Fuzzy Logic Inference of Technological Parameters of the Combine-Harvester

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Abstract: - The problem of determining optimal values of the combine-harvester technological parameters in changing external conditions is considered. A brief overview of the existing approaches to the solution of the given problem and the fields of their application is presented. We note the expediency of applying a new approach that is stipulated by the necessity of an efficient choice of values of the harvester technological parameters in field conditions when external factors constantly change and the assessment of their values is approximate and presented by experts. This type of assessments is referred to fuzzy data. To describe the environmental factors, the machine parameters and qualitative performance characteristics we have introduced linguistic variables, developed their membership functions and formulated production rules. We have considered the process of fuzzy logic inference of values of the most important adjustable parameters of the combine: travelling speeds and rotational speeds of a threshing drum. A knowledge base and an inference engine forming the basis of the expert system have been created. We have implemented the software that uses our fuzzy model for the automation of the harvester technological adjustment in the field.

Key-Words: - combine-harvester, technological adjustment, fuzzy knowledge, linguistic variable, expert system.

1 Introduction

The implementation of the potentialities included in the design of the combine harvester, achievement of the high quality performance harvesting and productivity and only possible with correct technological adjustment of working units and observance of operating rules. Complex and changing environmental conditions grain harvesters operate under require the operator to find optimal solutions promptly. Non-optimal decisions, made in the field, downtime due to technical and technological reasons result in substantial loss of resources and potentialities [1].

To develop optimal algorithms of technological adjustment it is necessary to know accurate values of environmental factors and also regularities between adjustable parameters and environmental factors. These interrelationships are quite often known approximately. As a result of the operator's inability to perform technological adjustment the harvester operates with unregulated working units and with the exceeded level of grain loss.

There are some investigations where the problem of technological adjustment is solved with the help of mathematical modelling, in particular, using regression models [2 – 4]. These models have a narrow area of the adequacy and are used only for evaluation procedures.

Among formal approaches of developing models the experimental and statistical approaches using correlation and regression analyses have got greater distribution. To eliminate the drawbacks of the traditional approach they use empirical formulae developed as a result of processing experimental data [2, 3, 5, 6]. The feasibility of empirical formulae for forecasting the values of quality indicators of operation is a positive property of the given approach. However the accuracy of the forecast is determined by the accuracy of the values of input factors, fluctuations of which in the experiment are reduced to a minimum, Therefore changes in output characteristics are stipulated, in great extent, by uncontrolled inputs and this calls into question the adequacy of the mathematical problem itself. Moreover, in these models it is necessary to take into account correlation factors, and to determine the influence of one of the factors with the fixed values of others is rather a difficult problem in the experiment. All this results in that the available correlation-regression models represent rather bulky mathematical constructions (and they don't always adequately reflect reality), and their real-time application in complex practical conditions is complicated.

At present grain harvesters rather widely use the facilities of control and management automation. Harvesters are also included into the automated system of "precision agriculture". Although application of a number of automatic control systems by important working units, devices and systems of the harvester is certainly effective, it should be noted that the available automatic systems mainly solve the problems of the harvester movement control and don't provide decision-making support for the operator when performing technological adjustment of the harvester working units.

The paper is organized as follows. Section 2 contains the formulation of the problem of values selection of the combine adjustable parameters in the field and justification for application of mathematical tools of the fuzzy set theory for its solution. Section 3 contains description of the fuzzification stage including description of linguistic variables, development of their membership functions, composition stage including development of fuzzy logic inference on the basis of the created base of fuzzy production rules, and the defuzzification stage consisting in making recommendations, on the basis of fuzzy logic inference, on determination of specific values of the combine adjustable parameters. Section 4 contains implications and results of application of the proposed approach.

2 Problem Formulation

Complexity of the system of the harvester operation results in that its mathematical model is difficult to be constructed in the traditional sense, and the available approximate models are not practically suitable in the field. This stipulates turning to fuzzy modeling and development of information systems for decision making (expert systems) based on using fuzzy expert knowledge and rules of fuzzy logics [7 – 9]. The methodology of fuzzy modeling is aimed at fuzzy information, its approximate character and also an expert method of forming solutions.

A linguistic approach is used for the purpose of formalizing real systems, and the relationship among the sets of input and output variables is described on the quality level in the form of statements by way of production regulations. Fuzzy models have already proved to be good in very different areas [7, 10 – 12].

The problem of choice of the adequate formal language is very important therefore we should note the advantages of the decision-making process description in a complex multi-level hierarchy system on the basis of the theory of fuzzy sets. This language makes it possible to reflect adequately the essence of the decision-making process itself in fuzzy conditions for the multi-level system, to work with fuzzy limitations and aims and also to set them with the help of linguistic variables. Therefore a mathematical apparatus of the theory of fuzzy sets is expedient to be used as the main tool for describing a multi-level hierarchy system – a grain harvester, processes of decision-making and control of technological processes in complex systems. The suggested approach of the decision-making processes modeling when performing technological adjustment and updating of technological adjustments of the harvester working units on the basis of fuzzy models meets the requirements of the system analysis – consistency of consideration of the complex hierarchy system (harvester) on the basis of accounting basic elements and processes in the system of relations between them and the sufficient degree of simplification during modeling allowing to reflect adequately a real process and take into account the determining factors in this system.

3 Problem Solution

The technique of modelling the decision-making process while performing technological adjustment of the harvester is based on application of mathematical apparatus of the theory of fuzzy sets and contains the stages of fuzzification, composition and defuzzification [13, 14].

At the stage of fuzzification it is necessary to give the conditions of solving the problem in a linguistic form. At the stage of composition all the fuzzy sets specified for each term of each input variable unite and the sole fuzzy set is formed – a value for each output linguistic variable (LV). As a result of application of the rule set – fuzzy knowledge base – we calculate the truth value for supposition of each rule on the basis of certain fuzzy operations corresponding conjunction or disjunction of terms in the left part of the rule. The main point of the defuzzification stage is in working out, on the basis of fuzzy logic output, recommendations on determining certain values of the adjustable parameters of the machine.

3.1 Linguistic description of input and output linguistic variable

Let us consider the problem when depending on possible values of the input situation (A_j) an expert draws a conclusion about the output situation (B_j) (about the values of the adjustable parameters). Let {*X*} denote a set of values of input parameters i.e. value part of environmental factors which substantially influence the value of the output parameter *V* (adjustable parameter). To solve the given problem it is necessary to solve the questions of modelling expert information about relations of characteristics under consideration and also about the decision-making procedures.

According to logic-linguistic approach [15, 16] we have developed the models of input and output characteristics *X, V* in the form of semantic spaces and corresponding them membership functions (MF):

$\{X_i, T(X_i), U, G, M\}$, $\quad \mu_R(x_1, x_2, ..., x_i) \in [0;1]$,

$\{\beta_v, T_v, V, G_v, M_v\}$, $\quad \mu_R(v_1, v_2, ..., v_j) \in [0;1]$,

where β is a name of the linguistic variable, *T* - set of its values, or terms, which are the names of the linguistic variables defined over the set *U*, *G* - syntactic procedure describing the process of deriving the new values of linguistic variables from the set *T*, *M* - semantic procedure, which allows one to map new value generated by procedure *G* into fuzzy variable, μ - membership functions.

The result of the analysis is a generalized model of domain "preliminary adjustment of the harvester" in the form of composition of fuzzy relations of the semantic spaces under consideration:

$$\mathrm{R} = X \to V,$$

where R is a fuzzy relation between environmental factors and adjustable parameters:

$$R\{X_i, T(X_i), U, G, M\} \times$$
$$\times \langle \beta_v, T_v, V, G_v, M_v \rangle \; \forall (x, v) \in X \times V.$$

Relation R can be regarded as a fuzzy set on the direct product *XV* of the complete space of suppositions *X* and the complete space of conclusions *V*.

As a result of fuzzification of the studied characteristics, MF of the adjustable parameters and external factors have been plotted. For this normal fuzzy sets for which upper bound of the membership function is equal to 1 ($\sup_{x \in E} \mu_A(x) = 1$) have been used. Fuzzy sets can be both unimodal, i.e. only on one *x* of *E*, and possessing an area of tolerance. To describe the terms we used typical functions of triangle and trapezoidal type [17].

Solution of the problem of choosing adjustable parameter values is considered by an examples of selecting the values of speed of the harvester-40 (for crop yield approximately 40 q/ha) and rotational speed of the threshing drum (for crop yield approximately 50 q/ha). It is known that these parameters are greatly influenced by the following environmental factors: crop yield, grain humidity, rough straw, grain dockage [5]. The yield of grain crops is a determining factor when selecting the values of the adjustable parameters of a combine. As there is a significant yield spread in edaphic-climatic zones of the country, it seems to be expedient to introduce several linguistic variables into the description of the subject domain: "crop yield-30", "crop yield-40", "crop yield-50", "crop yield-60". We consider the most relevant of them "crop yield-40" and "crop yield-50". The analysis of the subject domain allowed us to define linguistic description of the external factors under consideration and values of the MF parameters [15]:

LV tuple «Crop yield - 40» has the form:

<CROP YIELD-40, q/ha {Less 40, Approximately 40, More 40}, [34 – 46] >

CY40 ={CYL40, CYA40, CYM40} (Fig. 1 a).

LV tuple «Crop yield - 50» has the form:

<CROP YIELD-50, q/ha {Less 50, Approximately 50, More 50}, [44 – 56] >

CY ={CYL50, CYA50, CYM50} (Fig. 1 b).

LV tuple «Stand of grain humidity» has the form:

<STAND OF GRAIN HUMIDITY, % {Dry, Normal, Humid}, [0 – 30]>

SGH ={DrSG, NorSG, HumSG} (Fig. 1 c).

LV tuple «Rough straw» has the form:

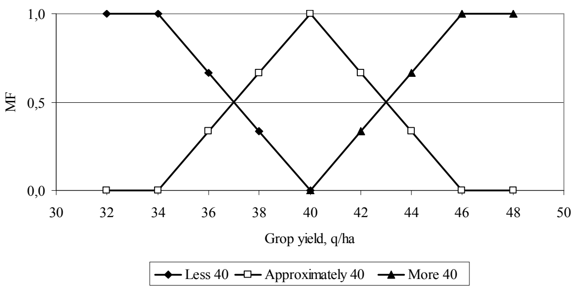
<ROUGH STRAW, % {Small, Normal}, [40 – 70]>RS ={SmRS, NorRS} (Fig. 1 d).

LV tuple «Stand of grain dockage» has the form:

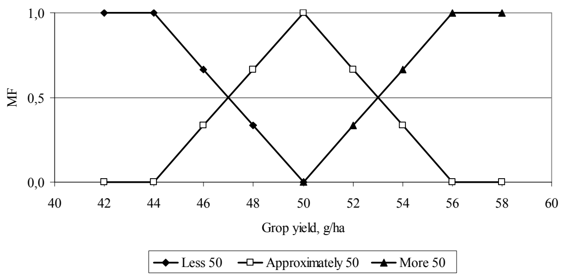
<STAND OF GRAIN DOCKAGE, % {Low, Large},

[0 – 40] >

SGD ={LwSGD, LgSGD, %} (Fig. 1 e).



a)



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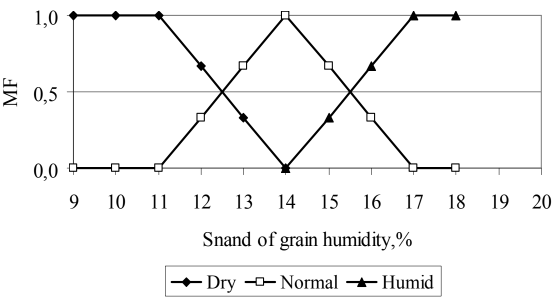

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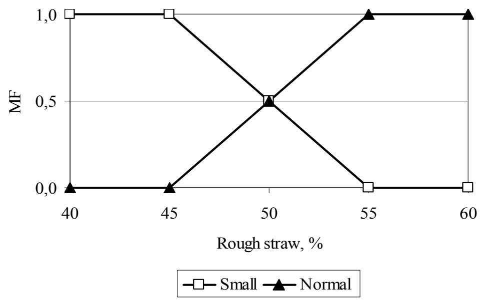

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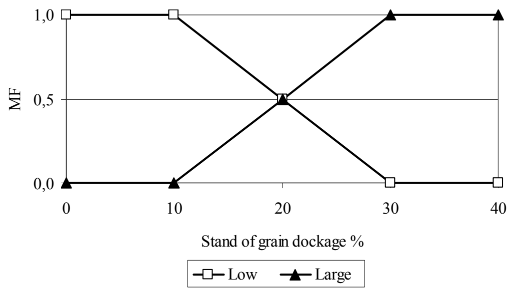

e)

Fig. 1: Membership functions of LV terms a)" Crop yield – 40", b) "Crop yield – 50", c) "Stand of grain humidity", d) "Rough straw", e) "Stand of grain dockage".

The tuple of the output LV "Speed of the harvester-40" (i.e. for crop yield approximately 40 q/ha) has the form:

< SPEED OF HARVESTER, km/h {Very low, Low, Lower than nominal, Nominal, Higher than nominal, High, Very high}, [2,5 – 5,5] >

SH = {VLSH, LSH, LNSH, NRTH HNSH, HSH, VHSH, km/h} (Fig. 2).

The tuple of the output LV "Rotational speed of the threshing drum for wheat-50" (i.e. for crop yield approximately 50 q/ha) has the form:

<ROTATIONAL SPEED OF THRESHING DRUM, rev/min {Very low, Low, Lower than nominal, Nominal, Higher than nominal, High, Very high}, [620 – 940] >

RSTD = {VLRSTD, LRSTD, LNRSTD, NRSTD, HNRSTD, HRSTD, VHRSTD, rev/min} (Fig. 3).

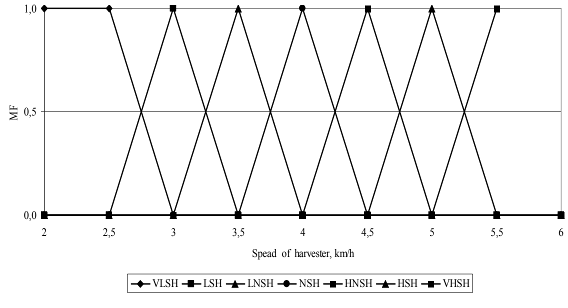

Fig. 2: Membership functions of LV terms "Speed of the harvester-40".

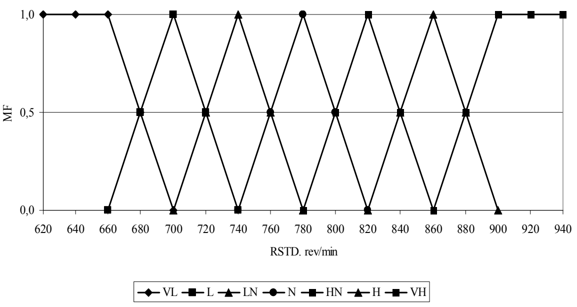

Fig. 3: Membership functions of LV terms "Rotational speed of the threshing drum for wheat".

3.2 Development of the fuzzy knowledge base

In the basis of the solutions output mechanism of intelligence information system there is a model of the given subject domain representing a composition of fuzzy relations of semantic spaces of input and output parameters.

With the pre-set system of logical statements for the values of input parameters the values of the output parameter V are such a set $V_0^{(1)}$, for each element of which $v \in V_0^{(1)}$ a derivation scheme

$$\begin{array}{c} \tilde{L}^{(1)} \\ \underline{A' - \text{true};} \\ B' - \text{true} \end{array}$$

as the greatest truth degree $\mu_{mp}^{(1)}$ of the fuzzy rule modus ponens which is determined by the expression:

$$\mu_{mp}^{(1)}(1) = \min\{1,[1-\mu_{W_1}(w')+\mu_{V_1}(v')],...,[1-\mu_{W_m}(w')+ +\mu_{V_m}(v')]\}.$$

The value $\mu_{mp}^{(1)}(1)$ is a truth degree of the modus ponens rule for a fuzzy system of expert statements. This concept reflects the correspondence degree of the value of the output parameter V to the value of the generalized input parameter w' when expert information is set by the fuzzy system (1). Let us designate the statements <β_W is α_{Wj}> and <β_V is α_{Vj}> through $\tilde{A}_j$ and $\tilde{B}_j$. Then the system fuzzy statements will be written in the form of:

$$\tilde{L}^{(1)} = \begin{cases} \tilde{L}_1^{(1)} : < \text{if} \quad \tilde{A}_1, \quad \text{then} \quad \tilde{B}_1 >, \\ \tilde{L}_2^{(1)} : < \text{if} \quad \tilde{A}_2, \quad \text{then} \quad \tilde{B}_2 >, \\ \ldots \\ \tilde{L}_m^{(1)} : < \text{if} \quad \tilde{A}_m, \quad \text{then} \quad \tilde{B}_m >. \end{cases} \quad (1)$$

Fuzzy statements correspond to the general form:

$$\tilde{A}_j :< \beta_W \text{ is } \alpha_{W_j} > \text{ и } \tilde{B}_j :< \beta_V \text{ is } \alpha_{V_j} >,$$

where $\alpha_{V_1}, \alpha_{V_2}, \alpha_{V_3}$ are corresponding values of the terms of the output LV [18].

In the basis of the solutions output mechanism of intelligence information system there is a model of the given subject domain representing a composition of fuzzy relations of semantic spaces of input and output parameters.

An expanded form of the fuzzy logic inference for the system of knowledge in the form of (1) can be presented as follows:

$$\mu_{B'} = \underset{k\in K}{\vee} (\underset{j\in J}{\wedge} \mu_{Bkj} y_j) \wedge \underset{i\in I}{\wedge} \mu_{Aki}(x_i')).$$

As a result of the analysis of the subject domain a knowledge base has been created. A logic inference of the solution is based on it. The knowledge base contains 36 rules for each of the output LV. A fragment of the knowledge base for LV "Rotational speed of the threshing drum for wheat-50" is presented below:

1. If (crop yield is less than 50) and (rough straw is low) and (dockage is low) and (stand of grain humidity is dry) then (rotational speed is very low) (1)
2. If (crop yield is less than 50) and (rough straw is low) and (dockage is low) and (stand of grain humidity is normal) then (rotational speed is less than nominal) (1)
3. If (crop yield is less than 50) and (rough straw is low) and (dockage is low) and (stand of grain humidity is damp) then (rotational speed is nominal) (1)

…

36. If (crop yield is more than 50) and (rough straw is high) and (dockage is high) and (stand of grain humidity is damp) then (rotational speed is very high) (1).

3.3 Visualization of interrelations of input and output variables

At the stage of defuzzification accurate values of the resulting LV are calculated. For these calculations a "centre of gravity" method is used [19]. This method is implemented in MatLab with the help of Fuzzy Logic Toolbox application package [20, 21].

Fuzzy inference is an application of a maximin composition as a compositional rule of fuzzy inference and the operation of taking minimum as a fuzzy implication:

Fig. 4 presents surfaces "inputs-output" for LV "Speed of the harvester-40".

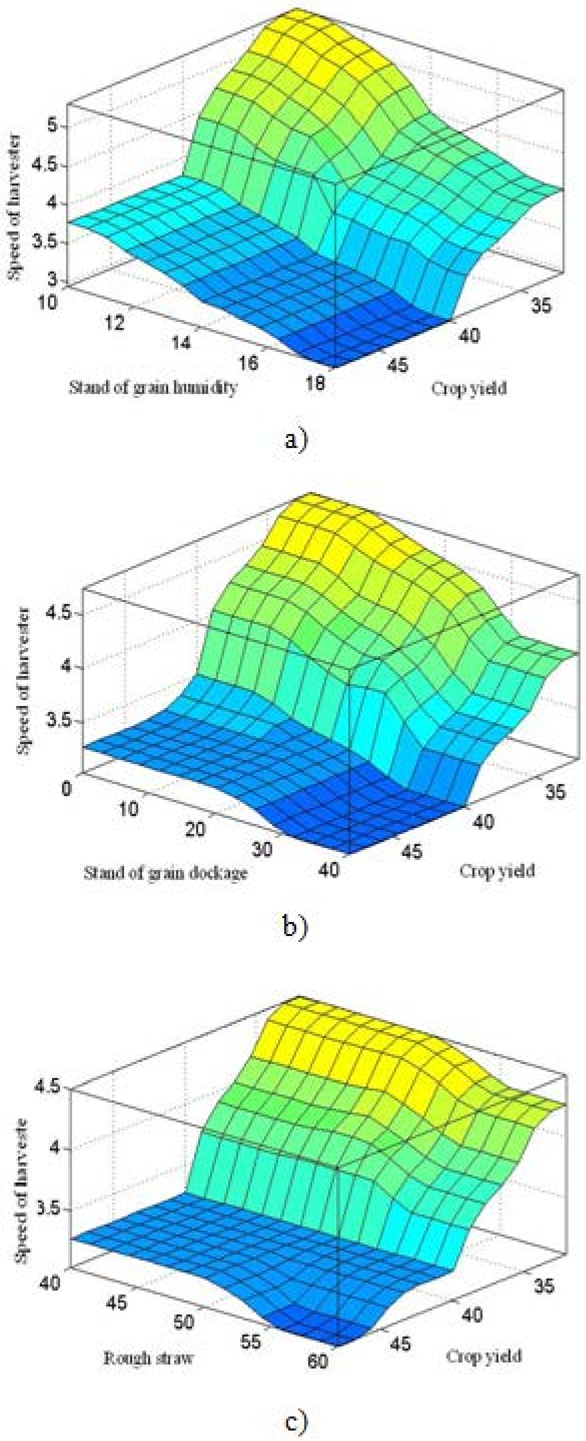

Fig. 4: Response surfaces of speed of the harvester vs a) humidity and crop yield;
b) dockage and crop yield;
c) rough straw and crop yield.

Surfaces “inputs-output” for LV “Rotational speed of the threshing drum for wheat-50” are shown in Fig. 5.

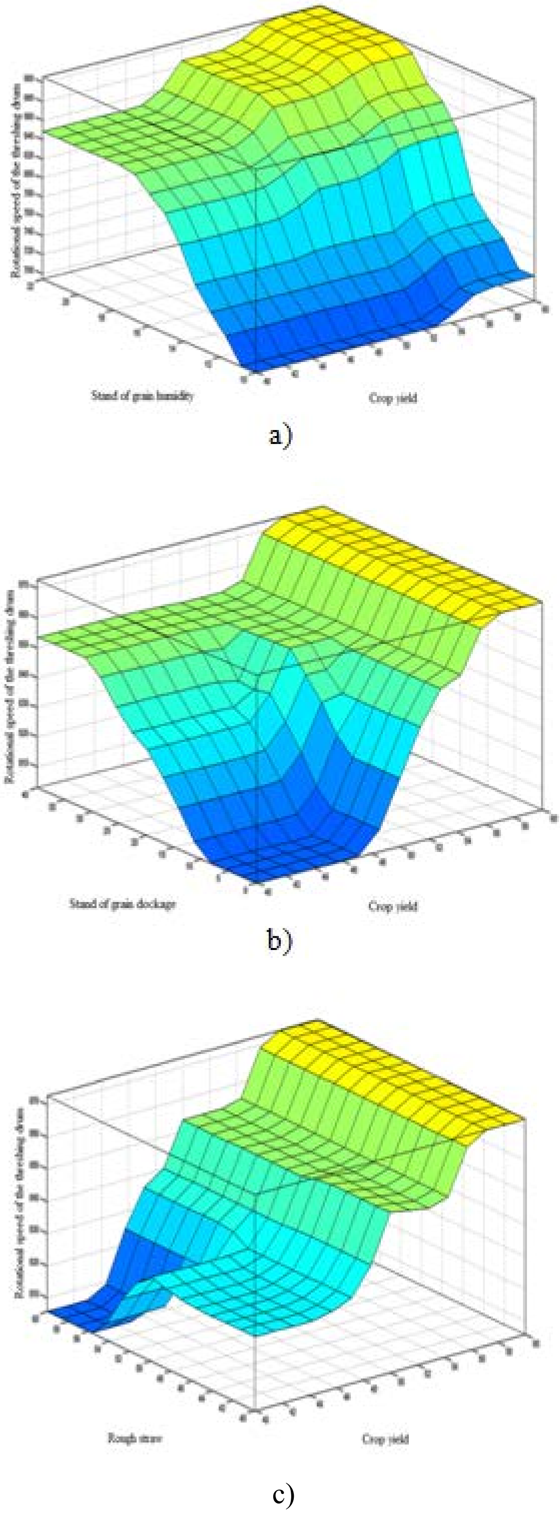

Fig. 5: Response surfaces of rotational speed of the threshing drum vs a) humidity and crop yield;
b) dockage and crop yield;
c) rough straw and crop yield.

Graphs, corresponding synthesized fuzzy systems of production rules are shown in Fig. 6 and Fig.7.

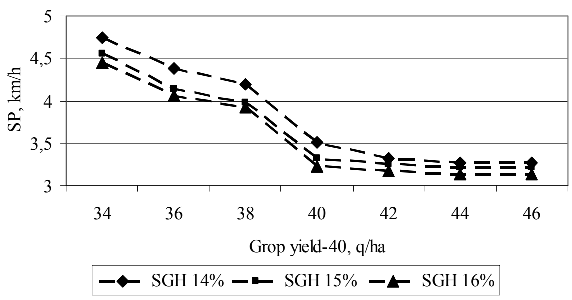

Fig. 6: Dependency of speed of the harvester on crop yield and grain humidity if rough straw is 50%, dockage is 10%.

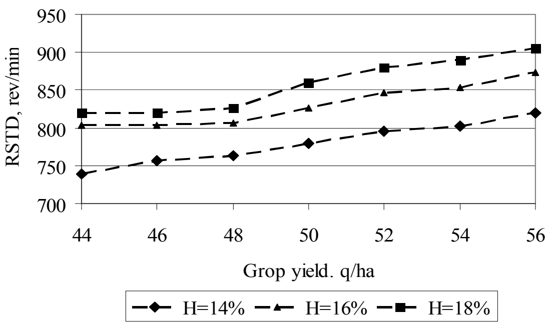

Fig. 7: Dependency of rotational speed of the threshing drum on crop yield and grain humidity if rough straw is 50%, dockage is 10%.

From Fig. 4 – 7 we can see that the system of fuzzy expert statements adequately describes relations: adjustable parameter – input factors.

4 Conclusion

The analysis of papers on theoretical and applied aspects of the theory of fuzzy sets shows that application of fuzzy models makes it possible to represent the properties of the initial system properly and to simplify the process of its analysis. The accepted degree of abstraction is the most reasonable as wider generalization will be fruitless from the point of view of practice. And an insufficient degree of abstractness will result in impossibility of solving the problem – it will be too difficult. In the context of the considered example the possibility of applying fuzzy inference has been displayed. They represent ascending conclusions from suppositions to conclusions while solving the problem of the harvester technological adjustment. Modeling of relations “external factor – value of the adjustable parameter” is carried out by the way of maximum-minimum composition and also by calculating centre of gravity of inference results according to each rule. On the basis of this approach the formalization of the subject domain has been performed and the mechanism of fuzzy inference of the expert system solutions has been constructed for solving the mentioned problem under the conditions of uncertainty.

The proposed method is innovative in the field of management of technological processes of complex agricultural machines. Application of fuzzy modeling made it possible to represent adequately and formalize not only quantitative but also qualitative information. An important component for making decision on setting technological parameters of the combine is information which is difficult to be represented in a quantitative form (dockage, rough straw and so on). The proposed approach not only gives the possibility of complete accounting of the expert qualitative information but it can be used in continuously changing external conditions of the combine operation as the given expert system is based on relational databases.

Created on the basis of the model the knowledge base and the solutions output mechanism make up the basis of the expert system. Application of this system in field allows reducing time for technological delays and decreasing the yield loss. Practical implementation of the developed algorithms is creation of software tools for an automated problem solution which were introduced at some agro-industrial enterprises of Rostov region (Russia). Application of the expert system in practice while performing technological adjustment made it possible to reduce this period 2-5 times compared to the traditional methods.

In further research for more perfect correspondence of mathematical model to real working conditions of the combine-harvester we are planning to provide fuzzy modeling of all interrelations between input factors and all adjustable parameters of the combine, an increase of the knowledge base of the expert system on the basis of the fuzzy production rules. The development of such expert system will make it possible to perform adjustments and corrections of the combine parameters in changing field conditions more accurately and quickly.

References:

[1] A.G. Rybalko, *Some Features of Harvesting High-yield Crops*, Moscow: Agropromizdat, 1988.

[2] E.F. Vetrov, M.D. Genkin, L.M. Litvin and others, Optimization of Technological Process According to Statistic Data, *Mashinovedenie*, No. 5, 1986, pp. 48-55.

[3] E.F. Vetrov, V.P. Tchernyavskaya, G.F Bobrineva and others, Optimal Adjustment of Combine Harvester (Electronic journal «Sovetchik kombainera»), *Proceedings,* 4/89, Moscow: NPO VISHOM, 1989, pp. 80-85.

[4] L.M. Litvin, E.V. Zhalkin, E.F. Vetrov, Generalized Estimation of Zone Operational Performance of Combine Harvesters, *Machinery in Agriculture*, No. 5, 1989. pp. 41-45.

[5] S.N. Yerokhin, A.S. Reshetov, Influence of Technological Adjustments on Grain Loss Behind the Thresher of the Combine Don-1500, *Mechanization and Electrification in Agriculture*, No. 6, 2003, pp. 18-19.

[6] Y.A. Tsarev, A.V. Kharkovsky, The Prospects of Using Electronic Control System in Combine Harvesters "Don" and "Niva", *Tractors and Agricultural Machines*, No. 1, 2005, pp. 37-38.

[7] A.N. Averkin, I.Z. Batyrshin, A.F. Blishun, V.B. Silov, V.B. Tarasov, *Fuzzy Sets in the Models of Management and Artificial Intelligence*, Moscow: Nauka, 1986.

[8] K. Asai, D. Vatada, S. Sugeno, *Applied Fuzzy Systems*, Moscow: Mir, 1993.

[9] Zhinong Jiang, Jinjie Zhang, Mengyu Jin, Bo Ma, An Expert system Based on Multi-Source Signal Integration for Reciprocating Compressor, *WSEAS Transactions on Systems,* Vol. 12, 2013, pp. 266-279.

[10] Ji-Feng Ding, Assessment of Customer Relationship Management for Global Shipping Carrier-based Logistics Service Providers in Taiwan: An Empirical Study, *WSEAS Transactions on Systems,* Vol. 11, 2012, pp. 198-208.

[11] S. Hrehova, A. Vagaska, Application of Fuzzy Principles in Evaluating Quality of Manufacturing Process, *WSEAS Transactions on Power Systems,* Vol. 7, 2012, pp. 50-59.

[12] G. Wang, S. Chen, Z. Zhou, J. Liu, Modelling and Analyzing Trust Conformity in E-Commerce Based on Fuzzy Logic, *WSEAS Transactions on Systems,* Vol. 14, 2015, pp. 1-10.

[13] L. Zadeh, Fuzzy Sets, *Information and Control*, Vol. 8, 1965, pp. 338-353.

[14] L. Zadeh, Knowledge representation in fuzzy logic, in *An Introduction to Fuzzy Logic Applications in Intelligent Systems, The Springer International Series in Engineering and Computer Science*, R.R. Yager, L.A. Zadeh Eds, Vol. 165, – New York: Springer, 1992, pp. 1-27.

[15] V.P. Dimitrov, L.V. Borisova, *Theoretical and Applied Aspects of Developing Expert Systems for Machines Maintenance,* Rostov-on-Don: DSTU Publishing Centre, 2007.

[16] L.V. Borisova, Modeling Technique of the Subject Domain "Technological Adjustment" in a Fuzzy Formulation, *Proceeding RASHN*, No. 6, 2005, pp. 62-65.

[17] L. Kofman, *Introduction in the Theory of Fuzzy Sets*, Moscow: Radio and Communication, 1982.

[18] N.G. Malyshev, L.S. Bershtein, A.V. Bozhenyuk, *Fuzzy Models for Expert Systems in CAD*, Moscow: Energoatomizdat, 1991.

[19] I.M. Makarov, V.M. Lokhin, S.V. Manko, M.P. Romanov, Artificial *Intelligence and Intelligence Control Systems*, Moscow: Nauka, 2006.

[20] S.D. Shtovba, *Designing Fuzzy Systems with MATHLAB Facilities*, Moscow: Hot line – Telecom, 2007.

[21] S. Hrehova, J. Mizakova, Using GUI of Matlab and Fuzzy Principles for Evaluation of Some Process Quality, *International Journal of Fuzzy Systems and Advanced Applications*, Vol. 1, 2014, pp. 7-14.