METHOD FOR ASSESSING AGRICULTURAL MACHINES FOR FOOD PROCESSING ON BASIS OF FUZZY PROBABILISTIC MODELS

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Abstract Agricultural machines are quite complex objects in terms of their design, as well as control systems. Cars characterize dozens, if not hundreds of indicators. Information on the efficiency of use of machines in operating environment is crucial for the consumer. However, the existing limitations in the test system do not allow the formation of a sufficient amount of statistical data. In order to maintain commercial advantages, equipment manufacturers prefer not to make the information about such important indicators as reliability public. In practice, technical reliability is distinguished as a structural assessment and technological reliability as an assessment of the stable operation of a machine when its operation changes, and these indicators are rather weakly correlated with each other. Due to the lack of information on the results of testing machines for evaluating machines, it is advisable to use expert knowledge that can be formalized using fuzzy-probabilistic models. The article proposes a method for constructing a fuzzy-probabilistic model for assessing the technological reliability of machines in a multidimensional space of factors affecting the performance of individual operations of fodder preparation. According to the constructed model, a dimensionless generalized indicator of the reliability of the technological process of silage procurement was calculated. The calculated values of the generalized reliability indicator of the technological process of silage harvesting by KDP-3000 trailed forage harvesters of Gomselmash OJSC and FCT 1060 MD Kongskilde Industries in the range of "above average" – "high", which corresponds to the execution of technology with reliability not less than 0.97, are given as an example.

Keywords: grass feed preparation, generalized technology assessment, technical and technological reliability, fuzzy-probabilistic models.

Introduction

Agricultural machines are designed to carry out one or more technological operations in the production of agricultural products in specific agrotechnical terms and under changing conditions. At the same time, the reliability of individual machines or assemblies is not only an important operational indicator, but also plays a significant role in the formation of the entire system of quality indicators of the final product.

In our opinion, when assessing the reliability of machines, one should clearly distinguish between their constructive and technological components. Here, the technological reliability of the equipment is defined as the ability of the machine (unit) to maintain, within specified limits, the values of the characteristics that determine the quality of the technological process in the allotted time period.

As a rule, special attention in literary sources is given to the economic factors of using machines [1; 2], or to the study of technologies for the processes of feed production from herbs, taking into account the indirect influence of technical means [3; 4]. Even sources of special surveys of agricultural machines [5] do not make it possible to obtain the information necessary to assess the technological reliability of the tested machines. The fact is that there is no methodology for assessing such a generalized indicator in the multifactorial space of acting factors.

This situation is especially characteristic of agricultural production. Thus, when performing the feed production technology, using the example of harvesting silage from dried herbs, a specialist has to take into account many factors that are heterogeneous in their physical properties, units of measure, and type of fulfillment. Combining and formalizing such information, containing not only measurable, but also unmeasured (verbal, organoleptic) factors, is possible only by applying a fuzzy-probabilistic approach using the knowledge and experience of highly qualified experts [6].

The successful application of this approach in agricultural production has been convincingly demonstrated by works [3; 4].

DOI:10.22616/ERDev.2020.19.TF174

Materials and methods

As regards the complex of mechanized work in the implementation of the technology of harvesting feed from grasses, all operations are interconnected, and each previous operation prepares the necessary conditions for the subsequent one. The selection of the most appropriate option for performing technological operations is necessary in order to make an effective decision according to the estimates of each of the variables of the factor space under conditions of limited time. Such a problem is weakly or difficult to formalize [6] and for a decision maker (DM) its practical implementation in specific conditions without the use of mathematical models is difficult [3; 4] due to the large number of indicators taken into account and the high cost of such studies.

A significant feature of assessing the structural reliability of machines in modern conditions is worth mentioning. Previously, specialists used data from machine test stations to select machines, which conducted relevant studies in different climatic conditions and issued a technical conclusion on the reliability of machines in a quantitative form based on the attached documented statistical data. The wide assortment and complication of the designs of agricultural machines presented in the modern market have created significant limitations in the test system, which currently do not allow the formation of a sufficient amount of statistical data on the efficiency of the machines. Therefore, in view of the complexity of evaluating machines in real conditions, it is proposed to use the knowledge and experience of experts with their subsequent formalization by mathematical models [6]. In such conditions, the expert acts as an "intelligent measuring system" [7], and his knowledge and experience can be formalized using fuzzy-probabilistic models, as shown in [3; 4].

To solve the task of assessing the possibility of implementing the technology of harvesting feed from grasses in real-life conditions of operation of the machines, the experts identified the following most significant factors:

- X_1 – agrotechnical harvesting time, days;
- X_2 – grass moisture, %;
- X_3 – grass yield, $t \cdot ha^{-1}$;
- X_4 – field microrelief, cm per 1 m of the width of the machine;
- X_5 – condition of harvesting equipment, $b \cdot r^{-1}$;
- X_6 – quality of the technological operation, $b \cdot r^{-1}$;
- Y is a generalized indicator of the reliability of the technological process of harvesting silage, non-dimensional.

Note that the factor space has the properties of consistency, evaluating the degree of fulfillment of the simulated phenomenon from the standpoint of the action of various variables. So, the characteristics of the mowed grass (X_1-X_3), the condition of the field (X_4), the state of harvesting equipment (X_5) and the influence of personnel in the human-machine system (X_6) were taken into account. It is a systematic approach that allows, on the one hand, to obtain a generalized characteristic, and on the other hand, to apply for this purpose a fuzzy-possible approach to formalize expert knowledge and experience in the form of a mathematical model. We also note that the fuzzy-probabilistic approach allows us to formalize the entire factor space in the form of one mathematical model, which, unlike the others, is called the "fuzzy-probabilistic model" [6].

To implement a fuzzy-possible approach, all factors are represented by linguistic variables. As applied to the solution of the problem posed, the form of a linguistic variable is presented for Y, as shown in Fig. 1.

The geometric structure of the linguistic variable [6; 7] consists of intersecting term sets ("low", ..., "high") of state levels Y, three scales along the abscissa axis: the upper one is linguistic, the lower one is for translating linguistic estimates into numerical ones, the third one is the values of the opposition term sets in the interval [-1,+1] according to the requirements of the theory of experimental design (not shown in Fig. 1), and one scale along the ordinate axis is the membership function $\mu\_(A)(x) \in [0,1]$. The interpretation of the term sets and their change intervals for translating the verbal estimates of the expert into quantitative values according to Fig. 1 are given in Table 1.

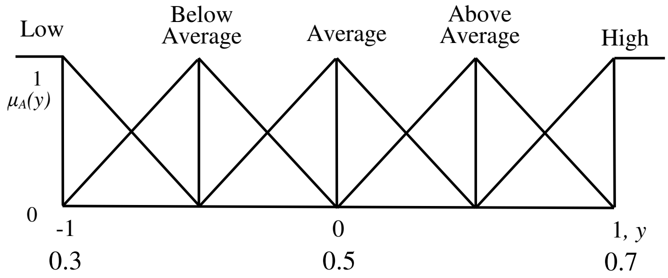

Fig. 1. **Generalized exponent *Y* as a linguistic variable**

Table 1

Verbal characteristics of intervals and their quantitative analogues

Intervals	Interval Mode	Interval Characteristic
0.4 and lower	0.3	**L** – is the lower level. The implementation of the technology is possible, but with a large (up to 23 %) deviation from the expected results due to the unfavorable combination of some factors, including natural
0.3-0.5	0.4	**BA** – is below average. Technology execution is possible with a deviation (up to 17 %)
0.4-0.6	0.5	**A** – is the average level. Technology implementation is possible with a deviation (up to 11 %)
0.5-0.7	0.6	**AA** – is above average. Implementation of the technology is possible with a deviation (not more than 6 %).
0.6 and higher	0.7	**H** – is a high level. Implementation of the technology is possible with a deviation (4 % or less).

The expert's knowledge is extracted for the purpose of further formalizing according to special questionnaire tables [6], in which, on a verbal level (according to Table 1), the expert assesses the influence of each variable on the output indicator (*Y*). A fragment of the interrogation matrix for assessing the feasibility of the technological process, as exemplified by harvesting feed from grasses (silage), is presented in Table 2.

Each line of Table 3 is a production rule of the implicative type "IF ..., THEN ..." [6; 7]. For example, line 30, according to the accepted methodology, reads completely like this: "IF x_1 – harvesting time – "high" and x_2 – grass moisture – "low" and x_3 – yield – "high" and x_4 – microrelief – "low" and x_5 – the state of the harvesting equipment is "high", x_6 – the quality of the technological operation is "low", the *Y* value is the reliability of the technological process of harvesting the silo – "above average" – "high".

It is necessary to interpret the numerical values of *Y* using a verbal-numerical scale (Table 1) as follows: on line 30, the value 0.65 is in the BC-B range and means that the technology will be respected, the process is performed with a slight deviation and generalized reliability will be about 0.94-0.96.

Processing the results of expert assessment according to the accepted methodology [6,7] led to a polynomial model:

$$Y = 0.486 + 0.039\, x_1 + 0.011\, x_2 + 0.048\, x_3 + 0.052\, x_4 + 0.036\, x_5 + 0.011\, x_6 - 0.011\, x_1 x_3 + 0.011\, x_1 x_4 - 0.014\, x_2 x_3 + 0.014\, x_2 x_4 - 0.011\, x_3 x_4 + 0.027\, x_4 x_5. \quad (1)$$

In model (1) all variables are presented on a standardized scale according to the formula

$$x_i = \frac{X_i - X_i^{\text{cp}}}{\Delta X_i}, \quad (2)$$

where X_i – measured estimate of the relevant variable;

$X^{cp}{}_{i}$ – average value of the variable measurement interval;
ΔX_i – interval of variation.

Results and discussion

The state of harvesting equipment is characterized by reliability, which is expressed by the coefficient of readiness and is in the range of 0.78-0.99. These numerical values are obtained from materials from machine tests at the North-Western MIS Federal State Budgetary Institution [3]. So, the KDP-3000 forage harvesters of Gomselmash OJSC and FCT 1060 MD Kongskilde Industries operating in agricultural enterprises of various regions of the Leningrad Region were tested. Judging by the data in Table 1, they all refer to the interval of a generalized indicator of the reliability of the technological process of harvesting silage Y, characterized by mode B – the level is high. The calculated values according to model (1) under almost identical operating conditions of the machines are characterized by the values 0.67 and 0.68, which allows them to be assigned, according to a generalized indicator, to a closer value of mode B. According to the verbal-numerical characteristics of the intervals given in Table 1, the values of the generalized indicator Y calculated by the model (1) correspond to the implementation of the technology with a reliability of at least 0.97.

Thus, regarding the results obtained, it can be stated with great confidence that forage harvesters of both companies are equally reliable in the tested operation.

Conclusions

Given the limitations of the agricultural machinery testing system and the lack of relevant statistics, it is advisable to use the knowledge and experience of experts in this field. A technique is proposed for extracting and formalizing expert knowledge in the form of fuzzy-possible models that combine both quantitative and non-quantitative (verbal, organoleptic) variables. Based on the constructed mathematical model, a generalized indicator of the feasibility of the technological process of fodder harvesting from grasses of trailed forage harvesters of various companies was evaluated and their practically high technological reliability in the North-West region of Russia was shown.

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