Use of intelligent technologies in agroeconomic data analysis

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Abstract. The article is devoted to the use of intelligent technologies, in particular fuzzy modeling technology, to solve the multicriteria problem of decision-making on the example of choosing the best development strategy for an agrarian enterprise. It showed the limited use of classical methods to solve this problem in terms of increased uncertainty of the enterprise's operational environment. An alternative approach to solving the problem of multicriteria choice was proposed on the basis of the fuzzy tools usage. The fuzzy statement and solution of the investigated problem was given. Calculations on multicriteria choice of the best strategy based on data of a particular enterprise of agro-industrial complex have been made.

1. Introduction
To date, the development of economic thought has come to a new realization of reality characterized in the scientific literature as the formation of the digital economy [1].

Now the process of data collection, processing and use is undergoing a major technological shift including the use of the latest technologies to make efficient and qualitative solutions. It allows us to think about the fact that we are going through revolutionary changes.

At this stage, the state level of Russia is solving problems related to the digital economy development, implementing programs for such an economy's development [2]. All the sectors were affected by this program; the agrarian industry was also involved in this process, yet the digitalization level of the agrarian sector is well below the level reached by other sectors. The main reason for this situation may be the fact that investors are extremely reluctant to consider agro-industrial complex as a potential base for investment.

It is extremely inappropriate to consider producers of the agricultural sector as investors because of low consumer demand and price disparity for agricultural and industrial products.

Nevertheless, in certain segments of the agricultural sector of the economy, in particular in livestock and crop production, there are some successes in the application of innovative and digital technologies [3], [4]. But these successes are associated exclusively with technological innovations, the development of which is determined by the priority need to modernize the material and technical base of the agricultural sphere of the economy. At the same time, new approaches to methods and models of economic decision-making based on the use of modern data analysis technologies are also important for the agricultural economy. This direction in agrarian science is still poorly developed.

2. Materials and methods
To date, optimization and econometric models have received the greatest application in agricultural science and practice. Traditionally, both are based on quantitative deterministic source information
and the account of uncertainty as an accident, for which probabilistic-statistical methods are used to describe.

Meanwhile, many of the decision-making tasks of planning and managing agrarian production, especially at the strategic level, may be characterized by a sufficient number of undefined factors, as well as non-deterministic and stochastic information. In this regard, it can be concluded that the tasks of managing the agrarian sector of the economy are poorly structured. Therefore, the problem of accounting for data uncertainty and incompleteness takes a key place in solving the management problems in the agro-industrial complex (AIC).

For setting and solving such problems, classical methods of decision theory are not applicable. In this case, it is necessary to use special formalization methods. In the past two decades, a new direction has been actively developing based on artificial intelligence techniques and models, which in particular include fuzzy models. The use of fuzzy models in the econometric study of agrarian processes was demonstrated by us in the study [5]. Here we will dwell on the possibilities of fuzzy modeling when solving multicriteria problems of economic decision-making in the agro-industrial complex.

Let us highlight those tasks that allow us to approach questions about the quality of decisions made on the basis of several traits (criteria).

The criteria taken into account are generally heterogeneous and contradictory. At the same time, tasks containing many criteria can have both qualitative and certain quantitative undefined elements; among them the dominant are qualitatively undefined elements.

We will study the tools of fuzzy set theory used in the theory of multicriterial evaluation [6—7].

A lot of implementation options for a certain purpose is represented as $X = \{x_1, x_2, \ldots, x_n\}$, by which it is possible to evaluate many different criteria of options - $K = \{K_1, K_2, \ldots, K_m\}$. Let us reduce the problem of selecting the necessary option to ordering all elements included in the $X$ set according to criteria from the criterion set $K$.

We use an approach that is based on the use of the fuzzy set theory apparatus [7]. The basis of this approach is the fact that all qualitative characteristics are quantified. The application method of this toolkit allows to perform a numerical assessment of any qualitative characteristic, and then further to make accurate mathematical calculations based on numerical information.

Here is a sequence of how we will carry out our research.

1) Using the fuzzy sets toolkit, we will make the transition from the qualitative characteristic of the studied criterion to its quantitative characteristic. This can be done by replacing qualitative values of our criterion with fuzzy variables:

$$
\tilde{K}_i = \left\{ \frac{\mu_{K_1}(x_1)}{x_1}, \frac{\mu_{K_2}(x_2)}{x_2}, \frac{\mu_{K_3}(x_3)}{x_3}, \ldots, \frac{\mu_{K_m}(x_n)}{x_n} \right\}, i=1\ldots m.
$$

where $\mu_{K_i}(x_j)$ is the membership grade of the element $x_j$ to the fuzzy set $K_i$.

2) The weights of criteria $\beta_i, i=1\ldots m$ are determined.

3) A fuzzy choice of the best alternative is being carried out. If there are $m$ criteria: $K_1, K_2, \ldots, K_m$, then the best is considered the alternative effective by all criteria. At the same time, the fuzzy decision to find a better alternative is based on the formula (2) as an intersection of the corresponding weighted fuzzy sets:

$$
\tilde{P} = \tilde{K}_1^\beta_1 \cap \tilde{K}_2^\beta_2 \cap \ldots \cap \tilde{K}_m^\beta_m
$$

Components of the vector $P$ are generalized membership functions of the studied variants taking into account all criteria.

4). The alternative $x^*$, which has the greatest degree of belonging in the vector $P$, is chosen as the best.
5). The method of paired comparisons of \( x_j \) variants was applied when constructing membership functions and for calculating weights. \((j=1\ldots n)\). Its implementation is as follows. The source information for the comparisons is expert paired comparisons \( x_i \).

For each pair of elements of a universal set, the expert evaluates the advantage of one element over another with respect to the fuzzy set property using the nine-point Saati scale: 1 — No advantage; 3 — Moderate advantage; 5 — Significant advantage; 7 — Clear advantage \( a_i \) over \( a_j \); 9 — Absolute advantage; 2, 4, 6, 8 — Intermediate solution between two adjacent judgments [8]. The results of comparisons are made in the form of matrix \( A = \begin{bmatrix} a_{ij} \end{bmatrix}_{n \times n} \), where \( a_{ij} \) is the level of advantage of element \( x_i \) over \( x_j \) \((i, j = 1\ldots n)\) on each property (criterion).

After all elements of the matrix of paired comparisons \( A \) are determined, the values of the membership grades of a fuzzy set are calculated according to the formula:

\[
\mu(x_i) = \frac{1}{a_{1j} + a_{2j} + \ldots + a_{nj}}
\]

(3)

3. Results and Discussion

We use the abovementioned algorithm to choose the strategy of an agricultural enterprise. The main goal of the investigated enterprise for the strategy choice is the development, production and marketing of the goods that has the greatest demand among the consumer. The basis of strategic planning is the general “market share expansion” strategy, which can be implemented in many ways.

The following four were considered as alternatives to achieving the general strategy of “expanding market share”: \( S_1 \) — lower the price; \( S_2 \) — modify the product; \( S_3 \) — develop a new product; \( S_4 \) — look for new markets.

Each of the alternatives was evaluated as follows: \( K_1 \) — criterion estimating the cost of production expansion; \( K_2 \) — criterion estimating project implementation time; \( K_3 \) — criterion estimating the costs of marketing research, \( K_4 \) — criterion evaluating risks from losses, \( K_5 \) — criterion evaluating product quality.

To find the best option, the algorithm described above was applied.

The results we have obtained from comparing different alternatives based on multicriteria evaluation will allow us to quantify each of the qualitative characteristics and show them in a matrix.

Table 1 contains a matrix that corresponds to paired comparisons of alternative strategies according to the criterion estimating the expansion costs.

| \( K_1 \) | \( S_1 \) | \( S_2 \) | \( S_3 \) | \( S_4 \) |
|----------|----------|----------|----------|----------|
| \( S_1 \) | 1        | 3        | 3        | 5        |
| \( S_2 \) | 0,3      | 1        | 3        | 3        |
| \( S_3 \) | 0,3      | 0,3      | 1        | 4        |
| \( S_4 \) | 0,2      | 0,3      | 0,25     | 1        |

Table 2 contains a matrix that corresponds to paired comparisons of alternative strategies according to the criterion estimating the time of implementation.

| \( K_1 \) | \( S_1 \) | \( S_2 \) | \( S_3 \) | \( S_4 \) |
|----------|----------|----------|----------|----------|
| \( S_1 \) | 1        | 5        | 7        | 5        |
| \( S_2 \) | 0,2      | 1        | 3        | 1        |
| \( S_3 \) | 0,14     | 0,3      | 1        | 0,2      |
Table 3 contains a matrix that corresponds to paired comparisons of alternative strategies according to the criterion evaluating marketing costs.

**Table 3. Pair comparison of alternatives “Marketing cost criteria” (K₁).**

| K₁ | S₁ | S₂ | S₃ | S₄ |
|----|----|----|----|----|
| S₁ | 1  | 3  | 4  | 5  |
| S₂ | 0.3| 1  | 3  | 4  |
| S₃ | 0.25| 0.3| 1  | 2  |
| S₄ | 0.2| 0.25| 0.5| 1  |

Table 4 contains a matrix that corresponds to paired comparisons of alternative strategies according to the criterion evaluating the risks from losses.

**Table 4. Pair comparison of alternatives to the “Risk from Loss Criteria” (K₂).**

| K₂ | S₁ | S₂ | S₃ | S₄ |
|----|----|----|----|----|
| S₁ | 1  | 0.14| 0.2| 0.3|
| S₂ | 7  | 1  | 5  | 7  |
| S₃ | 5  | 0.2| 1  | 3  |
| S₄ | 3  | 0.14| 0.3| 1  |

Table 5 contains a matrix that corresponds to paired comparisons of alternative strategies according to the criterion evaluating the quality of products.

**Table 5. Pair comparison of alternatives “Product quality criterion” (K₃).**

| K₃ | S₁ | S₂ | S₃ | S₄ |
|----|----|----|----|----|
| S₁ | 1  | 0.14| 0.2| 0.3|
| S₂ | 7  | 1  | 5  | 7  |
| S₃ | 5  | 0.2| 1  | 3  |
| S₄ | 3  | 0.14| 0.3| 1  |

The method of comparing them paired was also used to find the weights of the criteria. The results of paired criteria comparison on the Saati scale are given in Table 6.

**Table 6. Pair criteria comparison on the Saati scale.**

| The criteria | Pair comparison result |
|--------------|------------------------|
| K₁           | There is no advantage over other criteria. |
| K₂           | Substantial advantage K₂over K₁ |
| K₃           | Between absence and moderate advantage of K₃over K₁ |
| K₄           | The clear advantage of K₄over K₁and K₃. |
| K₅           | A significant advantage of K₅over K₁and K₃. Between absence and moderate advantage of K₅over K₄. |

Table 7 contains a matrix that corresponds to paired comparisons of criteria.

**Table 7. Matrix of paired comparison criteria.**

| The criteria | K₁ | K₂ | K₃ | K₄ | K₅ |
|--------------|----|----|----|----|----|
| K₁           | 1  | 0.2| 0.5| 0.14| 0.2|
| K₂           | 5  | 1  | 0.3| 0.2 | 0.3|
| K₃           | 2  | 0.3| 1  | 0.14| 0.5|
| K₄           | 7  | 5  | 7  | 1   | 0.5|
| K₅           | 5  | 3  | 5  | 2   | 1 |
Further, applying the formula (3) to the elements of Table 7, the following weights vector of criteria \( \beta = (0.050; 0.105; 0.072; 0.287; 0.400) \) was obtained. After determining the weights by formula (2), fuzzy sets of alternatives were calculated for each of the criteria:

For the first criterion, we get the following fuzzy set consisting of qualitative estimates of quantitative characteristics:

\[
\tilde{K}_1 = \left\{ \frac{0.969}{s_1}, \frac{0.926}{s_2}, \frac{0.906}{s_3}, \frac{0.880}{s_4} \right\}
\]

(4)

For the second criterion, we get the following fuzzy set consisting of qualitative estimates of quantitative characteristics:

\[
\tilde{K}_2 = \left\{ \frac{0.955}{s_1}, \frac{0.811}{s_2}, \frac{0.747}{s_3}, \frac{0.813}{s_4} \right\}
\]

(5)

For the third criterion, we get the following fuzzy set consisting of qualitative estimates of quantitative characteristics:

\[
\tilde{K}_3 = \left\{ \frac{0.959}{s_1}, \frac{0.896}{s_2}, \frac{0.857}{s_3}, \frac{0.836}{s_4} \right\}
\]

(6)

For the fourth criterion, we get the following fuzzy set consisting of qualitative estimates of quantitative characteristics:

\[
\tilde{K}_4 = \left\{ \frac{0.451}{s_1}, \frac{0.892}{s_2}, \frac{0.583}{s_3}, \frac{0.498}{s_4} \right\}
\]

(7)

For the fifth criterion, we get the following fuzzy set consisting of qualitative estimates of quantitative characteristics:

\[
\tilde{K}_5 = \left\{ \frac{0.348}{s_1}, \frac{0.451}{s_2}, \frac{0.779}{s_3}, \frac{0.546}{s_4} \right\}
\]

(8)

As a result of intersecting the fuzzy sets we obtained \( \tilde{K}_1, \tilde{K}_2, \tilde{K}_3, \tilde{K}_4, \tilde{K}_5 \) we have calculated a vector \( \tilde{M} \) whose components reflect generalized priorities of the alternatives being compared, taking into account all criteria:

\[
\tilde{M} = \left\{ \frac{0.348}{s_1}, \frac{0.451}{s_2}, \frac{0.583}{s_3}, \frac{0.498}{s_4} \right\}
\]

(9)

The best strategy is the strategy that has received the highest priority, i.e. strategy \( S_3 \) — the development of a new product.

4. Conclusions

In this article, we considered the possibility of using the theory of fuzzy sets to solve multicriteria decision problems often encountered in practice. Such tasks allow us to find a solution not only using quantitative deterministic baseline data, but also qualitative and expert data.

Data collection, processing and usage processes that can undergo a fairly large technological shift include the use of the latest technologies that enable the adoption of efficient and quality solutions. This type of solutions will make the best use of the initial information obtained during the study.

For setting and solving the example problem, classical methods of decision theory cannot provide an acceptable solution in the case of significant uncertainty. Therefore, we used fuzzy set theory and its application to the solution of multicriteria decision problems.

In addition to the problem discussed in the article, fuzzy modeling can be applied to solving a wide range of problems of the agrarian industry. Thus, our studies have shown that the use of fuzzy models in econometric research of agrarian processes is quite a promising direction [5].

We also considered the possibilities of setting and solving problems of fuzzy optimization, in particular when choosing the structure of various crops’ acreage. Models of fuzzy forecasts of agrarian processes dynamics were also investigated.
Great possibilities of fuzzy modeling are opened up to the researcher in the field of strategic AIC management tasks. As a particular example, on its basis is possible to identify, rank and evaluate factors influencing the development of the object in both external and internal environments.

In general, the use of the latest technologies in the agro-industrial complex will allow to move to the next development stage of agricultural production using all the possibilities of the modern world.

At the present development stage, the Russian agrarian sector undergoes quite significant changes. Quite wide prospects are opened up for researchers by the study and formalization of the tasks of this sector, allowing to make managerial decisions from the point of view of the digital economy development.

The very concept of economic information in the age of digital economy becomes the broadest, since it does not limit us either in space, in time, or in the possibility of using mathematical toolkit.

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