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INTELLIGENT DECISION-MAKING SUPPORT SYSTEM USING COGNITIVE MODELING FOR PROJECT FEASIBILITY ASSESSMENT ON CREATING COMPLEX TECHNICAL SYSTEMS

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Abstract: *The project feasibility assessment on creating complex technical systems (CTS) at the beginning of the life cycle is quite a complex and multi-factor procedure, which involves weak structuring of initial data on the project. Therefore, it is often not possible to create accurate mathematical description of the CTS creation process, which in turn gives rise to the problem of the management decision-making efficiency at an early stage of CTS designing and, as a result, achieving the necessary technical and economic project parameters. The existing decision-making support systems do not consider prefeasibility studies, and, in particular, the CTS project feasibility assessment, which often leads to incorrectly made organizational and technical decisions at the most challenging initial design stage, resulting in a substantial increase in the final cost of the project, failure to timely project deliver or its complete failure. In this paper, we propose to use the intelligent DMSS (IDMSS) that allows an efficient response to the changing external and internal environment of the project developing enterprise, foreseeing possible situation developments related to the creation of a CTS under the influence of various factors. The IDMSS inherently proposes to apply cognitive modeling and CTS decomposition method to the non-derivative structural elements (NSE), which can serve as the basis for creating an IDMSS knowledge base. The results obtained by applying cognitive modeling to assess feasibility of the CTS creation project used in IDMSS allow that the project leader and its team could fast process and analyze large volumes of diverse information, assess the feasibility of the CTS creation project in the face of uncertainty.*

Keywords: *cognitive modeling, complex technical system, decomposition method*

INTRODUCTION

Assessing feasibility of the CTS creation project is the most hard-formalizable, time-consuming process, because it is determined by the incompleteness and

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uncertainty of initial data, by the presence of a large number of project feasibility indicators (the time and cost for creating CTS, the number of executors, the cost of materials, etc.). A significant reduction in CTS creation deadlines results in exceeding the budgetary appropriations and/or breach of the CTS creation project timing, or just in its complete failure (Konar 2000; Lipaev 2006; McConnell 2007).

Despite the large number of programs used to manage the projects considering production processes and business processes of an enterprise (order processing, inventory management, quality management, personnel and finances management), their main drawback is the lack of prefeasibility studies, and, in particular, the CTS creation project feasibility assessment at the initial stage of its life cycle.

In this paper, we propose the IDMSS using cognitive modeling, which makes it possible to qualitatively improve the validity of administrative decisions under the hard formalizable conditions, reflect system problems in a model, explore the possible scenarios for occurrence of dangerous situations, and develop the ways to resolve these problems under a model situation. The "know-how" proposed by the IDMSS is a knowledge base, which is based on the cognitive modeling methodology, as well as on the method of CTS decomposition to the non-derivative structural elements, based on the categorical approach.

STAGES OF COGNITIVE MODELING FOR PROJECT FEASIBILITY ASSESSMENT

Currently, the term *"cognitive modeling"* refers to solving interrelated systemic challenges of cognitive analysis and synthesis (object identification, scenario analysis, analysis of a cognitive model's ways and cycles, connectivity and complexity analysis, sustainability analysis, forecasting, decision-making), which allows not only to analyze various aspects of a complex system, but also to clarify cognitive models (Gorelova, *et al.* 2014; Gorelova, *et al.* 2010; Kolodenkova 2016; Roberts 1978).

The following are the stages of cognitive modeling for assessing the CTS creation project feasibility.

Stage 1. Identifying the factors required to assess the CTS creation project feasibility and the connections there between.

Stage 2. Setting the current values of factor parameters and the connections there between.

Stage 3. Processing initial data (factor parameter values and connections there between).

The term "initial data processing" refers to the structuring and standardizing of clear and/or fuzzy values of factor parameters and the connections there between. The initial data processing is required to ensure that the numerical values of factor parameters would not differ in the measurement units and the order of values, while the connection values between the factors would be presented in the form of fuzzy numbers from the interval [-1; 1] (Kolodenkova 2016).

The term *"clear initial data"* refers to the data presented in the form of numbers that differ or do not differ in the units of measurement and the order of values. The term *"fuzzy initial data"* refers to the data presented in the form of numbers from the interval [-1; 1], the interval, fuzzy triangular and trapezoidal numbers, as well as the linguistic descriptions, the values of which are words.

Stage 4. Building a clear and/or fuzzy cognitive model.

The term *"clear cognitive model"* (CCM) means a cognitive map (a signed directed graph) (Gorelova, *et al.* 2010; Maksimov 2001):

$$G = \langle V, E \rangle,$$

where V are graph vertices, $V = \{v_i\}$, $v_i \in V$, $i = \overline{1, h}$, h is the number of vertices;

E are the graph arcs $E = \{e_i\}$, $e_i \in E$ reflecting the impact of the v_i vertex on the v_j ($j = \overline{1, h}$) vertex.

The term *"fuzzy cognitive model"*(FCM) means a fuzzy cognitive map (a parametrically weighted directed graph), wherein vertices represent factors, and edges represent fuzzy causal connections between factors (Kosko 1986; Kulinich 2002)

$$G_f = \langle V, W \rangle,$$

where V are graph vertices;

$X = \{x_{v_i}\}$ is a set of vertex parameters.

W are fuzzy causal connections between vertices. The impact degrees are presented in the form of elements w_{ij}, $w_{ij} \in W$ which characterize the direction and the degree of influence between the v_i and v_j vertices (Silov 1995).

Stage 5. Analyzing the structure of a clear and/or fuzzy cognitive model.

Stage 6. Conducting pulse modeling on a clear and/or fuzzy cognitive model, scenario analysis.

At this stage, different scenarios for the situation development forecasting related to the CTS creation can be built to mitigate the negative trends and/or strengthen the positive trends.

To conduct a pulse modeling on a CCM and/or a FCM, the time to parameter change dependencies x_{v_i} should be investigated. $x_{v_i}(t), t = 1, 2, \ldots$

The disturbance propagation process along the graph *G*, G_f, that is, the system transition from the state $t\,(n-1)$ into $t(n), t(n+1), \ldots$ is defined by the expression (Casti 1982; Gorelova, *et al.* 2010; Roberts 1986; Roberts 1978).

$$x_{v_i}(n+1) = x_{v_i}(n) + \sum_{v_j : e = e_{ij}}^{h-1} f(x_i, x_j, e_{ij}) P_j(n) + Q_i(n),$$

Here, $x_{v_i}(n+1), x_{v_i}(n)$ are the indicator values at the vertex *V* at simulation steps at time moment $t = n$ and the following $t = n + 1$, *n* are the modeling time-steps; $P_j(n)$ is a change at the vertex v_j at time moment $t(n)$; $Q_i(n)$ is the vector of external pulses q_i introduced into the vertices v_i at the time moment $t(n)$; *f* is the arc transformation function. Adding disturbances models a scenario that answers a question of scientific prediction, "What will happen at the time moment *t* (n+1), if …?"

Stage 7. Result analysis.

Making decisions on adjusting/not adjusting an initial CCM *G* and/or FCM G_f, on developing a new CCM and/or FCM, as well as on conducting repeated model studies.

Stage 8. Selecting a system development scenario.

To select a scenario, the expert estimates and mathematical comparison methods can be used (Sadovnikova 2011).

A Generalized cognitive modeling algorithm

Figure 1 shows a generalized cognitive modeling algorithm, which is supported by the software system.

Note that, in general, until the CCM and/or FCM are not operated as a mathematical model, we use the terms "factors" and "objects". As soon as the work with CCM and/or FCM started, we use the term "vertex".

Note that at the stage of CCM and/or FCM construction, not one clear and/or fuzzy cognitive model can be built, but a set of clear and/or fuzzy cognitive models.

Carrying out a computational experiment through pulse modeling requires its prior planning (Gorelova, 2013). It is proposed to arrange a plan of computing experiment for CCM and/or FCM in the form of a table (Table 1).

Table 1
Computing experiment plan

Scenario	*Disturbance*	*Vertices*				
		v_1	v_2	v_3	…	v_i
Scenario No. 1	q_1 = -1	-1				
Scenario No. 2	q_3 = +1			+1		
…	…	…	…	…	…	…
Scenario No. *p*	q_1 = +1 q_i = +1	+1				+1

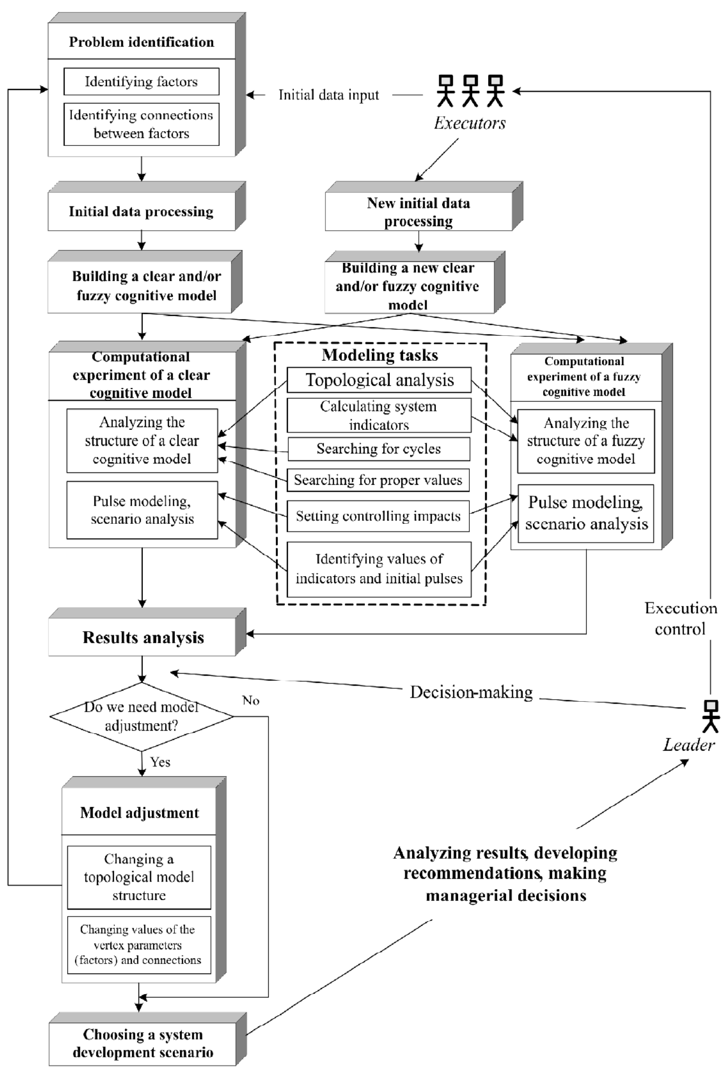

Figure 1: A generalized cognitive modeling algorithm

Figure 1 shows that after executors analyze the results, the project leader is proposed to make a choice, namely, to decide on CCM and/or FCM adjustments, or to move further and choose a system development scenario.

In the course of work, the project leader can monitor the execution of tasks by executors, as well as give instructions on adding or removing factors, on establishing new connections between factors, and on changing factor values.

Planning involves selecting vertices that should be exposed to disturbing impacts, setting a combination of vertices, and choosing time moments for inputting disturbances.

The term "topological CTS structure analysis" refers to the analysis of its

q-connectivity, which consists in analyzing simplicial complexes (Atkin 1997; Barcel, *et al.* 1998; Mnukhin 1996).

The term *"model adjustment"* refers to adding or removing any vertices and connections there between, as well as changing the values of factors and connections parameters.

The term *"system development scenarios"* refers to scenarios of situations development related to the CTS creation.

The proposed generalized algorithm for complex systems cognitive modeling and fuzzy cognitive modeling can be used to create a module structure of the intelligent DMSS knowledge base.

METHOD OF SYSTEM DECOMPOSITION INTO NON-DERIVATIVE STRUCTURAL COMPONENTS

Let us consider the CTS as a relationship between carriers and streams. The system dynamics uses a carrier to represent those real world objects, within which certain resources concentrate, such as financial, material, and human resources. The carriers define a static state of the modelled system. Their values change over time according to the current streams within the system. If the carriers set a static state of the modelled system, the streams set the system dynamics. The carrier values change over time exactly in accordance with the existing system streams. The streams included into the carrier increase its value, while the outgoing streams reduce it accordingly (Lyneis, *et al.* 2007).

It follows from the above mentioned that the point of roads intersection or a carrier is both a receiver V_i of transport stream and its source I_i. Then, for the next intersection, the incoming stream V_{i+1} will be equal to the outcoming stream from the previous carrier, given that all carriers have the same condition.

Based on the knowledge about a qualitative description of the incoming and outcoming TS streams, a matrix of their interrelation is built, which is analogue of the adjacency matrix in graph theory. Then on its basis, it is possible to build a graph $G' = (U', X')$, where $U = \{\{V_i, I_i\},...,\{V_n, I_n\}\}$ is a set of vertices, and $X = \{P_i, ..., P_m\}$ is a plurality of graph vertices connections given that the incoming and outcoming streams $V_j = I_k,\ j \neq k$ are equal. For example, for the matrix in Table 1, a graph $G' = (U', X')$ is built showing the structure of interrelations between streams (Batishchev, *et al.* 2012).

It is proposed to accept a general concept of a non-derivative structural element (NSE) as a unit component of such structure. The NSE is a system structure bounded domain, which is characterized by an inherent set of simple object properties interacting at the categorical level. On the topological level, NSE is a simplex.

FUZZY COGNITIVE MODEL OF THE CTS CREATION PROJECT FEASIBILITY ASSESSMENT

In order to characterize the CTS creation, a fuzzy cognitive model was developed for assessing the CTS creation project feasibility for a nuclear power plant, Figure 2 (Kolodenkova 2016).

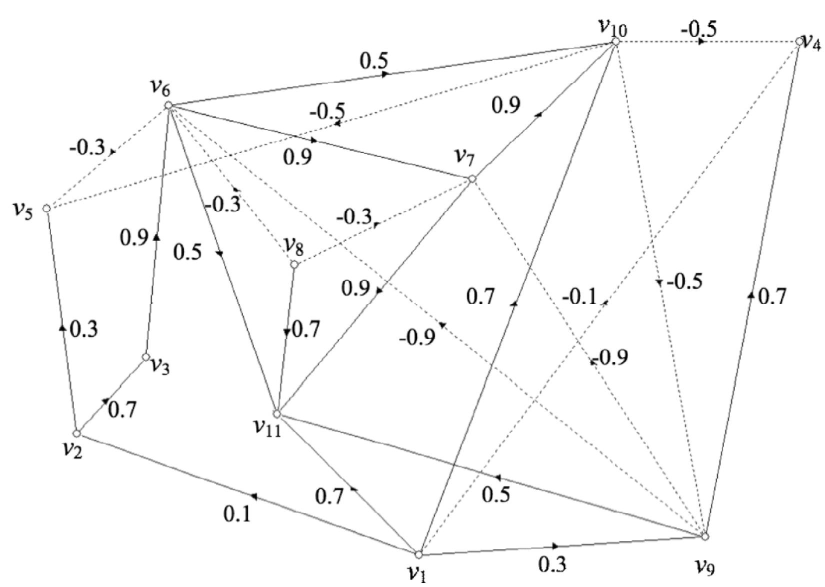

Figure 2: A fuzzy cognitive model for assessing the information-control system (ICS) creation project feasibility for nuclear power plants

Here, vertex v_1 is a number of tasks; v_2 is the performance of executors (work execution speed); v_3 is the number of CTS project estimates (estimates can be obtained through using various approaches and methods and are presented in the form, which allows the decision-making with respect to the methods of CTS feasibility); v_4 is the project completion (an unsuccessful project completion, that is, work schedule delay, project failure); v_5 is efficiency (work performance at the lowest costs); v_6 is CTS reliability (CTS is in working condition for a certain time interval); v_7 is CTS security and protection (CTS functions properly without causing any negative consequences for people and outer environment); v_8 are external factors (external influencing factors at a nuclear power station (seismic, climatic, floods)); v_9 are the executor errors (the number of errors); v_{10} is the time spent for creating a system; v_{11} are the financial resources spent for the CTS creation.

Note that the connection $v_1 \rightarrow v_2$ of 0.3 weight means that if the parameter value of vertex v_1 increases (decreases) by 10%, then the parameter value of vertex v_2 increases (decreases) ("+" sign) by 3% (10% $\cdot$ 0.3 = 3%). For example, connection $v_{10} \rightarrow v_9$ of -0.7 weight means that if the parameter value of vertex v_{10} decreases by 10%, then the parameter value of vertex v_9 increases ("-" sign) by 7% (10% $\cdot$ 0.7 = 7%).

In order to analyze the possible scenarios related to the CTS creation, their impulse modeling was conducted.

The following are examples of the most typical situation development scenarios related to the CTS creation. Each example is analyzed. The scenario 1 corresponds to the "negative" (pessimistic) scenario (Figure 3); the scenario 2 corresponds to the "positive" (optimistic) scenario (Figure 4). On X-axis (0*X*), simulation time-steps *n* are marked. On Y-axis (0*Y*), the values of pulses generated at the vertices under the influence of analyzed disturbing actions (figures characterizing the rate of signals rising at the cognitive model vertices) are marked.

Note that for the purpose of clarity, the impulse process graphic images are divided according to 4 vertices, wherein the results of such a number of simulation time-steps are presented, which reflects the trends in changes. Further computational experiment showed that the trends of increase, decrease, and fluctuations do not change in the subsequent time-steps.

Scenario No. 1. Pulse comes into one vertex. Let us ask ourselves, "What happens if we increase the number of executor errors by q_9 = +10%?"

Figure 3 shows that as the number of executor errors increases by (+10%), the ICS reliability decreases by (-9%), and the time shortage (time to create an ICS) by (-14.4%) occurs. This increases the unsuccessful project completion by (+7%).

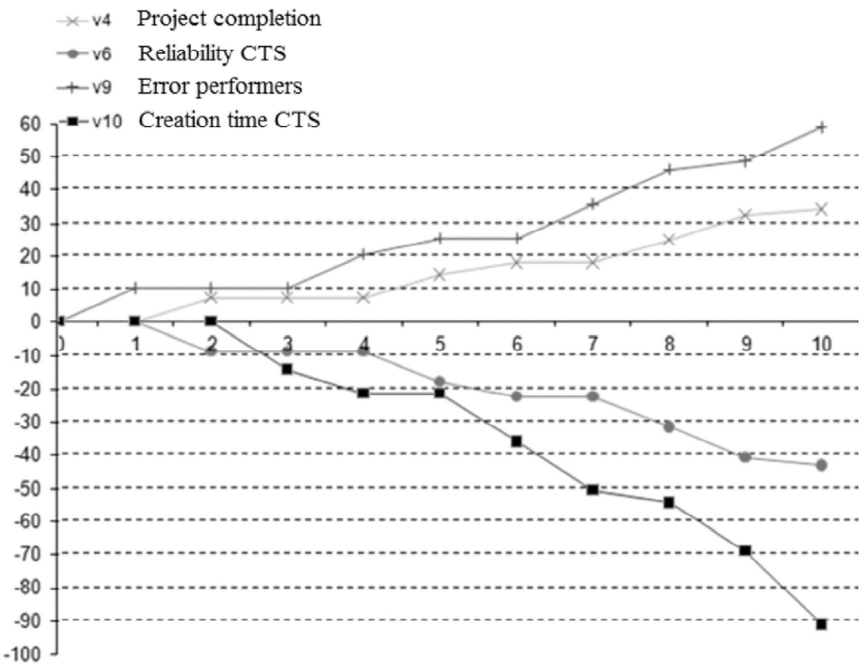

Figure 3: Scenario No. 1. The number of executor errors increases, q_9 = +10%

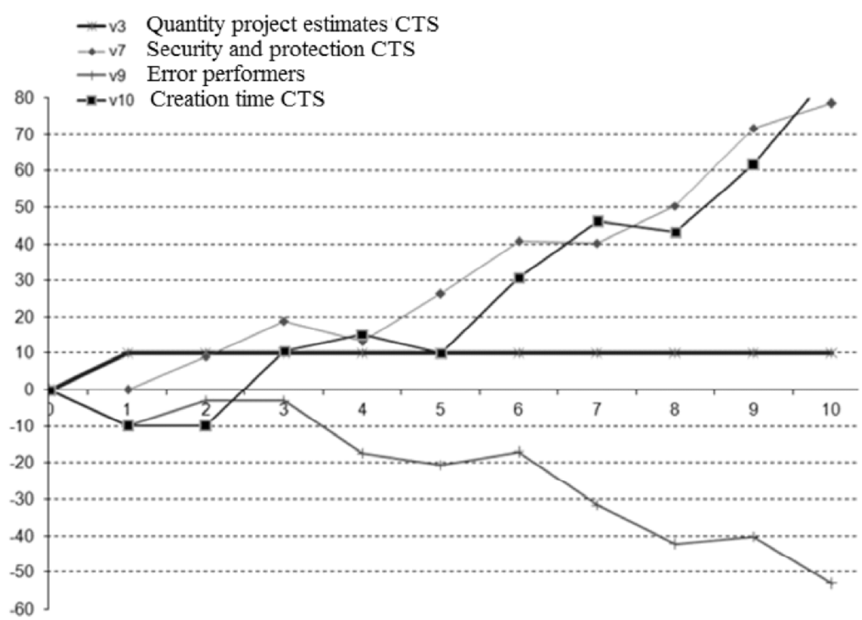

Figure 4: Scenario No. 2. The number of CTS project estimates increases by q_3 = +10%, the number of executor errors decreases by q_9 = -10%, and the time for CTS creation is reduced by q_{10} = -10%

Scenario No. 2. Pulse comes into **three** vertices. Let us ask ourselves, "What happens if we increase the number of ICS project estimates by q_3 = +10%, reduce executor errors by q_9 = -10%, and reduce the time for ICS creation by q_{10} = -10%?"

Figure 4 shows that increasing the number of CTS project estimates by (+10%), decreasing the number of executor errors by (-10%), and reducing the time for CTS creation by (-10%) leads to a sharp increase in the CTS security and protection by (+10%). However, increasing the CTS security and protection, starting with stage 5, entails a sharp increase in the time required to create a CTS (+30%).

CONCLUSION

To achieve the necessary technical and economic parameters upon the CTS project completion, at the very beginning of its life cycle it is required to assess the project feasibility, for which it is proposed to apply an IDMSS, wherein the knowledge base is based on the cognitive modeling methodology.

Applying the cognitive modeling to assess the CTS creation project feasibility in the face of uncertainty helps the project leader to structure knowledge, to conduct a systematic and comprehensive assessment, and to significantly reduce the risk of human factor. The results obtained by applying the cognitive modeling in IDMSS allow that the project leader and its team could fast process and analyze large volumes of diverse information, assess the CTS creation project feasibility, as well as answer a question such as "What will happen to the CTS creation if...?", and thus increase the efficiency of management decision-making at the initial stage of the CTS life cycle. The studied generalized cognitive modeling algorithm can be used to create a module structure for the IDMSS knowledge base.

The proposed method of CTS decomposed into non-derivative structural elements, which is based on a categorical approach, will also help to generate an IDMSS knowledge base including a few dozen of CTS NSE.

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