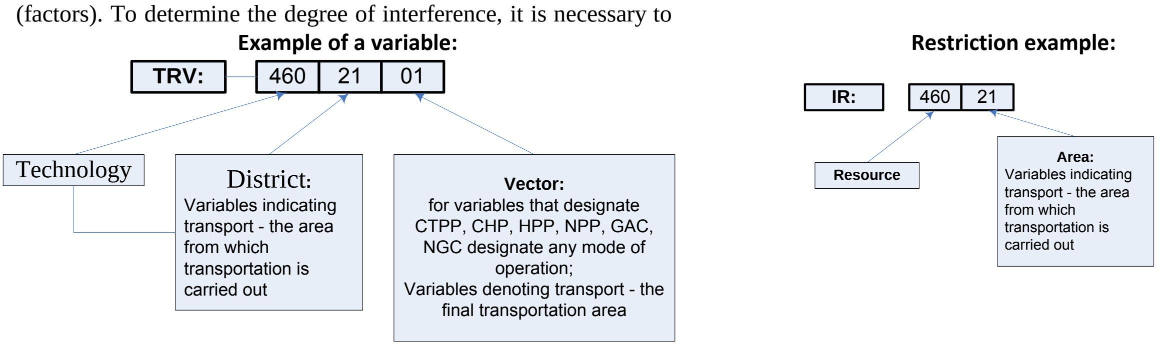

Figure 3 - Description of the TRV-model.

Until recently, traditional cognitive maps were used in energy research. The author proposes to extend their application by implementing two additional steps: 1) to reduce the expert's load when analyzing cognitive models by visualizing the development of cause-effect relations in dynamics; 2) to integrate semantic and mathematical models.

Then the general scheme of the tools interaction within the intelligent IT- environment will look like this (Figure 4).

To facilitate the construction of cognitive models of this type, it is necessary to add the directories of technologies, regions and vectors. The technology of connecting directories in the form of ontologies for constructing cognitive models has already been debugged and described in [18]. At this stage, work is underway to create an ontological knowledge space, the ontologies of which describe the main elements of the used TRV-model.

In addition to the use of directories, it is necessary to specify as DCM characteristics, and such information as the time step, various coefficients and limitations of mathematical models.

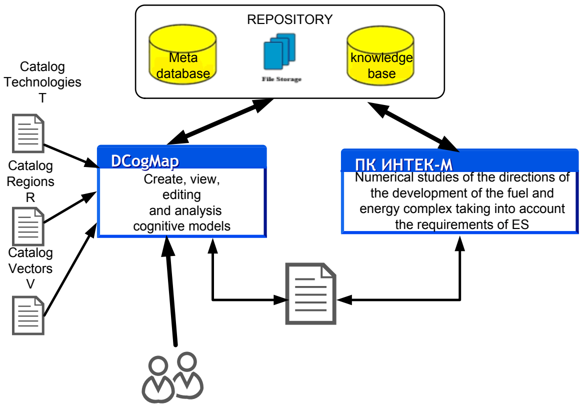

Figure 4 - General scheme of tools interaction within the intelligent IT environment

In addition to the use of directories, it is necessary to specify as DCM characteristics, and such information as the time step, various coefficients and limitations of mathematical models.

An inverse problem can also be solved: automating the construction of cognitive models using the results of a computational experiment.

Conclusion.

The article deals with the use of cognitive maps in energy research, suggests a transition to the use of FDCM, and also the possibility of integrating semantic and mathematical models is shown.

The proposed approach will provide a new quality of research by reducing errors (reducing the influence of the human factor) in the construction of cognitive models. Integration of mathematical and semantic models will help solve problems with incompleteness and possible unreliability of the initial data for a computational experiment, allowing in some cases to replace exact data in mathematical models with expert estimates.

The use of visual analytics and the ability to visualize calculations using cognitive maps will help improve the quality of the scientific justification for the recommended strategic solutions.

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References

1. Pospelov D.A. Principles of situational management. – News of USSR AS, Technical Cybernetics. - 1971.- №2 .- Pp. 10-17 (in Russian)
2. Klykov Yu. I. Situational management of large systems. - M.: Energy.- 1974.- 134 p. (in Russian)
3. Pospelov D.A. Situational management. Theory and practice. - Moscow: Science, 1986. - 284 p. (in Russian)
4. Vasiliev VI, Ilyasov BG Intelligent control systems. Theory and practice - Moscow: Radio Engineering, 2009. - 392 p. (in Russian)
5. Trakhtengerts E.A. Computer support for decision-making. - Moscow: SINTEG, 1998. –376 p. (in Russian)
6. Mpelogianni, V., Marnetta, P., Groumpos, P.P.Fuzzy Cognitive Maps in the Service of Energy EfficiencyIFAC-PapersOnLine 48 (24), p. 1-6
7. Anninou, A.P. Groumpos, P.P. Polychronopoulos, P.Modeling health diseases using Competitive Fuzzy Cognitive Maps. IFIP Advances in Information and Communication Technology. Volume 412, 2013, Pages 88-95
8. Groumpos, V.P. Biniari, K. Groumpos, P.P.A new mathematical modelling approach for viticulture and winemaking using fuzzy cognitive maps. ELEKTRO2016 - 11th International Conference, Proceedings. Pages 57-61
9. Mica R.Endsley, Daniel J. Garland, Situation awareness: analysis and measurement, Lawrence Erlbaum Associates, 2000, ISBN 0805821341, 9780805821345
10. The Boyd Cycle (OODA cycle) and second-order cybernetics. - Open systems .- №7. - 2013. - Pp. 23-26.
11. Masel L.V. Application of ontological, cognitive and event modeling for the analysis of the development and consequences of emergencies in the energy sector / Problems of safety and emergency situations. - № 2.- 2010. - Pp. 34-43.
12. Massel L.V., Arshinsky V.L., Massel A.G. Intelligent information technologies for decision support in research and energy security providing / Proceedings of the International Conference "Intelligent decision-making systems and problems of computing experiment", Evpatoria, 2010. - Pp. 192-196.
13. Massel A.G. Intelligent IT- environment for research of the energy security problem // Information technologies in science, education, telecommunications and business: Proceedings of the International Conference - Ukraine, Gurzuf, 2010. - Pp. 306-309.
14. Massel A.G. Methodological approach to the organization of intelligent support for research on energy security problem/ Information technology. - №9. - 2010. - Pp. 32-36.
15. Massel A.G. Cognitive modeling of threats to energy security / Mining Information and Analytical Bulletin (scientific and technical journal), separate issue №17. - M.: Publishing house "Mining Book", 2010. - Pp. 194 - 199.
16. Massel A.G. Cognitive modeling of energy security treats / Proceedings of the 11th International Conference “Computer Science and Information Technologies”, vol. 1, 2009.- Greece, Crete. - P. 78-80.
17. Arshinsky V.L., Massel A.G., Fartyshev D.A. Multiagent software complex for research of the energy security problem // Proceedings of the XIV Baikal All-Russian Conference "Information and Mathematical Technologies in Science and Management". Vol. 3. - Irkutsk: MESI SB RAS, 2009. - Pp. 283-289.
18. Massel A.G., Kopaygorodsky A.N., Pascal K.K. Application of the cognitive modeling system in the research of energy security problems // Vestnik IrSTU. - 2012. - № 10 (69). - Pp. 29-33