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Formalization of Fuzzy Statements in the Task of Technological Adjustment of Grain Combines

V.P. Dimitrov*, *L.V.* Borisova, and *I.N.* Nurutdinova

Don State Technical University, Gagarin Square, 1, Rostov-on-Don, 344000, Russian Federation

Abstract. The article considers various types of statements used in the linguistic description of input factors and regulated parameters of a combine harvester when solving the problem of its technological adjustment. The linguistic description of the environmental conditions, the regulated parameters of the combine and the characteristics of the quality of harvesting operations is presented. The technique of modeling fuzzy statements for the formalization of knowledge in an expert system designed to inform the operator of the combine when choosing the values of adjustable parameters corresponding to the operating conditions of the combine is presented. The technique is illustrated by an example of fuzzy inference.

Decision-making is traditionally attributed to one of the most important types of human activity, and in the operator-combine system, the task of determining the values of the regulated parameters of the combine is complicated by a large amount of information linking factors of external conditions, characteristics of the quality of harvesting and parameters. Moreover, a significant part of the data is evaluative in nature and has a different degree of reliability, which depends on the qualifications of experts and the experience of the operator. The subject area under consideration is characterized by complex relationships describing the relationship between the parameters of the quality of harvesting (the values of which should not exceed the permissible ones), the regulated parameters of the working bodies of the combine and environmental factors. In addition, it is necessary to take into account the operating conditions of the combine, which can be described as working under conditions of uncertainty (fuzzy information about input and output parameters). These features are the main reason for the low efficiency of the existing models (largely regression models) of the functioning of the combine. As a consequence, the main tasks of managing the harvesting process, which also include the task of technological adjustment of the combine, involve the use of a mathematical apparatus of fuzzy logic [1], capable of modeling human reasoning and using human decision-making techniques. Currently, fuzzy logic is used in the creation of intelligent systems that solve the problems of managing technical, social and economic systems in conditions of uncertainty, fuzzy and incomplete information; they are used for image processing and analysis, etc. [2, 3]. In recent decades, research interest in the study and application of

* Corresponding author: kaf-qm@donstu.ru

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fuzzy models in various fields of agriculture has increased [4-6]. The ability to use fuzzy logic to display the uncertainty and inaccuracy of information, to provide an objective assessment of this information and use it to deduce solutions has determined the widespread use of fuzzy modeling to solve various problems of agriculture. This includes crop yield assessment, weed species identification, determination of soil parameters, the effectiveness of fertilizer application, and many others [7-9]. Fuzzy logic is also successfully used in intelligent systems for technological tuning of a combine harvester of the classical type [10 -12]. The expediency of using a fuzzy approach to this and similar management tasks is due to the following circumstances. The lack of sufficient amount of information for traditional modeling methods forces us to turn to fuzzy expert knowledge. If it is impossible to find a solution using traditional formalisms, the expert nevertheless finds a solution based on the acquired experience, empirical and statistical data. This allows us to formulate a set of fuzzy rules that actually mimic his reasoning and can be used as the basis for an intelligent operator support system. The formulated fuzzy verbal concepts make it possible to formalize qualitative descriptions, take into account the uncertainty and incompleteness of information and as a result obtain a model that adequately describes the interrelationships of the subject area under study.

To model the decision-making process, we will consider many external factors and one output parameter, the choice of the value of which is due to the influence of external factors. Obviously, the technological adjustment of the combine is carried out by adjusting a whole set of parameters. In general, the decision-making process can be described as a process with many inputs and outputs. The relationships between outputs and inputs are mostly presented in the form of heuristic (not formalized expert) knowledge. Thus, it is advisable to formalize this knowledge in the form of statements of various types, in the format of fuzzy variables that provide a transition from verbal descriptions to numerical ones. Numerical representation of difficult-to-formalize relations between factors is achieved using fuzzy sets and fuzzy relations. The use of the mathematical apparatus of fuzzy logic to formalize the processes of solving the problems of tuning and adjusting the adjustments of the combine is complicated by the identification of expert knowledge, which is not an easy task. The effective solution of the above tasks is directly related to the development and use in practical cleaning conditions of intelligent systems serving as an adviser to the operator [2, 3]. Such systems rely on a base of expert knowledge, on the adequacy of which the conclusion of the solution significantly depends on the real conditions. This makes the problem of presenting knowledge one of the central ones. This article is devoted to the problem of presenting expert knowledge in an intelligent system designed for technological adjustment of a combine harvester.

Identification of the subject area of this task includes the definition and linguistic description of a variety of environmental factors, a variety of adjustable parameters of the working bodies of the combine and a variety of characteristics of the quality of harvesting. Based on this research, a system of linguistic variables is formed. In Table 1, several variables are selected for each of these sets and their linguistic descriptions are presented [13].

The next stage is the formalization of knowledge, at which the input and output fuzzy relationships should be formulated in the form of fuzzy expert statements. Statements of the form [14,15] are relevant for this task:

$$< \beta \ there \ is \ \alpha > \quad (1)$$

$$< \beta \ there \ is \ m\alpha > < there \ is Q_{\alpha} > \quad (2)$$

$$< \beta_x \ there \ is \ \alpha_{x1} \ and \ there \ is \ \alpha_{x2} > \quad (3)$$

$$< \beta_x \ there \ is \ \alpha_{xji} \ and \ \ \beta_y \ there \ is \ \alpha_{yji} \ and ... and \ \beta_z \ there \ is \ \alpha_{zji} > \quad (4)$$

Table 1. Linguistic variables of the task of technological adjustment of the combine

Groups of factors and parameters	Linguistic description
Environmental factors	< Yield, c/ha >; < Grain moisture content, % >; < Grain to straw ratio, %> < Blockage, % >
Adjustable combine parameters	< Combine speed, km/h >; < Rotation speed of the threshing drum, min $^{-1}$ >; < Rotation speed of the reel, min $^{-1}$ > < Cut height, mm >
Quality indicators	<Loss of free grain in straw, %>; < Grain crushing, % > < Grain contamination in the hopper, % > <Losses by puny grain, %>

Let us characterize each of the types of statements in relation to the problem under consideration. Consider a statement of type (1):

$$< \beta \ is \, \alpha >,$$

here β is the name of a linguistic variable describing an external factor, a characteristic of the quality of the combine or its adjustable parameter, the fuzzy evaluation (fuzzy variable) of which is the statement α.

Here are examples of statements of this type. For the factors determining the conditions of harvesting, these may be statements <wet stem>, <dry grain>, etc. An example of a statement about adjustable parameters may be the following: <the speed of the combine is 5 km/ h>. In this statement, the value of 5 km/h is a clear assessment of the linguistic variable β: <speed of movement of the combine>. For indicators of the quality of work, there are statements: <increased grain crushing> or <grain clogging in the hopper 2.7%>.

In a fuzzy statement of type (2), α is a fuzzy subset on the universe U, which is the set of values of the variable β. Statement (2) induces the distribution of possibilities π_β equal α, that is $\pi_\beta = \alpha$. If $u \in U$ and $\mu_\alpha : U \to [0; 1]$ – the membership function α, then the degree of confidence that β = u, set as [14]:

$$poss\left\{\beta = u \middle| \beta \ is \ \alpha\right\} = \mu_\alpha(u), u \in U,$$

where poss {β = u} – the notation of the statement is <the possibility that β can take the values u>. The measure of this possibility of a fuzzy set A is defined as [14]:

$$\pi(A) \overset{\Delta}{=} poss\left\{\beta \text{ is } A\right\} \overset{\Delta}{=} \sup\left(\mu_\alpha(u) \wedge \mu_A(u)\right).$$

The modification rule translates the statement <β is α> into an expression of the assignment of a possibility $\pi_{(\beta 1, \ldots, \beta n)} = \alpha$, and the broadcast of the modified utterance <β is mα> set by the expression:

$$\alpha \text{ is } m\alpha \to \pi_{(\beta 1, \ldots, \beta n)} = \beta^+,$$

where *m* – modifier, such as "VERY", "APPROXIMATELY", "MORE OR LESS", "INSIGNIFICANT", etc.; β^+ - modification of β by means of the m modifier. An example is the statement: "The grain is very dry".

Grain <very dry>→ π_{Grain} = (<arid >)^2.

In statements of the form <β there is Qα> Q – a quantifier that corresponds to words like: "MOST", "A LOT", "A LITTLE", "LITTLE", "VERY LITTLE", etc. An example of such a statement: <most of the quality characteristics are higher than acceptable>.

An example of statements of the type (3) can be statements that can be used to form so-called generalized statements or the antecedent of the core of the product, for example, "bread – low-crust" and sparse".

An example of statement (4) can be rules containing the operations of composition: "AND", "OR", "IF, ..., THEN", etc.

For our task of pre-setting the parameters of the combine, we can write [16]:

"IF the crop is rye, and the yield is about 20 c / ha, and the straw content is low, and the clogging is low, THEN the speed of the combine is lower than nominal";

"IF the crop is wheat, AND the yield is more than 40 c / ha, AND the straw content is low, AND the clogging is high, AND the grain is wet, AND the rotation frequency of the threshing drum is increased," THEN the grain crushing is "high."

In theory, there are different groups of rules: for truth estimates; for probability estimates; for possibility estimates. In this task, only the rules for truth estimates are applied. Let βx and βy be linguistic variables defined on sets X and Y, and their values are αX1 and αY1 with corresponding fuzzy sets [14]:

$$C_{X1} = \{< \mu_{X1}(x)/x >\} \; u \; C_{Y1} = \{< \mu_{Y1}(y)/y >\}.$$

Consider the question of evaluating the truth of statements of the following type:

$$< \beta_X \text{ there is } \alpha_{X1} \text{ and there is } \alpha_{X2} >;$$

$$< \beta_X \text{ there is } \alpha_{X1} \text{ and there is} \alpha_{X2} >;$$

$$< \beta_X \text{ there is } \alpha_{X1} \text{ and } \beta_Y \text{ there is } \alpha_{Y1} >;$$

$$< \beta_X \text{ there is } \alpha_{X1} \; or \; \beta_Y \text{ there is } \alpha_{Y1} >;$$

$$< \text{tckb} \beta_X \text{ tcnm} \alpha_{X1}, \text{so } \beta_Y \text{ tcnm } \alpha_{Y1} >;$$

$$< \text{tckb} \beta_X \text{ tcnm } \alpha_{X1}, \text{that } \beta_Y \text{ there is } \alpha_{Y1}, \text{otherwise } \alpha_{Y1} > .$$

Such statements with the help of transformation rules lead to the form <β is α> under the assumption that there is no interaction of variables. In accordance with the rule of transformation of the conjunctive form , the expression is valid [14]:

$$< \beta_X \text{ есть } \alpha_{X1} \text{ or } \beta_Y \text{ is } \alpha_{Y1} > \rightarrow < (\beta_X, \beta_Y) \text{ is } \overset{\leftrightarrow}{\alpha}_{X1} \cap \overset{\leftrightarrow}{\alpha}_{Y1},$$

where is the symbol $\rightarrow$ a wildcard. Expression $\overset{\leftrightarrow}{\alpha}_{X1} \cap \overset{\leftrightarrow}{\alpha}_{Y1}$ there are values of a linguistic variable (β_{X1}, β_{Y1}) with a fuzzy set $C_{\cap} = \overset{\leftrightarrow}{C}_{X1} \bigcap \overset{\leftrightarrow}{C}_{Y1}$. $\overset{\leftrightarrow}{C}_{X1}$ и $\overset{\leftrightarrow}{C}_{Y1}$ – cylindrical continuations of fuzzy sets C_X and C_Y, defined as fuzzy sets of the following form:

$$\overset{\leftrightarrow}{C}_{X1} = \{< \overset{\leftrightarrow}{\mu}_{X1}(x,y)/x\} \quad \overset{\leftrightarrow}{C}_{Y1} = \{< \overset{\leftrightarrow}{\mu}_{Y1}(x,y)/y\},$$

where $(x, y) \in X \times Y$, and

$$(\forall x \in X)(\forall y \in Y) \qquad [\overset{\leftrightarrow}{\mu}_{X1}(x,y) = \mu_{X1}(x); \overset{\leftrightarrow}{\mu}_{Y1}(x,y) = \mu_{Y1}(y)].$$

To illustrate the process of modeling statements, let's consider one of the rules of fuzzy production, obtained on the basis of heuristics:

«If the grain moisture is high, the drum rotation frequency increases»

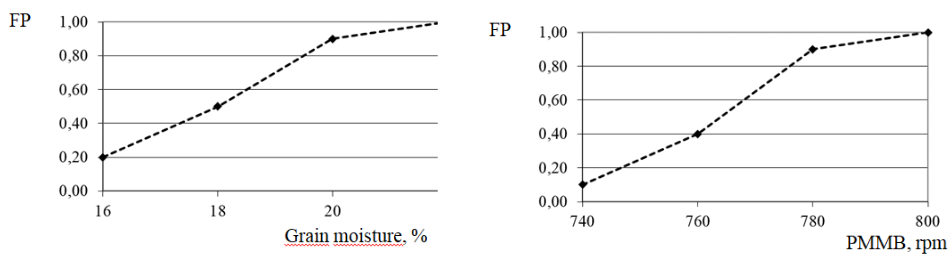
Linguistic variables Grain moisture β_X and the rotation frequency of the threshing drum β_Y defined on sets:

$$X = \{16; 18; 20; 22\}; \qquad Y = \{740; 760; 780; 800\},$$

and fuzzy sets C_{X1} and C_{Y1}, with corresponding values α_{X1} and α_{Y1}, presented in the form of:

$$c_{X1} = \left\{\frac{0,2}{16}; \frac{0,5}{18}; \frac{0,9}{20}; \frac{1}{22}\right\}, \quad c_{Y1} = \left\{\frac{0,1}{740}; \frac{0,4}{760}; \frac{0,9}{780}; \frac{1}{800}\right\}. \tag{5}$$

Graphs of the membership functions of the considered LP are shown in Fig. 1.



a) b)

Fig 1. Functions of the FP accessory a) Grain moisture; b) The frequency of rotation of the threshing drum (PMMB)

Cylindrical transformations for sets (5) have the form:

$$\overleftrightarrow{C_{X1}} = \left\{< \frac{0,2}{16,740} >; < \frac{0,2}{16,760} >; < \frac{0,2}{16,780} >; < \frac{0,2}{16,800} >; < \frac{0,5}{18,740} >; < \frac{0,5}{18,760} >; < \frac{0,5}{18,780} >; < \frac{0,5}{18,800} >;\right.$$

$$\left.< \frac{0,9}{20,740} >; < \frac{0,9}{20,760} >; < \frac{0,9}{20,780} >; < \frac{0,9}{20,800} >; < \frac{1}{22,740} >; < \frac{1}{22,760} >; < \frac{1}{22,780} >; < \frac{1}{22,800} >\right\};$$

$$\overleftrightarrow{C_{Y1}} = \left\{< \frac{0,1}{16,740} >; < \frac{0,1}{18,740} >; < \frac{0,1}{20,740} >; < \frac{0,1}{22,740} >; < \frac{0,4}{16,760} >; < \frac{0,4}{18,760} >; < \frac{0,4}{20,760} >; < \frac{0,4}{22,760} >;\right.$$

$$\left.< \frac{0,9}{16,780} >; < \frac{0,9}{18,780} >; < \frac{0,9}{20,780} >; < \frac{0,9}{22,780} >; < \frac{1}{16,800} >; < \frac{1}{18,800} >; < \frac{1}{20,800} >; < \frac{1}{22,800} >\right\}.$$

In accordance with the rules of transformation of statements of the implicative form , we will write this statement in the form:

$$<(\beta_X, \beta_Y) \text{ is } \overset{\leftrightarrow}{\alpha}_{X1} \Diamond \overset{\leftrightarrow}{\alpha}_{Y1}>,$$

where is the sign $\Diamond$ - the threshold amount, defined as follows:

$$\mu\Diamond(x, y) = 1\&(1 - \mu_{\overset{\leftrightarrow}{\alpha}_{X1}}(x, y) + \mu_{\overset{\leftrightarrow}{\alpha}_{Y1}}(x, y)), \quad \forall x \in X, \forall y \in Y.$$

Let 's define the membership function $\mu\Diamond$ on the set $X_1 \cdot Y_1$:

$$\mu\Diamond(16{,}740) = 1\&(1 - 0{,}2 + 0{,}1) = 0{,}9; \qquad \mu\Diamond(18{,}740) = 1\&(1 - 0{,}5 + 0{,}1) = 0{,}6;$$

$$\mu\Diamond(20{,}740) = 1\&(1 - 0{,}9 + 0{,}1) = 0{,}2; \qquad \mu\Diamond(22{,}740) = 1\&(1 - 1{,}0 + 0{,}1) = 0{,}1;$$

$$\mu\Diamond(16{,}760) = 1\&(1 - 0{,}2 + 0{,}4) = 1{,}0; \qquad \mu\Diamond(18{,}760) = 1\&(1 - 0{,}5 + 0{,}4) = 0{,}9;$$

$$\mu\Diamond(20{,}760) = 1\&(1 - 0{,}9 + 0{,}4) = 0{,}5; \qquad \mu\Diamond(22{,}760) = 1\&(1 - 1{,}0 + 0{,}4) = 0{,}4;$$

$$\mu\Diamond(16{,}780) = 1\&(1 - 0{,}2 + 0{,}9) = 1{,}0; \qquad \mu\Diamond(18{,}780) = 1\&(1 - 0{,}5 + 0{,}9) = 1{,}0;$$

$$\mu\Diamond(20{,}780) = 1\&(1 - 0{,}9 + 0{,}9) = 1{,}0; \qquad \mu\Diamond(22{,}780) = 1\&(1 - 1{,}0 + 0{,}9) = 0{,}9;$$

$$\mu\Diamond(16{,}800) = 1\&(1 - 0{,}2 + 1{,}0) = 0{,}9; \qquad \mu\Diamond(18{,}800) = 1\&(1 - 0{,}5 + 1{,}0) = 0{,}6;$$

$$\mu\Diamond(20{,}800) = 1\&(1 - 0{,}9 + 1{,}0) = 0{,}2; \qquad \mu\Diamond(22{,}800) = 1\&(1 - 1{,}0 + 1{,}0) = 1{,}0.$$

The result is a fuzzy variable $\alpha_{X1}\Diamond\alpha_{Y1}$ characterized by a fuzzy set:

$$C\Diamond = \Big\{ < \frac{0{,}9}{16{,}740} >, < \frac{0{,}6}{18{,}740} >, < \frac{0{,}2}{20{,}740} >, < \frac{0{,}1}{22{,}740} >,$$
$$< \frac{1{,}0}{16{,}760} >, < \frac{0{,}9}{18{,}760} >, < \frac{0{,}5}{20{,}760} >, < \frac{0{,}4}{22{,}760} >,$$
$$< \frac{1{,}0}{16{,}780} >, < \frac{1{,}0}{18{,}780} >, < \frac{1{,}0}{20{,}780} >, < \frac{0{,}9}{22{,}780} >,$$
$$< \frac{0{,}9}{16{,}800} >, < \frac{0{,}6}{18{,}800} >, < \frac{0{,}2}{20{,}800} >, < \frac{1{,}0}{22{,}800} > \Big\}.$$

Similarly, fuzzy statements that make up the base of fuzzy production rules for the task of adjusting the parameters of the combine are transformed.

It is advisable to form the knowledge base of an intelligent information system on the basis of fuzzy expert knowledge. At the same time, the knowledge base should include the basic values of groups of linguistic variables of external factors, regulated parameters and quality characteristics, as well as systems of fuzzy expert statements reflecting the relationships between the listed groups. The proposed method of formalization of fuzzy statements performs the function of modeling fuzzy knowledge, which makes it possible to further apply the expressions obtained for membership functions in the fuzzy inference mechanism based on the "modus ponens" rule, in which the degree of truth of the statement in question takes the maximum value.

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