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Intelligent management system of production and quality products for the small and medium business enterprises

***Abstract**. The article presents a model of fuzzy quality control of a company. The practical relevance of the research consists in the potential use of the developed system as a universal tool to assess efficiency of food production process quality management and to develop a package of actions to increase efficiency of the quality management system. The developed model enables to forecast and manage quality parameters of the manufactured products.*

***Streszczenie.** Artykuł przedstawia model rozmytej kontroli jakości firmy produkcyjnej. Praktyczne znaczenie badania polega na potencjalnym wykorzystaniu opracowanego systemu jako uniwersalnego narzędzia oceny efektywności zarządzania jakością procesu produkcji żywności oraz wypracowania działań mających na celu zwiększenie efektywności systemu zarządzania jakością. Opracowany model umożliwia prognozowanie i zarządzanie parametrami jakościowymi produkowanych wyrobów. (**Inteligentny system zarządzania produkcją i jakością produktów dla małych i średnich przedsiębiorstw**).*

Keywords: QMS, model rules base, fuzzy inference algorithm, expert evaluation database, forecasting.
Słowa kluczowe: QMS, podstawa reguł modelu, algorytm wnioskowania rozmytego, baza danych oceny ekspertów, prognozowanie.

Introduction

To At present, high quality of products is one of the key factors for successful food industry companies, ensuring their competitiveness and cost efficiency.

The quality management system (QMS) for food industry is the most important condition for ensuring food safety [1]. One of the main tasks in the development of modern companies in market conditions is to increase competitiveness. High quality of products will be one of the main factors for successful performance in conducting competition, increasing economic efficiency.

Efficient solution of problems requires using management potentiality by introducing quality systems and international standards. The key standard for establishing procedures in organizations and for confirming compliance, if so required, is ST RK ISO 9001, Quality Management Systems. Requirements standard. This standard establishes that "an organization must develop, record, implement and maintain quality management system and improve its performance continuously." Quality management system is a tool for achievement certain results in the market.

Now, enterprises all over the world including those in the Republic of Kazakhstan, implement quality management systems based on ISO 9001 standard [2].

The President of the Republic of Kazakhstan, N.A. Nazarbayev, established tenders by his Decree and today many domestic goods are able to compete in the international market [3]. One of the main conditions for participation in tender is to introduce management systems which obviously promotes QMS implementation. QMS implementation is voluntary and reflects the state of production processes and gives certain information of bakery processes.

This paper is aimed at the development of a model for food production process quality management using a fuzzy logic. To achieve this goal, the following tasks were set:

- to identify factors affecting the quality of food production;
- to develop a fuzzy model for food production process quality management;
- to implement the developed model through the definite example;
- to evaluate the results and prospects of further research.

The paper is organized as follows. Following the introduction, in section 2, Analysis of research and publications in the field of quality management and modeling systems using fuzzy logic are introduced. Then in section 3 analysis of intelligent management technologies is done. In section 4 the quality indicators in the form of a tree, the generated base of rules of systems of fuzzy inference are defined, membership functions of input and output variables and the simulation results are given. Finally, brief conclusions are deduced.

2. Analysis of studies and publications

Some process quality management modeling issues are discussed in works of scientists such as Walter A. Shewhart – development of process management statistical methods [4], Joseph Juran is known for his Quality Trilogy [5]. The quality trilogy includes a cycle of quality planning, quality control, and quality improvement activities. Juran is a developer of a concept of CWQM (Company-Wide Quality Management). W. Edwards Deming was a founder and developer of a concept of Total Quality Management [6]. He contributed greatly to development of the statistical process management methods. He is also known for development of a system approach to quality enhancement presented as the PDCA cycle (Shewhart-Deming cycle). Armand Feigenbaum is a developer of Total Quality Control principles, was a founder and the Chairman of the Board of the International Academy for Quality [7]. Kaoru Ishikawa is a developer of quality tools: cause-consequence Ishikawa diagram [8]. Genichi Taguchi worked on development and use of statistical methods in the manufacturing industry (so called Taguchi methods), he has also developed industrial experiment planning techniques and proposed a concept of quality improvement while reducing costs [9]. Shigeo Shingo is one of the developers of Just-in-Time, a famous Japan planning and production system, and the author of SMED (single minute exchange of die) method and Poka-Yoke (mistake proofing) system, which are currently parts of the Lean Production System. Philip Crosby is a developer of the widely known Zero Defects quality program, contributed greatly to development of the quality improvement methods which are basically formulated as 14 steps to quality improvement [10].

Human intelligence is characterized by ability to make right decisions in situations where information is incomplete or unclear. Building models approximated to human reasoning, utilization of the models in corporate management systems is currently one of the most important challenges in automation of industrial processes. Significant progress in this area was made by Lotfi A. Zadeh, professor of University of California, Berkeley [11]. Zadeh has developed a device for description of the intellectual processes, including fuzziness and ambiguity of expressions.

The research is focused on dynamics, process and discrete event simulation of B.Ya. Sovetov, S.Ya. Yakovlev [12], intellectual computing methods – neural networks, fuzzy logic – are considered in the works of V.P. Borovikov [13], S.D. Shtovba [14].

All known models do not describe simulation object comprehensively. Each of them has its own specific focus. Building of a model encompassing the maximum of operation types and functions and the use of a system approach is the primary objective of mathematical simulation of quality management of a food company's manufacturing processes.

3. State-of-the-art

The mathematical tool used in traditional methods of automatic control cannot always satisfy the needs of the modern production in full. Therefore, such information technologies [15] as expert systems [16], neural networks [17], fuzzy systems [18], genetic algorithms [19] and a number of others are used in terms of uncertainty. The basis for such technologies is an attempt to formalize the human brain activity to some extent and development of living organisms.

Processing the QMS of food production is characterized by work in conditions of uncertainty; therefore searching for an efficient control method and developing an optimal management model is important [20].

When automating the food production process management, the automated control system should be based on expert knowledge which is possible only using intelligent control technologies.

Today, intelligent methods are used to solve management tasks. The following types of intelligent control systems are distinguished: based on neural network technologies and based on fuzzy logic [21].

Simulation using artificial neural networks based on learning algorithms and generalization allows in a number of cases successfully predicting time series, leveling down standards for mathematical training of subject domain experts. However, neural network models have neither formal representation nor interpretation of the results of time series analysis. Application of networks is limited. Networks can receive data and process them independently. However, the process of network training is rather long. Besides, the analysis of the resulting network is quite complicated. At the same time any reliable information cannot be introduced into the neural network.

While considering systems based on fuzzy logic, we can state the opposite things: data obtained at the output of such systems are easy to understand [22].

4. Proposed model

The developed intellectual decision support system is a multifunctional and dynamic system that is aimed at solving problems of strategic management, planning, control, analysis and forecasting. The algorithm of functioning of the automated system is shown in Figure 1.

Let's designate index Q (quality), $Q \in [0,100]$ as a quality criterion of bakery products. The higher is the value of this criterion, the higher is the quality of bread and the higher is its market position.

The main indicators of a bakery affecting the quality whose change cannot be described using clear mathematical functions, are quality indicators. Let's denote them as X_1, ..., X_n, then the company's quality management model will represent a functional mapping of the following form:

(1) $$X = \{X_1, X_2, \dots, X_n\} \rightarrow Q \in [0,100]$$

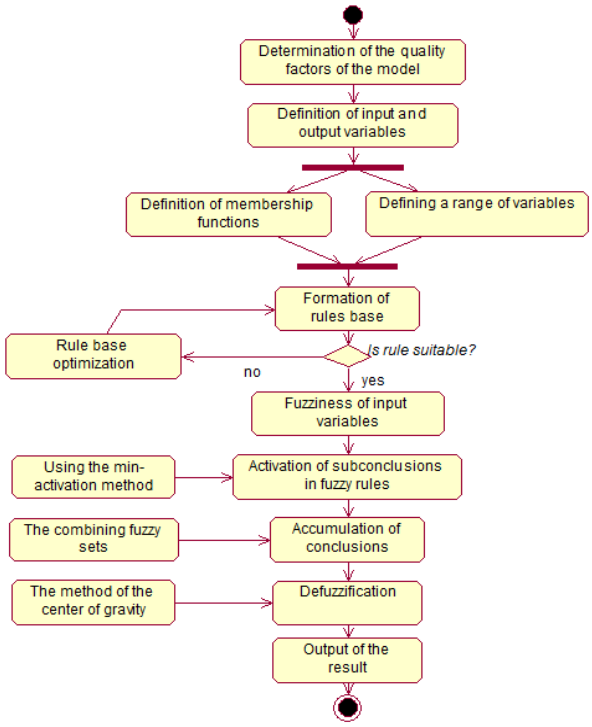

Fig.1. The algorithm of functioning of the automated system

For a large number of factors, it is convenient to represent them in the form of a tree (Fig. 2).

Elements of the graph are interpreted as follows:

- the root of the tree represents the quality of the bakery products (Q);
- terminal vertices represent particular influencing factors (X_i, $i = 1...9$);
- nonterminal vertices represent enlarged influencing factors (Y_1, Y_2, Y_3, Q)

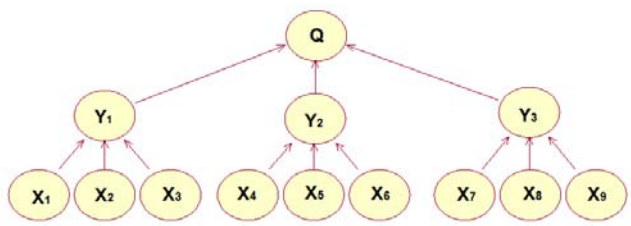

Fig.2 – Hierarchical tree of company's quality factors

Description of the selected quality factors is presented in Table 1.

Let's imagine the process of developing a model of bakery product quality management ($Y_1 \in [0,50]$). Functional model of the following type is given below:

(2) $$X = \{X_1, X_2, X_3\} \rightarrow Y_1 \in [0,50]$$

where X is a vector of influencing factors.

The Mamdani algorithm [20] is used as an algorithm for fuzzy logic inference.

Table 1. Model quality factors

Term	Description
Y_1	Bakery product quality
X_1	Assortment (quantity of baked products)
X_2	Exclusivity (number of unique bakery products)
X_3	Cost of bakery products (average price of bakery products)
Y_2	Bakery's management quality
X_4	Bakery staff qualification
X_5	Duration of relations for providing population with bread
X_6	Distribution network branching degree
Y_3	Quality of bakery's IT
X_7	IT productivity
X_8	Convenience of IT operation
X_9	IT functionality

Each of the input X_1, X_2, X_3 and the output Y_1 variables are determined in accordance with a set membership function. A range for basis variable for X_1 was determined from 0 to 100 (where the measuring unit is the planned production output, and integral value.)

Add three membership functions of *trimf* type. *The membership functions* are designated as *high, average, and low,* i.e. high, average, and low range of bakery products, respectively. The current membership function editor window is shown in Figure 3. X_2 variable determined the baseline variable range as equal [0, 30] (in percentage) aligned three membership functions designated as *high, average, low.* X_3 variable determined the baseline variable range as equal [0, 30], too, (measured in a monetary unit), and also designated the three membership functions as *high, average, low.* Therefore, the manufactured bakery quality variable will take the following values: high, average, and low quality.

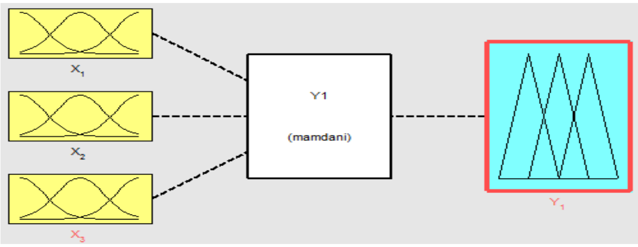

Fig.3. The membership function editor

First of all, the base of rules of fuzzy inference systems is established. The generation of a set of rules out from possible combinations of fuzzy statements in the premises and conclusions of the rules is made. According to such rules the maximum number of their in the database is determined by the following ratio: $N=N_{x1}\cdot N_{x2}\cdot\ldots\cdot N_{xm}\cdot N_y$, where $N_{x1}\cdot N_{x2}\cdot\ldots\cdot N_{xm}\cdot N_y$ is the number of membership functions for setting input and output variables ($N = 81$) [23].

There is a possibility that some of the rules will be contradictory. This applies to rules with the same premise (condition), but with different consequences (conclusions). One of the methods for solving this problem is to assign to each rule a so-called degree of truth with a subsequent choice of conflicting rules for the one whose degree is the greatest. Thus, not only the problem of contradictory rules is resolved, but their total number is significantly reduced [24].

Expert fuzzy knowledge bases are given in Table 2, where high, average and low are bread production quality indicators. Elements of fuzzy rules are bound by AND logical operation; the weighting coefficients of the rules are equal to 1. Fuzziness is defined (introduced) at the stage of fuzzification. The value of the membership function of the corresponding term of the input linguistic variable is put in correspondence [25] to each definite value of a separate input variable of the fuzzy control system. Three sets: T_1 = {low, average, high}, T_2 = {low, average, high}, T_3 = {Low, average, high} will be used as the term set for X_1, X_2, X_3 input linguistic variables and set T_4 = {low, average, high} will be used for the output linguistic variable Y_1.

Table 2 - Fuzzy rule base

X_1	X_2	X_3	Y_1
high	high	high	average
low	low	low	average
average	average	average	average
high	high	low	high
high	high	average	high
average	high	low	high
low	low	high	low
low	low	average	low
low	average	high	low
average	average	low	average
average	average	high	low
low	low	high	low
low	average	average	low
low	high	high	average
low	high	average	average
high	average	low	high
high	average	average	average

The membership functions for input variables were developed using the expert information statistical processing method, and for the output variable those functions are based on the method of paired comparisons [26]. The following piecewise linear membership functions were used in development: triangular and trapezoidal which are given in Figure 4.

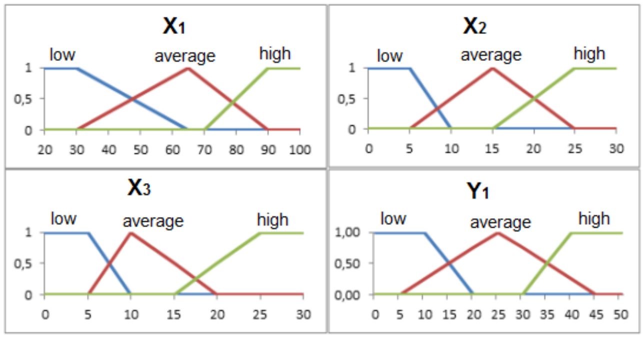

Fig.4. Diagrams of fuzzy set membership functions

The degrees of truth conditions of each rule of fuzzy productions were determined using aggregation. Paired fuzzy logic operations (min-conjunction and max-disjunctions) are used. The rules are deemed active and are used for further calculations if the degree of truth conditions is other than zero.

Activation of subconclusions in fuzzy rules of products is made using the min-activation method; accumulation of conclusions is made by combining fuzzy sets; defuzzification of output variables is made by the method of the center of gravity [27].

The model of fuzzy quality control of bakery products is developed based on the expert knowledge; therefore it is necessary to train the model on experimental data to ensure reliable results and to assess the developed model adequacy. 100 pairs of experimental input-output data were used to train in the fuzzy model. The parameters of the membership functions of terms were adjusted in such way as to mitigate the root-mean-square error [28,29].

An example of the developed model implementation in Matlab for the following values of input variables: if x_1 = 60,

$x_2 = 15$, $x_3 = 15$, then the quality index of the baked products is in average $y_1 = 23{,}9$ (Fig. 5).

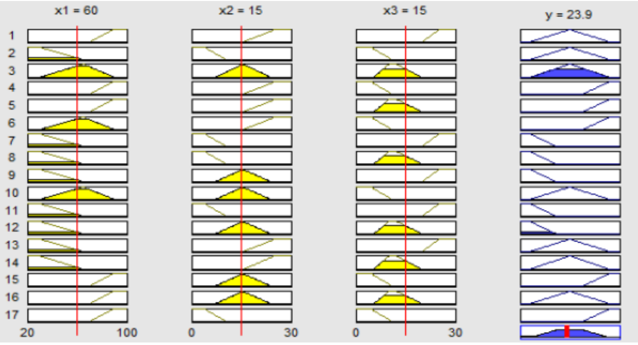

Fig.5. Output of results in Matlab

The values of the three input variables arrive at the input of the multiplexer, in which the data is combined. Next is the evaluation of the quality of bakery products produced with the use of fuzzy logic device on the basis of the developed fuzzy rules (Fig. 6).

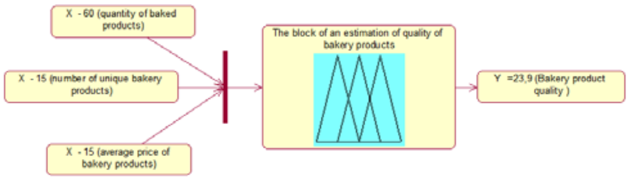

Fig.6. The system for evaluating the quality of baked products using the Fuzzy Logic Toolbox package of the MatLab software

In this model, the optimal variant of improving the quality of products up to the established limit is chosen. At the same time there are "narrow" places and new problems that need to be solved in order to influence the project development in the required direction. This result allows to evaluate the dependence of the output variable Y_1 "Quality of baked goods produced" on the values of different pairs of input variables. Analysis of these dependencies can serve as the basis for changing the parameters of the fuzzy inference model to improve its adequacy for various bakery strategies.

For example, if a bakery needs to raise the level of bakery product quality to 35 points and at the same time the indicator of the bakery product cost can change within $X_3 \in [10,30]$, then the number of exclusive products is $X_2 \in [5,20]$ and the quantity of baked products X_1 is fixed.

Possible combinations of X_2 and X_3 factors which provide a baking company with a quality level equal to 35 items as well as combinations that ensure the current state of a bakery are shown in Figure 7.

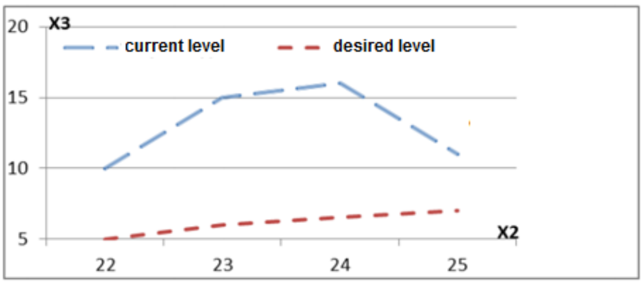

Fig.7. Current and desired levels of baked product quality

Reaction to a step change in the specified quality of bakery products. These dependencies show how accurately the system tracks the given cost of the baked product.

5. Conclusions

The given model enables to forecast the baked product quality indicators and to manage such indicators using such factors as the quantity of bakery products, exclusivity and product cost. It will allow the bakery management determining the appropriate values of the influencing factors for the purpose of ensuring the required level of quality of bakery products, thereby ensuring a leading position in the food market with high level of competition [30].

Applying the theory of fuzzy time series to forecast data presented in verbal form, unlike expert estimates and other heuristic methods, allows obtaining a quantitative estimate of a forecast and values of confidence interval and confidence probability of a forecast. Much of the information has a fuzzy structure for complexly organized systems such as, for instance, large technological complexes. Forecasting based on fuzzy logic should be an integral part of the complex forecasting and decision-making system [31].

The prospect for further research is the development of a fuzzy model of competitiveness with the addition of such factors as IT quality and bakery's management quality as well as further introduction into food production process intelligent control.

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