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Data Analysis Methods for Support Decision Making at Management of Complex Systems

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***Abstract*—Problems of organizing decision support in the management of complex systems based on data mining are discussed in this article; also, the state of the art is presented. The specificity of data used for analysis is noted, along with the array of historical and current data. The problem is stated, methods for organizing decision-making information support with set of recommendations are proposed. The proposed methodology includes collection and preparation of data for analysis, identification of new knowledge based on similarity of objects using clustering, their integration with expert knowledge, formalization of knowledge and formation of the knowledge base, obtaining solutions while making use of knowledge and inference engine. Tools for data mining, namely, the analytical platform Deductor Studio, are shown. The results of experimental studies based on the proposed method are provided. The system of production rules and the inference engine are proposed to use for organization of decision-making support. In this case, a consequent set of rules is presented in the form of recommendations for opening branch, which is shown as the boundary values of several characteristics. The boundary values are determined by results of an object entering the cluster, which is revealed by conducting cluster analysis using neural network apparatus. The specially developed software solution is used to implement solutions based on the system of production rules.**

Keywords—Data mining, production rules, Kohonen maps/Self-organizing map, inference engine, decision support.

I. INTRODUCTION

Information technologies improvement in terms of storage and transmission led to “raw” data accumulation in various activity fields. Such features as “unlimited” data volume, their heterogeneity, “usefulness” of analysis results, and simplicity of tools conduct should be taken into account for their use.

It should be noted that such analysis tools as methods of mathematical statistics are useful, and often these methods are used for “rough” exploratory analysis, which refers to preliminary data analysis in order to identify the most common patterns and trends, nature and properties of data, distribution law [1]. The author [1] also defines such analysis goals as selection of the most important variables, detection of deviations and anomalies, testing of hypotheses, and development of initial models.

The technology of Data Mining is characterized by concept of patterns that reflects multidimensional data relationships. G. Piatetsky-Shapiro [2] noted the specifics of detecting previously unknown, non-trivial, practically useful and accessible interpretations of the knowledge in "raw" data for making decisions in various human activity fields. Especially useful are solutions for support decisions in socio-economic systems. Such solutions were described by works of G.A. Samigulina [3], L.A. Mylnikov, B. Krause , M. Kutz, K. Bade , I.A. Schmidt [4], B.A. Lagovsky, A.B. Samokhin, A.G. Chikina [5], I.O. Sevostyanova, L.V. Kurzaeva [6], M.A. Kozyrev [7], D.V. Gorishniy [8], A.A. Dorofeyuk, Yu.A. Dorofeyuk [9], E. Novikova, N. Demidov [10], V.V. Fomin [11], M. Chapot [12, 13], K.V. Rodionov [14], R.G. Stepanov [15], A.A. Barsegyan, M.S. Kupriyanov, V.V. Stepanenko, I.I. Kholod [16], J. Han, M. Kamber [17], A. Konar [18], S. Mitra, T. Acharya [19].

In addition, issues of obtaining implicit knowledge based on Data Mining are discussed in the works of Evsyukov V.V. [20], Asci F.H. [21], Wei C., Xiaodong L., Lihong M., Liang C. [22], Yu L. [23-25], Bi Y., Jia L., Wang, QB [26], Li M. [27] et al.

Formalized data is used for decision making. Many specialists, both in Russia and abroad, in particular, S.N. Vasilyev [28], A.N. Raikov [29], L.J., Gressgard, T. Nesheim [30], J.L. Medina Moya, B. Jarauta Borrasc, J. Menegaz [31], et al., research issues of knowledge formalization. However, the interpretation of knowledge requires an analysis of problem areas, and, consequently, additional research.

In this article, its authors view decision support tools for managing complex systems on the example of managing development of an organization’s branch network. A wide range of data is used for analysis. The system of production rules and logical inference mechanism are proposed to be used for organization of decision support. In this case, consequent rules are presented as recommendations for opening a branch; this is shown as boundary values of several characteristics. The boundary values are determined by results of an object entering the cluster, which is revealed by conducting cluster analysis using neural network apparatus.

II. THE STATE OF THE ART

The use of Data Mining methods for identifying implicit knowledge and decision-making support has been explored at present by many Russian and foreign scientists [3–19]. In studies, the following solvable problems are considered: the task of forming images with super-resolution [5], the task of managing customer relationships [6], the task of diagnosing railway automation devices [8], the task of structural identification for complex objects management [9], the task of situational management [10], the task of process approach to management [12], the task of modeling an enterprise management information system [14]; additionally, the scope of application is described [3, 4, 7, 14, 19, 20]. Software packages for analysis are recommended for analysis in such

fields as banking sector, health / medicine, trade, finance, and others.

Many authors describe issues of modeling complex processes using data mining [10, 14] and data mining design system automation [7, 11, 18], concepts, methods and technologies of data mining [15, 16, 17]. Main methods of data mining in socio-economic systems are association, classification, clustering, forecasting, decision trees, etc. These methods allow to identify implicit knowledge. Issues of obtaining implicit knowledge based on data mining are discussed in [3, 4, 6, 12, 20-23, 26, 27].

Many specialists, both in Russia and abroad, are engaged in knowledge formalization research. Their research results are presented in [28-31]. However, the specificity of subject and problem fields requires additional research as well as knowledge formalization.

Issues of branch network development of organizations are described by both Russian and foreign specialists, i.e., B. Zhalilo [32], D.V. Tyurin [33], S.V. Nikolaev [35], C. Gundet, A. Minibat, R. Yolalan [35], F. Aleskerov, H. Ersel [36], T.N. Al-Faraj, A.S. Alidi, Bu – Bshait Khalid [37], M.I. Alpert, J.F. Bibb [38], A. Berger , J. Leusner , J. Mingo, P.V. Boufounou [39], A. Charnes, W. W. Cooper, E. Rhodes, D. Giokas [40], J.T. Pastor [41], C.A. Lovell Knox, H. Tulkens [42].

III. Characteristics of Subject field and Data Used for Analysis

Analysis of solid reasons for building branch networks (expanding the possibility of promoting own goods or services; increasing profitability through vertical integration, etc.) is carried out to solve the problem of decision-making in managing branch network development. An organization with branch network may be viewed as complex socio-economic system. Consider the trading network that sells equipment, and has service centers.

In system analysis conducting process of subject field, factors that have influence on efficiency of the company's activities have been identified, in particular, presence of enough customers (solvency or purchasing power of population in the region, geographical location of the office (store) or the company); professional staff (work experience, presence of an appropriate educational organization in the region, or availability of on-line education); quality of goods and services (maintainability of goods, presence of service centers for maintenance or repair); presence of competitors, etc.

Since data that can be collected for analysis is not always presented in the necessary form, an availability data assessment and preliminary processing are required. When choosing the most suitable location for the company's office / store, a point on "red line" can be selected and "people flow" can be estimated, then data on the population in different age categories, as well as on average wages should be collected for assess of purchasing power.

According to recommendations of experts to assess potential to open a branch office selling equipment, the authors considered such factors as location of branches being 0 - poor availability of transport, lack of parking, 1 - location within 800 meters from the "red line" with average transport accessibility; 2 - location on the "red line", with good transport accessibility and availability of parking; share of equipment cost in average wage: 0 - high, more than 0.8; 1 - above average, more than 0.5; 2 - average, in the range [0.3: 0.5]; 3 - low, not exceeding 0.3; proportion of working population in total population: 0 - less than 0.3; 1 - within [0.3: 0.53]; 2 - above 0.53; presence of competitors: 0 - competitors market share exceeds 0.8; 1 - competitors market share is in the range [0,4:0,8]; 2 - competitors market share does not exceed 0, 4; 3 - no competitors; presence of personnel with experience: 0 - no experience; 1 - small experience, no more than 3 years; 2 - average experience, within [3:6] years; 3 - high experience, over 6 years; presence of educational organization for training or accessibility of on-line education: 0 - absent; 1 - present; possibility of training in a branch: 0 - absent; 1 is present; presence of service center: 0 - no service center and none is planned; 1- no service center, but opening is planned; 2 - there is a service center; branch efficiency: 0 - low branch activity; 1 - the average efficiency of a branch; 2 - high efficiency of a branch. Indicators (Key Performance Indicators (KPI), formed Balanced Scorecard (BSC)) in accordance with the concept) that reflects the activities results, are used to assess effectiveness of branches.

Based on the proposed concept, according to which it is necessary to reveal implicit knowledge and use this new knowledge to support decision-making, values of selected factors for existing branches are filled in an information array (historical data), which is complemented by values of branch performance (current data).

IV. Statement of Research Problem and Solution Method

The formal statement of the problem consists in identifying similar branch facilities with similar values of indicators in order to obtain implicit knowledge, interpretation within the problem field, formation of the system of production rules and general recommendations for opening branch. Mathematical formulation of the problem can be provided as follows: given – a set of data X (n - factors values (characteristics) for each s branch) and a set of recommendations Y (recommend for opening / not recommend / recommend with condition); it is necessary to find rule system mapping of set $\overrightarrow{x_{s+1}} \rightarrow y_j$, where $\overrightarrow{x_{s+1}}$ – information about potential branch without taking into account effectiveness of this branch, y_j – specific recommendation.

The methodology of solving problem (Fig. 1) includes four stages. The first stage is to collect and prepare data for analysis. Data preparation means are cleaning algorithms (detection of anomalies, filling of gaps, duplicate detection and disambiguation). At the second stage, data is analyzed. The purpose of analysis is detection of objects similarity by clustering using neural networks, in particular Kohonen network. Checking the influence of various factors on the result, it is carried out before the cluster analysis. The main task of factor analysis is to find the reduced system of essential or significant criteria in the variables space.

Statement of the factor analysis task: for the set of source data $X = \{X_{i1}, X_{i2}, \dots X_{in}\}$, where n is the number of factors $i = \overline{1, s}$, s is the number of branches; it is necessary to

find the set of data with reduced system of factors $X' = \{X_{i1}, X_{i2}, \dots X_{ik}\}$, where k is reduced number of factors. Setting the cluster analysis task is as follows: for the number of data $X = \{X_{i1}, X_{i2}, \dots X_{in}\}$, where $i = \overline{1,s}, n$ is the number of factors, s is the number of branches ; it is necessary to find the set of clusters $\cup Y_i = X, i = \overline{1,c}$, where Y_i is cluster $Y_i \cap Y_j = \emptyset; i, j = \overline{1,c}; i \neq j; \emptyset \subset Y_i \subset X, i = \overline{1,c}; V = \sum_{i=1}^{k} \sum_{x_i \in Y_i} (x_i - \mu_i)^2 \to min$, where μ_i is cluster center.

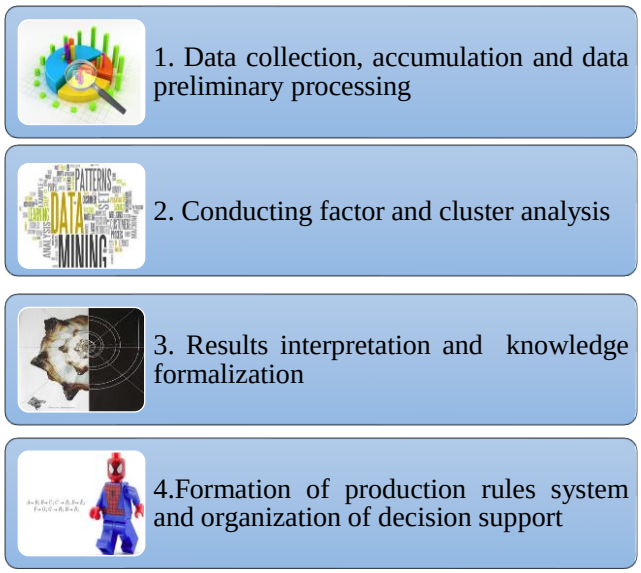

Fig. 1. Methodology of Solving Problems

Similarity of objects according to characteristics and identification of the cluster or clusters with high efficiency of object (branch) activity will allow formulating recommendations. These actions are carried out at the third stage of the proposed methodology. In addition, at this stage, identified knowledge is formalized. The production model is used as the knowledge representation model. At the final stage of the proposed methodology, the production knowledge base is formed, also decision support is implemented.

The main objectives of the factorial analysis are reduction of variables number and determination of relationships between structure variables. Stages of factor analysis include problem formulation, construction of a correlation matrix, and choice of method, as well as determination of factors number, rotation and interpretation. Earlier factor analysis tools were reviewed in more detail by the authors [43].

Clustering problem arises when there are no sufficient data for generating required output vector. Branches with similar characteristics should be divided into clusters to solve clustering problem. The number of algorithms and techniques has been developed for solving such problems, based on artificial intelligence technology: method of fuzzy K-means clustering, genetic algorithm and Kohonen neural network. Problem solution using Self-organizing map is based on the fact that neural network focus on the structure of input vectors supplied, relating the object to the specific class. Previously, the authors described the features of development and training algorithm of Kohonen network in more detail [44].

Comprehensive analytical platform Deductor Studio and software solution that allows realizing the production system are used to implement the proposed methodology.

V. Results Analysis and Results Interpretation

The data analysis uses Deductor Studio analytical platform, which allows to determine data quality in the form of a comprehensive quality assessment of data sets based on gaps number, outliers and detected extreme values, and also allows to configure parameters of further processing by nodes; Varimax method is used to factor analysis; Kohonen's neural network is used to cluster objects. Objects (characteristics, i.e., data about each branch) are described by some feature vector (9 in total, see the second section of this article 2). Branch efficiency is output value, the rest are input values.

Factors number decreased as the result of factor analysis. The following factors were identified at threshold of factors significance over 0.5: the factor that characterizes regions in general (share of equipment cost in the average wage, share of working-age population to total number), branch location and presence of the service center; other factors that are related to possibility of obtaining education and presence of staff.

The aim of this analysis is to identify similar objects in order to form general recommendations for opening a branch. Kohonen network includes input and output layers of neurons. Clustering procedure consists of training network and cells integration into clusters.

Cluster analysis results (Fig. 2) and their interpretation allow formulating recommendations.

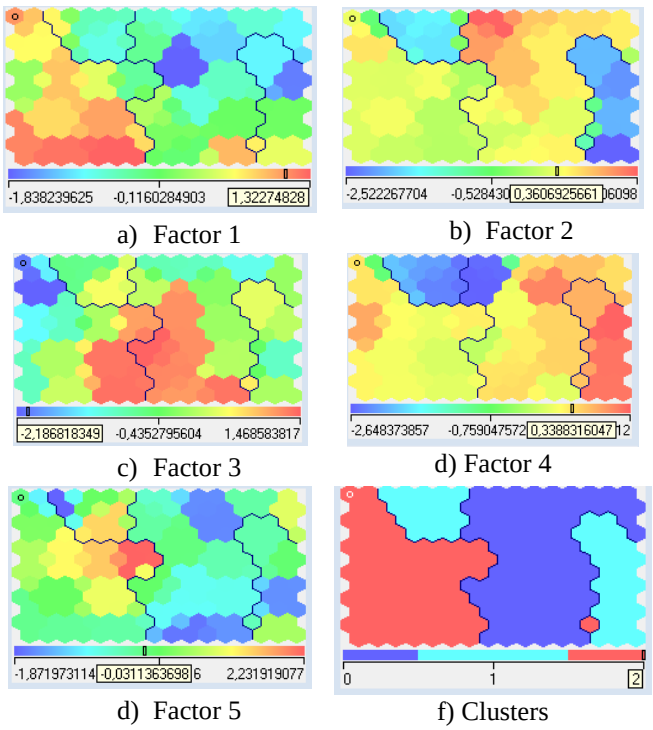

Fig. 2. Cluster analysis results

As the analysis of results shows (Table 1), the most efficient branches were in cluster 2 (37% branches). Some problems in branches of this cluster related to lack of staff

with experience. However, conducting training in the workplace helps to eliminate these problems.

Low efficiency of branches activities included in the first cluster (21% of branches) is largely due to inability to receive relevant education and training in the workplace. Presence of competitors does not have such significant impact on effectiveness of branch activities, as well as lack of a service center.

TABLE I. CLUSTERS CHARACTERISTICS

Cluster number	2	1	0
Branch location	2	0-2	0-1
Share of equipment cost in the average wage	2-3	1-2	0-2
Share of working population in the total number of the region	1-2	0-1	0-2
Presence of competitors	2-3	0-2	0-2
Presence of staff with experience	0-3	1-2	1-3
Possibility of training in the branch	1	0-1	0-1
Presence of an educational organization for training or access to on-line education	1	0	1
Presence of service center	1-2	0-2	0-2
Evaluation of activities branch effectiveness	2	0-1	0-2

Branches included in cluster № 0 (42% branches) are characterized by a wide range of activity efficiency from low to high. Indicators average values are typical for branches with high efficiency activities. Problems arise with branches where there is no possibility for training in the workplace or where branches are not located successfully.

VI. KNOWLEDGE FORMALIZATION

The above interpretation allows forming the system of production rules. Examples of production rules are below:

RULE1: IF «branch location»=1 AND «share of equipment cost in the average wage»=3 AND «share of working population in the total number of the region»=2 AND «presence of competitors»=3 AND «presence of staff with experience»=3 AND «possibility of training in the branch»=1 AND «presence of an educational organization for training or access to on-line education »=1 AND « presence of service center »=2 THEN «recommend to open a branch».

RULE2: IF «branch location»=0 AND «share of equipment cost in the average wage»=1 AND «share of working population in the total number of the region»=1 AND «presence of competitors»=1 AND «presence of staff with experience»=1 AND «possibility of training in the branch»=0 AND «presence of an educational organization for training or access to on-line education»=1 AND «presence of service center»=1 THEN «don't recommend to open a branch».

RULE n-1: IF «branch location»=0 AND «share of equipment cost in the average wage»=0 AND «share of working population in the total number of the region»=1 AND «presence of competitors»=1 AND «presence of staff with experience»=3 AND «possibility of training in the branch»=1 AND «presence of an educational organization for training or access to on-line education »=1 AND «presence of service center»=0 THEN «conditionally recommend to open a branch; the mandatory conditions for opening are a more convenient branch location and opening of a service center ».

RULE n: IF «branch location»=0 AND «share of equipment cost in the average wage»=1 AND «share of working population in the total number of the region»=1 AND «presence of competitors»=1 AND «presence of staff with experience»=1 AND «possibility of training in the branch»=0 AND «presence of an educational organization for training or access to on-line education»=1 AND «presence of service center»=1 THEN «conditionally recommend to open a branch; the mandatory conditions for opening is more convenient branch location and possibility of training in the branch ».

The system contains little more than 150 rules. A specially designed shell is used to implement solutions based on system of production rules.

VII. CONCLUSION

The improvement of information technologies in terms of data storage and transmission led to accumulation of “raw” data in various activity fields. The research results confirm possibility of detecting previously unknown in "raw" data, non-trivial, practically useful and accessible interpretation of knowledge, which is necessary for decision-making in various fields of human activity. Especially the use of implicit knowledge is useful to support decisions in socio-economic systems.

Wide range of historical data which describe the region where it is supposed to open the branch, locations and infrastructure of the potential branch as well as possibility of training is used for analysis. Information about effectiveness of existing branches is used as current data.

Analytical platform Deductor Studio is used for Data Mining, in particular, for assess of data quality in the form of a comprehensive quality assessment of data sets based on gaps number, outliers and detected extreme values; Varimax method is used for factor analysis; Kohonen's neural network is applied for clustering objects.

The system of production rules and inference engine is proposed to use for organization of decision support. In this case, consequent rules are presented as recommendations for opening a branch which is shown by boundary values of several characteristics.

Subsequently, authors use this technique for other activity fields.

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