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A methodology for diagnosing ecological situation in workplace in wood industry companies

Metodologija utvrđivanja ekološkog stanja radnog okruženja u drvnoindustrijskim tvrtkama

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ABSTRACT • *In the recent years the environment-friendly way of thinking has started to penetrate into areas where its opponents initially seemed to be the most strong – areas of economy and industry. This paper presents a methodology for diagnosing the existing ecological situation in the workplace in wood industry companies. Mathematical model, which is based on fuzzy logic, allows determining critical ecological parameters in the workplace. Taking into consideration the current situation and business objectives, this mathematical model can also be used for developing an optimal business strategy by using the method of fuzzy logic.*

Key words: *wood industry company, ecological situation, workplace, fuzzy logic, diagnostic tree*

SAŽETAK • *Posljednjih nekoliko godina razmišljanja o prostoru koji nas okružuje sve su više počela prodirati i u područja koja su u početku bila najveća barijera za to – u ekonomiju i industriju. U radu je prikazana metodologija utvrđivanja postojećega ekološkog stanja radnog okruženja u drvnoindustrijskim tvrtkama. Metodologija se temelji na matematičkom modelu fuzzy logike. Modelom je moguće utvrditi kritične ekološke parametre radne okoline. Dobivenim rezultatima tvrtka stječe uvid u stvarno stanje na temelju kojega razvija svoje optimalne poslovne strategije.*

Ključne riječi: *drvnoindustrijske tvrtke, ekološko stanje, radna okolina, fuzzy logika, dijagnostičko stablo*

1 INTRODUCTION
1. UVOD

In the recent years the ecological movement has gained in strength all over the world, and will undoubtedly lead to market changes of scope and pace as never before. However, companies' management responsible for environmental protection and acceptable ecological conditions in the workplace cannot be ensured overnight. Ecological problems are very complex, so they must be treated systematically, e. i., they require target-oriented, step-by-step and continuous efforts. A miraculous solution to these problems is not available. Furthermore, it is also unreasonable to complain about the scarcity of financial resources for such purposes (Motik and Oblak, 1998).

As wood industry is one of significant environmental polluters, orientation towards environment-frie-

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ndly production and products has become a necessity and one of the key strategic goals of wood industry companies (Oblak and Tratnik, 1997). As the result of such direction, problems relating to environment-friendly production and products have started to be studied through numerous research programs (Majer, 1995; Hillary, 1997; Hudson, 2000; Zadnik Stirn, 2000; Lipušček, 2005). However, such researches, both in wood industry and in other branches of industry, haves been carried out mainly at the analytical level, and what is lacking is a comprehensive decision-making support system. Real-life systems, such as various types of production in wood industry, are systems where, in addition to numerical data, one has also to deal with social development goals and preferences of employers in assessing their ecological quality. It is precisely for this reason that such problems cannot be solved by using traditional and deterministic mathematical methods and models. The selecting of the optimal ecological decisions in wood industry systems is a very complex and demanding process. Thus, it is absolutely necessary to study new and more effective methods and models adapted to the complex multi-criteria problems (Oblak, 1998).

This paper provides the methodology by which the above problems are solved in a much superior way. By the use of the theory of fuzzy logic, adequately adapted to specific systems and problems, diagnosis is given of the existing ecological situation in the workplace in wood industry companies. Membership functions are established for particular ecological parameters and appropriate operator functions and implications are selected to develop a diagnostic model, and consequently critical ecological parameters are identified.

2 METHODS
2. METODA RADA

2.1 Fuzzy logic and fuzzy sets
2.1. *Fuzzy logika* i *fuzzy postavke*

Fuzzy logic is based on assigning an element to a fuzzy set. In case of ordinary sets, there are only two possibilities: an element either belongs to a set or does not. Fuzzy logic, on the other hand, introduces the notion of fuzzy set, which is defined by elements x and their grade of membership function μ(x). The elements considered in connection with this kind of set have numerical values, which indicate the membership of the elements to fuzzy set. The grade of membership can acquire all values of real numbers between 0 and 1, where 0 indicates that the element concerned does not belong to the set, 1 indicates that the element belongs to the set, and all intermediate values indicate that the element belongs to the said set just to a certain degree (specific membership). This is why in contrast with ordinary linear program (Tilli, 1991):

$$\max Z = CX,\ AX \leq B;\ X \geq 0,$$

where coefficients A, B and C are deterministic values, the problems, where the precision of coefficients and the compliance with constraints are only assumed, are solved by means of fuzzy sets and membership functions.

2.2 Fuzzy operators
2.2. *Fuzzy operatori*

In the universal set there are several fuzzy sets, assigned A, B, C, ... For each of them a corresponding membership function, assigned $\mu_A(x)$, $\mu_B(x)$, $\mu_C(x)$, ... , is defined as described in the previous chapter. In order to reach a new fuzzy set, new membership functions must be adapted. The fuzzy operators are used in determining the grade of membership of elements (parameters) to a new fuzzy set. There are two basic classes of operators: operators for the intersection and union of fuzzy sets - referred to as triangular norms and co-norms, and a class of averaging operators, which model connections between fuzzy sets by t-norms and t-conorms. Each class contains parameterized as well as non-parameterized operators (Zadeh, 1965).

2.3 Diagnostic tree
2.3. Dijagnostičko stablo

The main tool used in diagnostics is a diagnostic tree, where based on implications one passes from basic events to higher tree levels, to composite events, and from these to composite events at still higher levels, etc., finally arriving to the ’top’ event, i.e., the final composite event, presenting the current state of the system.

2.4 Logical inference and implications
2.4. Logični zaključci i utjecaji

For new fuzzy sets, new grades of membership of elements have to be determined. This task is carried out by the use of an appropriate inference, which is a key factor in determining and regulating priority relationships between parameters on lower branches and fuzzy sets at higher levels of the diagnostic tree (Bandemer, 1996). The basic operation of logical inference is implication. Implication is governed by the simple rule (Zimmermann, 2001):

$$\text{if } X = A \text{ then } Y = W$$

where A and W are input and output linguistic variables and X and Y are elements of fuzzy sets. In developing a diagnostic system based on fuzzy logic, a particular type of implication must be chosen. The choice of appropriate implication permits to system designers a high degree of subjectivity (innovative approach, intuition). In our case, the choice of the particular implication results from the fact that within individual rules the input variables, which are presented in mathematical form by the membership function, should have an equal impact on the membership of an output variable. In implication ’average’, this is defined by the following equation (Zimmermann, 1987):

$$\mu_{\overline{A,B}}(y) = \frac{\mu_A(x) + \mu_B(x)}{2}, \tag{1}$$

within the framework of a set rule an average of membership of input variables ($X_i = A_{ij}$) to fuzzy sets is calculated, and the result represents the membership of the output variable to the fuzzy set ($\mu_{A,B}(y)$). This matches the impact (weight, priority) of individual input parameters (input fuzzy sets) with the output parameter (output fuzzy set).

3 RESULTS
3. REZULTATI

3.1 Membership functions
3.1. Pripadajuće funkcije

On the basis of a finding, the theory of fuzzy logic is applied to the problem when dealing not only with parameters defined by numerical variables but also with subjective assessments and value judgments that are difficult to define in absolute values and are represented by variables not clearly defined in an ecological system such as a wood industry company (Oblak, 1998). As fuzzy logic is used to deal with descriptive (linguistic) variables and data representing indeterminate and subjective assessments, such as for example 'critical value of wood dust in air', 'great noise', 'acceptable temperature' etc., the fuzzy logic was modified according to the system and problem involved.

Defining the complex wood industry system in time and space as a system, based on mathematical theory of systems, and on established ecological criteria in the working place, parameters - linguistic variables, as for example, temperature, noise, wood dust etc., are used to determine the current state of the wood industry system. They represent the basic events - independent variables of the wood industry system. Each of these linguistic values is adapted in the form of a fuzzy set and a membership function. Figure 1 shows a form of a membership function for the linguistic variable 'temperature in the workplace', created based on expert estimation.

Each linguistic value can be expressed as a membership function, which is defined for each element x of the fuzzy set. For example, acceptable temperature x_i is defined as:

$$\mu_{\text{acceptable temperature}}(x_i) = \begin{cases} 1 & if \;\; 20 \le x_i \le 25 \\ \frac{1}{10}(x_i - 10) & if \;\; 10 \le x_i \le 20 \\ \frac{1}{10}(35 - x_i) & if \;\; 25 \le x_i \le 35 \\ 0 & if \;\; 10 \ge x_i \ge 35 \end{cases} \tag{2}$$

Let us take an example: if the 'temperature in the workplace' (x) is 17 °C, the following grades of membership are obtained (Figure 1 and equation (2)):
$\mu_A(x)$ = acceptable temperature in the workplace = 0.7
$\mu_B(x)$ = unacceptable temperature in the workplace = 0.3

3.2 Fuzzy operators
3.2. *Fuzzy operatori*

After studying and testing several operators, we have chosen the max-operator of disjunction or union as defined by Zadeh (1965):

$$\mu_{A \cup B}(x) = \max(\mu_A(x), \mu_B(x)). \tag{3}$$

The changing of the membership grade value in space is clearly shown by relief representation of the max-operator in Figure 2.

$$\mu_{A \cup B}(x) = \mu_{\text{acceptable temperature in the workplace} \cup \text{unacceptable temperature in the workplace}}(x) =$$
$$= \max(0.7, 0.3) = 0.7$$

This example is presented in Figure 2 through point T, which has the co-ordinates ($\mu_A(x)$, $\mu_B(x)$, $\mu_{A \cup B}(x)$) = (0.7, 0.3, 0.7).

3.3. Fuzzy diagnostics and diagnostic tree
3.3. *Fuzzy dijagnostika* i dijagnostičko stablo

A mathematical model consists of determining the membership functions of individual linguistic variables, determining the operators, writing down a system of rules of logical inference, and finally developing a diagnostic tree. It is used for diagnosing the current situation (state) in the workplace in wood industry company.

A diagnostic tree, developed for the purpose of diagnosing the ecological situation in the workplace in

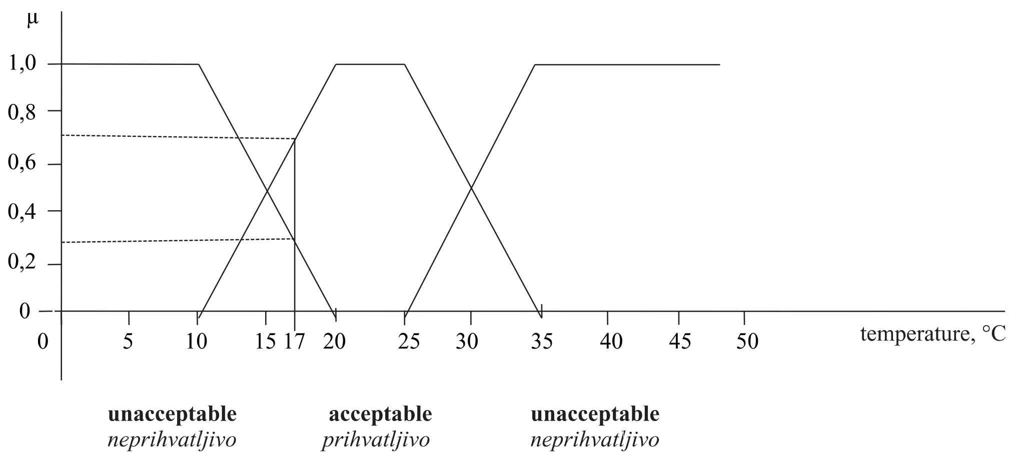

Figure 1 Membership functions for the variable 'temperature in the workplace'
Slika 1. Pripadajuće funkcije varijable *temperatura u radnoj okolini*

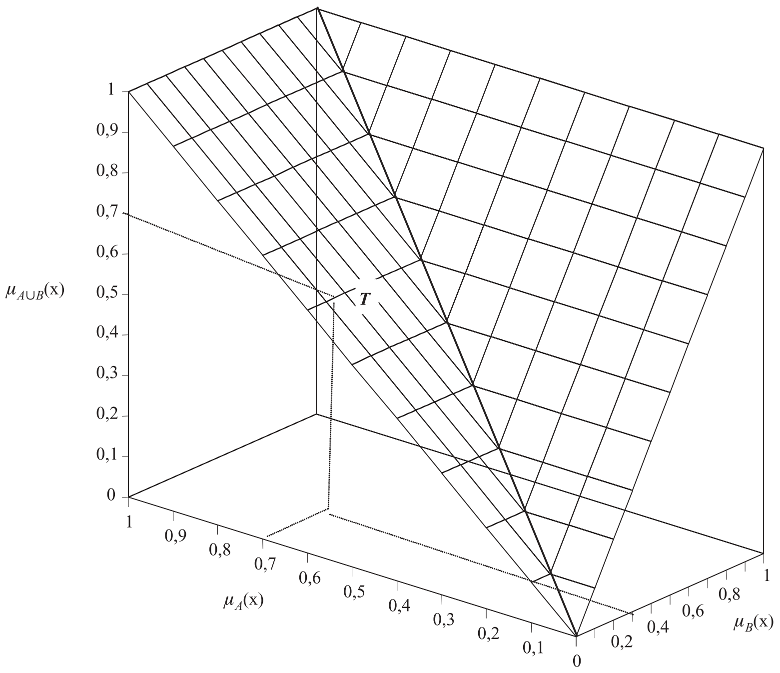

Figure 2 Relief representation of max-operator
Slika 2. Trodimenzionalni prikaz maks-operatora

wood industry companies, is shown in Figure 3. The lower level branches represent the basic events - 9 ecological parameters (temperature, moisture, quality of air, movement of air, dust, vapour, noise, lighting, vibration), which can be measured or can be determined descriptively. Composite events on the next branch of the diagnostic tree (microclimatic parameters, other parameters) are obtained by means of implications, that is, by operations of logical inference written down in the form of logical rules. In this way, the ecological situation in the workplace can be determined on each branch of the tree and the critical points can be established. The top of the tree represents the diagnosis relating to ecological situation in the workplace in wood industry company concerned.

3.4 "If-then" rules
3.4. *If-then pravila*

After having determined the grade of membership to a fuzzy set of elements (parameters), in our case of all 9 parameters, which present the basis for defining the state in the workplace in a wood industry company,

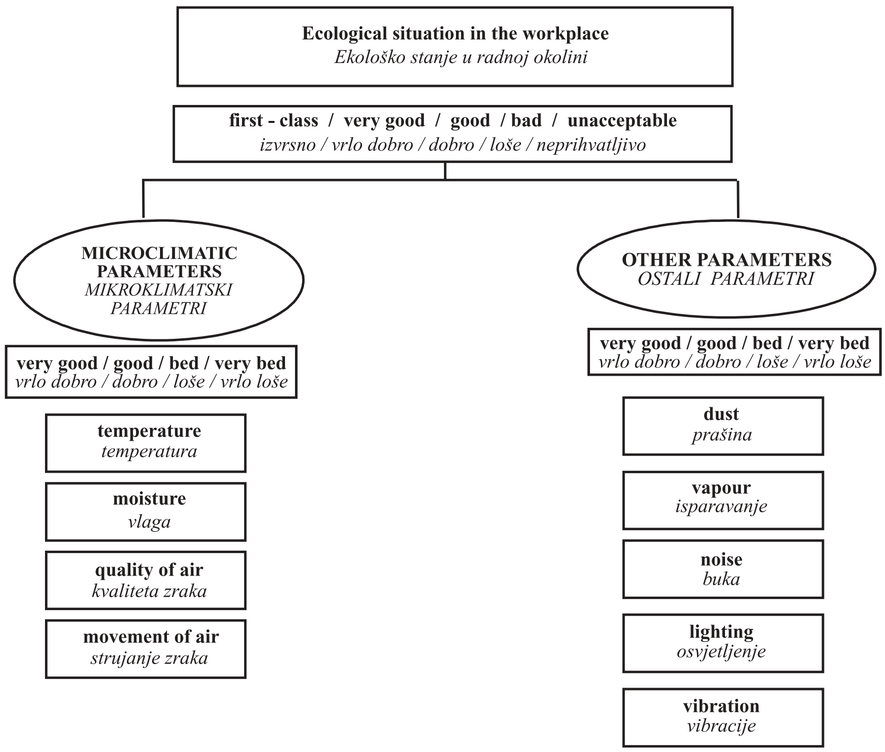

Figure 3 A diagnostic tree used in determining the ecological situation (state) in the workplace in wood industry companies
Slika 3. Prikaz ekološkog stanja radne okoline u drvnoindustrijskim tvrtkama pomoću dijagnostičkog stabla

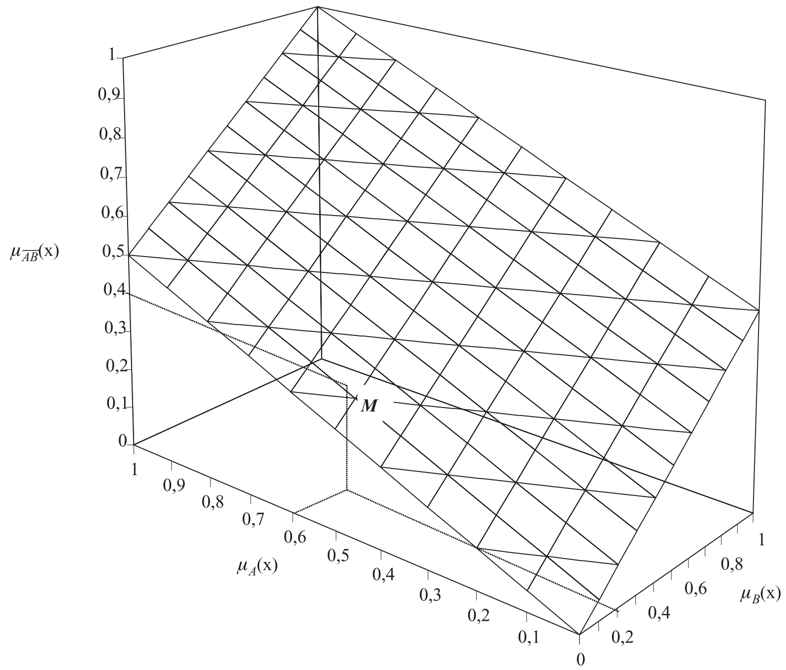

Figure 4 Relief representation of the implication 'average'
Slika 4. Trodimenzionalni prikaz utjecaja srednje vrijednosti

i.e., the first level of the diagnostic tree, we have to reach the new fuzzy sets at higher levels.

An example is taken using the idea presented in Figure 3, which shows the ecological situation in the workplace as a diagnostic tree:

if the microclimatic parameters are good with the grade of membership 0.6 and *if* the other parameters are good with the grade of membership 0.2, *then* the ecological situation in the company workplace is good with the grade of membership 0.4, according to (1):

if $\mu_{\text{microclimatic parameters}}(x) = 0.6$ and
if $\mu_{\text{other parameters}}(x) = 0.2$

$$\textit{then}\ \mu_{\text{microclimatic parameters, other parameters}}(x) = \frac{0.6+0.2}{2} = 0.4$$

This example is presented in Figure 4 by point *M*, which has the co-ordinates (0.6, 0.2, 0.4):

A diagnostic tree was defined, membership functions were determined for particular parameters and appropriate operator functions were selected. By using all these elements, a diagnostic model was developed, which provides the basis for diagnosing the ecological situation in the workplace in wood industry companies. Critical ecological parameters as revealed by the model provide a good basis for the determination of environmental protection goals to be incorporated in the system of business objectives of the company. The results obtained on the basis of the diagnostic model, are then absolutely necessary when developing the business strategy and selecting the best solution for companies.

4 CONCLUSION
4. ZAKLJUČAK

Due to the fact that, in addition to the existing economic criteria, environment-friendly production, ecologically acceptable products and better ecological situation in the workplace have also become a necessity in wood industry companies, as well as one of the key strategic goals, a research study has been dedicated to this issue.

Some problems cannot be solved by using traditional and deterministic mathematical methods and models. Diagnosing the ecological situation and selecting the best ecological decisions in wood industry companies is such a problem. Some of the parameters in our model cannot be expressed quantitatively and they can only be 'described' by linguistic variables. Therefore, undetermined and subjective assessments are expressed descriptively by means of fuzzy logic. This method can deal with descriptive (linguistic) variables and data representing indeterminate and subjective assessments, and hence the developed mathematical model for diagnosing the ecological situation in the workplace in wood industry companies is based on the method of fuzzy logic.

The basic concept of this model-type approach to the diagnosing of ecological situation in the workplace in wood industry companies can also be used, with minor adjustments, for diagnosing similar problems in other branches of industry, which means that the results of the research are important not only theoretically but also in terms of their practical application.

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