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© A. A. ZAKHAROV, I. G. ZAKHAROVA

azaharov@utmn.ru, izaharova@utmn.ru

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SIMULATION MODEL FOR MULTISTEP PROCESS OF MAKING TRADE-OFFS

ABSTRACT. This article describes an approach to the construction of a stochastic model of making trade-offs based on a given set of parent clauses. The peculiarity of decision making process is determined by some starting conditions, as well as criteria of transition from one stage to another, including the final stage of decision making. Generation decision algorithm includes the initial ranking of the parent clauses characteristics, the special rule for determining the measure of proximity clauses, test of compatibility proposals taking into account the specific characteristics of the subject area, the clauses themselves, and the probability matrix, which describes the compatibility of parent clauses. Next, we construct a plurality of intermediate formed decisions that use random combinations of all original proposals and the selected method, which determines the values of the random characteristics of the interim proposals. Significant proposals for the selection of the utility function are used. The process is repeated until a trade-off is made. Computer implementation of the model has been tested on the example of the coalition governments' formation, with and without consideration of the parties' compatibility.

KEY WORDS. Simulation, computational experiment, decision making, stochastic models.

The task of development, analysis and computer implementation of decision-making models has remained vital for quite a long time. Traditional approaches and methods of discrete mathematics (linear and nonlinear programming, system analysis) are highly in demand for decision support tasks, but their scope is confined, as a rule, to solution construction and further analysis on the basis of relatively simple deterministic models.

Recently due to high-performance computer systems, it has become possible to get closer to creation and computer implementation of stochastic models that take into account the fact that real management decisions have usually to be made in an uncertain environment, and the procedure of working them out has a complex multistage nature. Moreover, it is the simulation modelling that allows to elicit a possible course of decision-making process on the basis of computational experiments [7, 12].

The peculiarity of decision-making is determined by some starting conditions, as well as criteria for the transition from one stage to another including the final stage of decision-making. The corresponding stochastic model can appropriately describe processes like training and estimated results, expert assessment of various objects, formation of working groups, sports teams or party coalitions, as well as other social processes with the above features [1, 2, 3, 4, 5, 9].

Of a particular interest is the use of stochastic models to identify factors that influence the course and results of the simulated process when solving poorly formalized problems [12], including problems of phased working-out trade-offs in an uncertain environment. This task in the present paper is approached in a way that considers developing simulation models [10, 11] using approaches [3, 6, 8] proposed for simulation modelling of coalition government formation.

Suppose, we are given a set of parent clauses to further work out trade-off decisions. These clauses are represented by R_j (j = 1, 2, ... *J*) one-type objects, defined by a certain K set of characteristics, whose values p_{jk}, (j = 1, 2, ... *J*; *k* = 1, 2, ... *K*) can be measured in arbitrary scale.

Each of R_j clauses is assigned c_j ($c_j > 0$, $c_1 + c_2 + \ldots + c_J = 1$) support ratio, which characterizes the weight of the clause (for example, the percentage of respondents or voters who supported it and who voted for a political party with the corresponding election pledges).

The final clause, which determines the required trade-off, is built by steps during the stochastic formation of intermediate clauses until the result that fits the set criteria is achieved or the number of iterations exceeds a predetermined critical value.

The multitude of intermediate clauses at each stage consists of 2^J–1 variations that are built on random formation of integrated clauses based on all possible, in general nonequiprobable combinations of parent clauses. In particular, in antagonistic parent clauses probability integration must be small, which can be automatically secured through additional factor of clauses consistency. Such factor is defined for a particular object domain, on the basis of structure, scaling and ranking of characteristics of parent clauses depending on their importance. It permits to compare clauses in terms of corresponding metrics. Suppose, there are two clauses with relevant characteristics and various values, the majority of which are of high importance and are measured in nominal scale (for example, two parties put forward non-overlapping sets of candidates for leading posts in government). Integration of the two clauses with sufficiently close and high support ratio for each is unlikely.

While defining an integrated clause, *M* parent clauses involved therein, are assigned randomly determined ratio of relative importance v_j ($v_j > 0$, $v_1 + v_2 + \ldots + v_M = 1$). Thus, intermediate clauses (*j* = 1, 2, ... 2^J–1) are characterized by random values (*j* = 1, 2,... 2^J–1; *k* = 1, 2,...*K*), defining of which as well as consistency criterion depends on the nature of parent clauses and the desired solution. In particular, to obtain normally distributed random values, both weighted average values (according to the ratio of relative importance of the clause) and randomly chosen property values of integrable clauses can be used.

Each of the obtained intermediate clauses can be analyzed from a number of angles:

a) the part in working out an integrated clause each of the parent clauses took (by the participants);

b) the role for an integrated clause each of the clauses involved in working it out played (according to the ratio of relative importance);

c) the integrated support (according to a support ratio) an integrated clause has;
d) how close an integrated clause (according to the corresponding metric) is to each of the clauses involved in working it out;

e) how close an integrated clause (according to the corresponding metric) is to each of the parent clauses.

Each of these approaches to analysis and evaluation of intermediate clauses (separately or jointly) permits to determine a necessity to repeat the stage of working out the clause or a possibility of choice (in case there are several clauses) of the final clause leading to a trade-off.

For example, the scalar criterion proposed for Marko's process of forming a coalition government [3], takes into account the a) and d) criteria and is consequently based on the evaluation of the utility function for all members of the coalition, which takes into consideration the share of the party in distribution of portfolios, as well as the proximity of positions of the party and the coalition government (the position is defined by two numbers).

Generalization of this criterion results in the following expression for the u_{ji} utility function, calculated in general for R_j clause of some subset of parent clauses with regard to working out an intermediate clause (with number i) versus an assumed final clause (initial property values for the first iteration can be chosen in an arbitrary way like the corresponding medians, for example):

$$u_{ji} = v_j - \alpha \frac{\|R_j - R^*\|}{\max\limits_j \|R_j - R^*\|}$$

Here α is weighting factor controlling the influence of the relative proximity of clauses on decision-making. Comparison of the utility evaluated function for the clauses obtained with its values received in the previous simulation cycle (initially $u_j = -\alpha$), defines further actions presented in the following description of the algorithm.

Assuming that an R* trade-off solution can only be based on a subset of parent clauses, but at the same time must have sufficient support, *conditions of total support for the clause* are expected to be fulfilled in future:

$$\sum_{i=1}^{N} c_i^* + \sum_{i=N+1}^{N+l} c_i^* > c^*$$

Here the first sum defines the value of the total support for the clauses involved in working out a solution, and the second describes the contribution of the l clauses that are not explicitly included in the integrated clause, but are actually close to it in accordance with the values of their parameters. The second sum should only be calculated when necessary, if computational experiments are conducted. For example, suppose, the process of coalition government formation is being considered, and the weighting factors correspond to shares of seats for a party in the parliament. The condition of the total support for the clause complies with the requirement to support the government by a constitutional majority in the parliament (c^* value) taking into account the votes of parties that are not included in the government, but stick to close positions on key issues.

The algorithm of working out the final clause is as follows:

1. Ranking characteristics of the initial clauses in order of importance.
2. Developing (selecting) a standard rate to determine proximity measure of clauses, if necessary, considering the importance of their characteristics.
3. Developing a consistency criterion for clauses taking into account characteristics of the specific subject area and the clauses themselves.
4. Constructing a probability matrix of consistency of initial clauses.
5. Constructing a variety of intermediate (integrated) clauses based on random combinations of all parent clauses and a selected method for determining the characteristics of random values of intermediate clauses.
6. Evaluating utility function and correlating current values and values of this function obtained at the previous step of working out intermediate clauses.
7. Selecting integrated clauses that contribute to the increase of the utility function values for all corresponding parent clauses, as well as for any subset of other clauses that collectively ensure the conditions of the total support for the clause (see above).
8. Random selection of a single sentence, which determines R^* characteristic values for the next step (cycle of utility function recomputation), for which purpose jump to step 6. Computer implementation of the model involves setting the amount of such iterations.

If there are no clauses to meet the given conditions, the process is repeated from step 5 in the same way, when the number of iterations is previously restricted in case stipulated conditions for intermediate clauses were not fulfilled.

Besides, alternatively, there is a solution that describes adequately the real process when failed attempts to work out a tradeoff can reduce antagonism between parent clauses. With the proposed model, this corresponds to an increase in the probability of consistency of parent clauses and, consequently, the probability of constructing a variety of integrated clauses. In this case, it is possible to jump to any to any of steps 1–4 for a more or less drastic adjustment of the starting conditions.

On the basis of the proposed simulation model, a computer program for computational experiments was developed. It was tested using the example of formation of coalition governments with and without consideration of the compatibility of certain parties in the coalition. Baseline data (distribution of seats in the parliament and vector positions of parties) were determined using an application that implements the election simulation model [10]. The results of calculations without compatibility characteristics are consistent with the results of [3], at the same time, model extension has allowed to set the original problem less formally.

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