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APPLICATION OF USER INTERFACE FUZZY LOGIC TOOLBOX
FOR QUALITY CONTROL OF PRODUCTS AND SERVICES

Abstract. In this work, the solution for the quality control of products and services is illustrated for the first time on examples of wine production and the provision of educational services in the university by creating a heuristic analyzer based on the Fuzzy Logic Toolbox interface of the Matlab program. There were also considered the problems of constructing quality control models with fuzzy logic for solving problems arising in cases when it is not possible to use classical statistical methods. The factors influencing the quality of products, in particular wine, and services on the example of providing education are analyzed, the possibility of using the fuzzy logic apparatus for determining the weight contribution of factors that ensure maximum quality is proved. Computer simulation using the Mamdani algorithm is performed, which consists of fuzzification with the definition of ranges of change of input values for each example, assigning the distribution functions for each input parameter; calculation of the rules, based on the adequacy of the model; defuzzification with the transition from linguistic terms to quantitative evaluation; graphical construction of the response surface using a centroid method with determination of the center of gravity of the response surface. The modeling has confirmed that the creation of a heuristic analyzer for determining the quality of wine and the quality of education is appropriate and necessary for preventing the production of substandard products and the provision of substandard services.

Keywords: fuzzy logic; heuristic analyzer; fuzzification; defuzzification; quality control.

Introduction

Currently, there is an active scientific search for methods to improve the quality of products and services to ensure a high competitive level due to the European integration of Ukraine. The very actual remains the scientific and applied task of improving the quality of products and services, by identifying the weakest stage of production or service delivery, the impact on which will improve the quality and the competitive level.

In most cases, for objects of qualimetry, the input parameters have one unit of measure, and the output parameter is different. Under such conditions it is impossible to carry out the mathematical operations and determine the share of influence of the factor on the final result. In addition, products and services can be attributed to poorly formalized ones, and ones that are affected by inaccuracy, ambiguity, ambiguity, non-stationarity, uncertainty, etc. In this case, it is advisable to use fuzzy logic, which by means of fuzzification allows you to move from numbers to linguistic terms, make up rules, and then, thanks to defuzzification, return to numbers.

The subject of fuzzy logic is the study of judgments in conditions of fuzziness, which are similar to judgments in the usual sense, as well as their application in computer systems [1-3]. Serious development theory received in the works of the scientist Jerry M. Mendel, who gave a definition for the basic algorithms of fuzzy logic. This was reflected in his works [4-6].

Currently, there are many algorithms for fuzzy logic. Most commonly used are the following: the algorithms Mamdani [7], Tsukamoto [8], Sugeno [9], Larsen [10]. In work [6] models were chosen for linguistic variables in the fuzzy logical derivation of Mamdani and its advantage over other methods in assessing quality was proved. The basic analytical relations describing the functioning of this algorithm are presented in the works [11,12].

Further literary analysis shows an increased interest in using the mathematical apparatus of fuzzy logic in the industry and the socioeconomic sphere. The paper [13] presents a new system identification methodology for industrial systems. The efficacy of the proposed approach is demonstrated through the experimental trails from a compressor in an industrial gas turbine system. So in [14] the solution of the problem of classification of defects of metallic pipes of oil and gas pipelines with the help of the algorithm of fuzzy logic inference Mamdani and fuzzy knowledge base Sugeno is presented. In [15] a method for increasing the accuracy of detecting defects in metal products was proposed, and the possibility of using the apparatus of the theory of fuzzy sets to determine such parameters of an eddy current transducer was proved, which would make it possible to minimize the risk of making an error in determining the defect. In the work [16] solution for the control of parameters accuracy of technological process of manufacturing kefir and increase of its quality by creating the heuristic analyzer is considered. In the work [17] the examples of use of the fuzzy-logic device in the business, medical diagnostics, in various control and ecology and environmental protection spheres has been considered. The paper [18] aims to establish a non-linear regression model based on Mamdani fuzzy inference system and the data used in this operation is collected with pollutants. The resultant air quality index is then measured.

The described above analysis sets the goal to consider the practical implementation of the use of the fuzzy-logic device in terms of quality control of products and services by modeling a heuristic analyzer using the Fuzzy Logic Toolbox user interface in a software environment MATLAB.

Fuzzy logic inference using the Mamdani algorithm

False logical conclusion based on Mamdani's algorithm is performed by fuzzy knowledge base:

$$\bigcup_{p=1}^{k_j}\left(\bigcap_{i=1}^{n}x_i=a_{ijp},u_{ijp}\right),y=T_j,j=\overline{1,m}, \qquad (1)$$

where the values of the input and output variables are given by fuzzy sets.

Enter the following notation: $\textit{м}_{jp}\left(x_i\right)$ – the membership function of the entry x_i is a fuzzy term a_{ijp}:

$$a_{ijp}=\int_{\underline{x_i}}^{\overline{x_i}}\mu_{jp}\left(x_i\right)\big/x_i,\,x_i\in\left|\underline{x_i},\overline{x_i}\right|, \qquad (2)$$

$\textit{м}_{T_j}\left(y\right)$ – function of the output of the fuzzy term T_j:

$$T_j=\int_{\underline{y}}^{\overline{y}}\mu_{T_j}\left(y\right)\big/y,\,\,y\in\left|\underline{y},\overline{y}\right|. \qquad (3)$$

The degrees of membership of the input vector $X^*=\left(x_1^*,x_2^*,...,x_n^*\right)$, fuzzy terms T_j of knowledge base is calculated as follows:

$$\mu_{T_j}\left(X^*\right)=\bigcup_{p=1,k_j}\omega_{jp}\bigcap_{i=1,n}\left[\mu_{jp}\left(x_i^*\right)\right],j=\overline{1,m}, \qquad (4)$$

where $\bigcup\left(\bigcap\,\right)$ – operation with s-norms (t-norms), that is calculated from the set of implementations of logical operations OR (AND). The most commonly used are the following implementations: for OR operation – finding the maximum and for operation AND – finding the minimum. The result is this fuzzy sets $\tilde{y}$, the appropriate input vector X^*:

$$\tilde{y}=\frac{\textit{м}_{T_1}(x^*)}{T_1}+\frac{\textit{м}_{T_2}(x^*)}{T_2}+...+\frac{\textit{м}_{T_m}(x^*)}{T_m}. \qquad (5)$$

The peculiarity of this fuzzy set (5) is that the its universal term is the term set of the output variable y. For the transition from the fuzzy set given on the universal set of fuzzy terms $\{T_1, T_2,…, T_m\}$ to the fuzzy set on the interval $\left|\underline{y},\overline{y}\right|$ the following steps should be taken:

1) "cut" function of membership $\textit{м}_{T_j}\left(y\right)$ at the level $\textit{м}_{T_j}\left(X^*\right)$;

2) aggregate the resulting fuzzy sets:

$$\tilde{y}=agg_{j=\overline{1,m}}\left(\int_{\underline{y}}^{\overline{y}}min\left(\mu_{T_j}\left(X^*\right),\mu_{T_j}\left(y\right)\right)\big/y\right). \qquad (6)$$

The exact output value y corresponding to the input vector X^* is determined by the defuzzification of the fuzzy set $\tilde{y}$.

This algorithm at this time received the greatest practical application in the problems of fuzzy modeling. A distinctive principle of this model from others is that its rules of inference on the right side contain fuzzy values (membership functions). When using the maximum as an aggregation operator and a minimum as an implication operator, the procedure for obtaining a fuzzy output value is a composition of max-min.

Formation of the rules base for the system of fuzzy inference is carried out in the form of an ordered coordinated list of fuzzy production rules in the form "IF A THEN B", where the antecedents of the fuzzy rules kernels are constructed with the help of logical "I" links, and the consequent kernels of the rules of fuzzy production are simple.

The fuzzification of the input variables is carried out in the manner described above, just as in the general case of constructing a fuzzy inference system.

Aggregation of the subconditions of fuzzy products rules is carried out with the help of the classical fuzzy logic operation "AND" of two elementary statements A, B: $T(A \cap B)$ = min$\{T(A);\,T(B)\}$. Activation of subcontracting rules of fuzzy products is carried out by the method of min-activation $\mu(y)$ = min$\{c;\,\mu(x)\}$, where $\mu(x)$ and c – are, respectively, the membership functions of terms of linguistic variables and the degree of truth of fuzzy sentences forming the corresponding consequent of the kernels of fuzzy product rules.

Accumulation of subcontracting rules of fuzzy products is performed using the classic for fuzzy logic max-combining the membership functions

$$\forall\,x\in X\mu ABx=\max\{\mu Ax;\,\mu Bx\}.$$

The defuzzification is carried out by the method of the center of gravity and the center of the area:

$$y=\int_{\underline{y}}^{\overline{y}}y\cdot\mu_{\tilde{y}}\left(y\right)dy\big/\int_{\underline{y}}^{\overline{y}}\mu_{\tilde{y}}\left(y\right)dy. \qquad (7)$$

The most commonly used method of defuzzification is the center of gravity. However, applying this method, it is necessary to remember that the range of clear values of output variables will always be the interval at which it is defined. This defect is deprived of the second most frequently used method of dephasing - the center of maxima. When using the method of the center of maxima, one should take into account the fact that the result of dephasing is not sensitive to the rules contribution, that have small degree of fulfillment and that depends only on the rules, the degree of fulfillment of which is maximal.

Building a heuristic analyzer of the fuzzy knowledge base of Mamdani to determine the factors most influencing the quality of products and services

To build a heuristic analyzer, we use the interface of the fuzzy logic system of the MATLAB computer program and in it the Mamdani knowledge system in it. Calculations and construction of fuzzy logic diagrams are performed using the same application.

1. Construction of a heuristic analyzer for quality control of wine

The main parameters affecting the quality of the wine are the observance of the technology in production and the quality of raw materials used for production. Thus, the model must have two inputs and one output. As the first entry, we choose compliance with technology, and as the second input - the quality of raw materials. As the initial value, we choose the quality of the products (Fig. 1).
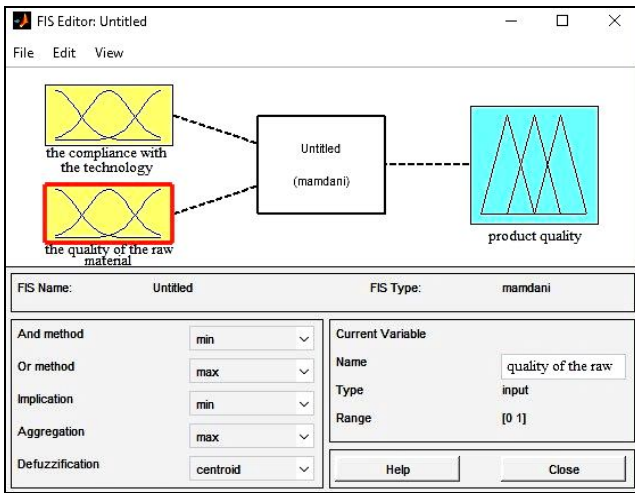
Fig. 1. Window task input and output parameters
for wine quality control

We assign membership functions for the selected input variable - compliance with the technology. In Range, we set the range in which the function changes (from 1 to 10 points). We set the type of the membership function in the Type column: for three membership functions, namely the technology is not followed (after) (range from 0 to 3 points), partially adhered to (good) (range from 4 to 7 points), and is completely (excellent) (range from 8 to 10 points) choose the distribution of Gauss (Fig. 2).

We assign membership functions for the input variable - the quality of the raw material. In Range, we set the range in which the function changes (from 1 to 10 points). We set the type of the membership function in the Type column: for two membership functions, namely, bad quality (range from 0 to 5 points), good quality raw materials (range from 6 to 10 points) (trarmm), trapezoidal distribution law (Fig. 3).
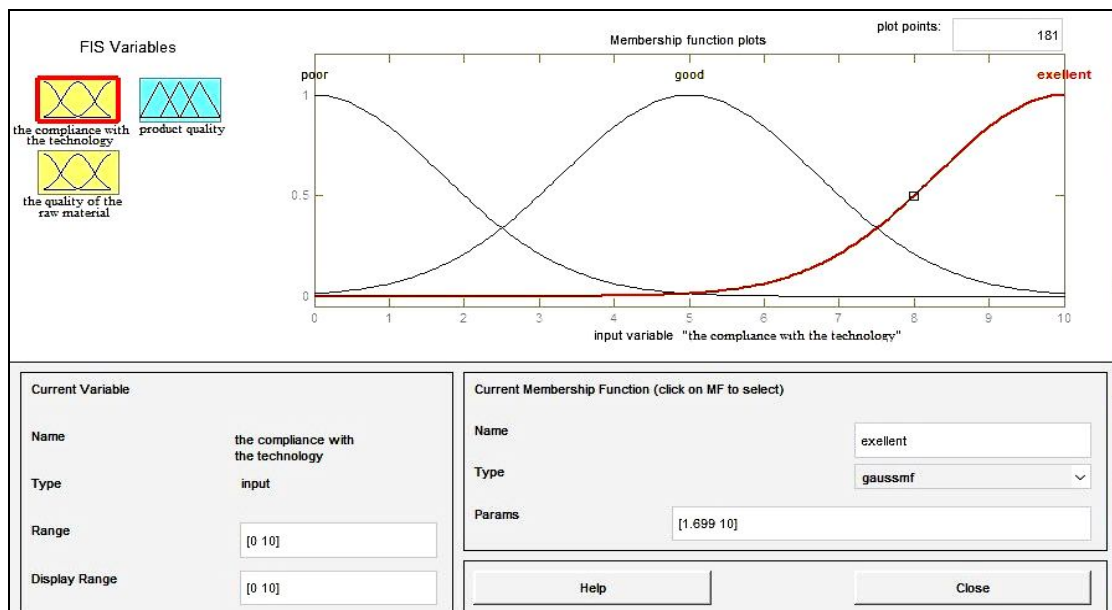
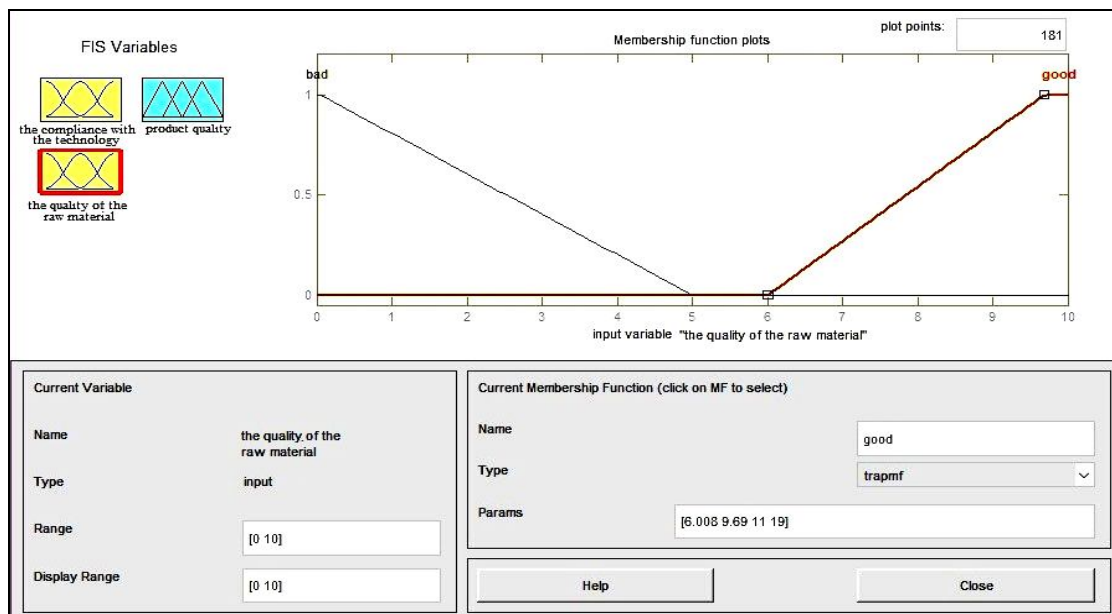**Fig. 2.** Specifying a technology compliance parameter window

Fig. 3. Specifying a technology compliance parameter window

We assign membership functions for the selected output variable - product quality. In Range, we set the range in which the function changes (from 1 to 100%). Specify the type of membership function in the Type column: for three membership functions, namely, the unquality (range from 0 to 50%), suitable for use (range from 50 to 70%) and quality products (range from 70 to 100%) choose the distribution (trimf) trapezoidal

distribution law (Fig. 4). We set the rules for which the model will operate. In the "rules" window we will make rules that characterize each of the parameters (Fig. 5).

Since the system has two inputs (each coded as 00, 01, 10), so the maximum output states 3*2=6 different output combinations, but there are critical conditions that clearly classify the quality of products, as appropriate rules to reduce the number to five.
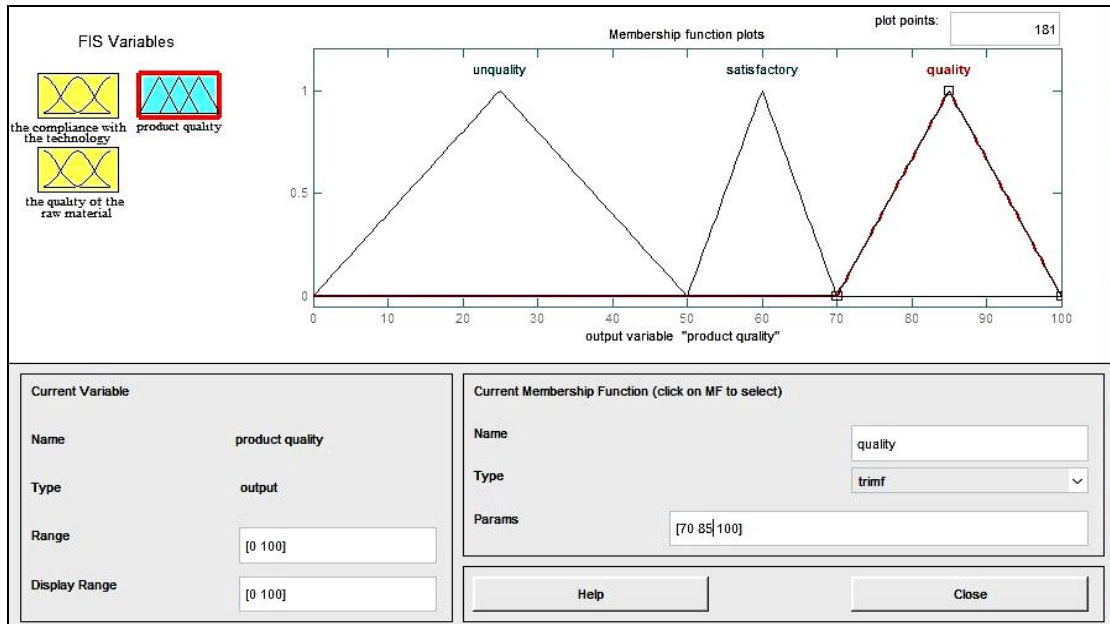

Fig. 4. The task window of the parameters of the output parameter is the quality of the wine
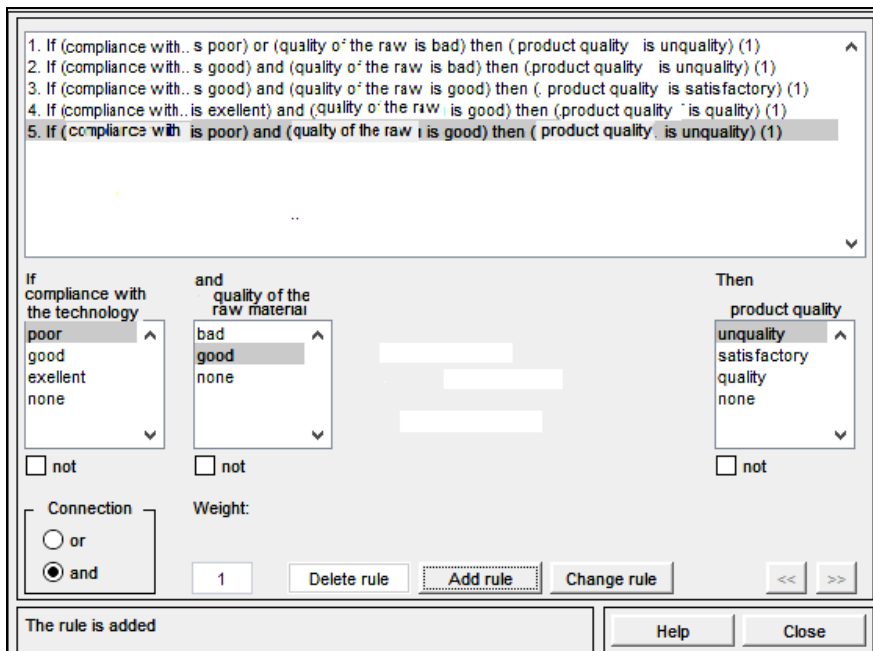

Fig. 5. Window rules editor

Some of them:

1. If the technology is "bad", and the quality of raw materials is "unsatisfactory", then the quality of the product is "poor".

2. If the technology is "good" and the quality of the raw materials is "unsatisfactory", the quality of the product is "poor".

3. If the technology is "good" and the quality of the raw material is "qualitative", then the quality of the product is "suitable for use".

From Fig. 6, a it is evident that fifty percent compliance with technology and the same quality of raw materials provide twenty-five percent of the product quality.

Full compliance with the technological regime and the use of quality raw materials give only 84.6% of quality (Fig.6, b). Graphic representation of values of variables and response surface are shown in Fig. 7.
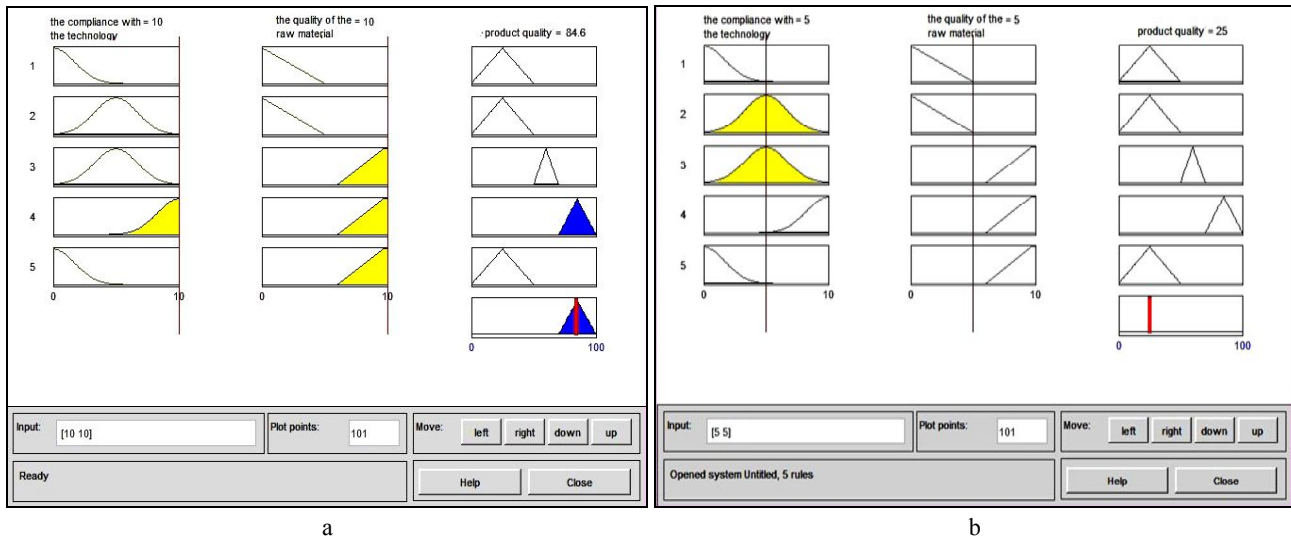

Fig. 6. Window of values of variables:
a – at 50% compliance with the input parameters; b – at 100% compliance with the input parameters
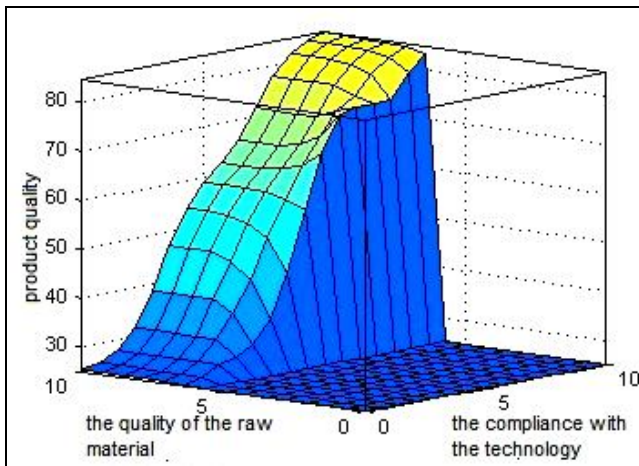

Fig. 7. The surface of the fuzzy model response in the control of wine quality

2. Building a heuristic analyzer for monitoring the quality of educational services

The main indicators of quality (IQ) educational services was chosen "Quality of entry", "Quality of the learning process" and "Quality of the results of education".

The output value will be the quality of education (Fig. 8). We assign membership functions for the selected input variables. Each variable has three terms "low", "medium" and "high" quality.

We describe the fuzzy variable "Quality of entry". In Range we will set the range in which the function changes, from 100 to 200 points (according to the rules of admission to institutions of higher education).

We set the type of the membership function in the Type column: for three membership functions, namely low quality (range from 100 to 140 points), average quality (range from 110 to 190 points) and high quality (range from 160 to 200 points) choose a triangular form (Fig. 9, a).

We describe a fuzzy variable "Quality of the learning process". According to the European scale ECTS we will assume that the minimum rating that characterizes the quality of training is the assessment of E (60 points), and the maximum - A (100 points). Therefore, at the Range point we will set the range in which the function changes, from 60 to 100 points (since the quantitative assessment of the student's learning outcomes is the average score of the exam session). In the Type box, select the Gaussian distribution (Fig. 9, b).

Similarly, we define the membership functions for the selected input variable - the quality of the results of education (Fig. 9, c).

We assign membership functions for the selected output variable - the quality of education. In the Range setting we set the range of the change of the triangular membership function - from 1 to 100%. (Fig. 10).
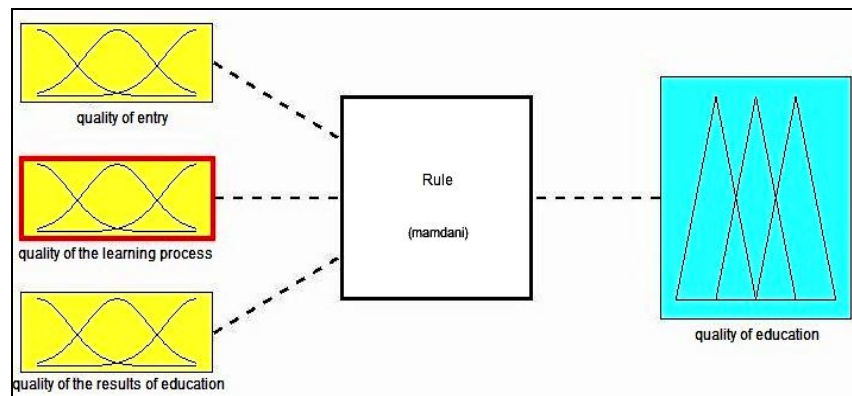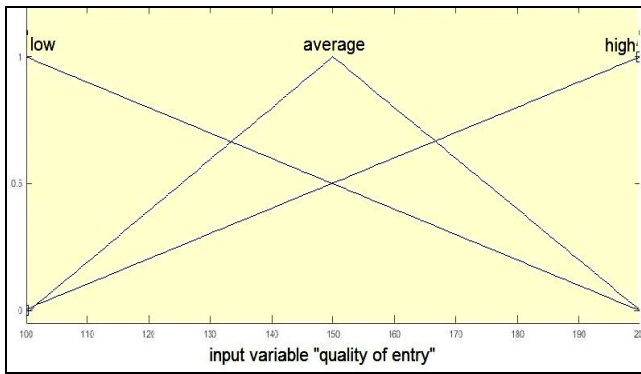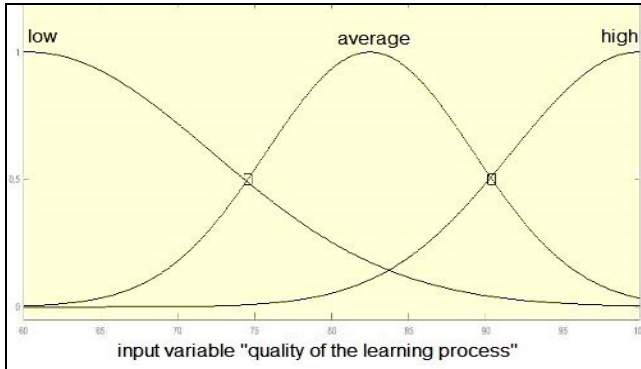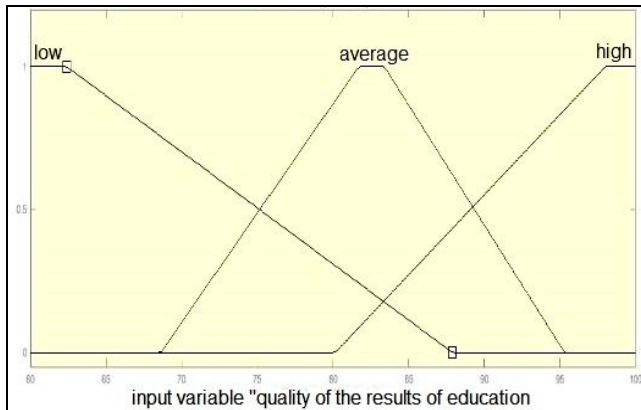

Fig. 8. Window task input and output parameters for quality control educational services

Then we set the rules of the fuzzy conclusion and get the response surface (Fig. 11, a-c), which shows three different combinations of input parameters from the original.

a

b

c

Fig. 11. The surface of the fuzzy model response
in controlling the quality of educational services:
a – the dependence of the quality of education
on the quality of admission and the quality of education;
b – the dependence of the quality of education
on the quality of the entry and quality of the result;
c – the dependence of the quality of education
on the quality of the learning process and the quality
of the result of education

a

b

c

Fig. 9. Window task parameters
for the quality of educational services:
a – membership function for the input parameter
"Quality of entry";
b – membership function for the input parameter
"Quality of the learning process";
c – membership function for the input parameter
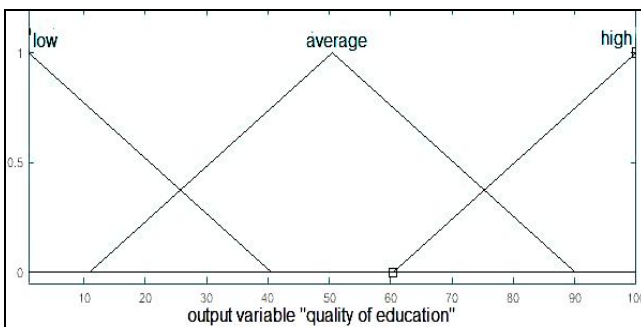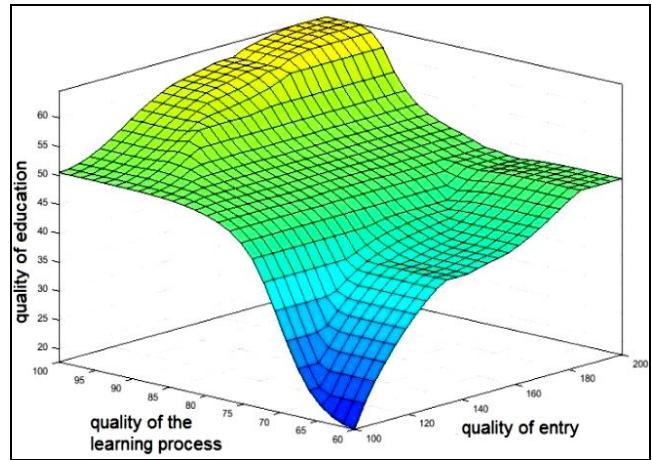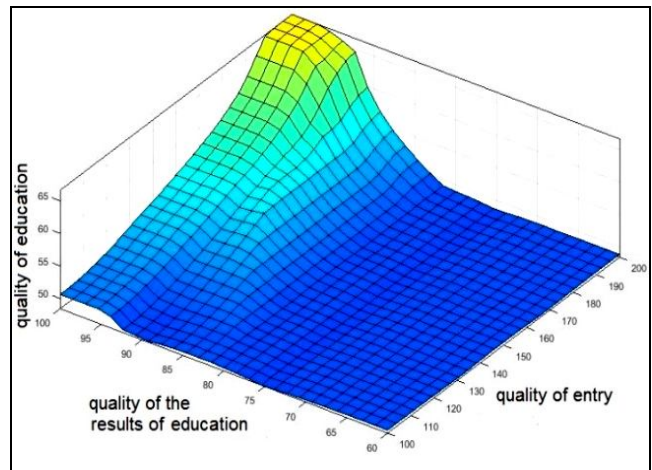"Quality of the results of education"

Fig. 10. The window of the problem
of the initial parameter is the quality of education

Using the graphical user interface, we managed to build a fuzzy logic system that solves the tasks of monitoring and evaluating the quality of both products and services.

In the first case, this system made it possible to determine the impact on the quality of production of compliance with the production technology and the quality of raw materials in the production of wine.

In the second case, the system slows the influence of the quality of all stages of student training on the resulting quality of education.

The obtained simulation results (Fig. 7, 11) illustrate the adequacy of the fuzzy system for both cases considered, allow us to determine the optimal conditions for achieving the desired result.

It should be noted that for both examples, the criterion of optimality is one hundred percent quality of products and services, which from the very beginning is a difficult task.

However, it is this quality that is both a criterion for economically profitable production and a consumer of consumer health.

In our cases, this phenomenon is illustrated in the following way: with one hundred percent observance of all input parameters, the value of the output parameter does not reach the given maximum. This can be explained by taking into account the various risks that affect the system.

A better variant of the resulting quality can be achieved by choosing another method of defuzzification, but the fuzzy model becomes richer and inferior to adequacy.

Conclusions

1. The proposed approach, based on fuzzy logic, provides an opportunity to take into account the parameters of influence on the technological process to determine the optimal relationships between them. At the same time, its use is correct for quality control of both products and services. Thus, it is possible to solve the problem of quality control of products and the quality of service provision precisely thanks to the fuzzy-logic apparatus.

2. Using the graphical user interface of a built-in fuzzy logic system allows you to set what should be the input parameters in order to provide high quality output.

3. The proposed heuristic analyzer serves as an advisor for a technological engineer or specialist in the field of service provision and can be used in any field of the national economy.

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Застосування призначеного для користувача інтерфейсу Fuzzy Logic Toolbox для контролю якості продукції та послуг

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Анотація. В роботі вперше проілюстровано рішення задачі контролю якості продукції та послуг на прикладах виробництва вина і надання освітніх послуг у ВНЗ за допомогою створення евристичного аналізатора на базі інтерфейсу системи нечіткої логіки Fuzzy Logic Toolbox програми Matlab. Розглянуто питання побудови моделей контролю якості з нечіткою логікою для вирішення завдань, що виникають у випадках, коли немає можливості використовувати класичні статистичні методи. Проаналізовано фактори, що впливають на якість продукції, зокрема вина, і послуг на прикладі надання освіти, доведена можливість застосування апарату fuzzy logic для визначення вагового внеску факторів, які забезпечують максимальну якість. Проведено комп'ютерне моделювання за алгоритмом Mamdani, який складається з фазифікації з визначенням діапазонів зміни вхідних величин для кожного прикладу, завданням функцій розподілу для кожного вхідного параметра; обчислення правил, виходячи з адекватності моделі; дефаззифікації з переходом від лінгвістичних термів до кількісної оцінки; графічного побудови поверхні відгуку, використовуючи центроїдного метод з визначенням центру ваги поверхні відгуку. Моделювання підтвердило, що створення евристичного аналізатора для визначення якості вина і якості освіти доцільно і необхідно для того, щоб не допустити виробництво неякісної продукції і надання неякісних послуг.

Ключові слова: нечітка логіка; евристичний аналізатор; фазифікація; дефазифікація; контроль якості.

Применение пользовательского интерфейса Fuzzy Logic Toolbox для контроля качества продукции и услуг

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Аннотация. В работе впервые проиллюстрировано решения задачи контроля качества продукции и услуг на примерах производства вина и предоставления образовательных услуг в вузах посредством создания эвристического анализатора на базе интерфейса системы нечеткой логики Fuzzy Logic Toolbox программы Matlab. Рассмотрены вопросы построения моделей контроля качества с нечеткой логикой для решения задач, возникающих в случаях, когда нет возможности использовать классические статистические методы. Проанализированы факторы, влияющие на качество продукции, в частности вина, и услуг на примере предоставления образования, доказана возможность применения аппарата fuzzy logic для определения весового вклада факторов, которые обеспечивают максимальное качество. Проведено компьютерное моделирование по методу Mamdani, который состоит из фаззификации с определением диапазонов изменения входных величин для каждого примера, задачей функций распределения для каждого входного параметра; вычисления правил, исходя из адекватности модели; дефаззификации с переходом от лингвистических термов к количественной оценке; графического построения поверхности отклика, используя центроидного метод с определением центра тяжести поверхности отклика. Моделирование подтвердило, что создание эвристического анализатора для определения качества вина и качества образования целесообразно и необходимо для того, чтобы не допустить производство некачественной продукции и предоставления некачественных услуг.

Ключевые слова: нечеткая логика; эвристический анализатор; фаззификация; дефаззификация; контроль качества.