E3S Web of Conferences **398**, 01001 (2023) https://doi.org/10.1051/e3sconf/202339801001
*ABR 2023*

# Criteria-Based Approach to Solving the Problem of Technological Regulation Rotary Combine

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**Abstract.** The task of technological adjustment of the working bodies of a rotary combine harvester is not trivial. The complexity of the task is due to the need to take into account a large number of signs (environmental factors and parameters of the technical condition of the machine), and the level of uncertainty of the values of these signs is quite high. Therefore, when searching for optimal values of the regulated parameters of the combine harvester, ensuring that the values of the work quality indicators do not exceed the permissible ones, it is advisable to use an intelligent information system. The use of this system will allow using various methods and algorithms for finding the desired solutions. In the conditions of uncertainty characteristic of the problem under consideration of adjusting the adjustable parameters of the machine, it is advisable to use a game-theoretic approach when creating an intelligent system for setting up a combine harvester. This approach will provide variability of methods for choosing the optimal strategy for finding a rational solution.Based on the analysis of the subject area, the concepts of performance indicator matrices and the risk of making an ineffective decision are introduced. The choice of a strategy for finding the reason for the deviation of the harvester's performance indicator is considered based on three criteria: Laplace, mathematical expectation and Savage, widely used in decision-making tasks in the so-called "games with nature".An example of choosing a strategy for finding the cause of a violation of the technological process of grain harvesting and an adequate response to eliminate it is given. The analysis of the calculation results is carried out, the conditions and scope of the proposed approach are presented.

The efficiency of using combine harvesters, and therefore the efficiency of harvesting operations, depends on the successful solution of the problem of managing the technological process of harvesting. [1, 2].

The influence of external factors on the quality indicators of the combine, their significant variability, necessitate the search for optimal strategies for solving the problem of adjusting the technological adjustments of the combine. Its solution is complicated by a sufficiently high level of uncertainty of the task features and a significant number of qualitative (not numerical) indicators.

The successful solution of the problem of technological adjustment of the combine with the use of intelligent decision support systems depends on the level of adequacy of the for-

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mal (mathematical) model of this process. To date, there is no methodology for a formal logical description of the subject area (for a rotary combine).

As a result of previous studies, various models have been obtained, in particular regression models, which give a certain idea of the relationship "external factors - regulated parameters - performance indicators for drum (classical) type combines [3-6]. However, the general disadvantage of these models is that they take into account only quantitative factors, have a limited scope due to the small limits of variability of the arguments of the model, I do not take into account the fuzziness of the input information. Because of this, regression models are not widely used and are currently not actually used, including due to the complexity of their use in real time in the field. Obviously, the use of such an approach for rotary combines is also irrelevant. In this regard, the task arises of finding new methods for finding optimal strategies for technological adjustment of a rotary combine.

In the modern market of grain harvesting equipment, high-performance combine harvesters with an axial-rotor threshing and separating device (ARMSU) are becoming increasingly widespread [1]. However, unlike combine harvesters with a classical threshing scheme, optimal control of a rotary combine is difficult due to the low knowledge of the dependencies of the combine's performance indicators on external factors, which, due to the large variability, can lead to violations of the harvesting process and, as a result, the appearance of significant product losses. When detecting changes in the values of the cleaning factors (for example, the moisture content of the grain stand, flatness, clogging, etc.), it is necessary to adjust the values of the regulated parameters of the machine, that is, to solve the multifactorial problem of decision-making. The solution of this problem is complicated by the presence of uncertainty in determining the specific values of factors and parameters of the machine.

The analysis of expert opinions of practitioners, as well as their own experience of harvesting grain crops using a rotary combine harvester, allowed us to formulate a set of external signs of possible violations of the technological process [16] (Fig. 1).

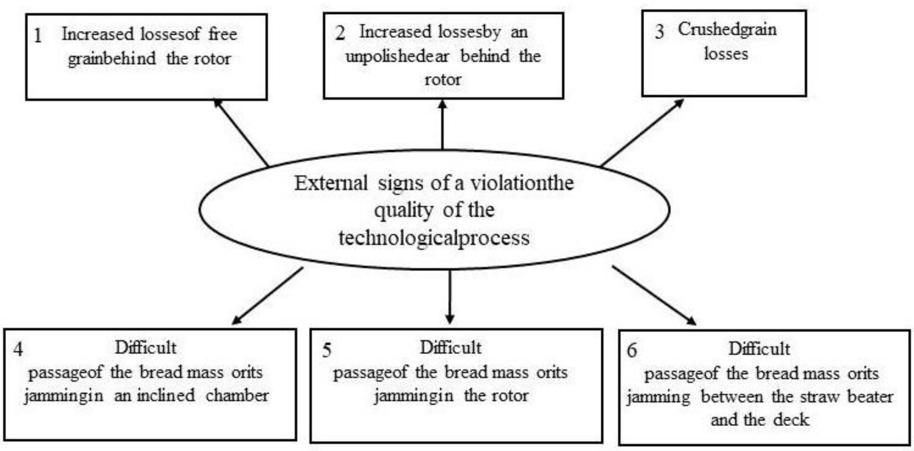


**Fig. 1.** Possible violations of the technological process

The effective solution of the problem of technological adjustment of the working bodies of the rotary combine is largely difficult due to the presence of the following facts:

• the presence of several deviations of work quality indicators (violations) from acceptable values;

• the possibility of the existence of several reasons for the occurrence of a violation;

• the possibility of using various options to eliminate the violation;

• the possibility of an additional violation when eliminating the originally identified violation;

• * lack of reliable information about the possible cause of the violation.

Identification of the subject area made it possible to establish the main parameters of the ARMSU (Table. 1) and their relationship with the external signs of the violation (Fig. 2).

**Table 1.** Main parameters of ARMSU

| № | Name of parameters | Conditional designation |
|---|---|---|
| 1 | he angle of attack of the turns of the separating part of the deck | $\Pi_1$ |
| 2 | Rotor speed | $\Pi_2$ |
| 3 | The gap between the straw beater and the deck | $\Pi_3$ |
| 4 | The speed of movement of the combine | $\Pi_4$ |
| 5 | The state of the rotor turns | $\Pi_5$ |
| 6 | The state of the turns of the separating part of the deck | $\Pi_6$ |
| 7 | The gap between the whips of the rotor and the whips of the deck | $\Pi_7$ |
| 8 | Angle of attack of the turns of the threshing part of the deck | $\Pi_8$ |
| 9 | Condition of the rotor scourges | $\Pi_9$ |
| 10 | The condition of the deck 's beeches | $\Pi_{10}$ |
| 11 | The condition of the turns of the threshing part of the deck | $\Pi_{11}$ |
| 12 | The condition of the deck support rollers | $\Pi_{12}$ |
| 13 | Condition of the inclined chamber drive (NC) | $\Pi_{13}$ |
| 14 | Condition of the chain and sprockets of the drive of the NC beaters | $\Pi_{14}$ |
| 15 | The condition of the knives on the winding part of the rotor | $\Pi_{15}$ |
| 16 | Condition of the straw beater drive | $\Pi_{16}$ |

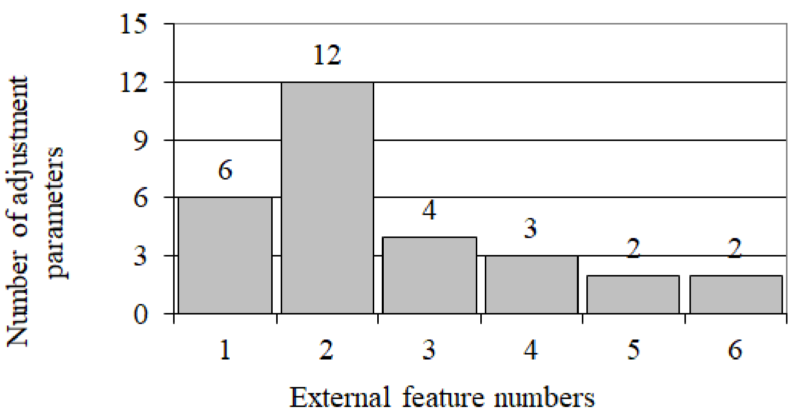


**Fig. 2.** Relationship "violations - parameters"

Figure 2 shows the numbers of external signs along the abscissa axis (see Fig. 1)

Rational use of mathematical methods of decision-making involves the creation of a mathematical model of a real system. To model the process of adjusting technological adjustments at the initial stage of the analysis, we will set the following general assumptions.

Assumption 1. At the same time, only one violation of the cleaning process may occur in the analyzed system.

Assumption 2. For the studied technical system, the significance of the influence (weight) of the combine parameters (regulated and technical condition) on the probability of violations of the technological process (and, as a consequence, the appearance of an external sign of a violation) is often set.

The accepted approach. Consider a combine harvester that is in the process of working. A signal is received either from an automatic control system or visual observation about the deviation of the cleaning quality indicator from the permissible value. Denote $S=\{B_j\}\big|_{j=1}^{n}$ - a lot of violations that could lead to this deviation. The set of actions that can affect the detected deviation is denoted by $G=\{A_i\}\big|_{i=1}^{m}$, we will call G the set of acceptable solutions or, as is customary in game theory, the set of strategies. Each of the strategies has a different degree of influence on the detected violation of the quality indicator, the measure of this influence will be called the effectiveness of the strategy and we will introduce a numerical indicator for it, varying from 0 to 1. Each such indicator $c_{ij}\ (i=\overline{1,m},\ \ j=\overline{1,n}.)$ will reflect the degree of effectiveness of the strategy $A_i$ to eliminate the violation $B_j$. Let's denote the matrix of performance indicators with. Let's turn to the paradigm of finding the optimal strategy using the criterion approach used in "games with nature" for decision-making in conditions of uncertainty [7, 8]. In this case, the theory provides a number of criteria, the choice of which is determined by the initial conditions. Let's look at the criteria, the application of which is appropriate in this task.

In the absence of a knowledge base on the empirical frequencies of the causes causing deviations in the quality indicators of harvesting, it is possible to accept the hypothesis of an equally probable distribution, based on the principle of insufficient justification [8]. Then, according to the Laplace criterion [8], a solution is chosen $A^{*}\in G=\{A_i\}_{i=1}^{m}$, corresponding to the strategy with maximum expected efficiency:

$$\max_i L(i)=\max_i \frac{1}{m}\sum_{j=1}^{m} c_{ij}\,. \tag{1}$$

This situation may be typical for an operator who does not have experience and the ability to rely on a base of expert knowledge. In modern conditions, there is often a database ranked by the frequency of occurrence of the causes of the violation, it allows you to obtain estimated probabilities. Taking them as a priori probabilities $p_j\ (j=\overline{1,m}\ )$ the presence of reasons $\{B_j\}$, it is advisable to use a similarly constructed criterion of maximum mathematical expectation:

$$\max_i M(i)=\max_i \sum_{j=1}^{m} c_{ij}p_j \tag{2}$$

You can use the Savage criterion [7], also called the minimum risk criterion. For its application, a risk matrix R is constructed, the elements of which are $r_{ij}\ (i=\overline{1,m},\ \ j=\overline{1,n}.)$ reflect the risk of ineffective application of the strategy $A_i$ to eliminate the violationя $B_j$. If the reason for the violation $B_j$ if it were known, then we would apply the strategy $A_i$

with the maximum efficiency indicator, which corresponds to the maximum element $\beta_j$ in the column with the number j. Elements of the risk matrix $r_{ij}$ calculated by the formula:

$$r_{ij} = \beta_j - c_{ij}. \tag{3}$$

Optimal according to the Savage criterion is a strategy with minimal risk in the worst conditions:

$$\min_i S(i) = \min_i \max_j r_{ij}.$$

The choice of one or another criterion depends on many factors. An essential role is played by the presence of an expert knowledge base on the empirical probabilities of the causes of typical violations of quality indicators. The basis for using the Savage criterion is the high importance of risk in making a decision. The selection of the criterion is carried out by the operator taking into account the specific situation.

Let us turn to the problem of adjusting the adjustable parameters of a rotary combine and consider, by the example of a specific violation of the cleaning quality indicator, the application of the above criteria for choosing the optimal strategy to eliminate the detected deviation. One of the most common external signs of deviation of quality indicators during harvesting of grain crops is the following "Increased losses of free grain behind the rotor" (see Fig. 1). As a final step in solving the problem, an analysis of the relationship "causes – possible strategies for eliminating violations" is necessary (Fig. 3).

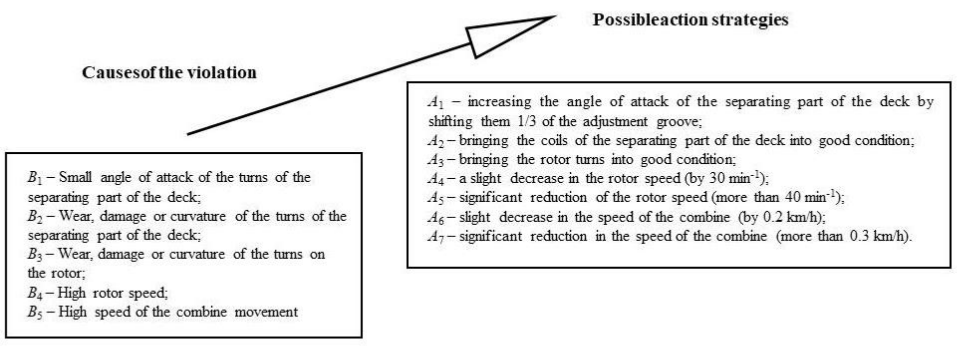


**Fig. 3.** Diagram of the relationship "causes – possible elimination strategies"

Based on empirical data and expert judgments, a matrix of performance indicator values is obtained $\left\{C_{lj}\right\}$ (table.2).

A characteristic feature of the subject area under consideration is the ignorance (a priori) of the exact values of the probability of the specific reason that caused the deviation of the value of the quality indicator of the cleaning process from the permissible value. For this case, consider the use of the Laplace criterion (1). Table 2 shows the calculated values of the criterion for the strategies under consideration. It can be seen that as the optimal strategy in this case, you can choose the strategy $A_6$ (см. рис. 3).

The next step is to use the Savage criterion. In this case, the optimal strategy is chosen based on the risk analysis r of making an ineffective decision. The values of the criterion are determined based on the risk matrix, the elements of which are determined by the formula (3). The calculated values are presented in Table 3.

**Table 2.** Matrix of performance indicator values

| *Ai* | $B_j$ | | | | | *L*(*i*) | *M*(*i*) |
|---|---|---|---|---|---|---|---|
| | $B_1$ 0,32 | $B_2$ 0,1 | $B_3$ 0,15 | $B_4$ 0,28 | $B_5$ 0,25 | | |
| $A_1$ | 0,98 | 0,07 | 0,09 | 0,4 | 0,35 | 0,378 | 0,5336 |
| $A_2$ | 0,1 | 0,18 | 0,07 | 0,08 | 0,05 | 0,096 | 0,0954 |
| $A_3$ | 0,08 | 0,08 | 0,18 | 0,1 | 0,05 | 0,098 | 0,1011 |
| $A_4$ | 0,2 | 0,05 | 0,07 | 0,98 | 0,6 | 0,38 | 0,5039 |
| $A_5$ | 0,25 | 0,09 | 0,09 | 0,75 | 0,65 | 0,366 | 0,475 |
| $A_6$ | 0,3 | 0,1 | 0,08 | 0,6 | 0,95 | 0,406 | 0,5235 |
| $A_7$ | 0,35 | 0,1 | 0,1 | 0,65 | 0,8 | 0,4 | 0,519 |
| $\max_i c_{ij} = \beta_j$ | 0,98 | 0,18 | 0,18 | 0,98 | 0,95 | | |

**Table 3**. Risk matrix

| *Ai* | $B_j$ | | | | | $\max_J r_{ij}$ |
|---|---|---|---|---|---|---|
| | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | |
| $A_1$ | 0 | 0,11 | 0,09 | 0,5 | 0,6 | 0,6 |
| $A_2$ | 0,88 | 0 | 0,11 | 0,82 | 0,9 | 0,9 |
| $A_3$ | 0,9 | 0,1 | 0 | 0,8 | 0,9 | 0,9 |
| $A_4$ | 0,78 | 0,13 | 0,11 | 0 | 0,35 | 0,78 |
| $A_5$ | 0,73 | 0,09 | 0,09 | 0,15 | 0,3 | 0,73 |
| $A_6$ | 0,68 | 0,08 | 0,1 | 0,3 | 0 | 0,68 |
| $A_7$ | 0,63 | 0,08 | 0,08 | 0,25 | 0,15 | 0,63 |

From Table 3 we see that according to the Savage criterion, the optimal strategy will be A1 – increasing the angle of attack of the separating part of the deck by shifting them 1/3 of the adjustment groove.

If there is empirical data on the relative frequencies of the causes of the deviation in question, taking them as probabilities, we use the criterion of maximum mathematical expectation (2). Since the probability estimates are obtained empirically, their sum is not equal to 1, the probabilities are indicated in Table. 2 in cages $B_j$ $(j = 1,...,5)$, a criterion values $M(i),\ (i = 1,...,10)$ presented in the rightmost column of the table. 2. According to this criterion, the strategy turned out to be optimal, as in the case of applying the Savage criterion $A_1$.

Modern requirements for the quality of harvesting operations involve both the improvement of harvesting equipment designs and the introduction of intelligent automated control systems [11-13], which use pre-technological adjustment procedures [14] and feedback procedures [15]. The presence of a feedback system is equally important, since it includes the detection of deviations in cleaning quality indicators and the adjustment of settings to eliminate deviations. Adjustment of settings is an intelligent search for the optimal strategy for solving a problem. This task is not trivial due to the complex system of interdependencies between regulated parameters and indicators of harvesting quality, and its solution is largely based on expert judgments and empirical data and is contained in the block of adjustment of the intelligent decision-making system for managing the combine.

The proposed approach to finding the causes of deviations in the performance indicators of the rotary combine and choosing a strategy for their elimination is based on the application of various criteria to the knowledge base created on the basis of expert information and empirical data. In the given example, the Laplace criterion, the mathematical expectation criterion and the Savage criterion are used. In addition to the listed criteria, other synthetic criteria can be used [16, 17], as well as other approaches to decision-making in conditions of uncertainty [18-20]. It should be noted that the choice of the criterion is largely due to the practical experience of the decision-maker. Despite the fact that such a criterion approach is poorly formalized, its use will allow to accumulate information about the effectiveness of various strategies and expand the knowledge base. A significant advantage of the proposed methodology for finding the optimal strategy in an intelligent information system for decision support is that it does not require significant time and computational costs. The application of this approach in the intelligent system adjustment block will allow you to quickly choose the optimal strategy for responding to the detected deterioration in the quality of harvesting, taking into account the cleaning conditions, the type of combine and its technical condition.

## References

1. Yerokhin S.N., Reshetov A.S. Influence of technological adjustments on grain loss behind the thresher of the combine Don-1500. *Mekhanizaciya i ehlektrifikaciya sel'skogo hozyajstva* = Mechanization and electrification in agriculture. 2003; 6: 18-19.

2. Krasnoshchekov N.V. Agroengineering strategy: from mechanization of agriculture to its intellectualization// Tractors and agricultural machines – 2010, No. 8, pp. 5-7.Vetrov E.F., Genkin M.D., Litvin L.M. and others. Optimization of technological process according to statistic data.// *Mashinovedenie* = Machine Science. 1986, 5: 48 – 55.

3. Vetrov E.V., Chernyavskaya V.P., Bobrineva G.F. and others. Optimal adjustment of combine harvester (Electronic journal «Sovetchik kombainera») // Proceedings, 4/89. Moscow: NPO VISHOM, 1989: 80 – 85.

4. Litvin L.M., Zhalkin E.V., Vetrov E.F. Generalized estimation of zone operational performance of combine harvesters. // *Tekhnika v sel'skom hozyajstve* = Machinery in agriculture. 1989; 5: 41 – 45.

5. Tsarev Y.A., Kharkovsky A.V. The prospects of using electrone control system in combine harvesters “Don” and “Niva”. // *Traktory i sel'skohozyajstvennye mashiny* = Tractors and agricultural machines. 2005. №1. C.37 – 38.

6. Wentzel E.S. Operations research. Tasks, principles, methodology. – M.: Higher School, 2007.- 208 p.

7. Taha H. Introduction to Operations Research. - M .: "Williams". -2007.- 912 p.

8. Lipovsky M.I. Combines of a new generation – a high technical level. Mechanization and electrification of agriculture, No. 3.-2006.-pp.8-11.

9. Tsarev Yu.A., Kharkov A.V. Prospects of using an electronic control system in combines "Don" and "Niva" //Tractors and agricultural machines.- 2005.- No. 1.- pp. 37-38.Dimitrov, V., Borisova, L., Nurutdinova, I.. Intelligent Support of Grain Harvester Technological Adjustment in the field. Advances in Intelligent Systems and Computing. 2019; 875: 236-245.

10. Omid M., Lashgar M., Mobli H., Alimardani R., Mohtasebi S., Hesamifard R. Design of fuzzy logic control system incorporating human expert knowledge for combine harvester// Expert Systems with Applications. 2010; 37: 7080–7085.

11. Craessaerts G., De Baerdemaeker J., Missotten B., Saeys W. Fuzzy control of the cleaning process on a combine harvester// Biosystems Engineering. 2010; 106: 103–111.

12. Dimitrov, V., Borisova, L., Nurutdinova, I.. Intelligent Support of Grain Harvester Technological Adjustment in the field. Advances in Intelligent Systems and Computing. 2019; 875: 36-245.

13. Borisova L.V., Nurutdinova I.N., Dimitrov V. P., Tugengol'd A.K. choice of strategy in the problem of updating the harvester adjustable parameters. // ENGINEERING TECHNOLOGIES AND SYSTEMS. 2020. Vol . 30, № 1. P. 60-75. DOI: 10.15507/2658-4123.030.202001.060-075

14. Gorelik V.A., Zolotova T.V. Upravlenie riskom v igrah s prirodoj na osnove svertki kriteriev Val'da i Sevidzha. / Modelirovanie, dekompoziciya i optimizaciya slozhnyh dinamicheskih processov. 2008; 23-1(23): 99-144.

15. Labsker L.G., Aybazova S.H. Cost optimization within transport aspect of the logistics system with application of synthetic Hurwitz criterion. / Upravlenie riskom. 2013, 2(66): 52-72.

16. Malyshev V.V., Piyavsky B.S., Piyavsky S.A. A decision making method under conditions of diversity of means of reducing uncertainty / Journal of Computer and Systems Sciences International. 2010; 49-1: 44-58.

17. Orlovsky S.A. Decision making with a fuzzy preference relation. / Fuzzy Sets and Systems. 1978. 1: 155-167.

18. Kunal Sengupta. Fuzzy preference and Orlovsky choice procedure. / Fuzzy sets and system. 1998. 93: 231-234.