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Multicriteria problem of evaluation of the enterprise labor protection management system efficiency

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Introduction of the system of enterprise labor protection management still remains a topical question for business entities of production and non-production activity spheres. The effectiveness evaluation of enterprise labor protection management is based on the method of multicriteria choice of alternatives using the fuzzy preference relations. The application of the chosen method allows, unlike the other methods, to identify its shortcomings in all objectivity detecting the adverse consequences. Therefore, the situation can be normalized in time.

Keywords: *labor protection management system, efficiency of system functioning, multicriteria choice of alternatives, fuzzy preference relations.*

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1. Introduction

The labor protection management system (LPMS) is an effective tool that allows the business entity to ensure the appropriate level of labor protection at the enterprise, satisfying the necessary requirements to ensure safe and healthy working conditions for employees. The issue of LPMS implementation remains the relevant one for the subjects of productive and non-productive spheres of activity. The approaches to the construction and operation of LPMS are constantly improved, taking into account the international experience. In particular, using the risk-oriented approach, the principles, directions, and objectives of constructing a system of occupational safety and health in Ukraine are identified to create a national system preventing occupational risks and providing safe and healthy working conditions [1].

The issue of developing an effective LPMS is relevant for the domestic and foreign companies as well, as one can obviously see in the international regulations adopted at different times [2, 3]. A lot of publications, in particular, [4–9], are devoted to the formulation, optimization, and efficiency evaluation of LPMS problems.

2. Problem formulation

The issue of evaluating the effectiveness of LPMS can't been exhausted since there are different approaches to its solving, due to the characteristics of the business entity — production or non-production activities; the presence of facilities, equipment, high-risk work; features of production and technological processes; relationships within departments; number and training of staff, etc. The proposed approach to evaluate the effectiveness of LPMS of the enterprise is based on the method of multi-criteria choice of alternatives using the fuzzy preference relations [10–14]. There are the well-known examples of this method application to solve problems being related to the economic security of business entities [15–17].

The effectiveness of LPMS is modeled and studied basing on this approach. Also in the paper there is constructed and studied a mathematical model of LPMS operation for a specific enterprise in the chemical industry as an example. To solve the problem there is considered a method [12] basing on an algorithm for alternative's choice in the case of multi- criteria of optimality (fuzzy preference relations).

3. Algorithm description

Let on the universal set X of alternatives, the preference relations R_1, R_2, …, R_m (fuzzy or unfuzzy) with membership functions $\mu_j(x, y)$ be given, as well as the weight coefficients ω_j of the corresponding relations, where $j = \overline{1, m}$.

A convolution (composition) of fuzzy relations R_1, R_2, …, R_m in the form of meet of sets ($Q_1 = \cap_{j=1}^{m} R_j$), with the membership function is constructed as:

$$\mu_{Q_1}(x_i, x_j) = \min\left\{\mu_{R_1}(x_i, x_j), \mu_{R_2}(x_i, x_j), \ldots, \mu_{Rm}(x_i, x_j)\right\}. \tag{1}$$

Determine the set of non-dominant alternatives Q_1^{nd} in the set (X, Q_1):

$$\begin{aligned} \mu^s_{Q_1}(x_i, x_j) &= \max\left\{0; \mu_{Q_1}(x_i, x_j) - \mu_{Q_1}(x_j, x_i)\right\}, \\ \mu^{nd}_{Q1}(x) &= 1 - \max \mu^s_{Q1}(x_i, x_j). \end{aligned} \tag{2}$$

Using the convolution of criteria in the form of the sum (give definition), one can construct a fuzzy preference relation Q_2 in the next form:

$$\mu_{Q2}(x_i, x_j) = \sum_{j=1}^{m} \omega_j \mu_{Rj}(x_i, x_j), \quad \sum_{j=1}^{m} \omega_j = 1, \quad \omega_j \geqslant 0. \tag{3}$$

Obtaining a fuzzy subset of non-dominant alternatives by means of Q_2, there is constructed a membership function

$$\begin{aligned} \mu^s_{Q2}(x_i, x_j) &= \max\left\{0; \mu_{Q2}(x_i, x_j) - \mu_{Q2}(x_j, x_i)\right\}, \\ \mu^{=4}_{Q_2}(x) &= 1 - \max \mu^s_{Q2}(x_j, x_i). \end{aligned} \tag{4}$$

Having found the meet of sets Q_1^{nd}, Q_2^{nd} and the common set of non-dominant alternatives $Q_{nd} = Q_1^{nd} \cap Q_2^{nd}$ with the membership function

$$\mu^{nd}_{Q}(x) = \min\left\{\mu^{nd}_{Q_1}(x), \mu^{nd}_{Q_2}(x)\right\} \tag{5}$$

a choice of alternatives can be derived from the set X_{chnd}:

$$X_{chnd} = \left\{x^* \colon \mu_{nd}(x^*) = \sup_{x} \mu_{nd}(x), x \in X\right\}. \tag{6}$$

We will consider the choice of alternatives from the set X_{chnd} with the greatest degree of non-dominance to be the best one.

4. Modeling of LPMS efficiency of the enterprise with application of the suggested algorithm

Using the results [18], consider the following threats related to the activities of the labor protection service, which may adversely affect the effectiveness of LPMS (alternatives, x_i): x_{25} is a low level of visual agitation on occupational safety; x_{26} is a non-compliance with current requirements for record keeping on labor protection; x_{27} is a failure to implement the planned activities in a timely manner; x_{28} is a non-compliance with the labor protection regulations in a timely manner; x_{29} is the control periodicity violation over the state of labor protection in the structural units; x_{30} is an excess of the injury frequency at the enterprise over their frequency in the industry; x_{31} is an excess of the injury severity at the enterprise over their severity in the industry; x_{32} is a failure to comply with the measures provided for in the acts of the accident investigation in a timely manner; x_{33} is an unpreparedness of the labor protection personnel; x_{34} is the violation of the briefing frequency, certification and re-certification of the occupational safety; x_{35} is gross violation of occupational safety rules, accidents; x_{36} is non-use of personal protective equipment and overalls by workers; x_{37} is the level of provision with the domestic premises; x_{38} is the unscheduled implementation of measures to improve working conditions; x_{39} is the implementation of proposals to improve working conditions. Each alternative reflects a different degree of impact on the effectiveness of LPMS.

According to the criteria R_j, the choice is made among the identified alternatives (threats) that may adversely affect the effectiveness of LPMS: R_1 stands for the threat occurs infrequently and irregularly; R_2 is the appearance of a threat from time to time; R_3 means the threat occurs frequently and regularly over a period of time.

To determine ω_i (the weight of the i-th criterion) using the T. Saati's scale of relative importance of objects [19], let us form a matrix of paired comparisons of criteria (when the criterion located in the row is compared with all the criteria specified in the column of matrix), according to which the choice among threats to the effectiveness of LPMS is performed:

$$A = \begin{Vmatrix} 1 & 1/7 & 1/9 \\ 7 & 1 & 1/3 \\ 9 & 3 & 1 \end{Vmatrix}.$$

Using the algorithm [11–14, 19], one can obtain the weights of the criteria ω_i,consequently the choice is made among the specified threats: threats that occur infrequently and irregularly $\omega_1 = 0.054$; occurrence of a threat from time to time $\omega_2 = 0.289$; threats that occur frequently and regularly (recurrence of the threat) over a period of time $\omega_3 = 0.655$, $\sum_{i=1}^{n} \omega_i = 1$. The consistency index of the matrix of pairwise comparisons A is within the norm ($\leqslant 0.1$), i.e. we get satisfactory results of comparisons.

The threats were compared according to all relations in the R_j criteria, so they could adversely affect the effectiveness of LPMS. The results were evaluated by the membership function:

$$\mu_R(x_i, x_j) = \begin{cases} 1, & \text{if} \quad x_i \succ x_j \quad \text{or} \quad x_i \approx x_j, \\ 0, & \text{if} \quad x_i \prec x_j \end{cases} \tag{7}$$

where x_i, x_j are threats related to the activities of the labor protection service, that can adversely affect the effectiveness of LPMS.

From Eq. (7) one can see that if one threat prevails or is equal to another, in the corresponding matrix cell would be 1, if it is $\prec 1$ in the matrix cell would be 0. Construct a matrix of relations $\mu_{Rj}(x_i, x_j)$ (Tables 1–3).

A convolution of the relations R_1, R_2, R_3 is constructed in the form of meet of sets $Q_1 = R_1 \cap R_2 \cap R_3$ with the membership function $\mu_{Q_1}(x_i, x_j)$ (1). The results are presented in the Table A.1.

Results of the ratio of strict preference Q_1^S (results of $\mu_{Q_1}^s(x_i, x_j)$ calculations by formula (2) are presented in the Table A.2.

The set of non-dominant alternatives Q_1^{nd} is determined in the set (X, Q_1),and the membership function $\mu_{Q1}^{nd}(x)$ is constructed in the following form:

$$\mu_{Q1}^{nd}(x) = [0; 0; 0; 0; 0; 1; 1; 0; 0; 0; 1; 0; 0; 0; 0]\,.$$

There is calculated the fuzzy preference relation $Q_2 = \sum_{j=1}^{m} \omega_j f_i(x)$ and its membership function $\mu_{Q_2}(x_i, x_j) = \sum_{k=1}^{3} \omega_k \mu_{R_k}(x_i, x_j)$. The results of calculations under the condition (3) are presented in the Table A.3).

Taking into account the ratio of the strict preference by the second convolution Q_2^s, the membership function $\mu_{Q2}^s(x_i, x_j)$ is constructed by Eq. (4), and the calculation results are presented in the Table A.4.

Determine the non-dominant alternatives by the second convolution Q_2^{nd} and construct the membership function $\mu_{Q_2}^{nd}(x)$:

Table 1. Relationship matrix $\mu_{R_1}(x_i, x_j)$.

x_i/x_j	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}	x_{38}	x_{39}
x_{25}	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x_{26}	1	1	1	1	1	0	0	1	0	1	0	1	0	1	1
x_{27}	1	0	1	1	1	0	0	0	0	1	0	0	0	1	1
x_{28}	1	0	0	1	1	0	0	0	1	1	0	1	1	1	1
x_{29}	1	0	0	0	1	0	0	0	1	1	0	1	1	1	1
x_{30}	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
x_{31}	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
x_{32}	1	0	1	1	1	0	0	1	1	1	0	1	1	1	1
x_{33}	1	1	1	0	0	0	0	0	1	1	1	0	0	1	1
x_{34}	1	0	0	0	0	0	0	0	0	1	0	1	1	1	1
x_{35}	1	1	1	1	1	0	0	1	0	1	1	1	1	1	1
x_{36}	1	0	1	0	0	0	0	0	1	0	0	1	1	1	1
x_{37}	1	1	1	0	0	0	0	0	1	0	0	0	1	0	1
x_{38}	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
x_{39}	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Table 2. Relationship matrix $\mu_{R_2}(x_i, x_j)$.

x_i/x_j	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}	x_{38}	x_{39}
x_{25}	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x_{26}	1	1	1	1	1	0	0	0	1	1	0	1	1	1	1
x_{27}	1	0	1	0	0	0	0	0	1	0	0	0	0	1	1
x_{28}	1	0	1	1	0	0	0	1	1	1	0	0	0	1	1
x_{29}	1	0	1	1	1	0	0	1	1	1	0	0	0	1	1
x_{30}	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1
x_{31}	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1
x_{32}	1	1	1	0	0	0	1	1	1	1	0	1	1	1	1
x_{33}	1	0	0	0	0	0	1	0	1	1	0	1	1	1	1
x_{34}	1	0	1	0	0	0	1	0	0	1	1	1	1	1	1
x_{35}	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
x_{36}	1	0	1	1	1	0	0	0	0	0	0	1	1	1	1
x_{37}	1	0	1	1	1	0	0	0	0	0	0	0	1	1	1
x_{38}	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
x_{39}	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Table 3. Relationship matrix $\mu_{R_3}(x_i, x_j)$.

x_i/x_j	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}	x_{38}	x_{39}
x_{25}	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1
x_{26}	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1
x_{27}	0	0	1	1	1	0	0	1	1	1	0	1	1	1	1
x_{28}	0	0	0	1	1	0	0	1	1	1	0	1	1	1	1
x_{29}	0	0	0	0	1	0	0	1	1	0	0	1	1	1	1
x_{30}	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
x_{31}	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1
x_{32}	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1
x_{33}	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1
x_{34}	1	0	0	0	1	0	0	0	0	1	1	1	1	1	1
x_{35}	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1
x_{36}	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
x_{37}	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
x_{38}	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
x_{39}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

$$\mu_{Q_2}^{nd}(x) = [0; 0.112; 0; 0; 0; 0.112; 0; 0; 0; 0.112; 0.690; 0; 0; 0; 0] .$$

It is found a common set of the non-dominant alternatives by both convolutions $Q^{nd}(X) = Q_1^{nd}(X) \cap Q_2^{nd}(X)$ with the membership function $\mu_Q^{nd}(x)$ by the equality (5):

$$\mu_Q^{nd}(x) = [0; 0; 0; 0; 0; 0.112; 0; 0; 0; 0; 0.690; 0; 0; 0; 0] .$$

According to the dependence (6), the most important alternative should be considered as one with the maximum degree of non-dominance for both convolutions. The obtained results show that the most significant threats to the effectiveness of LPMS of the analyzed enterprise are x_{30}, namely the exceeding injury frequency at the enterprise over their frequency in the industry and x_{35}, that is gross violation of occupational safety rules, accidents.

5. Conclusions

The obtained simulation results indicate that an accident has occurred or may occur at the assessed enterprise. The application of the method of multi-criteria choice of alternatives based on fuzzy preference relations in the process of evaluating the LPMS effectiveness, considered in this paper, allows, unlike a lot of other methods, to obtain more objective identification of LPMS shortcomings which could potentially lead to undesirable consequences and, accordingly, to take the necessary measures in time to normalize the situation.

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Appendix

Table A.1. Relationship matrix $\mu_{Q1}(x_i, x_j)$.

x_i/x_j	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}	x_{38}	x_{39}
x_{25}	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x_{26}	0	1	1	1	1	0	0	0	0	1	0	1	0	1	1
x_{27}	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
x_{28}	0	0	0	1	0	0	0	0	1	1	0	0	0	1	1
x_{29}	0	0	0	0	1	0	0	0	1	0	0	0	0	1	1
x_{30}	1	0	1	1	1	1	0	1	1	1	0	1	1	1	1
x_{31}	1	0	1	1	1	0	1	0	0	0	0	1	1	1	1
x_{32}	1	0	0	0	0	0	0	1	1	1	0	1	1	1	1
x_{33}	1	0	0	0	0	0	0	0	1	1	0	0	0	1	1
x_{34}	1	0	0	0	0	0	0	0	0	1	0	1	1	1	1
x_{35}	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1
x_{36}	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
x_{37}	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
x_{38}	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
x_{39}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Table A.2. Matrix $\mu^s_{Q1}(x_i, x_j)$.

$\mu^s_{Q1}(x_i, x_j)$	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}	x_{38}	x_{39}
x_{25}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x_{26}	0	0	1	1	1	0	0	0	0	1	0	1	0	1	1
x_{27}	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
x_{28}	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1
x_{29}	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1
x_{30}	1	0	1	1	1	0	0	1	1	1	0	1	1	1	1
x_{31}	1	0	1	1	1	0	0	0	0	0	0	1	1	1	1
x_{32}	1	0	0	0	0	0	0	0	1	1	0	1	1	1	1
x_{33}	1	0	0	0	0	0	0	0	0	1	0	0	0	1	1
x_{34}	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1
x_{35}	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1
x_{36}	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
x_{37}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
x_{38}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
x_{39}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A.3. Matrix $\mu_{Q2}(x_i, x_j)$.

$\mu_{Q2}(x_i, x_j)$	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}	x_{38}	x_{39}
x_{25}	1	0.655	0.655	0.655	0.655	0	0	0	0	0	0	0.655	0.655	0.655	0.655
x_{26}	0.345	1	1	1	1	0.655	0.655	0.711	0.944	1	0	1	0.944	1	1
x_{27}	0.345	0	1	0.711	0.711	0	0	0.655	0.944	0.711	0	0	0	0.345	0.345
x_{28}	0.345	0	0.289	1	0.711	0	0	0.944	1	1	0	0.711	0.711	1	1
x_{29}	0.345	0	0.289	0.289	1	0.289	0	0.944	1	0.345	0	0.711	0.711	1	1
x_{30}	1	0.345	1	1	0.711	1	0.944	1	1	1	0.711	1	1	1	1
x_{31}	1	0.345	1	1	1	0.056	1	0.711	0.711	0.711	0.711	1	1	1	1
x_{32}	1	0.289	0.345	0.056	0.056	0	0.289	1	1	1	0.655	1	1	1	1
x_{33}	1	0.056	0.056	0	0	0	0.289	0	1	1	0.711	0.944	0.944	1	1
x_{34}	1	0	0.289	0	0.655	0	0.289	0	0	1	0.944	1	1	1	1
x_{35}	1	1	1	1	1	0.289	0.289	0.345	0.289	0.056	1	1	1	1	1
x_{36}	0.345	0	1	0.289	0.289	0	0	0	0.056	0	0	1	1	1	1
x_{37}	0.345	0.056	1	0.289	0.289	0	0	0	0.056	0	0	0	1	0.944	1
x_{38}	0.345	0	0.655	0	0	0	0	0	0	0	0	0	0.056	1	1
x_{39}	0.345	0	0.655	0	0	0	0	0	0	0	0	0	0	0	1

Table A.4. Matrix $\mu^s_{Q_2}(x_i, x_j)$.

$\mu^s_{Q_2}(x_i, x_j)$	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}	x_{38}	x_{39}
x_{25}	0	0.310	0.310	0.310	0.310	0	0	0	0	0	0	0.310	0.310	0.310	0.310
x_{26}	0	0	1	1	1	0.310	0.310	0.422	0.888	1	0	1	0.888	1	1
x_{27}	0	0	0	0.422	0.422	0	0	0.310	0.888	0.422	0	0	0	0	0
x_{28}	0	0	0	0	0.422	0	0	0.888	1	1	0	0.422	0.422	1	1
x_{29}	0	0	0	0	0	0	0	0.888	1	0	0	0.422	0.422	1	1
x_{30}	1	0	1	1	0.422	0	0.888	1	1	1	0.422	1	1	1	1
x_{31}	1	0	1	1	1	0	0	0.422	0.422	0.422	0.422	1	1	1	1
x_{32}	1	0	0	0	0	0	0	0	1	1	0.310	1	1	1	1
x_{33}	1	0	0	0	0	0	0	0	0	1	0.422	0.888	0.888	1	1
x_{34}	1	0	0	0	0.310	0	0	0	0	0	0.888	1	1	1	1
x_{35}	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1
x_{36}	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1
x_{37}	0	0	1	0	0	0	0	0	0	0	0	0	0	0.888	1
x_{38}	0	0	0.310	0	0	0	0	0	0	0	0	0	0	0	1
x_{39}	0	0	0.310	0	0	0	0	0	0	0	0	0	0	0	0

Багатокритеріальна задача оцінювання ефективності системи управління охороною праці підприємства

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Питання впровадження системи управління охороною праці підприємства впродовж багатьох років залишаються актуальним для суб'єктів господарювання виробничої та невиробничої сфер діяльності. У роботі оцінювання ефективності СУОП підприємства базується на застосуванні методу багатокритеріального вибору альтернатив на основі нечіткого відношення переваги. Застосування обраного методу дозволяє, на відміну від низки інших методів, більш об'єктивно виокремити її недоліки, які можуть призвести до небажаних наслідків і, відповідно, вчасно вжити необхідні заходи для нормалізації ситуації.

Ключові слова: *система управління охороною праці, ефективність функціонування системи, багатокритеріальний вибір альтернатив, нечіткі відношення переваги.*