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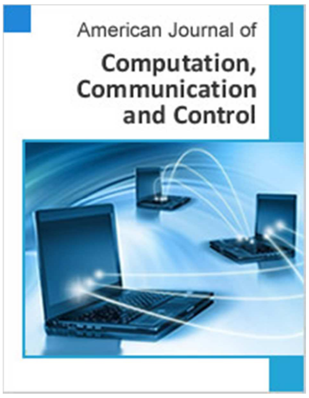

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The Reflexive Multi-valued Logical Procedures of the Expert Data Analysis

Natalya Isaeva, Vladislav Gusev*

Institute of Control Sciences RAS, Moscow, Russia

Email address
nat_i@ipu.ru (N. Isaeva), gusvbr@ipu.ru (V. Gusev)
*Corresponding author

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Abstract
The procedures of the calculation of estimations for the lasting effects of interaction of factors on the basis of expert data are developed. The evaluations of the influence of some factors on others as the estimation of the changes in factors are interpreting as the objects of valued logic. The object of examination is the method of expert analysis, which uses reflexive procedures of multi-valued logical conclusion for obtaining the transitive closing of the estimations of the mutual influence of the factors in question.

1. Introduction

Decision-making in the management of complex objects requires consideration of a large number of simultaneously acting factors. Since an exhaustive quantitative analysis of the entire operational set of factors under consideration for complex objects is very difficult, it makes sense to investigate their systemic influence at a qualitative level with the use of models of cause-effect effects that simulate chains of reasoning [1, 2]. As a result of the addition of the effect from all the chains of influences emanating from each factor-cause and ending with the factor-effects, a systemic effect is formed, determined by the complete set of direct and emerging indirect links. The initial ("primitive") system of influences as a result of such a reflexive summation of all indirect effects generates a system of total influences as their transitive closure. However, a person without the help of technical means, as a rule, is able to trace only a limited length in the chains of conclusions (a limited number of influences).

The aim of the work is to develop procedures for calculating estimates for the long-term consequences of the interaction of the set of factors under consideration. Estimates of the influence of some factors on others, as well as estimates of changes in factors, are specified in a point system with positive and negative values and interpreted in terms of many-valued logic. The estimates used for the mutual influence of factors as a result of their interaction are more conservative than estimates of the state of the factors themselves, which over time can have a wide spread. Values of assessments of the transitive closure of the influence of factors on themselves allow us to judge the degree of stability of these estimates.

An initial analysis of the mutual influence of factors consists in the study of pair interactions [3, 4]. Of all pairs on a set of considered factors, pairs are singled out, for which a mechanism of direct interaction of the "cause-effect" type can be represented. These are the so-called "primitive" interactions. Indirect influences at this stage are eliminated. The topology of the links is determined on the basis of the expert's views on the processes being studied. The structure of primitive bonds and the values of coupling coefficients are refined in the process of verification of the model.

The applied problem of analyzing the transitive closure of interactions from the set of factors under consideration is to derive the conclusions about the effectiveness of control mechanisms from the point of view of their effect on the monitored indicators. The results of reflexions of the evaluations of interactions can be used as clues in the rational choice of control factors and the adoption of managerial decisions.

2. The Procedure of Reflection with a Logical Conclusion When Evaluating the Results of the Mutual Influence of Factors

Suppose that numerical values of the state indicators x_i can be assigned to the factors under consideration. The change in these indicators, due to the direct action of the disturbing factors, will be characterized as the result of primitive interactions. The observed results of interactions of factors (total interactions) are determined by both primitive and indirect influences. Primitive interactions can differ in degree (intensity) and nature of influence. The latter is determined by the properties of the group action: independent or joint. When combined, its result is estimated by nonlinear convolution, in particular, by the least of the estimates of the influence of the components of the group.

The scheme of primitive interactions of factors is represented by an expert matrix $\mathbf{A}$. The coefficient a_{ij} of this matrix means an estimate from above of the primary increase in the factor i caused by the factor j increment (an analog of the channel capacity directed from factor j to factor i). The evaluation of the action is presented in a point scale. The values of the matrix $\mathbf{A}$ coefficients a_{ij} assigned by the expert method are in the interval [$a_{\min}$, $a_{\max}$]. Signs of coefficients are determined by the nature of the influence - positive or negative.

Since indicators of primitive interactions of factors are measured by expert means (for example, by determining the rating or scoring), they can be attributed properties of information objects, and the assumption of linearity of operations over these indicators is not justified. Impact evaluations can be considered as values of variables in many-valued logic. In this regard, it is advisable to use the rules of operations of a discrete type, reminiscent of the logic of operations with information flows. Namely, rules are adopted that can be attributed to rules of many-valued logic, analogous to the rules of Boolean algebra.

We will assume that the components x_i of the state estimation vector $\mathbf{X}$ are estimated on the same scale as the coefficients a_{ij} of the matrix $\mathbf{A}$. Operations on estimates (components of the state estimator $\mathbf{X}$ and matrix $\mathbf{A}$) are the following: a logical sum $\oplus$ (an analog of a disjunction, or a logical sum in a Boolean algebra), a logical product $\otimes$ (an analog of a conjunction, or a logical product in Boolean algebra).

The result of a single factor action translates the increment $\Delta\mathbf{x}$ of their initial state vector $\mathbf{x}$ into a state $\mathbf{y} = \mathbf{x} \oplus \Delta\mathbf{x}$ (here $\oplus$ denotes a vector logical sum) defined as the action of a logical vector operation

$$\Delta\mathbf{y} = \mathbf{A} \otimes \Delta\mathbf{x}, \tag{1}$$

The symbol $\otimes$ denotes the vector operation of the logical multiplication of a matrix by a vector. This operation includes the following scalar operations of multi-valued logic

$$\Delta y_{ij} = a_{ij} \otimes \Delta x_j ,$$

$$\Delta y_i = \bigoplus_j a_{ij} \otimes \Delta x_j .$$

The accepted rules of operations on the estimates of interaction can be attributed to the rules of multi-valued logic, which has the following properties:

a) the result of a sequential action in the chain of 2 operations (logical multiplication of operands) with opposite marks on the marks gives a negative impact evaluation;
b) if the link does not enter into any cycle of the graph of influences, then as a result of reflection its evaluation must retain its significance;
c) the result of the parallel operation of the links (the logical sum of the operands) with the same estimate must have the same estimate;
d) for two-valued logic, operations of multi-valued logic coincide with operations of Boolean algebra.

The following rules for operations of multi-valued logic have these properties. The result of the independent primitive effect of the factor j on the factor i is represented by the formula of logical multiplication

$$y_{ij} = a_{ij} \otimes \Delta x_j = \min(|a_{ij}|,\ |\Delta x_j|)\ \mathrm{sign}(a_{ij}\, \Delta x_j) .$$

The result of the joint mutually complementary effect of the group of factors $\mathbf{g}$, when the result requires the action of all factors of the group, is represented by the formula

$$\Delta y_{ig} = \min_j \{|\Delta y_{ij}|\}\ \mathrm{sign}(\prod_j \Delta y_{ij}),\ j \in \mathbf{g} .$$

To indicate the combined effects of factors other than the numerical value, the symbol of the influence group is used.

The result of the mutually compensating (sub-institutional) impact of the factors j and k on the factor i, when the result is sufficient for any of the acting factors, is represented by the formula of the logical sum

$$\Delta yij \oplus \Delta yik = \ max\,(\,/\Delta yij/,\ \ /\Delta yik/\,)\ \ sign\,(\Delta yij + \Delta yik \pm \varepsilon),$$

Where $0 < \varepsilon < 1$ is the additive that allows estimating the spread of results as a result of the computational ambiguity of the operation sign.

We assume that the nomenclature of the components of the vectors $\mathbf{x}$ and $\mathbf{y}$ coincide (the matrix $\mathbf{A}$ is square). Then the iterative application of operation (1) reflects the change in state in model time. To calculate the transitive closure of the interaction estimates, it is possible to use an iterative procedure that uses the operation (1) with the substitution $\mathbf{\Delta y}$ for $\mathbf{\Delta x}$, with respect to each vector from the set

$$(a_{\max}, 0,.., 0), (0, a_{\max}, 0,.., 0),.., (0,0,.. a_{\max}).$$

It is easy to see that the iterative process using transformation (1) can either converge to the state estimation vector taking into account the full set of impacts, or generate a cyclic sequence characterized by the boundaries of the change in the factor estimates.

If the iteration process converges, the resultant vectors form the columns of the full interaction matrix $\mathbf{B}$ (the transitive closure of the primary estimates). If the iteration process does not converge, in view of the finite values of the components of the estimation vector, the resulting vector can cycle through a certain set of states. In this case, it is possible to determine the boundary values of the components of the state vector.

An alternative, faster algorithm for calculating the matrix $\mathbf{B}$ of complete interactions is as follows. The result of two successive actions of the factors of the *i*-th on the *j*-th with the estimation a_{ji} and of the *j*-th on the *k*-th with the estimate a_{kj} in the chain of 2 interactions $a_{ji} \otimes a_{kj}$ is determined by one of the two initial estimates, Which is minimal in absolute value. If both successive effects have estimates of different signs, then their overall result will be negative. Otherwise, the result is positive. Estimation of successive operations can be represented in the form

$$a_{ji} \otimes a_{kj} = \min(|a_{ji}|, |a_{kj}|)\,\mathrm{sign}(a_{ji}\, a_{kj}).$$

If several other factors act on this factor, then their joint effect $a_{ki} \oplus a_{kj}$ (an analog of a logical sum) can be determined in various ways, depending on whether these factors are complementary or mutually compensating. Parallel application of operations affecting a factor can be estimated according to convolution rules, for example, according to the rules applied in the method of complex estimation [5]. In the case when the factors compensate each other, the result is determined by the principle of dominance: the result is equal to the maximum in absolute value evaluation of the factors-arguments

$$a_{ki} \oplus a_{kj} = \min(a_{\max},\ \max(|a_{ki}|, |a_{kj}|))\mathrm{sign}(a_{ki} + a_{kj}).$$

In the case when the factors acting in parallel are additional, the result is determined by the minimal absolute value of the factors-arguments

$$a_{ki} \oplus a_{kj} = \min(a_{\max},\ \min(|a_{ki}|, |a_{kj}|))\mathrm{sign}(a_{ki} + a_{kj}).$$

The result of the reflexive procedure can be obtained by successively summing the transformations $\mathbf{A}^k,\ k = 1,2,...$

$$\mathbf{B} = \mathbf{A} \oplus \mathbf{A}^2 \oplus \mathbf{A}^3 \oplus \ldots \tag{2}$$

with the condition of the convergence of this series. If a cyclic process occurs in the procedure (2), the algorithm must provide for a stop when the scatter bounds of the corresponding estimates are reached.

The results of the procedures (1) and (2) coincide if both the corresponding processes converge. Indeed, each summand of the sum (2) is the reflexive step given by the relation (1), so the resulting vector columns of the process (1) are columns of the matrix $\mathbf{B}$.

When executing algorithms with the sets of operations considered above, the initial set of estimates can extend to the interactions of all pairs of factors. In addition, there may be a replacement of some of the original indicators by values larger in absolute value.

3. Verification of the Scheme of Primitive Interactions

Varying the initial estimates, it is possible to determine the degree of their participation in the formation of a full picture of the influences of the factors. In addition, analyzing the result of the algorithm, we can determine the inconsistency of the initial estimates. The initial assessment is controversial (excessive), if as a result of reflection it is replaced by another estimate.

The uncertainty inherent in the expert approach can have a different origin. The first is the lack of accurate data, which is partially compensated by expert knowledge, also inaccurately reflecting reality. This type of uncertainty is taken into account during the verification phase in the dialogue with the expert. The second is the instrumental error in the processing of expert data, which arises as a result of the inadequacy of the hypotheses underlying the operations on expert data. The instrumental error can be estimated from the spread of results obtained by procedures using different hypotheses.

Verification procedures play a significant role in the designation of impact assessments. They are accompanied by an analysis of the influence of estimates of primitive links on system assessments. The purpose of such an analysis is to obtain a qualitative correspondence of the complex of assessments of the system interaction of factors with the expected expert evaluations of the effects. There can be no complete coincidence, which may indicate both a defect in the scheme and an insufficient adequacy of the expert's expectations, manifested in the objective impossibility of achieving the required configuration of the system interaction estimates.

Verification of the model (selection or refinement of the values of the matrix coefficients, conducted with the participation of the expert) is based on the requirement that the effect of monetary policy factors on the controlled factors is generally consistent with the dependencies based on statistical data, as well as the expectations of the expert. For example, in order for the control actions to give a positive result, they lead to an increase in the indicators of the controlled factors (the corresponding coefficients of influence had the required value or sign).

The following procedures can be used to verify the model.

a) Analysis of the sensitivity of the evaluation of a particular system link to the given variations in estimates of primitive connections
b) Finding links that depend on a particular primitive relationship for a given number of reflections
c) Search for primitive links that affect this system connection for a given number of reflections.

Verification can be considered as a solution to the inverse problem, when estimates of the observed dependences restore estimates of primitive relationships, which can then be used to calculate the change in equilibrium estimates of the state of the system in response to control actions.

4. The Analysis of the Expert Model of Autonomization and Cooperation

An expert model of an economic system interacting with the outside world is considered. With its help, conditions for the sustainable development of the system are studied with an emphasis on the factors of its interaction with the external environment.

The above study of long-term development regimes with the help of the expert model of the economic system can be interpreted in terms of researching possible ways of structural transformations of the economy at the end of the recession regime, both under the conditions of globalization of management and in the conditions of autonomous development.

Let's consider expert assumptions and their formalized record with a concretization of estimations of mutual influence of factors.

The relations are represented in view of formulas. Numbers before factors of the right side mean degree of influence on the factor of the left side. Mark “∨” of deviation in formulas means the concatenation.

Internal factors:

Import grows with the increase in working capital and the increase in globalization of management.

Import = 8 (Current assets) ∨ 4 (Globalization of management)

Current assets decrease with the growth of economic risks and grow with an increase in exports.

Current assets = -6 (Economic risks) ∨ 9 (Export)

Fixed assets increase with increasing current assets and decrease with the increase of technogenic risks.

Fixed assets = 6 (Current assets) ∨ -4 (Technogenic risks)

Localization of management grows with the increase in working capital, as well as with the increase of fixed assets and decreases with the growth of the division of labor.

Localization of management = 7 (Current assets) ∨ 5 (fixed assets) ∨ -3 (Division of labor)

Science-technical progress (STP) grows with increasing current assets, as well as in the localization of management.

STP = 3 (Current assets) ∨ 5 (Localization of management)

External factors:

Technogenic risks increase with the increase of fixed assets, decrease with the growth of Localization of management and STP.

Technogenic risks = 6 (fixed assets) ∨ -3 (Localization of management) ∨-5 (STP)

Economic risks increase with the increase in Technogenic risks and decrease with the growth of Localization of management, STP, Division of labor, Scaling effect.

Economic risks = -5 (Localization of control) ∨ -5 (STP) v 8 (Technogenic risks) ∨ -5 (Scaling effect) ∨ -3 (Division of labor)

External interests grow with the increase in Import, STP, Export, Scaling effect, Division of labor and decrease with the growth of Localization of management.

External interests = 6 (Import) ∨ -4 (Localization of management) ∨ 4 (STP) ∨ 5 (Export) ∨ 7 (Scaling effect) ∨ 8 (Division of labor)

Factors of cooperation:

Export grows with an increase in external interests and globalization of governance.

Export = 7 (External interests) ∨ 6 (Globalization of governance)

Globalization of management increases with the growth of external interests, exports, division of labor and decrease with the growth of localization of management.

Globalization of management = -9 (Localization of management) ∨ 8 (External interests) ∨ 5 (Export) ∨ 8 (Division of labor)

The effect of scaling increases with increasing Globalization of management, division of labor and decrease with the growth of Localization of management.

Scaling effect = -5 (Localization of control) ∨ 8 (Globalization of control) ∨ 7 (Division of labor)

The division of labor increases with increasing globalization of management and decreases with the growth of localization of management.

Division of labor = -3 (Localization of management) ∨ 7 (Globalization of management)

The results of calculating the transitive closure of the effects can be represented in the form of a square matrix. The diagonal elements of this matrix are presented in the following table.

Table 1. *The diagonal elements of matrix of transitive closure.*

Factors	Diagonal elements
1. Importation	6
2. Current Assets	-7
3. Fixed Assets	-6
4. Localization Of Management	-7
5. STP	5
6. Man-Caused Risks	-6
7. Economic Risks	-6
8. External Interests	7
9. Export	-7
10. Globalization Of Governance	7
11. Scaling Effect	7
12. Division Of Labor	7

The diagonal elements of this table make it possible to judge the long-term trends in the state of the factors: positive values – growth, negative values – reduction or stabilization.

Growth trend is: *Import, STP, External interests*, *Globalization of management, Scaling effect, Division of labor*.

The stabilization trend is: Current assets, Fixed assets, Localization of management, Technogenic risks, Economic risks, Export.

This regime has signs of stagnation and decline in the context of globalization. The change in the values of some of the coefficients of influence with the same nature of the dependencies allows us to radically change the qualitative picture of the long-term trend. Variable schema relationships are presented below.

The negative impact of factor Economic risks on factors Current assets and Fixed assets was reduced.

Current assets = -4 (Economic risks) $\vee$ 9 (Export)

Fixed assets = 6 (Current assets) $\vee$ -4 (Technogenic risks)

The positive influence of the factor *Circulating funds* on the factor *Localization of management* has been reduced.

Localization of management = 5 (Current assets) $\vee$ 5 (fixed assets) $\vee$ -3 (Division of labor)

The positive influence of factors External interests and Globalization of management on the factor Export is reduced.

Export = 4 (External interests) $\vee$ 4 (Globalization of governance)

The results of the calculation of the transitive closure of this version of the effects are presented in the following table.

Table 2. *The diagonal elements of changed matrix of transitive closure.*

Factors	Diagonal elements
1. Importation	4
2. Current Assets	4
3. Fixed Assets	4
4. Localization Of Management	4
5. STP	4
6. Man-Caused Risks	4
7. Economic Risks	-3
8. External Interests	7
9. Export	4
10. Globalization Of Governance	7
11. Scaling Effect	7
12. Division Of Labor	7

In this case, only one factor has a tendency to decline: *Economic risks*. Such a regime can be characterized as a growth regime in the context of globalization.

5. Conclusion

The proposed method of modeling, using the expert-reflexive approach, allows to make rational administrative decisions taking into account the system effect from the interaction of a large number of factors, which it is not possible to track manually, both in the field of monetary regulation [5] and in many other Areas. These decisions can be both operational and strategic. In the latter case, in order to find a solution, one can use an optimization task with natural limitations of a regulatory nature and with a goal function correlating with the strategic goal of management, in this case, ensuring the stable functioning of the system being designed.

The authors believe that the following statements and results are new in this paper: the subject of the analysis is the estimates of the influence of factors, interpreted as variables of many-valued logic; For the construction of a transitive closure of primitive dependencies, we propose operations of multivalued logic that are analogous to the conjunction and disjunction of Boolean algebra; Various types of interactions are considered – by the type of interchangeability and additionality. Procedures for verification of interaction schemes are proposed.

The method of expert analysis proposed found a use in such applied regions as control in the social and economic systems, credit- money policy [5 - 8], intangible assets [9 - 14], calculation of the estimations of the risk during control [15 - 17], decision making [18 - 20], and others [21 - 22].

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