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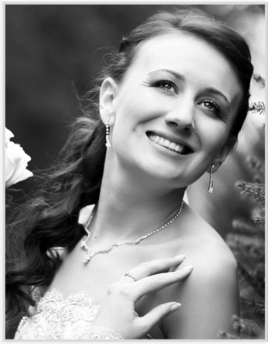

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MATHEMATICAL METHODS OF IDENTIFICATION OF UKRAINIAN ENTERPRISES COMPETITIVENESS LEVEL BY FUZZY LOGIC USING

Abstract. *The expediency to apply mathematic method based on fuzzy logic to evaluate enterprises competitiveness level is regarded in the article. This approach takes into account the various qualities and types of parameters, accurately and adequately determines the level of competitiveness with minimum time and expense. The purpose of the article is to develop mathematic method of enterprises competitiveness evaluation based on fuzzy logic that enables to reason its actions for further improvement. The main advantages of the method proposed by the authors are ability to analyze the influence of varied factors affecting on the level of enterprises competitiveness; to make rational decisions based on linguistic information under conditions of incomplete input information; clarity, transparency and possibility of automation which enable easy usage by Ukrainian enterprises.*
Keywords: *enterprises competitiveness; mathematical model; fuzzy logic.*
JEL Classification: *L29*

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ІДЕНТИФІКАЦІЯ РІВНЯ КОНКУРЕНТОСПРОМОЖНОСТІ УКРАЇНСЬКИХ ПІДПРИЄМСТВ НА ОСНОВІ ЗАСТОСУВАННЯ МЕТОДІВ НЕЧІТКОЇ ЛОГІКИ

Анотація. У статті розроблено математичний метод оцінки рівня конкурентоспроможності підприємств на базі математичного апарату нечіткої логіки. Такий підхід допоможе фахівцямураховувати різноякісні типи параметрів, а також точно і адекватно визначити рівень конкурентоспроможності підприємства з мінімальними тимчасовими та фінансовими витратами, що дозволить вжити адекватні заходи для її підвищення.
Ключові слова: конкурентоспроможність підприємства, математична модель, нечітка логіка.

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ИДЕНТИФИКАЦИЯ УРОВНЯ КОНКУРЕНТОСПОСОБНОСТИ УКРАИНСКИХ КОМПАНИЙ НА ОСНОВЕ ПРИМЕНЕНИЯ МЕТОДОВ НЕЧЕТКОЙ ЛОГИКИ

Аннотация. В статье разработан математический метод оценки уровня конкурентоспособности предприятий на базе математического аппарата нечеткой логики. Такой подход поможет специалистам учитывать разнокачественные типы параметров, а также точно и адекватно определить уровень конкурентоспособности предприятия с минимальными временными и финансовыми затратами, что позволит принять адекватные меры для ее повышения.
Ключевые слова: конкурентоспособность предприятия, математическая модель, нечеткая логика.

Introduction. Under conditions of financial, industrial and political crises, Ukrainian enterprises find difficult to improve their competitiveness. Many estimation models of competitiveness are weakly-formalized and automated [1]. Differentiations of these models do not lead to productive realization of this process for domestic enterprises in practice.

Due to today's quite critical economic situation, the task is to develop general and clearly algorithmic mathematic model for determination the level of competitiveness that can take into account the specifics of the modern enterprise system and shows the relationship between internal and external factors of influence on its activities, based on a single methodological basis.

Brief Literature Review. A significant contribution to the development of methods of the enterprises competitiveness evaluating made a lot of foreign and domestic scholars, in particular: G. Azov (2007) [2] who studied the problem of the competitive advantage and competitive strategy of enterprises formation in the Russian economy; G. Bagiev (2009) [3] who is a founder of the marketing research and competitive relations method; H. Fashiev (2003) [4] who pointed out that most of the methods for assessing the competitiveness of enterprises are based on the analysis of the production activities factors, financial position and efficiency investments.

The study of M. Porter (1979) is very notable. The author stated that the main source of competitive advantage is innovation provided by effective methods of competitiveness analysis and develop strategies in domestic and international markets.

Each approach of assessing the level of competitiveness uses a specific set of tools, techniques, strategies which improve the quality of the process, but their implementation in the current conditions remains problematic for businesses. Unfortunately, existing methods of evaluating the competitiveness of enterprises are not strictly formalized and algorithmic, based on a narrowly bounded set of only quantitative estimation parameters which do not allow counting effects of internal and external environments of economic entities functioning. As a result it is practically difficult to implement them [6]. Due to lack of computerized means, characterized limited information, the system does not allow estimation of the enterprise competitiveness. All these factors make it impossible to constructive usage and automation of this process.

The specificity of the modern enterprise competitiveness level assessment consists of counting not only quantitative, but also qualitative parameters. The best device, in our view, to solve this problem is fuzzy logic. The using of it is proven to be particularly effective in the treatment of expertise represented in verbal form, and obtaining accurate quantitative estimations of their values. In addition, the usage of this tool allows to save time costs of experts, which reduces the costs of their work, because it does not require analysis of all possible combinations of values of the subject estimated parameters to make a decision.

The purpose of the article is to develop a mathematical method of evaluation for the level of enterprises competitiveness based on fuzzy logic that enables its further improvement.

Results. The evaluation of modern enterprises competitiveness needs to use specific quantitative and qualitative information for this process. The best device, according to the authors, is the theory of fuzzy logic that gives the ability to process and consider relevant information. This application is effective in case of absence of clearly formalized evaluation of input parameters, dominated by economic experts whose conclusions are made in verbal form [7].

These considerations allow the authors of the article to substantiate their own choice of mathematical tools for the formalization of a mathematical model of competitiveness evaluation based on fuzzy logic.

The authors compiled the implementation of EEC method based on fuzzy logic, by performing the following steps.

Step 1 – Creating a set of input parameters for evaluation the values for the aggregate functions $f_i, i = 1, n$ **.** In order to correct and complete the assessment of enterprises competitiveness, at the same time avoiding the criteria of co-linearity duplication, and correlation the received estimates of indicators, the basic aspects of business including manufacture, financial, human resources, image, organizational culture and management, long-term communication relations with suppliers, intermediaries, consumers and other market players should be taken into account.

$$\mu^L(x)=\begin{cases}1, & x\in[a,c);\\ \left(\dfrac{b-x}{b-c}\right)^{1,5}, & x\in[c,b].\end{cases}\quad \mu^M(x)=\begin{cases}\left(\dfrac{x-a}{c_1-a}\right)^{1,5}, & x\in[a,c_1];\\ 1, & x\in(c_1,d_1);\\ \left(\dfrac{b-x}{b-d_1}\right)^{1,5}, & x\in[d_1,b].\end{cases}\quad \mu^H(x)=\begin{cases}\left(\dfrac{x-a}{d-a}\right)^{1,5}, & x\in[a,d];\\ 1, & x\in(d,b].\end{cases}\qquad (1.1)$$

Thus, to form aggregate functions $f_i, i=\overline{1,8}$ it is necessary to determine estimates of corresponding parameter xij subset of set X, including: f_1 – function of the products sales and promotion efficiency, which is based on a number of parameters, such as: x_{11} – rate of return on sales, x_{12} – factor pack of complete production, x_{13} – rate coefficient of efficiency of advertising and sales promotion; f_2 – function of the company production efficiency, which is based on x_{21} – relative index of unit costs, x_{22} – relative index of assets, x_{23} – relative rate of return on goods, x_{24} – the pack factor of production capacity; f_3 – human resources function formed with x_{31} – rate of employee turnover, x_{32} – coefficient of personnel constancy, x_{33} – productivity, x_{34} – rate of return on personnel; f_4 – function of products competitiveness, based on x_{41} – group index of economic competitiveness indicators, x_{42} – portion of returned goods, x_{43} – share of products of the highest category, x_{44} – share of new customers; f_5 – functions of the company financial condition, based on x_{51} – coefficient of autonomy, x_{52} – solvency ratio, x_{53} – absolute liquidity ratio, x_{54} – ratio of net profit; f_6 – function of the enterprise organizational culture within x_{61} – level of organizational culture, x_{62} – availability of business objectives and strategies to achieve them, x_{63} – efficiency of information system, x_{64} – level of training, x_{65} – index image manager; f_7 – external activities function, based on x_{71} – level of enterprise reputation in the market, x_{72} – level of competition among competing sellers, x_{73} – level of competition of substitutes, x_{74} – level of suppliers exposure, x_{75} – level of consumers exposure; f_8 – management function, based on x_{81} – performance management, x_{82} – share of management costs, x_{83} – the ratio of administrative staff to the average number of employees, x_{84} – economic efficiency of management.

Step 2 – Calculating the values of functions of the estimated parameters x_{ij} **,** $i=1,n,\ j=1,m$. After determining values of the set of input estimate parameters, it is necessary to calculate the values of membership functions. To do this, we defined a proximity parameter values for each of the three linguistic terms (t): L – low, M – medium and H – high level of this parameter [8].

The range of values for each linguistic term is described by the characteristic points of the irregular values c, c_1, d_1, d, b for each quantitative parameter x_{ij} separately. Based on expert knowledge, we offered for quantitative parameters (x_{11}, x_{12}, x_{13}, x_{21}, x_{22}, x_{23}, x_{24}, x_{31}, x_{32}, x_{33}, x_{34}, x_{41}, x_{42}, x_{43}, x_{51}, x_{52}, x_{53}, x_{54}, x_{55}, x_{81}, x_{82}, x_{83}, x_{84}) graphics of membership functions $\mu^t(x)$ of their values to t of fuzzy terms (t = 3). That is depicted in Figure 1.

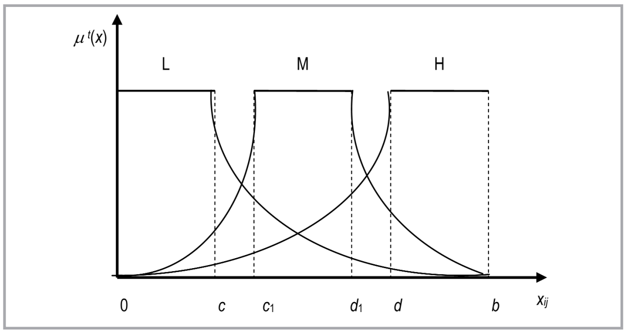

Fig. 1: **Graphs of membership functions for quantitative parameters**
Source: Created by Authors [8]

We describe these graphs corresponding to their function from the exponential factor 1.5, which approximates them into real functional dependencies:

The values of c, c_1, d_1, d, b for each quantitative parameter we can determine by proceeding from the appropriate range of changing parameters.

In general, we presented graphs of membership function $\mu^t(x)$ of quality parameters (x_{44}, x_{61}, x_{62}, x_{63}, x_{64}, x_{65}, x_{71}, x_{72}, x_{73}, x_{74}, x_{75}) values by t linguistic terms in Figure 2.

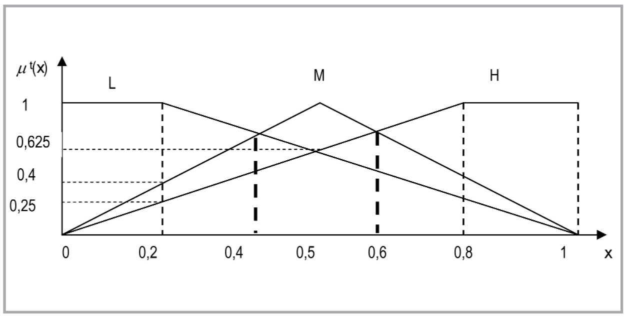

Fig. 2: **Graphs of membership functions for quality parameters**
Source: Created by Authors [8]

Mathematical expressions that describe these membership functions $\mu^t(x)$ of qualitative parameters take the form:

$$\mu^L(x)=\begin{cases}1, & x\in[0;0{,}2];\\ \dfrac{1-x}{0{,}8}, & x\in(0;1],\end{cases}\quad \mu^M(x)=\begin{cases}\dfrac{x}{0{,}5}, & x\in[0;0{,}5];\\ \dfrac{1-x}{0{,}5}, & x\in(0{,}5;1],\end{cases}\quad \mu^H(x)=\begin{cases}\dfrac{x}{0{,}8}, & x\in[0;0{,}8];\\ 1, & x\in(0{,}8;1].\end{cases} \tag{1.2}$$

Based on the graphics of functions in Figure 2, the value of $\mu^t(x)$ is determined as follows. If the quality parameter is characterized by term L – «low», then the value of membership function will be defined as X=0,2.

In this case $\mu^L(0{,}2)=1;\mu^M(0{,}2)=0{,}4\mu^H(0{,}2)=0{,}25$

We obtained these exact values of membership functions which are based on analytical expressions of the respective functions for x = 0,2; 0,5; 0,8.

The entire set of values of membership functions for t = 3 is presented in Table 1.

Tab. 1: **Value of membership functions for t = 3**

Term	$\mu^H(x)$	$\mu^C(x)$	$\mu^B(x)$
L	1	0,4	0,25
M	0,625	1	0,625
H	0,25	0,4	1

Source: Created by Authors [8]

Step 3 – Defining the level of enterprise competitiveness by logical equations usage, constructed on the basis of relevant knowledge matrices. For more accurate value of enterprises competitiveness level evaluation, we applied single scale of linguistic terms: L – low, BA – below average, M – medium, AA – above average, H – high.

Using agreed information provided by experts, we can represent a matrix for determining knowledge membership of each t-linguistic term for all aggregate functions.

Similarly, we compose a summarizing knowledge matrix for assess the competitiveness of enterprises. In Table 2 are decision rules that determine the resultant solution – y_s.

Tab. 2: **Generalizing function of competitiveness f_i**

Row number in a set of values for f_i of the functions x_i	Linguistic value of functions f_i, $i=\overline{1,8}$								Level of competitiveness y_s, $s=\overline{1,5}$
R	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	y_j
1	L	L	L	L	L	L	L	L	y_1=L
2	M	L	M	L	L	L	L	M	
3	L	M	L	L	L	L	M	L	
1	L	H	M	M	L	M	L	L	y_2=BM
2	M	L	M	M	M	L	L	M	
3	L	L	M	M	L	M	M	L	
1	M	M	M	M	M	M	M	M	y_3=M
2	H	M	L	M	M	H	M	M	
3	M	M	M	M	H	M	M	M	
1	M	H	M	H	H	M	H	H	y_4=AA
2	H	H	M	M	H	H	M	H	
3	M	M	H	H	M	H	H	M	
1	H	H	H	H	H	H	H	H	y_5=H
2	M	H	H	H	H	H	H	H	
3	H	H	H	H	H	H	H	M	

Source: Created by Authors [8]

Present decision rule for determining enterprises competitiveness level based on this knowledge matrix is to be described by following logical equations:

$$\begin{aligned}
\mu^H(f_1,\dots,f_8)&=\mu^H(f_1)*\mu^H(f_2)*\mu^H(f_3)*\mu^H(f_4)*\mu^H(f_5)*\mu^H(f_6)*\mu^H(f_7)*\mu^H(f_8)\vee\\
&\vee\mu^M(f_1)*\mu^M(f_2)*\mu^M(f_3)*\mu^H(f_4)*\mu^H(f_5)*\mu^H(f_6)*\mu^H(f_7)*\mu^H(f_8)\vee\mu^H(f_1)*\\
&*\mu^H(f_2)*\mu^H(f_3)*\mu^H(f_4)*\mu^H(f_5)*\mu^H(f_6)*\mu^H(f_7)*\mu^M(f_8);\\
\mu^{AA}(f_1,\dots,f_8)&=\mu^M(f_1)*\mu^H(f_2)*\mu^M(f_3)*\mu^H(f_4)*\mu^H(f_5)*\mu^M(f_6)*\mu^H(f_7)*\mu^H(f_8)\vee\\
&\vee\mu^H(f_1)*\mu^H(f_2)*\mu^M(f_3)*\mu^M(f_4)*\mu^H(f_5)*\mu^H(f_6)*\mu^M(f_7)*\mu^H(f_8)\vee\mu^M(f_1)*\\
&*\mu^M(f_2)*\mu^H(f_3)*\mu^H(f_4)*\mu^M(f_5)*\mu^H(f_6)*\mu^H(f_7)*\mu^H(f_8);\\
\mu^M(f_1,\dots,f_8)&=\mu^M(f_1)*\mu^M(f_2)*\mu^M(f_3)*\mu^M(f_4)*\mu^M(f_5)*\mu^M(f_6)*\mu^M(f_7)*\mu^M(f_8)\vee\\
&\vee\mu^H(f_1)*\mu^M(f_2)*\mu^L(f_3)*\mu^M(f_4)*\mu^M(f_5)*\mu^H(f_6)*\mu^M(f_7)*\mu^H(f_8)\vee\mu^M(f_1)*\\
&*\mu^M(f_2)*\mu^M(f_3)*\mu^M(f_4)*\mu^H(f_5)*\mu^M(f_6)*\mu^M(f_7)*\mu^M(f_8)\\
\mu^{BM}(f_1,\dots,f_8)&=\mu^L(f_1)*\mu^H(f_2)*\mu^M(f_3)*\mu^M(f_4)*\mu^L(f_5)*\mu^M(f_6)*\mu^L(f_7)*\mu^L(f_8)\vee\\
&\vee\mu^M(f_1)*\mu^L(f_2)*\mu^M(f_3)*\mu^M(f_4)*\mu^M(f_5)*\mu^L(f_6)*\mu^L(f_7)*\mu^M(f_8)\vee\mu^L(f_1)*\\
&*\mu^L(f_2)*\mu^M(f_3)*\mu^M(f_4)*\mu^L(f_5)*\mu^M(f_6)*\mu^M(f_7)*\mu^L(f_8)\\
\mu^L(f_1,\dots,f_8)&=\mu^L(f_1)*\mu^L(f_2)*\mu^L(f_3)*\mu^L(f_4)*\mu^L(f_5)*\mu^L(f_6)*\mu^L(f_7)*\mu^L(f_8)\vee\\
&\vee\mu^M(f_1)*\mu^L(f_2)*\mu^M(f_3)*\mu^L(f_4)*\mu^L(f_5)*\mu^L(f_6)*\mu^L(f_7)*\mu^M(f_8)\vee\mu^L(f_1)*\\
&*\mu^M(f_2)*\mu^L(f_3)*\mu^L(f_4)*\mu^L(f_5)*\mu^L(f_6)*\mu^M(f_7)*\mu^L(f_8)
\end{aligned} \tag{1.3}$$

Thus, the resulting s-decision of the competitiveness level defining should be based on the dependency:

$$y_s=\max\left[\mu^t(f_1,\dots,f_8)\right],\ s=\overline{1,5}. \tag{1.4}$$

Conclusions. For the first time the method of competitiveness evaluation on the basis of mathematical fuzzy logic was presented. This method takes into account different types of evaluation parameters, excluding all possible combinations of their values duplication, and in that way reduces the cost of the decision by saving time and unnecessary labor costs of experts.

The proposed method of evaluation for the enterprise competitiveness level are based on effectiveness functions of products sales and promotion; company, staff, product competitiveness, financial condition, organizational and enterprise culture, management of the external activities and the functioning of a company.

In our opinion, these functions are effective tools to describing all important aspects of economic activity accurately, eliminating duplication of individual indicators and to assess the prospects of industry or market quickly and efficiently.

The advantages of the method proposed by the authors are:

•it allows to analyze the influence of varied factors affecting the level of competitiveness, in particular, the parameters of external situation coupled with internal activities;

• it allows to make a rational determination of enterprise competitiveness level under incomplete input information based on linguistic information, which significantly simplifies the process of decision making by means of mathematical and computer simulations.

In addition, important advantages of the method are its clarity, transparency and possibility of automation that enables ease of usage by domestic enterprises.

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