Modeling based on retrospective quantitative information processing via virtual expert resource

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Abstract:

In modeling of complex systems, including objects with inhomogeneous characteristics, the effectiveness of the obtained models is strongly influenced by the applied methods of identification, focused on the similar system components. In this regard there is a need for the improved methods of identification of objects with inhomogeneous characteristics and the development of approaches to the quantitative evaluation of their quality characteristics. To solve this problem in the retrospective quantitative information processing, the use of expert and virtual resource, based on the interaction of an expert (s) and a computer system, is provided. An algorithm for building a mathematical model based on the combined use of expert and computer resources, is introduced. The approximate models obtained in that way are recommended to use in filling up the missing information at the preliminary stage of investigation and thinking of plenty of system development alternatives.

Keywords:

Objects with inhomogeneous characteristics, expert evaluations, expert and virtual resource, experiment planning, ranking.

ACM Computing Classification System:

Combinatorial algorithms, Algebraic algorithms, Nonalgebraic algorithms, Symbolic calculus algorithms, Exact arithmetic algorithms, Hybrid symbolic-numeric methods

Management quality and effective implementation of optimization models depend significantly on the identification techniques chosen in dependence of the features of single-type system components. Entities featuring inhomogeneous characteristics present a special class in that sense: being of identical physical nature and functional purpose they affect the experiment results differently as parts of models of managing complex systems.

Hence the need to upgrade theoretical foundations and principles of identifying and managing entities with inhomogeneous characteristics and develop approaches to quantitative assessment of qualitative characteristics.

The principles of identifying and managing entities with inhomogeneous characteristics were developed in publications [1, 2]. Traditionally, to study entities with inhomogeneous characteristics they resort to the class of techniques based on identifying and generalizing expert knowledge and opinions.

Publications mention mostly the technique of expert assessments (TEA) [3, 4] that has gained recognition during studies in planning R&D activities, engineering prognostic tasks of assessing the probable event occurrence time [5], tasks of factor ranging [6], and constructing global criteria [7]. Along with TEA they use the techniques of «brainstorming» the Delphi technique, the scenario approach, the «tree of goals», synectics, etc. [7]. Studies [1-4] demonstrate the possibility of using expert assessments to construct approximate mathematical models of complex entities via targeted polling of experts.

Study [8-10] reviewed the principle of identifying retrospective and expert information to obtain a mathematical description of dependence of indicators used for managerial decision making on varied variables.

In case it remains impossible to stage an active experiment and archive information is insufficient, it is suggested to use an individual prognostic virtual expert (IPVE), [1-4] to construct a mathematical model. The IPVE is used for preliminary definition of model structure. It is feasible to use the IPVE technique for poorly formalized problems in integrated environment of retrospective and expert information to assess the influence and direct effect of input variables and fill up the missing a priori information. Even a rough approximate assessment of regression factors for linear and paired interactions under the random balance technique calls for setting special experiments with the entity, and that may demand heavy expenditures. Meanwhile the suggested technique permits objective processing of subjective assessments of the state of complex entity by real experts and its numerical expression for a given situation.

Teams of real experts (TRE) include experts and scientists with large practical and scientific experience in handling the studied entity. Experts assess proposed situations not only subjectively but involving the a priori information available.

The technique of IPVE operation in integrated environment of retrospective and expert information follows these stages:

1) assessing expert competence;

2) forming teams of experts to participate in the experiment;

3) identifying input variables that affect significantly output variables;

4) selecting the model structure;

5) developing experiment plan;

6) designing questionnaires to poll experts;

7) dedicated polling of experts;

8) checking for expert agreement in assessing the situations envisaged by the experiment plan;

9) selecting the structure of mathematical model;

10) defining regression factors and assessing their statistical significance, testing the model adequacy;

11) testing the model experimentally against the current information on the normal functioning entity or against retrospective information, model adjustment following its experimental test;

12) interpreting the model for the entity.

Routinely, the ratings are calculated as arithmetic means over all the experts from their valuation of alternative options. Such an approach is quite acceptable when the degree of reliability and validity of TRE decisions has already been confirmed from problems previously solved. However managerial decisions are most often approved by the majority of votes by persons duly authorized to offer their opinions on particular issues, and subjective assessments cannot be considered or accepted on a par with those. The competency and consistency of experts shows in the spread of polling results. That is why it is recommended to initiate studies to identify most competent experts in their group and assess the consistency of opinions in advance of the experiment itself.

To understand experts' competency one may consider two approaches. One is the so-called self-competence or forced assessment of IPVE validity. When retrieving some group assessment one may introduce rating factors calculated on the basis of mutual assessment of competence by group members. It means that each *i*-th TRE member forms his/her own vector of preferences $\tilde{f}_i = \{a_j\}_{j \neq i}$, ranging other experts by their diminishing competence, as per his/her subjective assessment for the given problem. Then weight factors of competence are calculated for group members:

$$k_i = \frac{\sum_{j \neq i} a_i^j}{D - 1}, \tag{1}$$

where a_i^j is the rank attributed to *i*-th expert by *j*-th expert;

D is the total number of experts.

Accordingly, the assessment on to each criterion ψ_l by *i*-th expert is normalized with the account of k_i and the TRE group assessment is calculated as

$$\sum_{i=1}^{D} \psi_{l_i} \cdot \left| 1 - \frac{\sum_{j \neq i} a_i^j}{D - 1} \right| . \tag{2}$$

The second way is to analyze the entity assessments. To have a more objective assessment, it is suggested, before taking dedicated polling, to get the opinion of experts on the direction in which input variables affect the more informative output variables of the entity and further have an assessment by DMP (or the dominating expert) of some objective indicator retrieved from processing the polling data. It is not the weight assessment of competence of each separate expert that is important in this case, but identifying the minimum team of experts capable further to forecast successfully the state of entity on the basis of certain combinations of input variables.

Initially the IPVE forms a complete list of input and output variables and ranges them. Ranging matrices containing related ranks are then reduced to their normal form, concordance factors calculated and their significance found using Pearson's χ^2 -criterion [11].

In the result of such processing of subjective data the relationship is formalized between significant input variables (factors) and each more informative factor for the entity:

$$y_i = f(x_1, \ldots, x_n), \tag{3}$$

where *n* is the number of input variables (factors) that affect significantly the more informative *i*-th factor.

A questionnaire is put together on every more informative factor for the entity, and experts indicate the direction in which it is affected by each input variable following their subjective a priori information. The respective module of excess (decrease) within the constraints set by the IPVE or the dominating expert then yields each expert's weight in competence and the following coefficients are calculated:

1) the expert activity coefficient [11]

$$\gamma = \frac{d_1}{D}, \tag{4}$$

where d_1 is the number of experts answering the question;

D is the total number of experts;

2) the inconsistency coefficient for each κ-th input variable and i-th more informative factor for the entity:

$$\eta_{k_i} = \frac{d_{2i}}{d_{3i}}, \tag{5}$$

where d_2, d_3 are the numbers of experts giving opposing answers ($d_3 > d_2$), respectively;

3) the variation coefficient for the sum of ranks from the assessment of expert weights

$$V = \frac{S_{a_i^j}}{\overline{a}_i^j}, \tag{6}$$

where a_i^j is the value of sum of ranks for i-th expert in the opinion of j-th expert;

$\overline{a}_i^j$ is the average sum of ranks for the group of experts;

$S_{a_i^j}$ is the RMS deviation of the sum of ranks a_i^j.

The lower the inconsistency coefficient, the higher is the overall experts' confidence in their assessment of influence of the κ-th input variable. The activity coefficient yields a proxy characteristic of competence of the group of experts: if $\gamma = 0$ experts are incompetent and incapable to assess the process mechanisms. The variation coefficient V characterizes the level of competence of the group as a whole. The suggested technique of forced assessment (ranging) of competence of the group of experts is combined with objective indicators thus decreasing subjectivity of assessments typical for straightforward screening of experts.

To range input variables, the number of experts should be $D \geq 7$, and $D \geq 3$ for dedicated polling of experts [11-14].

Upon screening the insignificant input variables and identifying the more informative factors for the entity, one organizes collecting a priori data while meeting the necessary prerequisites for the coming active experiment. Using the IPVE one constructs the approximate mathematical model of entity according to subjective information.

Following equation (3) one designs the plan of active experiment; experts define the value of output variable (of the more informative factor of the process) for those states of the system that correspond to matrix lines. Apparently, the plan of experiment shall be fully randomized. The polling questionnaire describes the plan of experiment with the upper and lower basic levels of input variables indicated and the necessary constraints set.

Upon implementing the plan of experiment, the agreement is tested of expert assessment of the situation for each i-th line of the matrix using the data obtained. It is suggested to use the technique of rank correlation with Cochrane Γ-criterion for the purpose. Assume a full factor experiment (FFE) was conducted resulting in several parallel essays d, their number equal to the number of expert opinions. For each j-th column (j = l, 2, ..., N) of values of output variable we do the ranging to find the value [11, 15, 16]

$$f = A - a_i^j, \tag{7}$$

where A is the highest rank;

a_i^j is the rank attributed to i-th line of planning matrix according to j-th column.

First we reduce the table of ranges to its normal form in case "related ranks" are present [16, 17] and plot a visualization diagram, its abscissas showing the numbers of the forecast matrix lines and the ordinates being their respective values of f. Naturally, disagreements are possible between separate qualitative assessments of matrix lines among the experts. Their consistency is assessed as following.

First, the respective variance is estimated [11-13]

$$S_{vosp}^2 = \frac{\sum_{i=1}^{D} S_i^2}{D-1}, \quad i = 1,...D \tag{8}$$

for each matrix line, where S_i^2 is the estimated variance of output variable for i-th line:

$$S_i^2 = \frac{\left(f_i - \overline{f}_i\right)^2}{D-1}; \tag{9}$$

$\bar{f}_i$ is the average value of rank, attributed to i-th line:

$$\overline{f}_i = \frac{f_1 + f_2 + ... + f_D}{D}. \tag{10}$$

Then the maximum estimated variance of ranging, $S_{vosp\,\max}^2$ is found, plus the sum of assessed variances $\sum_{j=1}^{N} S_j^2 (j = 1,2,...N)$, where N is the number of lines in the planning matrix. Next the value is found of Cochrane's Γ-criterion. In case $G_{rach} < G_{krit}$ of the number of degrees of freedom, the hypothesis is accepted of homogeneous variances of ranging and consistency of experts in assessing situations in the planning matrix. If experts are found consistent in understanding these situations, the regular procedure is executed of retrieving regression coefficients for that assessment, testing their statistical significance and the adequacy of the obtained regression equation to the data of dedicated polling [1-4].

Next one tests experimentally the obtained mathematical description of entity against the data collected in the normal operation mode or its retrospective data. Note that the result of testing the model adequacy against experimental data with the use of Fischer's F-criterion being positive, the mathematical model may still contain a constant bias due to mutually compensated errors in expert assessments of output variables of the studied entity. That bias is excluded in the course of experimental test of the model [5-7].

Mathematical models yielded by the IPVE techniques operating in integrated environment of retrospective and expert information are considered to be approximate, used to retrieve lacking data during preliminary studies. They serve to form sets of alternative options of system development. The procedure used to construct mathematical model of entity based on processing retrospective quantitative information is shown in figure 1.

The proposed procedure for building a mathematical model of an object can be used in addressing a wide range of advanced application problems and it has been included in the developed software system of managerial decision making support in the public sector for organization of tendering procedure expert evaluation and in management of sectorial complexes project activity.

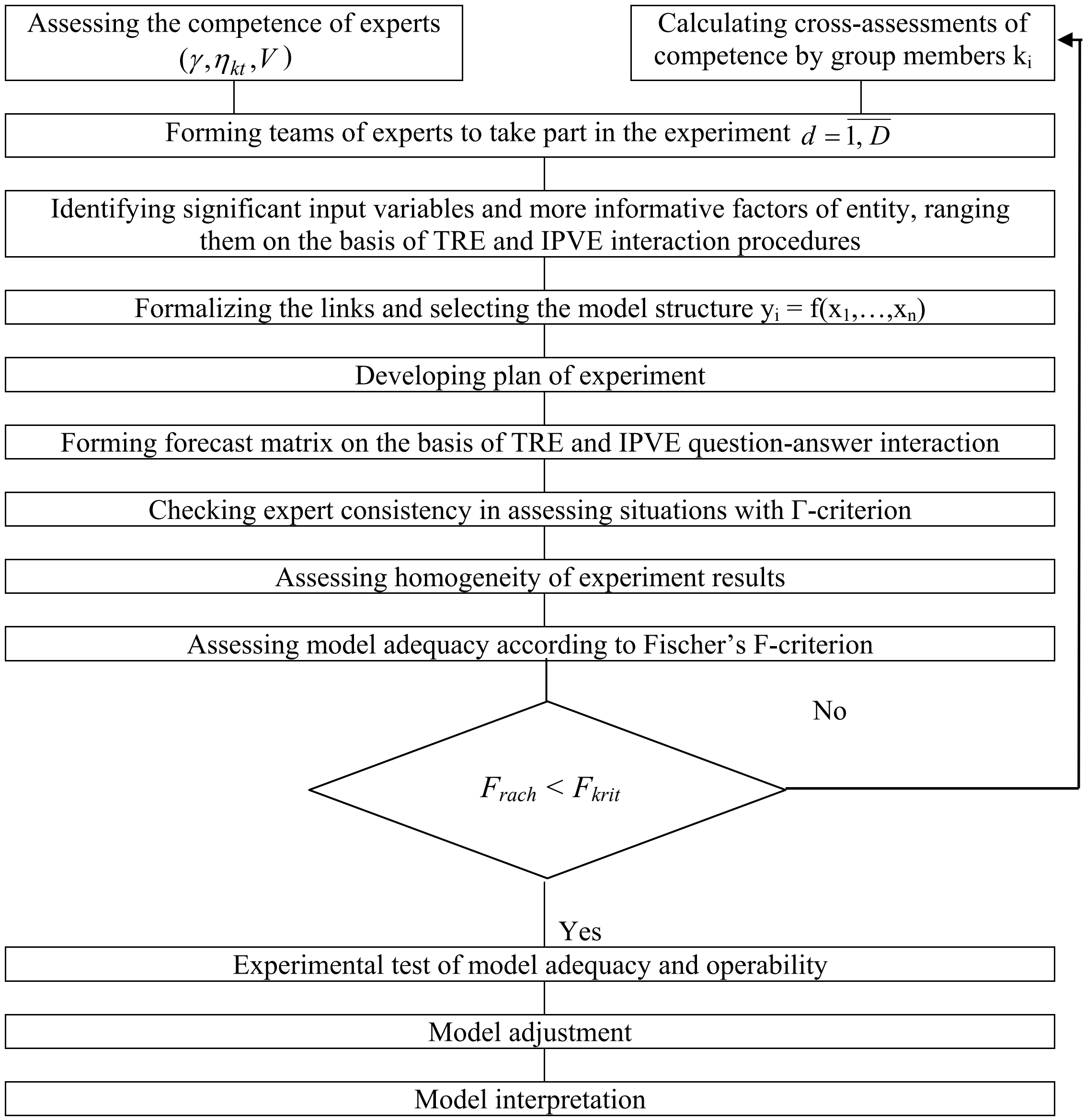

Figure 1. Constructing the mathematical model to assess retrospective quantitative information

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