Technique of the joint use of system dynamics and cognitive analysis for reengineering of complex economic and social-political systems

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Abstract: *The technique of the joint use of system dynamics and cognitive analysis for reengineering of complex systems has been proposed. The use of the system dynamics technique at the initial stage of reengineering processes faces the certain difficulties due to the fact of presence of large amount of parameters.It is rather difficult to choose correctly all levels' and variables' initial values and change rates. Arbitrary assignment of initial values leads to radical incorrect reengineering procedures. In order to avoid this undesirable result the approach presented in the article assumes the implementation of the cognitive analysis technique at the initial stage. After revelation of fundamental trends of development and screening of insignificant factors system dynamics methodology is proposed to be implemented.*

Keywords: cognitive analysis, system dynamics, reengineering, impulse oriented weighted graphs, qualitative assessment of processes, emergency management.

Nowadays simulation on the basis of the system dynamics is the most powerful and perspective tool for reengineering of complex economic and social-politic systems. However, as practice has shown, the use of the system dynamics technique at the initial stage faces the certain difficulties. It is due to the fact that there are tens or hundred parameters characterizing the processes in the system under study. So, it is rather difficult to choose soundly all levels' and variables' initial values and change rates. In the case of rough assignment the aptitude of analysis results is significantly reduced. Moreover, unjustified and arbitrary assignment of initial values leads to radical incorrect reengineering procedures. In order to avoid this undesirable result the approach presented in the article assumes the implementation of the cognitive analysis technique at the initial stage. Only after revelation of fundamental trends of development in the system and screening of insignificant factors it become possible to concentrate on

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determination of residuary levels' and rates' values.

The cognitive analysis and modeling are intended to structure, analyze and make managerial decisions in complex and uncertain situations (economic, social-political, environmental, etc.) when lacking complete quantitative and statistical information about processes being developed in such situations. When structuring (conceptualizing) knowledge the structures from obtained knowledge about situation under study are being created, i.e. the set of basic notions about data domain of situation under study is determined, interrelations between notions are revealed and decision making strategies are determined. Building of a cognitive model includes:

· selection of basic factors specific for the given problem; for example, economic and business problems can include: production and shipment rates, expected demand, inventory volume, workforce level, productivity, recruitment and attrition rates, competitor sales' growth rate, competitors profits' rate, etc.; for social- political problems the following factors: employment level, budget parameters, degrees of social tension, criminal situation , corruption level, etc. can be considered;

· selection of integral vector of objectives (set of objective factors); changes of the vector's component allow the degree of goal achievement to be monitored (for example, improvement of financial-economic state of the enterprise, provision of market requirement (price, quality, technical characteristics) to production and raising its competitive ability, improvement of personnel life conditions, improvement of efficiency and flexibility of governmental and local organizations, reduction of organizational sluggishness, etc.);

· selection of control actions which can affect situation in the desired direction (radical renewal of range of goods, transition to the range of goods currently required by the market (at the expense of flexible automated manufacturing), strict centralized management or decentralization of management (high degree of structural units' autonomy), more exact and careful determination of changes rates in wage raise, production and shipment, inventory volume and workforce levels, raising the level of personnel's skill, etc.);

· determination of cause-and-effect relations between the basic factors;

· determination of signs (positive and negative) and strength of influence (in the range 01) for the cause-and-effect relations.

Modeling of progress in the situation can be executed by 3 main options:

1. Development of situation without control actions (self-development).This option is intended to find the answer to the question: how the situation will develop by itself, i.e. accounting only for external trends. This option can be used to select those purposes (from ones generated by an analyst) that are achievable (or almost achievable) without additional influences from outside. The option is recommended to use at the initial stage of situation development' tendency research. Since it can occur that the situation is basically negative to solve the problem set, then it is necessary to reveal contradictions in the model structure and at first find feasible strategies of modification of the model structure.

2. Development of situation with the selected set of control actions (direct task). This option can be used to find such values of control factors which allow the desired result to be reached .

3. Synthesis of the set of control actions to achieve the desired direction of development of situation (inverse task). This option is intended not to form the situation development forecast , but to answer to the questions: is the desired result achievable, i.e. does the set of control actions leading to the desired result exist in the frame of the model being studied, and, if the desired result is basically achievable, then what values must have the control actions.

Stages of modeling:

1. Determination of initial conditions and trends characterizing the development of the situation by the starting moment.

2. Set of the objective vector in the form of desired directions (increase, reduction) and strength (strongly, weakly) of changes in objective factors' changes.

3. Selection of the set of control actions, determination of their possible and desired strength and orientation of influence on situation (when solving the direct task).

4. Selection of the set of possible influences (actions, factors) on situation, strength and orientation of which are to be determined.

5. Selection of the observed factors characterizing the development

of the situation.

As the mathematical ground for the suggested approach the apparatus of impulse oriented weighted graphs [1] has been used. Basic factors of a model are represented as the nodes of the graph u_1, u_2, u_3,……u_n. It is assumed that each node ui receives values $v_i(t)$ at moments t=0,1,2,…. It is also assumed that the value $v_i(t+1)$ is determined by the value $v_i(t)$ and by information about increase or decrease of values of other adjacent nodes at the moment t. If the arc from u_j to u_i is positive (negative), then the change in u_j at the moment t will be accounted for with the sign plus(minus) in the u_i at the moment t+1. The unit change in u_j causes the unit change in u_i. Thus, if the arc (u_j, u_i) with the weight $w(u_j,u_i)$ is positive and $p_j(t)$ is the value of the change in u_j at the moment t, then the influence on the u_i at the moment t+1 of the change in u_j increases u_i by the value $p_j(t)$. If the arc is negative, then the influence on u_i at the moment t+1 of the change in u_j decreases u_i by the value $p_j(t)$. The change of $p_j(t)$ (called the impulse) is determined by the difference $v_j(t)-v_i(t-1)$. Autonomous impulse process is: $v_i(t+1)=v_i(t) + p_i^0(t+1) + \sum_{j=1}^{n} w(u_j,u_i)\,p_j(t)$, where $p_j^0(t)$ is the external impulse in the node u_j at the moment t. Since $v_i(t+1)-v_i(t)=p_i(t+1)$, then the last equation can be represented in the form of the finite-difference equations:

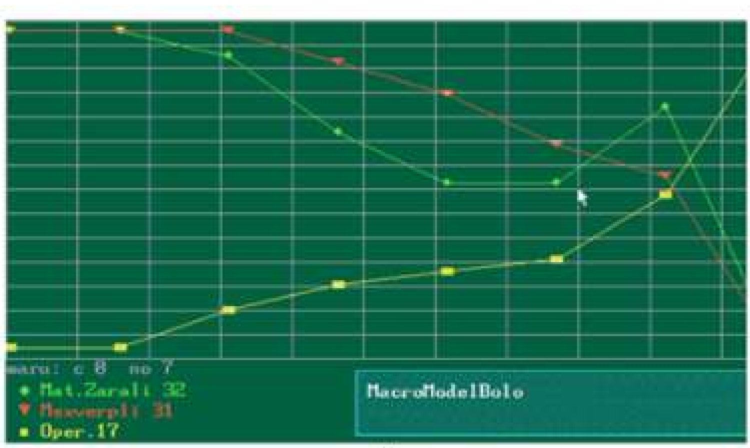
$p_i(t+1)= \sum_{j=1}^{n} w(u_j,u_i)\,p_j(t)$,with the parameters $w(u_j,u_i)$. It has been proved [1] that with some general assumptions the given equations can be used both to forecast the values of the nodes at any time and select strategies of entering external impulses in the nodes to achieve the desired values of nodes. The software packages based on the above mathematical approach have been developed [2].

In order to select the optimal strategies for reengineering of business and social-political systems the above software system have been implemented. In the submitted article the following cases are being considered: selection of the best organizational structure for the emergency management (EM) department of the Ministry of Internal Affairs and selection of the target scenario for development of a manufacturing company. For example, in the case of the emergency management department some basic factors (over then 120 factors in total) and their interrelations are considered:

Basic factors	Factors affecting the basic factors (with relevant signs)
Competitive activity between organizational sub-units	- Level of informational, equipment and resources integration level. + Amount of development programs
Level of infrastructure's development	+ Personnel's skills + Preparedness of EM system. + Efficiency of daily functioning mode -Scale of damage (after calamity)
Personnel's skills	+ Training actions intensity + Quality of development programs - Scale of victims (after calamity)
Responsibility of personnel	+ Salary level + Level of infrastructure's development + Personnel's skills + Level of financial control - Scale of victims (after calamity
Level of financial control	- Corruption scale - Criminal situation + Competitive activity between organizational sub-units - Existence of united informational system
Preparedness of EM system …………………………….	- Scale of victims - Scale of possible material damage + Effectiveness of preventive actions + Training actions intensity ……………………………………..

For the basic factors different values of influence strength (in the range 0-1), importance of factors (in the range 0-10) have been modeled. Modeling results show the rough approximations of direction and orientation of factors' changes needed to achieve the desire state, i.e.

relative values of factors (signs and intensity) providing the desired values of target objective have been determined. Modeling results allow the number of significant basic factors (affecting the basic model objective in the maximum extent) to be reduced (to 10-15 ones). For example, the modeling results below show the dependence of the scale of material damage, scale of victims and EM preparedness on the set of other significant factors (competitive activity, level of financial control, personnel's skills level, personnel's responsibility level, existence of the united informational system, etc.) over some period of modeling time :



For the case of manufacturing firm's development scenario the following basic factors (over then 85 factors in total) and target objectives can be considered as an example:

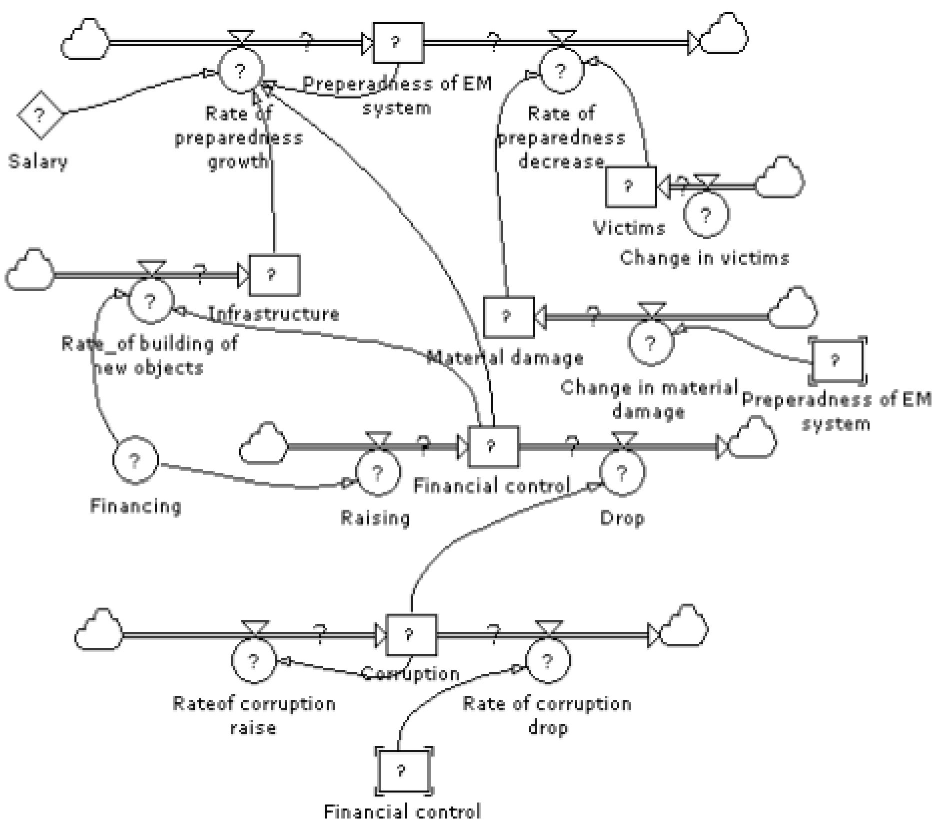
Target objectives	*Basic factors affecting the target objectives (with relevant signs)*
Increase in volume of goods orders	+ Advertising by TV, radio, periodical press +Advertising by Internet + Interaction with clients accordingly to Internet-shop + Using of air transport (along with motor transport + Raising of personnel’ skills + Wage raise + Improvement of life conditions + Deployment of LAN in orders service - Deterioration of goods quality due to the insufficient labour discipline

Reduction of clients service time	+Reduction of delivery time + Wage raise + Using of air transport (along with motor transport + Deployment of LAN in orders service -Excess of personnel
Raising of labour management level …………………..	+ Firm's financial position +Firm's funds condition +Reduction of personnel's excess + Deployment of LAN in orders service + Implementation of new technologies and advanced scheduling methods …………………………………….

Again, for the target objectives different values of basic factors' influence strength (in the range 0-1) and importance of factors (in the range 0-10) have been modeled. Modeling results show the rough approximations of direction and orientation of factors' changes needed to achieve the desire state.

It should be pointed out that the impulse weighted oriented graphs methodology allows analysts to obtain just qualitative *assessment* of processes developing in the system under consideration. That is, modeling results show just rough approximation of direction and orientation of basic factors' changes. Besides, they allow the significant (important) or hidden basic factors to be selected. Hence, it is useful to use the impulse graphs at the initial stage of complex systems reengineering. In order to obtain *quantitative* characteristics of the business processes the *system dynamics* technique seems to be the most appropriate. Having selected the significant basic factors and determined their progress trend, at the next stage it is necessary to find the precise values of factors and changes rates. Using system dynamics simulations allows us to see not just events, but also patterns of behavior over time. The behavior of a system often arises out of the structure of the system itself, and behavior usually changes over time. Understanding patterns of behavior, instead of focusing on day-to-day events, can offer a radical change in perspective. It shows how a system's own structure is the cause of its successes and failures. The proposed methodology uses the system dynamics package Powersim [3,4].

The main blocks used when building Powersim models are: flows, levels, rates, delays, information links, feedbacks, variables and constants. An analyst selects the needed blocks from the block toolbars, connects them and defines numerical characteristics, such as rates and levels values. Powersim automatically converts the created diagram into the system dynamics equations. Then the analyst enters various option of simulation (using graphs and numerical functions), duration of simulation session and obtains numerical results (again in the form of numerical values and graphical representation of basic factors and target objectives). For example, the system dynamic diagram of some factors and interaction between them for the case of the emergency management department reengineering are as follows (note that these factors have been selected by the impulse graph technique at the first stage of the proposed methodology):



Selected at the first stage (by the oriented graphs technique) significant levels, rates, variables and links reflect the behavior of the EM in more precise and reliable form. Further the refined model has to be completed by the numerical values (signs "?" means that the corresponding values are not yet defined). Now the analyst concentrates on determination of correct ranges of required data value, validate and enter them in the model. The next step is the definition and running of various simulation scenarios. Then the analyst obtains the results, analyze them with the aim to reveal the possible state of instability and dangerous tendencies. Finally the relevant recommendations on reengineering procedures, organizational changes, etc. are being generated and passed to the top executives for the closing decision.

References

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