Cognitive Approach to Control in Ill-structured Situation and the Problem of Risks

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1. Introduction

The decision theory studying control problems for systems of various natures (technical, biological, socio-economic) has become independent science branch during last decades. The decision theory actively uses methods of mathematics, psychology and informatics. The cognitive simulation is one of the new approaches of modern decision theory. The main purpose of this chapter is forming complete idea of cognitive approach actively developed now in the control science and interdisciplinary sciences (sociology, economy, etc.), further specification of basic concepts of this approach in the control science, as well as defining a class of control problems that are advisable to be solved by the cognitive simulation (simulation on the base of cognitive map).

The cognitive approach to simulation is directed to development of formal models and methods that support the intellectual process of problem solving owing to taking into account the cognitive abilities (perception, representation, cognition, understanding, explanation) of control agents. The basic technique of ill-structured problem solving is structurization of knowledge about object with further its environment and construction of a cognitive map (the static model of situation) and a dynamic model. The technique includes monitoring of dynamic of factors of the model (their tendencies), analysis of the model structure with the use of SWOT-approach, and modeling that permits to determine and solve ill-structured problems. This technique allows supporting of a vital control task that consists in goal setting of situation development, as far as solution of discovered problems turns into the system development control task. This technique application is useful when designing a strategy of development of social and economic objects.

The problem of risks for the results validity that arise due to the human factor in the cognitive approach is considered and two kinds of risks which we can pertinently treat as cognitive risks are exposed. On the example of a real cognitive map of a complex and ill-structured situation the analysis of some cognitive risks concerned with causal influence transitivity is carried out. Some explanatory mechanisms and criteria for the early detection of such risks are proposed. The issues important for further development of the cognitive approach to decision-making in the ill-structured situation control and especially of causal mapping techniques are highlighted.

The chapter includes the following topics:

1. Brief review of cognitive approach in control: evolution and some trends in its development. The problem of risks due to the human factor.

2. The models and methods of ill-structured problem solving on the basic construction and analysis of the cognitive map. Presenting the risks related with formalization of initial expert knowledge about ill-structured problem situation, by the example of cognitive map construction.
3. Analysis the experience of cognitive techniques application to control of socio-economic development and some trends of further development of cognitive approach.

2. Brief review of cognitive approach in control: evolution and some trends in its development. The problem of risks due to the human factor

2.1 Brief history of cognitive approach evolution

Origins of concept "cognitive map" lie in psychology (Tolman, 1946). Studying cognitive maps – subjective representations of spatial organization of outer world – has gained in fundamental importance in the framework of studying features of human perception of his surroundings. The cognitive map is the concept concerning cognitive processes related to gathering, representation, and processing of information on the environment during which an individual is not only a passive observer, but actively interacts with his environment. Forming cognitive maps by an individual is understood as the process consisting of series of psychological transformations. By means of these transformations, an individual gathers, stores, copies, recalls and manipulates information on relative locations and attributes of his spatial surroundings. This process is essential component of decision making for spatial behaviour. The psychological research is directed to a greater extent toward studying these very processes and their influence onto forming certain representations allowing an individual to act and make decisions in his environment.

In political science and sociology, the method of cognitive simulation was developed in 1960–1980 in papers of American researcher R. Axelrod and his colleagues from USA and Scandinavia (Heradstvein & Narvesen, 1978; Axelrod, 1976).

It should be noted that many authors also use the term "cognitive mapping". In any case, research of problem situation is based on model construction on the base of a cognitive map. The differences consist only in applied modifications of cognitive maps and methods of their formal processing.

In political science and sociology, "cognitive map" is not related to spatial orientation. It is interpreted as an individual's schematic representation of world image fragment relating to concrete problem situation. In this context, cognitive map is the way for representing thought structures directed toward a concrete problem and allowing to simulate politician's mentation during deliberation of action stimulating identification of further events (Heradstvein & Narvesen, 1978).

Construction and analysis of cognitive maps allow revealing causal structure of reasoning presented in political texts and, on this base, making conclusion on text author's vision of political situation, defining factors taken into account by politicians while making decisions.

Axelrod developed the method of cognitive simulation relying on ideas of psycho-logic (Abelson & Rosenberg, 1958), causal deduction (Shapiro & Bonham, 1973), as well as graph and decision theories (Axelrod, 1976). As the main problems of decision making, he distinguished the problems of situation explanation and test of hypothesis on situation arrangement, as well as prediction problems and problems of decision selection from a number of alternatives. On the base of these studies it was shown that in complex situations an individual is inclined to simplify situation representation, to not notice feedbacks, etc. As

a consequence, long-term effects, interrelations between different problems, etc., are not taken into account while making decisions.

Axelrod placed the models constructed on the base of cognitive maps among normative models in that sense that they organize cognitive activity of an individual during the process of decision making. Just as any formalization, the cognitive map and methods of its analysis prescribe an individual his way of making decisions in complex situations.

The methods of cognitive simulation have found an application in collective working out and making decisions (Hart, 1976; Roberts, 1976). English scientist K. Eden developed general approach to construction of cognitive maps (Eden, 1988), resting on research in the field of decision making psychology, in particular, on the theory of personal constructs by Kelly (1955). Eden outlined importance of Kelly's statement to the effect that effectiveness of interaction in group of individuals making decisions essentially depends on each member's understanding of ways for situation interpretation by other group members.

Empirical studies of some authors (Eden, 1988; Axelrod, 1976; Hart, 1976; Holsti, 1976; Roberts, 1976; Shapiro & Bonham, 1973) shown that application of cognitive simulation methods allows increasing effectiveness of decision making in problem situation. Analyzing his own and other's cognitive maps, an individual can define problem representation more exactly, find contradictions, understands other individuals. In addition, the cognitive map is the convenient tool for changing settled stereotypes contributing to generation of new viewpoints.

At the same time, Axelrod notes a lack of formal methods for construction of cognitive maps directed toward reliability and interpretability of results of problem situation analysis (Axelrod, 1976).

As a rule, application of cognitive simulation methods in sociology and political science is aimed to revealing representations of an individual making decisions in various situations, resolution of subjective conflicts due to difference between problem representations and lack of mutual understanding among interacting individuals.

The development of cognitive simulation methods is substantially conditioned by need in analysis of ill-structured systems and situations including multitude of elements with different nature, as well as relationships between elements having both quantitative and qualitative nature. The concept "ill-structured problem (situation)" was introduced by G. Simon (1973).

The cognitive approach to analysis of ill-structured situations was proposed by Axelrod, (1976) and Roberts (1976). Axelrod to a greater extent was engaged into development of methodology, while Roberts – into development of mathematical tool. The primary precondition for rising this approach consists in boundedness of accurate model applicability to ill-structured system behaviour analysis, as well as making control decisions on resolution of problem situations.

For this approach, the subjective understanding and individual's representation of the controlled system parameters and relationships between them in form of cognitive map consists foundation for construction of ill-structured model of system or situation. Subsequent choice of formal methods for processing of representations reflected in the cognitive map depends on goals of analysis, as well as characteristic features of ill-structured system or situation.

Nowadays, the cognitive approach to analysis of ill-structured systems and situations is actively developed in Russia and abroad (Avdeeva et al., 2007; Kuznetsov et al., 2006; Kulba

et al., 2004; Avdeeva et al., 2003; Chaib-draa, 2002; Maximov, 2001; Maximov & Kornoushenko, 2001; Kim, 2000; Huff, 1990; Kosko, 1986; Sawaragi et al, 1986; Heradstvein & Narvesen, 1978; Roberts, 1976). One of the typical trends of this development consists in looking for mechanisms joining various scientific areas of researching decision problems for control of ill-structured systems and situations.

The distinctive feature of cognitive approach consists in the following:

- process of solving of control problems is considered as cognitive human activity including application of formal models and methods as a part or stage of solution;
- another important stage is formalization of representation of ill-structured systems and situations, goals, interests and motivations of individuals involved into the problem solution processes.

2.2 Trends in development of the cognitive approach in decision-making

In theoretical researches on methods for searching and making decisions, such terms as cognitive approach, cognitive researches, cognitive modeling or cognitive mapping of complex objects, problems, and situations are used more and more often. It can explained by growing understanding of inevitable participation of people with their cognitive resources (and also restrictions) in the decision of practical problems of control, especially in case of complex and ill-structured situations (Abramova & Kovriga, 2008).

Recently the selective analysis of works proposed at International Conference "Cognitive analysis and situations evolution control" (CASC) has been carried out (Abramova, 2007b), with the following similar analysis of other publications using term "cognitive" in the context of solving the applied control problems. The conference has been held at the Institute of Control Sciences of Russian Academy of Sciences for the latter seven years, being focused on the integration of formal and cognitive (using resources of the person) problem solving methods.

The analysis has allowed seeing considerable distinction in understanding of what terms "cognitive approach" and "cognitive modeling" mean, in how the term "cognitive" operates, in scientific and applied problems being solved, in the formalization level, in considered cognitive aspects, in involved knowledge of the cognitive science. At all distinctions, it is possible to identify two basic directions in accordance with understanding of the cognitive approach in narrow and wide sense (in the context of decision-making and ill-structured situations).

Two directions of the cognitive approach. Today, the direction of the cognitive approach corresponding to narrow sense of the term is the most developed one. It means that various models of cognitive maps are applied as models for representation and creation of knowledge about ill-structured situations,. The most conservative branch of this direction focused on formal methods, at all does not consider specificity of human factors and features of structurization by the person of difficult situations et all; so the word "cognitive" bears purely nominative function of a label for models applied.

However as a whole it is relevant to speak about two trends in development of this direction. On the one hand, the positive tendency to larger account of such human-dependent stages as formalization of primary knowledge and representations of a problem situation, targets definition, etc is observed. On the other hand, the accepted models of knowledge and activity of the people solving practical problems (experts, analysts, decision-makers) are normative in relation to those people, and the justification of the models is

defined by theorists at the level of common sense and traditions. Any knowledge of how people really think and what knowledge the cognitive science in this respect has, today are not usually involved today.

The cognitive approach in wide sense is not limited by the choice of cognitive maps as models for representing knowledges about complex objects and situations (Abramova & Novikov, 2006). The accent initially is made on human-dependent stages. Basically, the approach covers a wide spectrum of the models applied in decision-making for ill-structured problem situations. However, today the same tendencies in this direction dominates, as in the previous one.

Review (Abramova, 2007b) represents perspectives of more advanced development of the cognitive approach, with integration of formal methods and knowledge of psychology and the cognitive science as a whole. However, today bridging the gap appears to be difficult, at least, because of distinction in scientific languages. Among few exceptions it is useful to mention (Obal et al., 2007; Gabriel & Nyshadham, 2008; Vavilov, 2006).

2.3 The problem of risks due to the human factor

The problem of risks due to the human factor in the field of formal methods for searching and making decisions to control complex and ill-structured situations essentially consists in that because of inevitable and substantial human beings' participation in solving practical problems (at least, for formalization of primary representations) formal methods basically cannot provide validity of received decisions. Note that validity of method application results is understood here in wide intuitive sense as capability to rely upon these results in solving a specific practical problem. It is also possible to speak about validity of a method as its capability to yield valid results. Simplier speaking, such methods (which we refer to as subjective-formal ones) are basically risky concerning validity of their results.

The pragmatical importance of the given problem of risks obviously depends on how much significant are risks obtaining invalid results in solving practical problems. By present time theoretical, experimental and even practical knowledge is accumulated, leading to under-standing or directly saying that human factors can be the significant source of risk for quality of results (Abramova, 2007a).

The most impressing is the research on "logic of failure", presented in D. Dörner's known book (Dörner, 1997). By means of vast computer-based simulation of how real people solve problems of the complex and ill- structured dynamic situation control, a number of typical errors is revealed which are inherent not only in dilettantes but also in experts at work with complex situations. These results lead to conclusion that some of the above errors should be expected for any kinds of cognitive maps whereas others should be characteristic of dynamic map modeling. Strictly speaking, in Dörner's experiments it is possible to admit that the risks of errors stem not only from natural ways of thinking but also from the accepted model for representation of knowledge about situations in the computer. However, Dörner finds evidences in favor of his theory in the analysis of known natural-thinking decisions concerning Chernobyl.

One more class of risk sources is revealed by O. Larichev (Larichev & Moshkovich, 1997). with his school in the traditional formal decision theory. It refers to methods and operations of receiving initial information from decision-makers (in other terms, knowledge acquisition) for subsequent processing with formal methods. Stemming in the accumulated psychological knowledge of more than 30 years, the inference has been drawn that "soft"

qualitative measurements such as comparison, reference to a class, ordering are much more reliable, than appointment of subjective probabilities, quantitative estimates of criteria importance, weights, usefulnesses, etc. To increase reliability of such operations (in our terms, to decrease risk of human errors) the idea of psychologically correct (in other terms, cognitively valid) operations has been advanced by the school. From the above results it follows that validity of cognitive modeling should be various for different kinds of cognitive maps depending on kinds of estimates demanded from experts.

There is also a wide spectrum of psychological researches in the field of the limited rationality of the person, not relating to solving control problem activities, which evidencing to numerous types of risks in intellectual activity of a person.

To add evidences of practical significance of cognitive risk factors in decision-making, it is relevant to mention that some significant risk factors have been found out by these authors in the applied activity on safety-related software quality assurance including formal-method quality estimation and control. This practice along with further theoretical analysis have considerably expanded representations of the risk spectrum produced by theorists developing or choosing models for knowledge representation and activity of people solving practical problems, in comparison with the risks exposed by Larichev's school (Abramova, 2004; Abramova, 2006). For example, it has appeared that application of very natural, from the mathematical point of view, method of linear convolution of normalized estimates on partial quality indicators for estimation of a complex indicator creates paradoxical risk of loss of controllability on partial indicators.

Moreover, the analysis has confirmed presence of some general cognitive mechanisms of risk for diverse models of subject-matter experts' knowledge and related formal methods what serves evidence of reasonability of the general approach to the problem of risks due to the human factor in decision-making.

The subjective aspect of the problem of risks is that even more or less widely spread peaces of knowledge relative to risks and their sources mainly are not noticed by scientific community or, at the best, are underestimated. This ignorance is quite explainable theoretically with taking into account psychological risk factors (with the models presented in (Abramova, 2006; Abramova, 2007a). Thereby, there is a soil for theoretical development and practical application of subjective-formal methods, which cannot provide decision quality (adequacy, validity, reliability, safety) comprehensible for critical domains.

Among few works in the field of cognitive mapping, with recognizing not only the human factor influence, but also necessity of researches in this direction, it is worthwhile to note (Bouzdine-Chameeva, 2006), where validity of cognitive maps with internal validity between the data and the conceptualization of the data, including the definitions of concepts and influences, has been discussed, proceeding from the general ideas of content-analysis reliability.

Cognitive risks. Two kinds of risk factors. In diversity of risks due to the human factor in the considered field the special class is formed by cognitive risks which are explainable with taking into account factors (mechanisms) concerning cognitive sphere of a person. All risks mentioned above are referred to cognitive risks as well as a number of others, which are reported about in publications and private communications without doing them subject of the scientific analysis.

First of all, researchers are interested in the factors that, on the one hand, have regular nature (i.e. do not concern to dysfunctional cognition), and on the other hand, are hardly explainable from positions of common sense or even contradict it; so usually they are not

assumed by the mathematicians developing working out normative models for expert knowledge representation or ignored if known.

Earlier cognitive processes have been analyzed in which subjects of intellectual activity (analysts, experts, decision makers and other staff who participates in searching and making decisions at collaboration with computers) turn to be under the influence of "ambient intelligence" due to imposed forms of thinking (Abramova & Kovriga, 2006; Abramova, 2006; Abramova, 2007a). This influence leads to dependence of decisions on theoretical beliefs of specialists on formal methods and computer-aided decision support systems and technologies. Therefore, results in risks of invalid decisions. Two kinds of risk factors explainable with the suggested models have been exposed which are pertinently considered as cognitive risks.

The risk factors psychologically influencing validity of expert methods during their application by experts belong the first-kind factors, or factors of direct action. Such factors can either objectively promote invalidity of results, or raise subjective confidence of experts in objective validity for the method application outcomes. One can tell that the latter represent themselves as factors of belief. Agents of these factors of influence are experts; just they appear in conditions which that may lead, eventually, to insufficiently valid (in the objective relation) outcomes.

The second-kind risk factors or factors of an indirect action psychologically influence upon validity of expert methods during their creation and justification. The agents of influence of such factors are the creators of methods, scientists and experts producing standards who, in turn, are subject to influence of scientific norms, paradigms, etc., that is the strongest factors of belief. Typical examples of the first-kind risk factors are the natural mechanisms of thinking with risk of errors, as in the case of the errors discovered by Dörner. Typical second-kind risk factors are psychologically incorrect models of knowledge of the experts, creating risk of unreliable (unstable or inconsistent) data from experts, with the models being supported by belief (often unconscious) in their validity.

Amongst a number of cognitive risk factors having been found out by these authors both in theoretical and experimental researches, as well as in practice, there are risks related to belief in universality of the principle of pairwise preference transitivity in decision-making (Abramova & Kovriga, 2006 ; Abramova & Korenyushkin, 2006). The principle means that from $a \succ b$ ("a is preferable over b") and $b \succ c$ it always follows $a \succ c$, though rationally reasoned violations of this principle are known (for example, preferences based on multicriteria comparisons).

From now onwards, the given work concerns one family of cognitive risks having been discovered quite recently. Risks take place in cognitive mapping based on causal maps. They are related to the property of causal influence transitivity and its violations. They have been admitted as a hypothesis by analogy to known rationally reasoned violations of transitivity of pairwise preferences and later found out in real causal maps.

3. Some methods of ill-structured problem solving on the basic a cognitive map. Some risks concerned with causal influence transitivity

For further turning to the cognitive approach in the narrow sense, it is necessary to clarify the concept of cognitive map in the meanings used in the decision-making context.

In this field of knowledge the concept of cognitive map is used more and more widely beginning from (Axelrod, 1976), but it takes various meanings, without saying about

essentially differing concept of cognitive map in psychology. Recent years have brought out a number of reviews and articles with extensive reviews in which the diverse types of cognitive maps and other concept maps are compared, differing in substantial and formal interpretation, as well as in sights at their role in searching and making decision processes and control of complex objects and situations (in particular, Eden, 1988; Kremer, 1994 ; Mls, 2006;. Kuznetsov et al., 2006; Bouzdine-Chameeva, 2006; Abramova, 2007b; Avdeeva et al., 2007; Peña et al., 2007).

In this work term "cognitive map" refers to the family of models representing structure of causal (or, that is the same, cause-effect) influences of a mapped situation. Formally, the obligatory base of all models of the family is a directed graph, the nodes of which are associated with factors (or concepts) and arches are interpreted as direct causal influences (or causal relations, connections, links) between factors (Kuznetsov, Kilinich & Markovskii, 2006). Usually the obligatory base (that is the cognitive map in the narrow sense) is added with some parameters, such as an influence sign ("+" or "-") or influence intensity, and some or other interpretations both substantial, and mathematical are given to the map (Fig. 1).
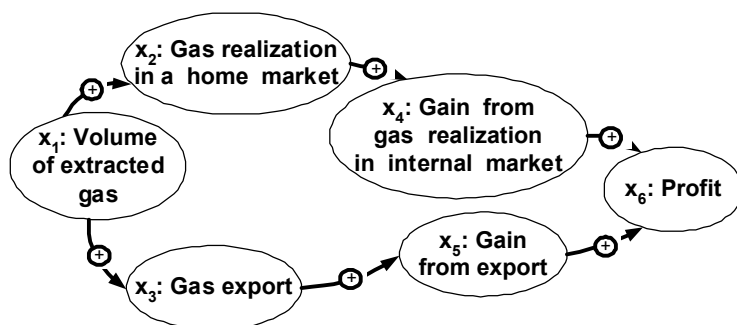

Fig. 1. Example of cognitive map

Various interpretations of nodes, arcs and weights on the arcs, as well as various functions defining influence of relations onto factors result in different modifications of cognitive maps and formal means for their analysis (Kuznetsov, Kilinich & Markovskii, 2006). Owing to multitude of cognitive map modifications, one can distinguish different types of models based on cognitive maps (in short, cognitive map models). Models of this family that are often referred to as causal maps or influence diagrams cover a wide spectrum of known types of models for cognitive mapping.

By type of used relationships, five types of cognitive maps are distinguished (Huff, 1990):

1. Maps that assess attention, association and importance of concepts: With these maps, the map maker searches for frequent use of related concepts as indicators of the strategic emphasis of a particular decision maker or organization, for example, and look for the association of these concepts with others to infer mental connection between important strategic themes. He also can make judgments about the complexity of these relationships or differences in the use of concepts;

2. Maps that show dimension of categories and cognitive taxonomies: The map maker investigates here more complex relationships between concepts. He can dichotomize concepts and construct hierarchical relationships among broad concepts and more specific subcategories. The maps of this type have been used to define the competitive

environment, and to explore the range and nature of choices perceived by decisions makers in a given setting;

3. Maps that show influence, causality and system dynamics (causal maps): These maps allow the map maker to focus on action, for instance, how the respondent explains the current situation in terms of previous events, and what changes are expected in the future. This kind of cognitive map is currently, has been, and is still, the most popular mapping method;

4. Maps that show the structure of argument and conclusion: This type of map attempts to show the logic behind conclusions and decisions to act. The map maker includes here causal beliefs, but looks more broadly at the text, as a whole, to show the cumulative impact of varied evidence and the links between longer chains of reasoning;

5. Maps that specify frames and perceptual codes: This approach supposes that cognition is highly conditioned by previous experience, and that experience is stored in memory as a set of structured expectations.

Applied practice shows that the maps of the third type are expedient for studying of ill-structured systems. Choice of method for structuring of ill-structured systems and situations in a form of set of factors and causal relations are conditioned by that the events and processes of operation and development of ill-structured systems include various events and trends defined by many factors, at that each of them in turn has an influence on some number of other factors. The networks of causal relations between them are formed (Kuznetsov et al., 2006; Dorner, 1997). Book of well-known German psychologist Dorner (1997) devoted to studying thought on control subject and analysis of causes of mistakes while resolving problem situations in operation and development of complex systems indicates that a momentary situation with its features is only actual state of system and its variables. One should not only understand events that happen, but also foresee events that will happen or may happen in the future, as well as suppose a way for situation changing depend on concrete interference. It requires structured knowledge, i.e. the knowledge of relationships and mutual influences of system variables. Dorner notes that in ideal case this knowledge is represented in the form of "mathematical functions", but in case when the latter cannot be constructed one can apply diagrams of causal relations allowing to reconstruct various assumptions (hypotheses) in mind of the subject of control, at that not in the form of "causal chains", but in the form of "causal networks".

According to Kuznetsov, Kilinich & Markovskii (2006), the situation analysis problems on the base of cognitive maps can be divided into two types – static and dynamic. Static analysis or influence analysis is analysis of considered situation via studying structure of mutual influence in a cognitive map. The influence analysis chooses factors with the strongest influence onto goal factors that are the factors with values to be changed. The dynamic analysis lies in the base of generating possible scenarios of situation development with time. Thus, abilities of solution of analysis and control problems are defined by type of used models, static or dynamic.

As a rule, two types of mathematical tools are used for carrying out these kinds of analysis – linear dynamic systems and fuzzy mathematics.

Nowadays, the research abroad is mainly devoted to the development of models on the base of fuzzy mathematics and static models using different mathematical tools (Chaib-draa, 2002; Kim, 2000; Kosko, 1986; Sawaragi et al, 1986; Heradstvein & Narvesen, 1978).

In Russia, along with the development of methods for static analysis of cognitive maps, special efforts are directed to research of ill-structured systems and situations using linear

dynamic models that are presented in this paper by works of Russian scientists (Avdeeva et al., 2007; Avdeeva, 2006; Kulba et al., 2004; Avdeeva et al., 2003; Maximov & Kornoushenko, 2001; Maximov, 2001).

In linear dynamic model based on cognitive map, factor is formally defined as variable taking values from some numerical scale.

The model construction is based on the cognitive structurization of knowledge about object and its environment.

The purpose of structuring consists in revealing of the most essential factors describe a "boundary" layer of interaction between object and external environment, as well as establishing of qualitative relationships between cause and effect between them.

The cognitive structurization is finished by formalization of singled out knowledge that consists in generalization of essential information into a system of basic factors.

Analysis of a graph model of a situation associated with a cognitive map allows to reveal the structural properties of a situation. The basis of the model is a weighed digraph G =(X, A), where X is a set of nodes that biuniquely corresponds to the set of basic factors, A is a set of arcs reflecting the fact of direct influence of factors. Each arc connecting some factor x_i with some factor x_j has the weight a_{ij} with the sign depicting the sign of influence of the factor x_i on the factor x_j, and the absolute value of a_{ij} depicting the strength of the influence. Thus, the cognitive map can be examined as the connectivity matrix A_g of the graph G.

When constructing a cognitive map , the set of basic factors, X, is grouped in blocks relevant to external environment, X^{ext}, and an internal environment, $X^{int} = X \backslash X^{ext}$. Besides determination of factors and influence between them the vector of initial factor trends, $X^{ext}(0) \cup X^{int}(0)$, is established.

Change of factor value with time is given by Kulba et al. (2004), Maximov (2001), Maximov & Kornoushenko (2001)

$$x_i(t+1) = x_i(t) + \sum_{j \in I_i} a_{ij}\left(x_j(t) - x_j(t-1)\right), \quad i = 1,...,N \tag{1}$$

where $x_i(t+1)$ and $x_i(t)$ are the values of i-th factor at instants t+1 and t, respectively, $x_j(t) - x_j(t-1) = \Delta x_j(t)$ is the increment of factor x_j at instant t characterizing the rate of change (trend) of x_j, a_{ij} is the weight of the factor x_j influence onto factor x_i, I_i is the set consisting of numbers of factors directly effecting the factor x_i.

With knowledge of the initial situation state X (0) and accepting x (t) =0 for all t <0, the state of a situation in self-development (without applied control) at any moment t can be characterized by the vector of factor values

$$X(t) = (E_N + A + A^2 + ... + A^t) X(0) \tag{2}$$

Estimation of the sum of this series can be obtained only if the graph G adjacency matrix A_g is stable. Then all elements of this series approach to finite limits at unlimited increase of t.

To determine the transitive closure, it is sufficient to consider N terms in a power series of matrix B, where N is the order of matrix B, i.e. the number of basic factors in the situation cognitive map. Then the transitive closure of the matrix B is estimated by the matrix

$$Q = E_N + A + A^2 + ... + A^N \cong \left(E_N - A\right)^{-1} \tag{3}$$

Matrix Q characterizes the direct and mediated influences effecting each factor.

Let $U(0)=(u_1(0),...,u_p(0))$ be the vector of pulse control effecting at the moment $t=0$ the factors X. Then, with knowledge of the initial state of situation X(0), the state of the situation at any moment can characterized by the factor value vector

$$X(t)=QX(0)+QBU \qquad (4)$$

where $u = (u_1,...,u_p)^T$ is the external input vector and B - (0,1) – is the (pxn)-matrix with nonzero elements specifying numbers of corrected coordinates of the initial state X (0).

The dynamic model is constructed to obtain a new knowledge of structure and dynamics of considering situations. On the basis of that model, one can carry out the scenario research with use of methods of computer modeling of self-development and controlled development of ill-structured situation (Maximov, 2001; Maximov & Kornoushenko, 2001; Avdeeva, et al., 2003; Makarenko, et al., 2004).

Our research group focuses special attention on the following:

1. searching and development of structuring methods aimed at construction of cognitive maps;
2. increasing technological effectiveness of scientific and instrumental support for solving practical control problems:
3. approach to revealing and prohibition of the semantic errors and risks of formalization (before application formal method to analysis of ill-structured situation).

The problem of risks outlined below in section 3.1 represents advanced approach in wide sense, with taking cognitive mapping as the representative example.

On the basis (1)-(4) has developed the following methods and approaches have been developed (Avdeeva et al., 2007; Avdeeva, 2006; Avdeeva et al., 2003; Maximov & Kornoushenko, 2001):

-   method of structure and goal analysis of ill-structured system development (section 3.3);
-   SWOT-analysis on the basis of analysis of the model structure (section 3.2);
-   approach and methods for solving ill-structured problems and deriving scenarios of ill-structured system development; (section 3.3);
-   approach to studying conflict situations generated by contradictions in interests of subjects influencing development of considered system and other.

At that, the problem is defined as discrepancy between current condition of ill-structured system and its dynamic and desired condition that is given by the subject of control. Complex application of the mentioned methods allows carrying out static and dynamic analysis while studying ill-structured systems. The socio-economic systems (SEO) constitute a typical class of ill-structured systems that are expedient for application of cognitive simulation for development problem solving.

But it is necessary to take into account that such methods essentially depend on techniques of revealing of the factors and definition of their interrelations describing situations under research. Construction of the cognitive map reflecting representation of complex system development includes forming of the conceptual scheme of the situation (the description of the subject domains defining complex system development); choice or revealing of the important factors (detailing of the conceptual scheme); definition of interrelations between the factors.

Despite of popularity of such methods, now there is no coordination in the literature concerning a way of revealing of the important factors influencing and defining the

situation under research. Methods of a cognitive map construction can be useful as to understanding cognitive processes of the persons participating in decision-making, and as a basis for control of active research of complex situations (Avdeeva, 2006). The analysis of works of scientists (Axelrod, 1976; Hodgkinson, Maule & Bown, 2004; Avdeeva, 2006, and other), actively applied cognitive methods for research of complex system, shows, that

- revealing of factors and interrelations by means of a content-analysis of documents, in particular, in the first work, devoted to a cognitive map application for support of decision-making, the author results bases of such analysis of stenograms of session of politicians;
- revealing of factors and interrelations by means of the analysis of expert opinions thus are involved experts on the subject domains;
- revealing of factors and interrelations by means of the analysis of quantitative data, for example, regression analysis.

The choice of a method for cognitive map construction depends on availability of data and also on the purposes of researchers. The listed above methods are not devoid of disadvantages. For example, the main problem in the documentary approach consists in that information is represented differently. Thus, the stenograms of debate of English politicians were represented as well structured material. Other documentary sources can unlikely be considered as well structured. One of the main disadvantages of the expert methods is insufficient validity of revealing of factors and their interrelations. The analysis of quantitative data assumes that the revealed factors and interrelations are impartial. But to get some factor in sight, the quantitative information about it and its influence should be collected.

On the basis of long-term experience of practical application of cognitive methods in the analysis of problem situations by the example of development of social and economic objects, our research group has developed techniques of carrying out strategic meetings and heuristic schemes of a cognitive map construction on the basis of PEST and SWOT (Strengths, Weaknesses, Opportunities, Threats) ideologies. This group of methods is directed onto structurization and coordination of primary representations of problem situation of non-uniform collective of experts.

As a whole, application of such techniques is complicated by lack of checking adequacy criteria for cognitive models as well as presence of reliability problem for results of application of expert methods.

3.1 Some risks concerned with causal influence transitivity and their analysis.

The example description. The facts. In fig. 2 the fragment of a real cognitive map slightly simplified to demonstrate action of risks is presented. Influence in pair of factors (3,2) at the verbal level is interpreted as follows: "increase in access of manufacturers to gas export pipelines (with other things being equal) causes increase in volume of extracted gas". This influence is positive (in mathematical sense) that means the same direction of changes of factors. Positive influence in pair (4,2) is verbalized similarly. Influence in pair (2,1) is negative: "increase in volume of extracted gas (with other things being equal) causes decrease in deficiency of gas in the country".

All three influences, as well as the set of factors significant for the investigated situation of dynamics of the market of gas in the country, are established by the expert. (Substantially, this map corresponds to a situation when there are stocks of gas and manufacturers have resources for increase gas production in volume but their access to means for its delivery to consumers is limited.)
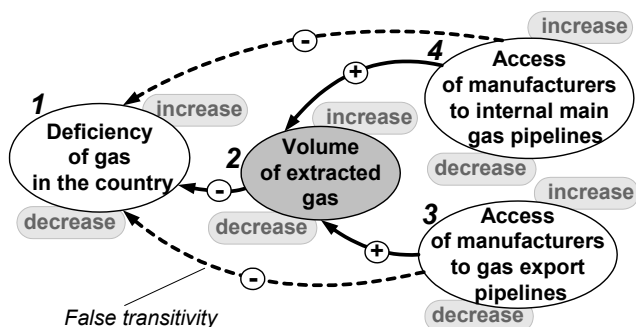
Fig. 2. An initial fragment of a cognitive map with false transitivity

According to formal model of causal influences and intuitive logic, from positive influence $3\xrightarrow{+}2$ and negative influence $2\xrightarrow{-}1$ follows transitive negative (in mathematical sense) influence $3\xrightarrow{-}1$; influence $4\xrightarrow{-}1$ is deduced similarly.

However later the expert has noticed that "logically deduced" influence $3\xrightarrow{-}1$ is absent in reality: thereby false transitivity of influences takes place in the map. The analysis of expert knowledge of the situation leads to the following correction (fig. 3).
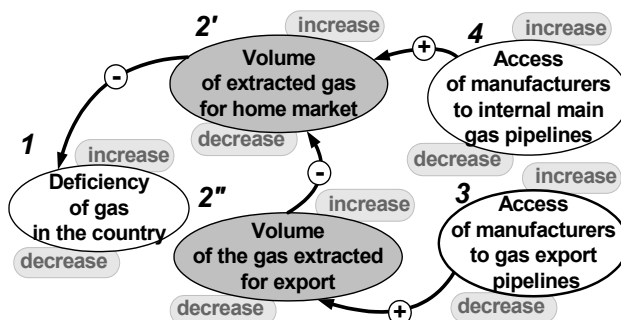

Fig. 3. The corrected fragment of a cognitive map

It is worth while to underline that at such refinement replacements of influence $3\xrightarrow{+}2$ with $3\xrightarrow{+}2''$, $4\xrightarrow{+}2$ with $4\xrightarrow{+}2'$ and $2\xrightarrow{-}1$ with $2'\xrightarrow{-}1$, in essence have not changed expert's interpretation of influences: only the form of representation of knowledge has changed only. However, in this way the chain $3\xrightarrow{+}2\xrightarrow{-}1$ generating false influence $3\xrightarrow{-}1$ has disappeared.

Essentially different situation occurs with introduction of additional negative influence $2''\xrightarrow{-}2'$. This influence means that at increase of access of manufacturers to export gas pipelines (with other things being equal) it is possible to increase volume of the gas extracted for export not only by means of increase in volume of extraction, but also by simple «valve switching». Thus growth of volume of gas for export is made at the expense of decrease in volume of gas for home market. In this case knowledge is entered into a map, well known to experts, but not represented within the frame of initial system of concepts (factors).

As a result of correction new transitive influences $3\xrightarrow{\quad -\quad}2'$, $3\xrightarrow{\quad +\quad}1$ have appeared. Instead of positive (in substantial sense) situation in the map of fig. 1, when it is possible to reduce deficiency of gas at the expense of access of manufacturers both to internal, and to external gas pipelines, more complicated and more realistic situation comes up in the map of fig. 3.

Along with positive (as a matter of fact) transitive influence $4\xrightarrow{\quad -\quad}1$, negative (as a matter of fact) influence $3\xrightarrow{\quad +\quad}1$ takes place, and their proportion at the decision of the problem of gas deficiency in the country demands comparative estimation of influences.

The invalidity of the fragment of cognitive map in fig. 2 relative to reality, or in other words, error in cognitive mapping is obvious.

The above practical example along with some other ones serve as actual evidences of the fact that in cognitive modeling of complex situations there are possible cases of erroneous inferences by transitivity, i.e. false transitivity.

The analysis of cognitive risks. In the above example the false transitivity can be explained with cumulative action of two modes of risk factors in the course of cognitive mapping: assumption of causal influence transitivity as the universal principle and disproportion of extension of concepts.

First, in each of the three direct influences between factors of the initial map having been set by an expert, there is disproportion of extension of concepts with excess of extension of concept 2, which denotes the influence receiver in pairs (3,2), (4,2) and the influence source in pair (2,1).

Denote that in cognitive mapping it is traditional to speak about factors (concepts) as causes and effects. However we prefer, at least in the analysis, to speak about sources and receivers of influences , because, in modeling of complex and ill-structured situations substantial cause-effect interpretations of individual influences in a map quite often happen more or less difficult. (There is such a situation in the above example.) Moreover, in the theoretical analysis which we spend it is more exact to distinguish "factors" and "concepts of factors" (that is concepts designating factors). It is relevant to speak about factors at the analysis of situation content, and more pertinently to speak about concepts of factors when it is a question of the logic analysis of concept extensions.

Excess of extension of concepts in some direct influences informally means that it would be possible to take concepts with smaller extension for mapping the same substantial cause-effect influences. Just this action has been made at correction.

It is hardly admissible to consider such disproportions with excess of extension of concepts as errors because they are typical for the conceptualization of complex and ill-structured situations. This is evidenced both with practice of cognitive mapping and with informal reasonings of experts on such situations. Therefore we consider such disproportions as cognitive risks. They are natural for carrying to first-kind risk factors , the carriers of which are experts and which objectively reduce validity of cognitive modeling in complicated situations.

Causal influence transitivity is accepted as the universal principle by theorists. It leads to an automatic inference of indirect influences by transitivity at the formal simulation of a given map. Thus the given assumption should be considered as the second-kind risk factor.

Some criteria for early detection of risks. Let us more formally define some criteria which could help an expert to monitor risks and make the decision on possibility to correct disproportional concept extensions in case of false influence transitivity detection. In the

definition, the fact, which has been found out in practice, is taken into account: the same (as a matter of fact) causal influence can be represented in a cognitive map in different forms so that we speak about different representations of the influence. Let we have factors A, B_1 (represented with the same name concepts), which are linked by direct causal influence $B_1 \rightarrow A$, and let there exists (is found by an expert) factor B_2 such that replacement of representation of influence $B_1 \rightarrow A$ with $B_2 \rightarrow A$ does not change the influence substantially, and herewith

$$\mathcal{V}_{B_1} \supset \mathcal{V}_{B_2} \,,$$

where $\mathcal{V}_{B_i}$, $i = 1,2$, stands for the extension of the corresponding concept, and the relation between extensions is treated as usual inclusion or, that is the same, verbally: "c_1 has smaller extension than c_2". Then the factor B_2 is **more proportional in its concept extension** than B_1 as the source in the direct influence on A, and factor B_1 is **extensionally excessive** in this influence.

The proposed expert criterion of extensional proportionality, $K^S(B,A)$ is applicable to any pair of factors of a cognitive map, connected by direct influence. It allows to estimate whether factor-source of influence B is extensionally proportional to influence (or set of influences) on the receiver being modeled with link (B, A).

For example, factor 2 in fig. 2 is extensionally excessive in the influence (2,1), according to $K^S(2,1)$. The criterion of extensional proportionality for the influence receiver $K^D(A,B)$ is formulated and applied similarly, though in case of many influences onto one factor it is less informative at risk detection and error correction.

Summary. The problem of risks due to the human factor in the field of formal methods of searching and making decisions in the control of complex and ill-structured situations is considered as the general problem for diverse models of subject-matter experts' knowledge and related formal methods (Abramova & Novikov, 2006; Abramova, 2007a).

Earlier the idea about productivity of the uniform approach to the problem for diverse models of experts' knowledge, solved problems and formal methods has been stated, and some theoretical and empirical evidences in favor of this idea have been found (Abramova, 2007a).

The idea has found the reinforcement and further development at current studying risks concerned to causal influence transitivity in cognitive modeling, with carrying out analogies to risks in decision-making based on pairwise preferences. It is enough to say that just the analogy of principles of transitivity of paired preferences and causal influences has led to a hypothesis on possible violation of the axiom of causal influence transitivity, i.e. to risk of false transitivity at formal cognitive mapping what has been confirmed in practice.

However, in few practical situations of violating the axiom of causal influence transitivity which we have analyzed by now, violations took place in cases when detection of false transitivity was perceived by experts as a signal of an error with necessity of cognitive map correction, and herewith correction was successful. Nevertheless, by analogy situations are conceivable when modeling of expert knowledge in terms of the chosen general formal model of cognitive maps appears impossible without separate violations of the axiom of influence transitivity, and the violations are estimated by subject-matter experts not as a signal of an error but as limitation of the formal model.

The question on existence or possibility of such situations in practical cognitive maps of the complex and ill-structured situations is opened by today. Further research on the empirical

material of practical cognitive maps of complicated situations is planned with the aim to revealing such situations, their practical importance, and also rational experts' reasoning in such situations.

3.2 SWOT-analysis on the basis of analysis of the model structure

Generally, SWOT-analysis is expert determination of strength and weaknesses of SEO, opportunities and threats of its environment, and estimation of their interaction. Results of SWOT-analysis are represented as a matrix called "Window of opportunities".

The mathematical procedure of generation of matrix "window of opportunities" on the basis of analysis of structural features of SEO development cognitive map has been worked out. Thus, there is no need in regular attraction of experts with all accompanying procedures.

The essence of the procedure of SWOT-analysis is the following.

Analyzing a situation of SEO development, it is possible to put forward various hypotheses about desirable dynamics of any factor of the model. So, the parameter "attitude to factor dynamics" (AFD) is brought in for each factor of the model. If dynamics of a factor is positive (negative) AFD is equal 1 (–1). If it is difficult to evaluate the factor dynamics its AFD is equal to 0. The set of AFD vector on some set of model factors reflects desirable change of a situation in SEO.

Let's designate through $R^{ext}(X^{ext})$, $R^{int}(X^{int})$ vectors of AFD of factors of the external and internal environment, where $X^{ext} \cup X^{int} = X$; $X^{ext}(0)$, $X^{int}(0)$ – vectors of initial trends accordingly.

While the situation evolves each factor is being influenced not only by "neighbouring" factors, but also by more "distant" ones and these indirect influences are transferred through chains of the appropriate factors and graph arcs that connect them. Set of influences both direct, and indirect to which each factor in a situation is subject to, is described with the use of concept of transitive closure of a cognitive map of the situation (matrix Q (3)).

When constructing a matrix "Window of opportunities", opportunities and threats of the environment, strengths, and weaknesses of SEO are determined on the basis of observation of the dynamics of model factors and estimations of their integrated influence on desirable dynamics of factors $R^{ext}(X^{ext})$ и $R^{int}(X^{int})$. The significance of strengths and weaknesses of SEO is determined as well.

Let us introduce the basic definitions.

Definition 1. If the initial trend of the internal environment factor, $x_i^{int}(0)$, is negative, i.e. does not correspond to a desirable direction of change (AFD), the given factor is regarded as a weakness of functioning and development of SEO, otherwise (the trend is favourable) - as a strength of object. The weaknesses determine internal threatening trends to SEO development, and strengths - internal favourable trends.

Using a terminology of SWOT-analysis, we shall designate X^{st} – a subset of factors the strengths determine of SEO, X^w – a subset of the factor–weaknesses of SEO, $X^{st} \cup X^w \subset X^{int}$.

Definition 2. The initial factor trend from X influences positively on desirable dynamics of the factor from X if the following equality holds true

$$\text{sign}(x_i(0)q_{ij}) = r_j(x_j),$$

where q_{ij} – (i,j) element of a transitive closure matrix Q, which determines integrated influence of i factor on the j factor; $q_{ij}=0$ if x_i does not influence x_j.

If AFD of some factors are given equal to zero ($r_j(x_j) = 0$) such factors are excluded from the analysis (integrated influences on them of other factors are not taken into account).

The following definitions follow from definition 2.

Definition 3. The factor of an environment x_i^{ext} is neutral for X^{int}, if the initial trend of this factor does not influence ($q_{ij}=0$) the desirable dynamics of all factors of the internal environment of SEO, X^{int}.

Definition 4. The factor of environment x_i^{ext} characterizes the opportunity for SEO development if the factor is not neutral and its initial trends does not negatively influence (through the appropriate integrated influences) the desirable dynamics of all factors of internal environment of SEO, $R^{int}(X^{int})$. In other words the initial trend of factor x_i^{ext} promotes SEO development in a desirable direction.

Definition 5. The trend of the environment factor x_i^{ext} threatens the SEO development, if it negatively influences (through the appropriate integrated influences) desirable dynamics even of one factor of internal environment $x_j^{int} \in X^{int}$.

Using a terminology of SWOT-analysis, we shall designate X^{op} – a subset of factors–opportunities for SEO development, X^{th} – a subset of factors–threats to SEO development, $X^{op} \cup X^{th} \subset X^{ext}$.

Definition 6. The internal environment factor, x_i^{int} ,is neutral for X^{ext}, if the initial trend of the factor does not influence ($q_{ij}=0$) the desirable dynamics of the environment factors X^{ext}.

Definition 7. The internal environment factor, x_i^{int}, promotes strengthening of the opportunity of environment x_j^{op} if x_i^{int} is not neutral and its initial trend favourably influences (through the appropriate integrated influence) the desirable dynamics of the factor x_j^{op}. Otherwise x_i^{int} promotes decrease of the opportunity of environment.

Definition 8. The internal environment factor x_i^{int} promotes parrying of threats of environment x_j^{th} if x_i^{int} is not neutral and its initial trend favorably influences (through the appropriate integrated influence) the desirable dynamics of the factor x_j^{th}. Otherwise x_i^{int} promotes strengthening of threats of environment.

On the basis of definitions 1-8 SWOT-analysis comes to the following stages:

1. Building of cognitive map of SEO development with extraction of external X^{ext} and internal blocks of factors. Vector of initial trends of factors $X^{ext}(0)$ and $X^{int}(0)$ is set.

2. AFD for each factor $R^{ext}(X^{ext})$, $R^{int}(X^{int})$ is set.

3. Strengths and weaknesses for each object (X^{st} and X^{w}) are found on the basis of the vector $X^{int}(0)$.

4. 4. Matrix of transitive closure Q (2) is used to build

- matrix "Window of opportunities ext-int" on the basis of which opportunities X^{op} and threats X^{th} of environment and their importance (how great is their influence on factors of internal environment) are determined, $X^{op} \cup X^{th} \subset X^{ext}$;

- matrix "Window of opportunities int-ext" with the purpose of determination of internal opportunities of SEO that can neutralize the threats of environment X^{th}, and also the problems connected with possible negative influence of SEO on environment X^{ext};

- matrix "Window of opportunities op-th". The analysis of interferences between opportunities and threats allows to reveal opportunities which promote parrying of threats;

- matrix "Window of opportunities st-w" for revealing the latent internal opportunities allowing to remove weaknesses of SEO due to advantages.

As a result of the analysis all factors are being grouped into the following classes: S (Strengths), W (Weaknesses), O (Opportunities), T (Threats). Factors inside of each class are

being ranked according to the force of their favourable (unfavourable) influence on the factors of another class. This procedure lets us estimate the importance of strengths and weaknesses, opportunities and threats for SEO development.

3.3 Structure and goal analysis of SEO development

When setting the goals of a SEO development a decision maker doesn't always manage to trace if the goals he has set are inconsistent, i.e. reaching of a goal will prevent from reaching of another one. Inconsistency of goals can also be influenced by the chosen ways of their reaching.

Thus, it is very important to reveal the contradictions already at the stage of goal setting.

The technique of the structure and goal analysis of SEO development (Avdeeva et al., 2003) allows to determine integrated (direct and all possible indirect) influences of one factor on the other and due to it to reveal inconsistencies between goal and control factors. The structure and goal analysis also allows to determine the most effective controls.

The goal of a situation development is described by a subset of goal factors of cognitive model. That means that the vector of goals of a situation development is a vector of values of goal factors (fixed goal), or a vector of directions of change of these values (unfixed goal).

Definition 9. The fixed vector goal includes vector of goals Y^* and preset values of trends of change of each goal Y_i^* .

The fixed vector goal is a point in m-dimensional space of trends of goal change. In other words, goal is a vector of some "ideal" values of trends of goal factors change.

Definition 10. The unfixed vector goal includes vector of goals Y^* and directions of favourable trends of change of its coordinates according to their AFDs.

Vector of favourable trends is a vector of interests of a decision maker (analyst). Restrictions are not imposed on the value of favourable change of goal factors (the more - the better).

Thus, the structural analysis of cognitive model of a situation development under control consists of the following stages:

Stage 1 - analysis of goals (coordinates of a vector of goals) on mutual consistency in order to answer the question "whether the vector of goals (fixed or unfixed) is inconsistent, i.e. whether the reaching of any of goals (coordinates in a vector of the given goals) will prevent from reaching of other goals?"

Let $Y = \{y_1 ... y_m\}$ be a set of goal factors and r(Y) - a vector of desirable AFDs.

Definition 11. Vector of goals Y is consistent if

$$r_j r_k = \text{sign}(q_{ik}) \text{ for any } y_i, y_k \in Y . \tag{5}$$

where q_{ik} - (i, k)-th element of matrix Q (3).

If (5) is fulfilled for goal factors y_i, y_k they refer to as consistent, otherwise these factors are inconsistent.

When the consistent vector of goals is formed the desirable integrated change of any of goal factors will not result in undesirable integrated change of other goal factors in a vector of goals.

Stage 2 - check of a consistency of the set of control factors with the given vector of goals, i.e. whether the change of the value of any control factor (with the help of the appropriate control) will promote reaching of some goals in a vector of goals and at the same time prevent from reaching of other goals of a vector of goals.

Definition 12. Vector of control factors is consistent with a vector of goals *Y*, if for each coordinate of a vector of control actions $U = (u_1...u_p)$ it is possible to determine such sign, that for a resulting sign vector sign (U) it will be fair:

$$r_s = \text{sign}(q_{st})\text{sign}(u_t) \text{ for any } u_t \in U, y_s \in Y \tag{6}$$

When control factors are consistent with the vector of goals and (6) is fulfilled, any change of control factors according to a vector sign (U) will not cause the change of any coordinate of a vector of goals Y in undesirable direction. Let U*(0) be a vector of control actions the signs of which are selected according to (6), and $\left|U^*(0)\right|$ - vector $U^*(0)$ in which all coordinates are replaced with their absolute values. The concepts entered above allow to formulate the following statement.

Statement. If the selected vector of goals Y is consistent and the set of control factors is coordinated with a vector of goals it is possible to choose such vector of control actions U for which it will be fair

$$\left|U^*_1(0)\right| \le \left|U^*_2(0)\right| \rightarrow Y\left(U^*_1(0)\right) \le Y\left(U^*_2(0)\right)$$

where $Y\left(U^*_i(0)\right)$ is a vector of changes of goal factors caused by activation of vector of control actions $U^*_i(0), i = (1...m)$, i.e. property of "domination" by modules of control transfers into property of "domination" by results of their influence on goal factors.

In other words, more "intensive" control (with large absolute values of coordinates) will cause more "intensive" changes of coordinates of the goal vector in desirable directions.

The mentioned definitions are used in situation analysis and modelling. Thus, violation of conditions of consistency of the selected vector of goals can help the analyst to understand the interaction of goal factors and set his vector of goals "more correctly", conforming to the situation. Analysis of the vector of selected control factors on consistency with a vector of goals will allow to resign inconsistent control actions and, on the contrary, to more actively use "advantageous" control factors, the change of which according to control actions affecting them will result in great favourable changes of goal factors.

Stage 3 - estimation of efficiency of influence of control factors on all coordinates of the vector of goals. Such estimation is useful when choosing the most effective control factors the changes of which with the help of the selected control actions will provide the purposeful development of a situation.

Formally, the parameter of efficiency $E(u_k)$ of the control factor u_k (i.e. the maximal positive effect from the change of u_k) is determined as absolute value of the sum of coefficients of influence of the given control factor u_k on the goal factors multiplied by AFDs of the goal factors, i.e.

$$E(u_k) = \left|\sum_{i=1}^{m} r_i q_{ki}\right|$$

where r_i is the AFD of the goal factor y_i,
q_{ki} - (k,i)-th element of matrix Q.

Really, the maximal positive effect Δy from realization of control u_k on the factor x_k is estimated as

$$\Delta y = \left(\sum_{i=1}^{m} r_i q_{ki} \right) u_k$$

where the sign of action g_k coincides with the sign of the sum $\sum_{i=1}^{m} r_i q_{ki}$, and its value is equal to 1.

On the basis of results of SWOT- and Structure and goal analysis we form the set of vectors of goals of SEO and vectors of controls that reflect possible strategy of secure SEO development. On the basis of modelling controlled development SEO general strategy of SEO purposeful development is worked out in view of trends in environment.

The combination of the stages described above enables one to diagnose and define problems in SEO development and find ways of its solution and form well-founded goals and strategy of SEO development.

3.4 Approach to deriving of strategy for problems solving

In general, the control of socio-economic system can be represented as construction of strategy for the system development, defining the main goals and general directions for their reaching, and its implementation.

Revealing the system development problems influencing negatively achievement of strategic control goals is one of the key stages of construction of strategy for socio-economic system control.

This section presents the general scheme of method for forming solution strategy for ill-structured problems on the base of linear dynamic models on the base of cognitive map in regard to socio-economic systems (Fig.4).
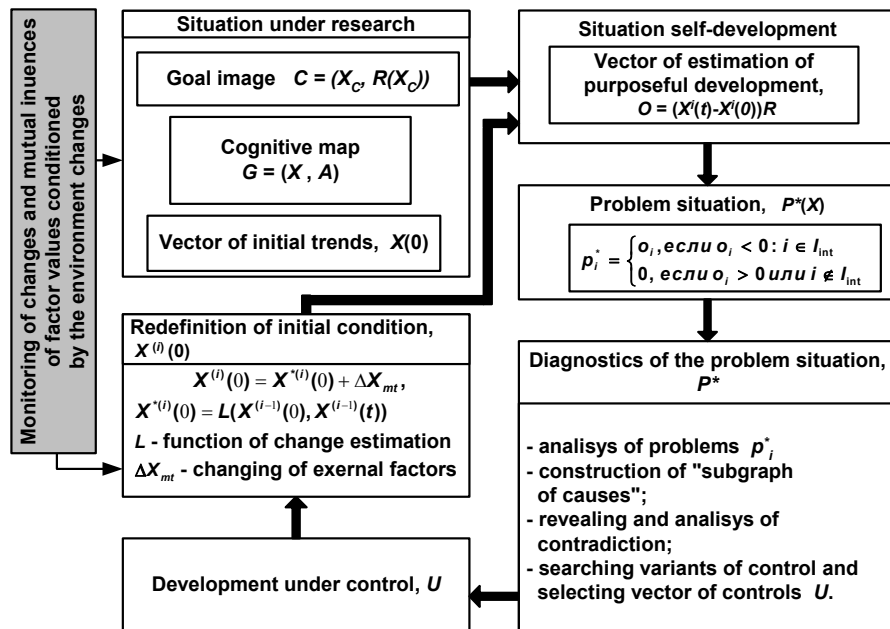

Fig. 4. General scheme of method for forming strategy for ill-structured problems solution

The control problem consists in transfer of socio-economic system into one of the states corresponding to goal image. At that, the proposed approach allows determining the system state in both values of model factors and rates of factor changes.

In the variant of approach described in this paper the state of socio-economic system is defined by rates of change of model factors. Correspondingly, the dynamics of change in simulated situation is analyzed on the basis of factor trends.

The goal image of socio-economic system defines desirable directions of changing of the system state from the position of control subject. Formally, it is represented as

$$C = (X^C, R(X^C)) \tag{7}$$

where X^C is the subset of goal factors, $X^C \subseteq X$ (X is the set of model factors), $R(X^C)$ is the vector of estimations of factor dynamics defining desirable directions for changing of goal factors:

$$R(x_i^c) = \begin{cases} +1, \text{ if acceleration of } x_i^c \text{ changing rates} \\ \quad \text{is desirable,} \\ -1, \text{ otherwise.} \end{cases}$$

The strategy for socio-economic system development problems solution consists of w strategic steps that define the sequence of system state changing

$$S^0 \rightarrow S^1 \rightarrow S^2 \dots \rightarrow S^m \rightarrow S^C$$

where S^0 is the initial state, S^C is the goal state (corresponding to goal image (7)), $S^i \rightarrow S^{i+1}$ is the strategic step, at which the problem is revealed, and, on the base of its analysis, from the set of model factors X, the subset of local goals (goal factors) and the subset of controls (control factors) are selected. At that, changing of control factors results in desirable changing of goal factors.

Each strategic step $S^i \rightarrow S^{i+1}$ includes the following:

Revealing the problem on the base of self-development simulation for initial state at i-th step (Maximov, 2001; Maximov & Kornoushenko, 2001). As a result, the problem becomes defined more precisely in form of the subset P^i of factors, which changes do not correspond to the goal image.

Diagnostics of the problem via construction of "subgraph of causes" and structure and goal analysis (Avdeeva, 2006; Avdeeva et al., 2003, Maximov & Kornoushenko, 2001) with the purpose of extracting the subset of local non-contradictory factors Y^i from P^i and searching variants of control (subsets of control factors) U_j^i facilitating change of Y^i in desired direction.

Non-contradiction of the goal factors means that the desired change of any goal factor from Y^i does not result in undesirable change of other factors form Y^i.

Simulation of the controlled system development consisting the base for forming various scenarios of the controlled development for resolving the problem applying obtained variants of control U_j^i and carrying out the comparative appraisal of scenarios with the purpose of selecting control being optimal for this strategic step (Avdeeva et al., 2007; Avdeeva, 2006; Avdeeva et al., 2003; Maximov, 2001).

Redefinition of initial condition for the next strategic step via transformation $L(S^{i*})$ of the resulting state factor values S^{i*} at current step (Avdeeva, 2006) taking into account results of

monitoring (control) of changes and mutual influences of factor values conditioned by the environment changes (Avdeeva et al., 2007; Avdeeva, 2006; Avdeeva et al., 2003).

At the next step, the cycle is repeated since new initial conditions can result in new problems preventing the desired development of socio-economic system.

The strategy construction process is finished with reaching satisfactory result that consists in reaching nearest approach to the desired system state corresponding to the goal image in conditions of given constraints (invariability of model structure, limitations on control resources, etc.) (Avdeeva, 2006). This means that, starting from some strategic step, estimation of purposeful development of the system given as functional of goal achievement degree does not change.

4. Conclusions

Experience of applying of various models and methods on the basis of cognitive approach (in Russia and abroad), as well as increasing interest of practical specialists to developments in this directions show expediency of development of this approach in control. At that, we should note some unsolved (or partially solved) problems. The problem of risks due to the human factor in the field of formal methods of searching and making decisions in the control of complex and ill-structured situations is considered as the general problem for diverse models of subject-matter experts' knowledge and related formal methods (Abramova & Novikov, 2006; Abramova, 2007a).

Let us outline some directions of research planned by the authors within the framework of development of cognitive approach.

- **Development of theoretical principles, methods, and technologies for constructing models on the base of cognitive approach while studying ill-structured systems and situations.** This direction supposes forming the main principles and system of criteria directed toward the following:
- increasing coordination and mutual understanding between participants of the process of resolving complex problem situation.
- increasing formalization authenticity for initial knowledge (representation) of the problem situation.

The general conceptual scheme for control of model construction process for ill-structured system (situation) is developed. The criteria of appropriate transition from initial representation of ill-structured system (situation) in form of the cognitive map to one or another mathematical model defining further formal processing of initial representations are formed. Applicability of formal model is estimated reasoning from features and specificity of considered system (situation).

The approach to formalization of initial representations of ill-structured problem in form of collective cognitive map with the purpose of generalization and agreement of different representations between problem bearers, which are competent in various object areas of knowledge. Solution of this problem rests upon the developed methods of conceptual structuring (Avdeeva, 2006; Avdeeva et al., 2003), as well as criteria and particular technologies of forming and agreement of collective concepts (Abramova et al., 1999).

The established problem of risks caused by human factor is now under research directed onto the following:

- generalizing results of empirical verification of hypotheses about control subjects put into typical methods of decision making support;

- making recommendations on estimation of adequacy of subject-formal methods for solving problems of control in ill-structured situations with describing the methods in a language using principles proposed at the first stage with selective empiric check;
- developing conception of cognitive simulator for users of simulation systems on the base of cognitive maps taking into account cognitive features and typical risks caused by human factor in the life circle of the considered subject-formal methods;
- making recommendations on revealing and blocking risks while applying the methods on the base of cognitive maps while solving practical control problems with selective empiric check of recommendations.
- **Development of instrumental tools for support of intellectual activity of subject in control of development of ill-structured systems and situations.** By now, the software analytical system (STRICE - Strategy Intelligent Creation Environment) implementing the function of model construction on the base of cognitive maps, scenario simulation and comparative estimation of scenarios has been developed (Avdeeva et al., 2007, Avdeeva, 2006, Avdeeva et al., 2003). The modular architecture of the developed system allows to build it up with other tools for solving various control problems, as well as interaction with modern information and analytical systems (for example, systems of gathering and analysis of information, ERP-systems).

Further development of this software system is aimed at the development of interface providing soft intellectual control of purposeful process of generation of formalized knowledge of subject (individual and collective).

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The book presents an excellent overview of the recent developments in the different areas of Robotics, Automation and Control. Through its 24 chapters, this book presents topics related to control and robot design; it also introduces new mathematical tools and techniques devoted to improve the system modeling and control. An important point is the use of rational agents and heuristic techniques to cope with the computational complexity required for controlling complex systems. Through this book, we also find navigation and vision algorithms, automatic handwritten comprehension and speech recognition systems that will be included in the next generation of productive systems developed by man.

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