Simulation Approach to Decision Support in Complex Systems

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Abstract

In the paper, the simulation approach to decision support in enterprise has been described. The role of the subject in the modelling of a complex system is discussed. It shows that the main problem in the modelling of complex systems derives from the complexity of the systems themselves and not from the shortcomings of the particular methodology. The article continues with the general simulation model of the business system described by Forrester's system dynamics. The methodology is sufficiently abstract to allow a qualitative and quantitative analysis of system functioning through feedback loops. The multiple criteria function used for the evaluation of different scenarios was defined with the aid of a decision group using the group support system. The methodology was successfully tested on real cases.

Keywords: decision making, simulation, multicriteria function, complex systems

1 Introduction

System simulation is one of the ways of solving decision problems in enterprises. System behaviour is studied with the model, which enables reasoning on consequences of the chosen strategy. Since system dynamics methodology has been introduced (Forrester, 1961) the use of simulation models has an important role in management science. Application of simulation methodology for business assessment has been less present in small and medium enterprises. Presently, the most intensive research efforts are spent on the combination of simulation methods and expert systems (Rajković, 1987; Kljajić, 1994a; Dijk, 1996). The modelling methodology and simulation models of business systems as well as their validation are described in (Kljajić, 1990). The model developed comprises soft and hard methodologies at the preparation and selection of the scenario. The evaluation criteria and business goals are gained by methods of Group Decision Support Systems GDSS, in connection with the Analytical Hierarchy Process method AHP (Saaty, 1990). GDSS enable participants a creative, independent and anonymous estimation of particular decision variables. The consequence is a variation of estimations that can violate the consistency axiom of the AHP method. One can obtain the consistency of the decision of the whole group by using suitable tools within the system for group decision making. In this way the decision makers should be able to creatively participate in the modelling of a business policy, consistently define the decision criteria and rationally choose the solution. The proposed methodology deals with the behaviour of the integrated simulation system for business decision-making support in an enterprise and for the pedagogical purpose. In a real case, the methodology will be demonstrated by means of the simulation system SIMLES and expert system DEX. It is shown that the main problem in the modelling of complex systems derives from the complexity of the systems themselves and not from the shortcomings of the particular methodology. The article continues with the general simulation model of the business system as an effective method for obtaining anticipative information. The proposed approach supports man-machine interaction in operation planning, and the evaluation of the strategy.

2 The Epistemological Problem of Modelling

A system represents a whole, which consists of parts and is the axiom for system philosophers. However, the General System Theory (GST) and cybernetics, clearly pointed out the relevance of the order and structure of elements within a whole for its behavior. Complex systems are usually understood by intuition, as a phenomenon consisting of a large number of elements organised in a multi level hierarchical structure where elements themselves can represent systems. The description of the system depends on the specific goal and researcher's point of view. The word complex is used only to point out the fact that the problem treated here can't be expressed only in hard (quantitative) relations but also in qualitative, frequently the most important, relations. Therefore, the criterion function for system value interpretation does not always have a unique solution. In cybernetics there is no ontological problem. On the manifestation level, the system is described as it appears, instead of as it is. By definition, we anticipate that the system consists of elements and is greater than its parts. An element is the smallest part of the whole necessary for system description, which can't or won't be divided further. The essence of the elements is very important from the epistemological point of view. From the general point of view system is defined by set:

$$S=(E,R) \tag{1}$$

where $e_i \in E, i=1,2,..n$ represents the set of elements and $R \subseteq E \times E$ the relation between elements. Construction of concrete systems requires some procedure $K(e_i) \in E$, knowledge, to identify the elements of the systems and theory $T(e_i,e_j) \in R$ to find the relationship between the elements. In other words, modelling represents the activity of describing our experiences by using one of the existing languages in the framework of a certain theory. In this way, our experiences also become accessible to others: they may be proven, confirmed, rejected, broadened or generalised. This paradigm can be stated (Kljajić, 1998a) with a triplet (O,S,M). O represents the real object, original, independent from the observer, while S represents the researcher (subject) or an observer with his knowledge, and M the model of the object. A "naive realist" supposes that: 1. An external world exists independently from the observer, 2. This world isn't directly observable and 3. For its representation, we set up simplified models. The relation between the observer S and the object O - is of essential significance in the cognitive method. The observer is a man, with all his cognitive qualities, while the object of research is the manifested world, which exists by itself, regardless of how we can describe it. In this case, the object and the system have the same meaning. The third article of the triplet M is the consecutive one and represents a model or a picture of the analysed system O. The $O \leftrightarrow S$ relation in Fig. 1 indicates the reflection of human experiences to concrete reality. This cognitive consciousness represents our mental model. The relationship $M \leftrightarrow S$ represents the problem of present knowledge, respectively the translation of the mental model into the actual model. The $O \leftrightarrow M$ relation represents the phase of model validation or proof of correspondence between theory and practice, which render possible the generalisation of experiences into rules and laws. The $S \rightarrow O \rightarrow M$ relationship is nothing else but an active relation of the subject in the phase of the object's cognition. The $M \rightarrow O \rightarrow S$ relation is nothing more than the process of learning and generalisation. A theory is an intellectual construction enabling us to give a more generalised form about the phenomena of the research to the directly obtained results from the experiment. In the cognitive process, the value standpoints of subject S_v are far more important to us in relation to the object of research in the modelling process. This can be stated in the following equations:

$$S_v \cap (O \cap M) = 0 \tag{2}$$

$$S_v \cap (O \cap M) \neq 0 \tag{3}$$

In the second part of the eqs. 1 and 2 $O \cap M \leq 1$ are always fulfilled. In the case of $O \cap M = 1$, the model and original are identical. The expression eq. 2 is valid for formal and natural sciences, where $S_v = \varnothing$ (empty set). This means that it's impossible to find any link between the axiom and the hypothesis linked to model M and value standpoints of the subject. That is of course not valid for the scientific hypothesis in the process of modelling, which is always the product of the intellect and historically conditioned by the progress of science: these hypotheses are always rejectable (Poper, 1973). In the case of organizational sciences and humanities in eq. 3 the value standpoints of the researcher and the object of the research are always $S_v \neq \varnothing$. Some qualities are always added to the description of the observer in question which are not provable. The conditions expressed by eqs. 2 and 3 have a key meaning in the choice of research methodology and for the scientific value of the statement (Kljajić, 1998a). The first expression renders possible the setting up of the principle testable hypothesis by means of active experiments of the subject, while the second can't and is not allowed to prove the hypothesis through experiment, but by observation and generalisation dependant on the qualities of the observer.

3 Cybernetic Aspect of Decision Making in Organisation

Human systems or organization consist of different interactions between people and nature in order to realize certain purposes. The sense and the goal are the main reasons qualities of this activity and are also the consequence of the past and present, knowledge, culture, religion, ethics and the anticipation of the future of society. The properties of the organisational system aren't only in the functioning and quality of achieving these goals, but in the goals themselves and in the means used to reach them. The humanistic vision of the organisation points out that the means are essential in achieving the goals. Only from the view of achieving goals because of interests, is the organisational system more than the sum of its parts, despite the fact that the interests of the master and his slaves were essentially different in history. In eq. 3, the observed system is complex and its model contents subjective assumptions of the observer. Prior knowledge about system behaviour is limited and experiments are not allowed. Vision and intuition is relevant component of creation. How good and useful these descriptions are is the problem of model validation. Man is creator of technology, religion, morals and aesthetics. As such, organisational systems are a function of the past, present and future state and represent an anticipatory system. Past states determine their non-destructive memory: biological, social, cultural and historical and strongly influence on the future state besides human vision. This statement are in good accordance with Robert Rosen (1985, p. 341), concept of an anticipatory system: "a system containing a predictive model of itself and/or of its environment, which allows it to state at an instant in accord with the model's predictions pertaining to a later instant...", cited after (Dubois,1998). Such systems are open, dynamic and goal oriented (Ackoff, 1994).

From the decision point of view, the organizational system is defined as $S = (P, D)$, if mapping exists (Mesarović and Takahara, 1989) $P : X \times U \to Y$ and $D : X \times Y \to U$ such that, it is satisfied $G : X \times Y \times U \to V \in R$ and $E : X \times Y \times V \to U$, where *X* and *Y* represent the input and output of the system, *P* process, D decision process, *G* objective function and *E* evaluation strategy.

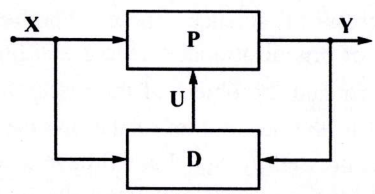

Fig. 1: General model of goal oriented system

Note that *G* represents the objective of alternative, while *E* represents the subjective evaluation of decision. Consequently, decision in enterprise is not primarily concerned only with feedback dynamics (selecting of proper parameters of rate elements) but on rate elements matched with possible input into the system and prescribed criteria (Kljajić et al., 1998b). As shown in Mesarović and Takahara (1989) according to Arrow's Impossibility Theorem, it is not possible to find a democratic solution of social choice, which will satisfy some socially acceptable conditions imposed on the decision problem. Arrow's axioms (1 to 5) are logically incompatible (Rapoport, 1986). The fifth axiom, which states the absence of a dictator (even in implicit form) is relevant in using GDSS.

In Fig. 1, loop $P \rightarrow Y \rightarrow D \rightarrow U \rightarrow P$ represents feedback information, which functions on the cause consequent principle, therefore we can call it reactive control. For small perturbances such control is satisfied. For decision making in organisational system information from the environment is necessary. Chain $X \rightarrow D \rightarrow U \rightarrow P$ provides feedforward information, which represents the anticipation of the future state of the environment. It is an important part of the strategy of goal-oriented systems. The relation between feedback and feedforward information in the course of time in decision making is shown in Fig. 2 (Kljajić, 1994b).

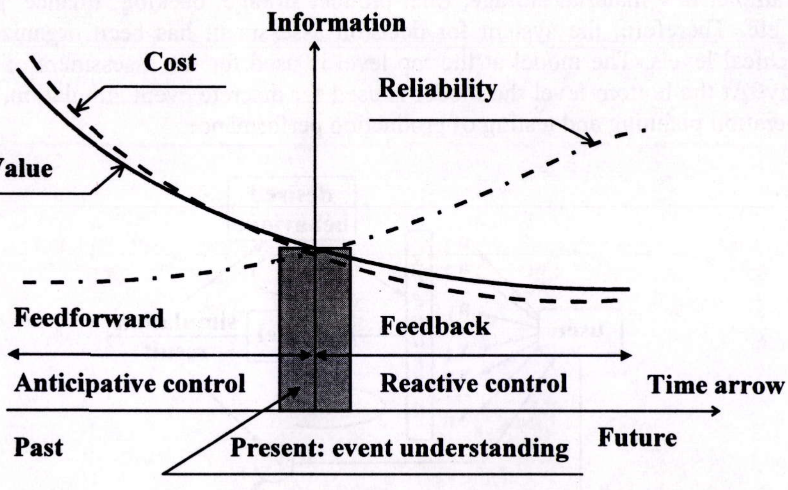

Fig. 2: Utility, cost and reliability of control information of a goal oriented system in course of time in arbitral units (Kljajić, 1994b).

In Fig. 2 an ordinate, which separates the time axis on past and future, utility, cost and reliability of information are shown. Understanding present events in the future (with delay) means a decrease of information value but an increase in reliability. Understanding the present state in the past (feedforward) means the foreseeing of events. Such information has higher utility but is more expensive and less reliable. From the decision-making point of view, time region from present to future events represents feedback information and reactive control (principle of action-reaction). The region from present to past events represents feedforward information (foresee future events) basis for anticipative control. Anticipative information is an immanent part of strategic decision making based on enviroment model and future desired behavior of the system. This description is very similar to idea of incursion, (Dubois, 1998): y(t+1) = F [..., y(t-1), y(t), y(t+1),...] where the value of a variable y(t+1) is a function of this variable at past, present and future times. Value of y(t+1) on the right side of expression represents information about systems obtained from simulation model shown on Fig. 3.

4 Decision Support Oriented Enterprise Simulation Model

The simulation approach seems to be one of the better methodologies used to achieve anticipative information for decision making in enterprise systems. Roughly speaking, it means the concept of state, goal, criteria, alternative and the state of nature connected in a dynamic model interacting with decision making groups. The production process was designed on the concept of the state variable approach. It signifies a quantity, which represents the main entity relevant for decision making at the top and operative level, as for example: raw material storage, final product storage, backlog, finance, production tools, etc. Therefore, the system for decision assessment has been organized in two hierarchical levels. The model at the top level is used for the assessment of enterprise strategy. At the bottom level the model is used for discrete event simulation, necessary for operation planning and testing of production performance.

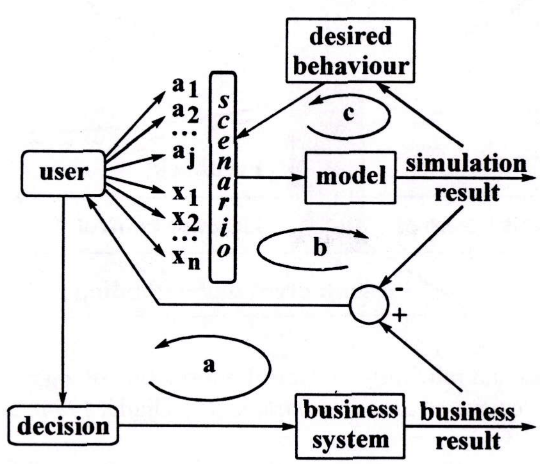

Fig. 3: The principle scheme of simulation methodology for decision making support in enterprises (Kljajić, 1994b).

The concept of state is convenient for achieving harmony among different levels through the whole system. In a practical sense, this means that when the discrete-event process is considered, variables are considered as entities as the level and rate in the system dynamics SD when the process is considered as continuous. The proposed approach supports man-machine interaction in operation planning, and the evaluation of the strategy is shown in Fig. 3 (Kljajić, 1994b).

The business simulation core consists of three parts: the basic model – a program for the scenario formulation, a program for the analysis of simulation results and selection of solutions and a program for normative analysis. The simulation scenarios are made of two subsets: a subset of input that anticipate the impact of the *environment* (exogenous scenarios) or the state of nature and a subset of management decisions that represent endogenous scenarios. They give the answer to the basic question, with regard to the problem situation for which the answer is being sought. In literature, it is known as the *what if, then, so what* analysis. The generation of scenarios of the simulation system that respond to the *what if,* is based on the variation of parameters of the basic scenario at the extrapolation of past behaviour and expert evaluation of development targets with the brainstorming method. Variants of business scenarios are evaluated with the linearly weighted sum of the multi-criteria decision function. The complete simulation system for decision support consists of commercially available packages.

Fig. 3 shows the interaction between the user, simulation model and scenario in the searching phase for the solution of a managerial problem for support in decision making of the business system. The following three basic feedback loops are emphasised:

a) the causal or the feed-back loop representing the business result as a consequence of former decision making, and being a part of management experiences and history of the system,
b) the aposteriori information about the model's applicability and former decisions making and
c) the anticipation or intellectual loop that provides feedforward information, which is important for the formulation of the system strategy.

Loops a) and c) are the basis for the acquisition of knowledge and experience for learning and quality decision making and b) represents the pragmatic validation of the model. The system structure consists of level elements and parameters defining the rate and the auxiliary elements connected in the flow diagram. The diagram is sufficiently abstract to allow a qualitative analysis of the system functioning through feedback loops. As soon as someone becomes satisfied with the "picture" of the model, he will proceed to the definition of the simulation model. The state equation of the simulated system is described by the equation:

$$y(k+1) = f(y(k), x(k), a(k)); k = 0,1,2,..N \tag{4}$$

where $y \in Y$ represents the vector of state variables such as inventory, cash, income, liabilities, backlog, etc., $x_i \in X$ represents the input to the system (exogen scenario) and

$a_j \in A$ represents the control variables (endogen scenario). Decision strategy was defined as: find the alternative a_j for scenario x_i and its probability $p_i \in P$, which solves the problem and satisfies the performance function reflected by the manager's preferences. The multiple criteria function used at the evaluation of different scenarios was defined with the aid of a decision group using the group support system.

The results of the simulation are collected in a decision matrix, which represents the payoff of the strategy. There are many different forms of the utility function. In actual case we considered two criteria: Maximal expected value (for profit) defined by eq. 5:

$$\max EV(a_j) = \sum_i C_{ij} p_i \qquad (5)$$

where C_{ij} represents the values of the i-th scenario at j-th strategy, and the second is linear weighted sum of multiple criteria:

$$\max J(a_j) = \sum_{r=1}^{m} w_r J_r(a_j) \qquad (6)$$

where w_r represent the weight of the r-th objective, which reflects the decision maker's preference of business politics. The individual objective $J_r = q(y,x,a)$ in eq. 6 is a function of the system state, state of market and chosen alternative in achieving the goal. Satty's AHP method (Satty, 1990) was used to determine the relative importance of objectives w_r and pairwise comparison of alternatives a_j for the r-th objective.

5 Results

The described methodology was tested in a medium sized factory of concrete goods for reengineering assessment. Due to a raised demand for the article and better quality requirements of the products, the firm's management considered investigating a new production line. There are three suppliers besides the existing technologies considered for decision-making. Suppliers denoted as alternatives $a_i = a_1, a_2, a_3, a_4$ and their cost in money unit is: c_i= 0, 371, 392, 532 respectively. a_1 represent current technology.

Estimation of the state of the market x_i for the next 8 years and its probability p_i are: x_1 - no change in market demands (p_1=0.15); x_2 - medium increase of demands (p_2=0.40); x_3 - high increase of demands (p_3=0.35) and x_4 - medium decrease of demands (p_4=0.10). The probability of the state of nature has been estimated by the application of the brainstorming method conducted in the meeting room and using GSS. Several requirements for the new technology were imposed: Quality of products, Net profit, Risk of company ruin, Market demands and Flexibility of technology.

We analysed alternatives from a technological point of view for different conditions relevant for operative planning with discrete event simulation models. A cost benefit analysis of alternatives was obtained with a continuous simulation model by using the system dynamic method. Four scenarios representing the state of nature were prepared and simulated for each alternative. Expected values of payoff for alternatives for an 8-year period were computed according to eq. 5 C_{ij} is a function of: cost of investment, production cost and market demands for i^{th} alternative and j^{th} state of market. The results of evaluation are shown in Fig. 4.

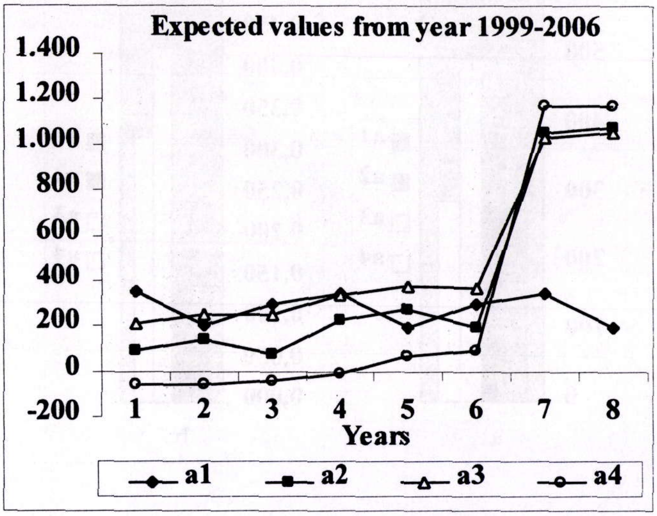

Fig. 4: Expected values of profit in MU for the four alternatives as a function of time.

The average expected value by alternatives for 8 years are shown in bar graphs in Fig. 5. Because of the well-known shortcoming of the expected value criteria (subjective probability, uncertainty of expected value, etc.), users like to additionally examine the linear weighted sum of the criteria. Satty's Analytical Hierarchy Process - AHP Method was used for this purpose. In our case, there are three levels of hierarchy. On the first level, the goal L itself is placed. At the second level there are five criteria: Net profit, Quality of products, Risk of company ruin, Satisfying market demand and Flexibility of technology. The last level offers alternatives for ranking. It is necessary to choose the best alternative from the five criteria so as to achieve the overall goal. Users gained information for their decision from the simulation of alternatives and discussions in the meeting room, as well as from provider properties. Here, the full advantage of visual interactive simulation connected with the Group Decision Support System in a reengineering process was achieved. For example, the comparison of alternatives under the criteria Risk of company ruin was estimated using data from Figure 4. For this reason the preference of alternative a_4 from the Risk of company ruin is less desirable. The decision horizon of 8-year use was defined by means of simulation methods. The results of multicriteria analysis of alternative choice according AHP methods are also shown in Fig. 5.

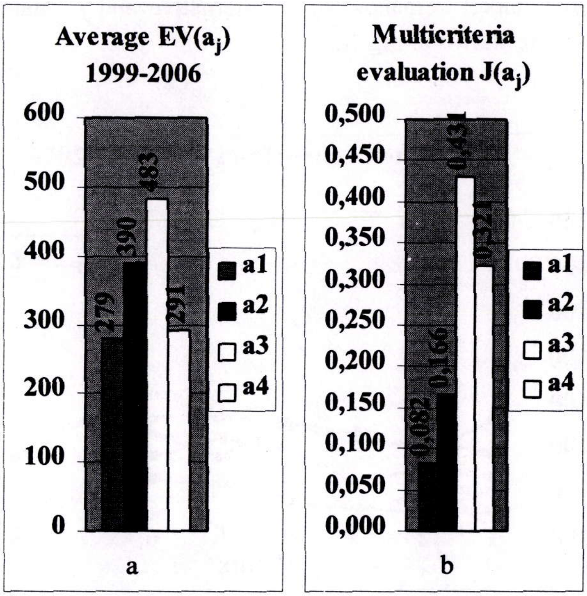

Fig. 5: Bar Graph results of average Expected Value of alternatives a) and the AHP method of four alternative evaluations b).

The right graph shows the multicriteria value of analysed alternatives. The alternative a_3 has the highest score according to the chosen preference. It is obvious that the a_3 alternative is most preferable in both criteria. Of course, such coincidence is incidental and a result of direct analyses. In the case where two different criteria gave different results, the simulation method together with GDSS is an excellent tool for group judgment about alternatives through simulation in different conditions.

6 Conclusion

In the paper, the simulation approach to decision support in enterprise has been described from a cybernetic point of view. The role of the subject in the modelling of a complex system is discussed. It shows that the main problem in the modelling of complex systems derives from the complexity of the systems themselves and not from the shortcomings of the particular methodology. The article continues with the general simulation model of the business system. The methodology is sufficiently rich to allow a qualitative and quantitative analysis of system functioning through feedback loops. The system simulation is one of the ways of solving decision problems in enterprises. The system behaviour is studied on the model, which enables reasoning on consequences of the chosen strategy. In this way, participants achieve cognitive support to better understand the decision problem in their environment. The multiple criteria function used for the evaluation of different scenarios was defined with the aid of a decision group using the group support system. The proposed approach supports man-machine interaction in achieving anticipative information, and the evaluation of the strategy. The methodology was successfully tested in real cases.

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