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Intellectual support for the analysis of the implementation of innovative development programs of the regional agro-industrial cluster

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Abstract. The paper is devoted to the problems of using modern digital technologies to manage the implementation of programs for the development of the regional economy's agro-industrial cluster. An approach based on the use of intelligent (knowledge-oriented) information systems for analyzing the progress of program implementation is proposed. As a model for representing knowledge about the subject area, it is proposed to use the apparatus of the linguistic variable theory and fuzzy production rules, which makes it possible to take into account the high level of uncertainty inherent in the agricultural sector of the economy. The inference engine included in the information system is based on explicitly interpreted Mamdani's procedure of fuzzy logical inference, which makes it possible to form explanations of the course of reasoning. The developed structure of the intelligent information system is a concretization and extension of the traditional one, taking into account the reflection of the specifics of the tasks of managing the implementation of programs for the development of the agro-industrial cluster. The preliminary results of the experimental operation of the research prototype of the developed system can serve as confirmation of the effectiveness of the proposed design solutions.

1. Introduction
Improving the functioning of the agricultural sector of the national economy is impossible without permanent attention of society and the state, interested not only in profitability of agribusiness, but also in ensuring integrated sustainable development of rural areas [1], including, in particular, issues of not only employment, but also improving the quality of life in rural areas. the general population [2]; introduction of knowledge intensive high-performance technologies [3]; environmental friendliness of both production processes and agricultural products [4]. The use of an innovative approach to solving these problems is associated not only with positive aspects [5-7], but also with risks (caused, in particular, by insufficient scientific study and absence of experience in using the latest agro-industrial technologies). This leads to the need for thorough working-out and monitoring of the implementation of projects and programs for the development of agro-industrial systems. The purpose of this study is to develop a toolkit for intellectual support for the analysis of the implementation of programs for the development of a regional agro-industrial cluster. The toolkit should be able to take into account the

high level of uncertainty characteristic of innovative agricultural production. The models and methods of artificial intelligence that underlie the developed information and analytical system (used for processing expert knowledge) make it possible to reduce the time for making and increase the scientific validity of managerial decisions with possible correction of projects (programs).

2. Materials and methods

Within the framework of the indicative approach, we will assume that the implementation of the program is associated with the achievement of social, environmental, economic, agro-technological and scientific-innovative indicators of the regional agro-industrial cluster at the specified time points t_1, t_2,..., t_n values, not worse than the normative ones. Formally this can be written in the form of a system of restrictions (inequalities):

$$IndSoc^-_j(t_i) \leq NormIndSoc^-_j(t_i), \quad IndSoc^+_j(t_i) \geq NormIndSoc^+_j(t_i)$$

$$IndEcol^-_j(t_i) \leq NormIndEcol^-_j(t_i), \quad IndEcol^+_j(t_i) \geq NormIndEcol^+_j(t_i)$$

$$IndEcon^-_j(t_i) \leq NormIndEcon^-_j(t_i), \quad IndEcon^+_j(t_i) \geq NormIndEcon^+_j(t_i) \tag{1}$$

$$IndTech^-_j(t_i) \leq NormIndTech^-_j(t_i), \quad IndTech^+_j(t_i) \geq NormIndTech^+_j(t_i)$$

$$IndIn^-_j(t_i) \leq NormIndIn^-_j(t_i), \quad IndIn^+_j(t_i) \geq NormIndIn^+_j(t_i)$$

where $IndSoc(t_i)$, $IndEcol(t_i)$, $IndEcon(t_i)$, $IndTech(t_i)$, $IndIn(t_i)$ are measured in time t_i, and $NormIndSoc(t_i)$, $NormIndEcol(t_i)$, $NormIndEcon(t_i)$, $NormIndTech(t_i)$, $NormIndIn(t_i)$ are the normative target values of social, environmental, economic, agrotechnological, and scientific – innovative indicators set by the program for these time points. The upper index $+$ ($-$) means that the indicator in question belongs to a group of positive (negative) indicators, for which the improvement is associated with an increase (decrease) in the value of the indicator. In the future (to avoid unnecessary cumbersomeness), without limiting generality, all indicators will be considered positive, which will allow us not to specify this index. The lower index j is the number of the indicator under consideration in the corresponding list of indicators *INDSoc*, *INDEcol*, I*NDEcon*, *INDTech*, *INDIn*.

For each inequality considered, we introduce a binary indicator that reflects its implementation and takes the values 1 (the constraint is met) or 0 (the constraint is not met). Thus, the progress of the regional agro-industrial cluster development program at time t_i is described by the tuple.

$$FIND(t_i) = < FINDSoc(t_i), FINDEcol(t_i), FINDEcon(t_i), FINDTech(t_i), FINDIn(t_i) > \tag{2}$$

each component of which reflects the fulfillment of the corresponding groups of inequalities from the system of constraints (1).

Let us consider more thoroughly the agrotechnological aspects of the program (corresponding indicators and limitations), bearing in mind that the analysis for the rest of the program indicators' complexes is carried out in the same way. We represent *FINDTech(t_i)* as a binary vector.

$$FINDTech(t_i) = < FIndTech_1(t_i), FIndTech_2(t_i),\ldots, FIndTech_k(t_i)> \tag{3}$$

$$FIndTech_j(t_i) \in \{0, 1\}, \qquad j = 1, 2,\ldots, k$$

We will assume that the *INDTech* list contains subgroups of" duplicate " indicators *INDTech₁*, *INDTech₂*,...., *INDTech_p* , such that in the framework of the program implementation analysis, it is sufficient to achieve the normative value of at least one of the indicators of the subgroup (the remaining indicators may not even be measured). Then the binary *FIndTech* indicator is calculated using the logical formula:

$$FIndTech(t_i) = \bigwedge_{s=1}^{p} \left(\bigvee_{IndTech_j \in INDTech^s} FIndTech_j(t_i) \right) \tag{4}$$

where, if the value *1* (true) means the execution of a set of agrotechnological indicators at time t_i, and *0* (false) – non-execution, $\wedge$, $\vee$ – the signs of the conjunction and disjunction operations.

For a more detailed analysis, formula (4) can be generalized to the fuzzy case, in which the indicators included in this formula can take intermediate values in range of *0* and *1*, which reflects the degree of fulfillment of the corresponding restrictions (the degree of truth of the statements about the fulfillment of the restrictions), i.e.

$$FIndTech(t_i), FIndTech_j(t_i) \in [0, 1], \qquad j = 1, 2, \ldots, k \qquad (5)$$

where the conjunction ($\wedge$) and disjunction ($\vee$) operations included in formula (4) are replaced by the min and max functions (in accordance with [8]). However, there are still questions of interpretation of the fuzzy values of $FIndTech_j(t_i)$ indicators and ways of determining them, which makes the use of model descriptions of the theory of linguistic variables more reasonable [9].

The formal linguistic description of the *FIndTech*, *FIndTech_j* indicators is represented as tuples

$$\langle LingFIndTech, UnIndTech, TbaseIndTech, GIndTech, MIndTech \rangle \qquad (6)$$

$$\langle LingFIndTech_j, UnIndTech_j, TbaseIndTech, GIndTech_j, MIndTech_j \rangle, \qquad j = 1, 2, \ldots, k$$

where *LingFIndTech*, $LingFIndTech_j$ – names of linguistic variables; *UnIndTech*, $UnIndTech_j$ – universal sets of linguistic variables containing all possible measured numeric values of *IndTech*, $IndTech_j$, (as a percentage of the normative numeric values of *NormIndTech*, $NormIndTech_j$); *TbaseIndTech = {low, medium, high}* – the general base term set for the values under consideration; $MIndTech_j$ – syntactic rules that allow generate term names from the names of the *TbaseIndTech* elements (which leads to the formation of the *TIndTech* term set); semantic rules that establish correspondences between terms from *TIndTech* and fuzzy subsets of *UnIndTech*, $UnIndTech_j$ *(j = 1, 2,..., k)*. The membership functions of these sets can have, in particular, a trapezoidal type, as shown in figure 1.
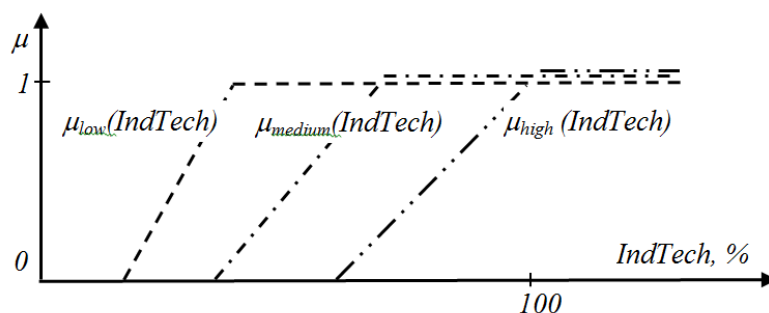

Figure 1. Graphs of membership functions μ_{low} *(IndTech)*, μ_{medium}*(IndTech)*, μ_{high}*(IndTech)* of fuzzy subsets of UnIndTech that define the semantics of the terms *low*, *medium*, *high*.

The relationship between the *UnIndTech* indicator, which reflects the overall degree of compliance with a group of agrotechnological standards, and the degree of compliance with individual $FIndTech_j$ standards *(j = 1, 2,..., k)* is set by fuzzy production rules of the form:

$$if \ F_{low}(FIndTech_1, FIndTech_2, \ldots, FIndTech_k) \ then \ (FIndTech - low)$$

$$if \ F_{medium}(FIndTech_1, FIndTech_2, \ldots, FIndTech_k) \ then \ (FIndTech - medium) \qquad (7)$$

$$if \ F_{high}(FIndTech_1, FIndTech_2, \ldots, FIndTech_k) \ then \ (FIndTech - high)$$

where F_{low}, F_{medium}, F_{high} are linguistic expressions relative to the correspondences of numeric values of $FIndTech_j$ *(j = 1, 2,..., k)* to terms from *TIndTech*. For example,

$$F_{low} = (FIndTech_1 - low) \wedge (FIndTech_2 - low) \wedge ((FIndTech_3 - low) \wedge (FIndTech_3 - medium))$$

Expressions *Flow*, *Medium*, *High* are set by experts according to their experience and knowledge of the subject area.

The analysis of the implementation of the development programs of the regional agro-industrial cluster at the time ti in terms of achieving the required values of social ($FINDSoc(t_i)$), environmental ($FINDEcol(t_i)$), economic ($FINDEcon(t_i)$) and scientific and innovative ($FINDIn(t_i)$) indicators is performed in the same way.

3. Results and discussion

The main result of the work is building of an information analysis system for implementation of regional agro-industrial development programs, the structure of which is shown in figure 2.
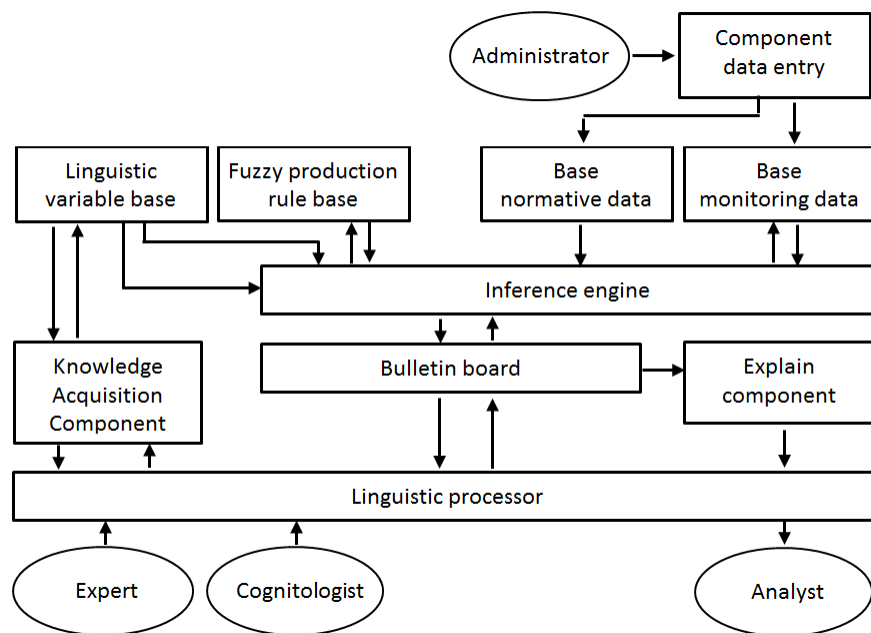

Figure 2. Structure of the information and analytical system for analyzing the implementation of regional agro-industrial cluster development programs.

The management of the operation of the information and analytical system is carried out by the administrator, whose functional responsibilities include entering the normative data of the program which are set during its initial development (adjustment) and data from monitoring for its implementation, for which a special component of the system (Component data entry) is provided. Separate storage of these types of data in different databases (Base normative data and Base monitoring data) allows to use various formats of information representation and to differentiate access to ensure the necessary level of data security.

Users of the system (*Expert*, *Cognitologist*, *Analyst*) interact with it in a limited subset of natural language (reflecting the specifics of the program) using the *Linguistic processor*. *Expert* and *Cognitologist* perform the filling of knowledge bases (*Linguistic variable base* and *Fuzzy production rule base*), the division of which reflects the specifics of the methodological apparatus used (and the subject area) and is another feature of the developed system.

Processing of knowledge and facts (data) based on the Mamdani fuzzy inference algorithm [10] is performed (as part of solving the analysis problem) by the *Inference engine*. After which its result (in the form of an assessment of the program progress and recommendations for its possible correction) is transmitted to the working memory area (*Bulletin board*) and then (through the *Linguistic processor*) is transmitted to the *Analyst* user who set the task. On a special request, the *Analyst* can get the justification

of the results generated by a special component (*Explain component*), which can serve as an additional check of the correctness of the system and increases the confidence in the recommendations developed.

4. Conclusion

The application of the program approach to solving the problems of sustainable development of the agro-industrial cluster of the regional economy is due to the high requirements for the management of social, environmental, economic, agrotechnological and scientific-innovative processes within the framework of the implementation of public-private partnership programs. The necessary level of management cannot be achieved without the extensive use of modern digital intelligent technologies.

The paper considers the task of developing tools for intellectual support of the analysis of the implementation of regional agro-industrial cluster development programs, taking into account the high level of uncertainty characteristic of innovative agricultural production. The success of the individual stages of the program is proposed to be evaluated by the degree of achievement of normative targets, for which the apparatus of representing knowledge about the subject area in the form of linguistic variables describing the indicators and fuzzy production rules defining the relationships between the indicators is used. The use of the interpreted Mamdani fuzzy inference procedure makes it possible to form explanations of the course of reasoning when obtaining (logical inference) values of indicators that cannot be directly measured.

The proposed design solutions are used in the development of an intelligent information system for analyzing the implementation of programs. The preliminary results of the pilot operation of the research prototype of the developed system can serve as a confirmation of the effectiveness of its use in managing the development programs of the regional agro-industrial cluster. It is proposed to develop further research in this direction, supplementing the system functionality with the possibilities of modifying programs based on expert judgments, as well as models and methods of evolutionary synthesis of discrete systems with a given behavior [11, 12], which will allow for timely support for the adjustment of regional agro-industrial policy when the conditions for its implementation change.

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