Experimental Research to Evaluation the Quality of the Working Environment

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Abstract: ***Objectives:*** *This paper is devoted to experimental research to evaluation the quality of the working environment. Methods.* ***Methods:*** *The evaluation was based on a basic assumption that the human organism during its work on different jobs affects various risk factors. We assume an ideal working environment with optimal or "zero" values of operating factors.* ***Results:*** *The evaluation process in this case, enters workplace factors: noise, vibration, lighting, dust, electromagnetic fields, radiant heat and ergonomics, stress and safety factors. The most important step is the selection and evaluation that will be based on an evaluation of information and also interviewed people from expert's evaluation. The experiment was focused on four basic physical factors (noise, vibration, dust and lighting) working environment, which are among the most risky in terms of assessing the health of employees and duration of exposure in the workplace during their work shift.*

Keywords: *Software SANNA, Risk assessment, Noise, Vibration, Dust, Lighting*

1 Introduction

Risk assessment is the **process of qualitative and quantitative risk assessment** for occupational health and safety of workers. The more negative factors applied to the working environment, the greater the negative effects on the human organism. In assessing the working environment are used various methods and procedures designed to assess the possibility of harm. Therefore it is necessary to choose a suitable complex multi-criteria method, which, according to obtained information could determine the size of load of a man within the working environment. Selection criteria for assessment are not simple, because there are many indicators that characterize the working environment load. Before the assessment method is determined, it is appropriate to combine qualitative and quantitative assessment, thereby establishing a system for measurement of working environment, taking into account: **the nature of the impacts of the working environment parameters, duration of the impact, the range of risk**

factors operating simultaneously, and the magnitude of the impact of individual parameters of the working environment.
With the mathematical formulation can be reached the target state, which is the idea of a display of the objective complete working environment quality in the spatial coordinates that define the different views, approaches and needs of the specification of the working environment parameters. In the designing of an experimental methodology of a comprehensive assessment of the quality of working environment we will build on the condition that the worker is affected during his work at different job positions by various risk factors. These factors vary by their intensity and duration on which depends their influence on human organism. To quantify these effects is difficult because: [7]

- Each parameter in the working environment **requires a different approach** in analysing its effect on humans,
- Each parameter has a **wide range of effects**,
- The impact of individual risk factors **varies with time and change of working activity**,
- The perception of the effects of the working environment is significantly an **individual** matter.

It is important to determine also whether the environment will be evaluated by one criterion or we have more criteria available. In our case we propose to deal with the evaluation of multiple criteria simultaneously. We propose the following evaluation procedure:

- **Selection of the methods of the working environment quality assessment,**
- **Selection and measurement of the risk factors,**
- **Determining the weights of criteria** (Saaty method and calculation by the software SANNA),
- **Normalisation of the measured values,**
- **Calculation of the total load,**
- **Risk assessment** (determination of the risk acceptability).

2 Materials and Methods

2.1 Selection of the Methods of the Working Environment Quality Assessment

Methods of decision making in general, present the summary of rules and procedures, using which we can come to choosing the best solution. The current situation offers us a wide range of methods of decision making. If we use a distribution based on mutual relation of empiricism and theory contained in the individual methods, it is possible to divide them into three groups of empirical, heuristic and exact methods [2].

In solving practical problems such as the comprehensive assessment of the working environment quality is appropriate to use one of the following methods of multi-criteria decision making. Specific methods, which can be used by a comprehensive assessment, can be as follows: **point method of assessment, proportion index method, Decision Matrix Method - DMM, Forced Decision Matrix Method - FDMM, Analytic Hierarchy Process - AHP, method of quantitative comparison - Fuller method, ranking method, etc.**

The specified methods of multi-criteria decision making vary mainly according to how they determine so called weight of individual criterion. The comprehensive assessment of working environment quality to determine the weights of the criteria we use one of the exact methods and the analytical multilevel evaluation method AHP, which provides a framework for effective decisions in complex decision making situations, it helps simplify and accelerate the natural process of decision making process [1, 3].

2.2 Selection and Measurement of the Risk Factor

By the comprehensive assessment of the working environment is evaluated the interaction of all risk factors. In this case enter the process the workplace factors: **noise, vibration, lighting, air purity, or dust, electromagnetic fields, ergonomics, radiant heat, physical stress, hygienic factors and safety factors**. The most important step is the selection and evaluation will be based on an evaluation of information of interviewed people and also from expert opinions. The next step of a comprehensive evaluation is the measurement of risk factors. The results should then be processed to evaluate and draw conclusions from them.

2.3 Determining the Weights of Criteria

The Analytic Hierarchy Process (AHP) method provides a comprehensive and coherent approach to structuring the problem to quantify the elements that relate to the overall objectives and for evaluating the alternative solutions. Before the application of the method, the valuation entity must define any criteria on the basis of which the evaluation will be conducted [5].

This method is based on pairwise comparisons of the degree of significance of individual criteria. The evaluation is based on so called expert estimation, by which the experts in the field can compare the mutual effect of two factors. These evaluate on the basis of the scale **[equal - weak - moderate - strong – very strong]**, and to this wording evaluation correspondents following values **[1 - 3 - 5 - 7 - 9]** [6, 11, 12].

The pairwise comparison the two criteria are placed in the opposite ends of the line against each other and compared, which is more important. In the middle of the line is number 1, which means that the compared criteria are equally important. Along the line are the numbers 1 to 9, where the number 9 means that the criterion on the relevant end was more important than at the other end criterion. In this case, the form for the evaluation are indicated two options (strong and very strong predominance of factor B over factor A), and as the resulting assessment will appear in the line of the factor B and the column of the factor A the value „1/4“, and in the line of the factor A and the column of the factor B will be indicated the inverse value i.e. the value „4“. If **n** is the total number of elements, which are compared, then the number of comparisons is $n \cdot (n-1)/2$ [5, 13, 14].

Further procedure for determining the weights of criteria is more complicated than other methods because it is necessary:

- For each pairwise comparison matrix to determine a **normalised self-vector** corresponding the maximum real **self-worth** (number) **matrix,** as considered in an absolute value,
- Its components which accordingly determine the weights of criteria and the resulting evaluation can be reached the same way as the **weighted sum** of the determined evaluations multiplied by the weights of criteria.

General procedure of solution

I. **Realisation of the pairwise comparison of the criteria and comparison of the scenarios according to the individual criteria – gaining the matrices.**

II. **Determination of self-worth** (self-number) **of each matrix**

A. Obtaining the characteristic polynomial

a) Solve the matrix determinant form $(\mathrm{A_i} - \lambda \cdot \mathrm{J}) = 0$

b) Use the Fadejev method

c) Use the available software (Matlab, Mathematica etc.)

B. Determination of the roots of the characteristic polynomial and get their self-number, for which is valid $\max|\lambda_i| = SN$

a) Procedures for dealing with such polynomials for example Bairstow method

b) To use the available software (Matlab, Mathematica etc.)

III. **Obtaining the values of the self-vector matrix**

A. Determined self-number of matrix introduced into the system in the form $(\mathrm{A} - \lambda \cdot \mathrm{J}) \cdot \mathrm{x} = 0$

B. We obtain a homogeneous system n – equations (with zero right sides). The solution of it we obtain values so called **self-vector.**

a) Use the method of LAR system solution, for example Gauss elimination method, LU decomposition, Gauss - Jordan method etc.

b) Use the available software (Matlab, Mathematica etc.)

IV. **The transformation of self-vector matrix to the normalised self-vector, which components determine the weights of individual**

criteria and weights of variations according to how they fulfil the requirements of individual criteria.

V. **The final evaluation and ranking by the weighted sums** [6].

In the Table 1 are shown the weights of criteria determined by Saaty´s method of evaluation.

Table 1

Saaty's method of weight criteria estimation

s(i,j)	**Criteria**				**R(i)**		**Weight**
Criteria	**F1**	**F2**	**F3**	**F4**	**Π a(i,j)**	**$[\Pi a(i,j)]^{1/4}$**	**v(i)**
F1	1	3	4	5	60	1	**0,5462**
F2	1/3	1	2	3	2	0,4253	**0,2323**
F3	1/4	1/2	1	2	1/4	0,2521	**0,1377**
F4	1/5	1/3	1/2	1	1/30	0,1533	**0,0837**
Total						1,8307	**1,0000**

2.4 Application of the Software SANNA

Calculation of the vector of weights from the paired comparison matrix is usually part of the special programs implemented by AHP method. The calculation is also possible to realise in Excel with the utilisation of so called Wielandt theorem. This mathematical theorem states that for a vector of weights reciprocal pairwise comparisons matrix is valid:

$$\lim_{r\to\infty} \frac{S^r.e}{e^T.S^r.e} = c.v$$

The relation states that the vector formed by sums of row elements ***r*-squared** matrix ***S*** divided by the sum of all elements of this matrix is close enough for sufficiently large ***r*** of the self-vector of the matrix **S** corresponding to the largest self-number. In individual interact will be calculated the relation **(S^r.e)/ (eT.S^r.e)** pre ***r* = 1, 2, 4, 8 ...** and it is followed how the calculated vectors differ in two consecutive interacts. We can achieve the sufficient accuracy at ***r* = 16** [4, 8, 15].

Such mathematical calculation is used also by the software **SANNA** – System for Analysis of Alternatives. The application utilises five methods of assessment *(TOPSIS, WSA, ELECTRE I, PROMETHEE II and MAPPAC)* and enables to determine the weights by three methods *(Point method, Fuller´s method and Saaty´s procedure)* and to solve multi-criteria problems by seven methods *(TOPSIS, WSA, ELECTRE I, ELECTRE III, PROMETHEE II, ORESTE and MAPPAC)*. With SANNA it is possible to solve up to 100 variations and 50 criteria [9].

3 Results

3.1 Normalisation of the Measured Values Within the Interval <0, 1>

The calculation of the measured values for indicators in the interval <0, 1> can be performed on the relation

$$F_{ij} = 1 - \frac{L_H - L_A}{L_H - L_D}$$

Where: F_{ij} – normalised value of the basic indicator j from the class of the factor i, L_H – upper limit value of the factor, L_D – lower limit value of the factor, L_A – actual (measured) value of the factor [7].

Noise (F1): $F_{ij} = 1 - \frac{80-60}{80-40} = 0{,}5$ **Dust (F2):** $F_{ij} = 1 - \frac{100-54}{100-0} = 0{,}54$

Lighting (F3): $F_{ij} = 1 - \frac{700-620}{700-500} = 0{,}6$ **Vibration (F4):** $F_{ij} = 1 - \frac{5-1{,}3}{5-2{,}5} = 0{,}48$

3.1.1 Calculation of the Total Load

Interpretation of the final coefficient calculation evaluating the level of the working environment at a workplace or in a group of workplaces is based on Table 2 and Figure 1.

Manual calculation is appropriate to process according to the procedure set in Table 2.

Table 2

Procedure of calculation of the factor values of the working environment at n-workplace or valid for n-worker

Factors of the working environment	**Normalised weight of a vector**	**Workplaces**										**Evaluation of each factor at all workplaces**
		1		**2**		**j**			**...**	**n**		
Factor 1	v_1	F_{11}	ζ_{11}	F_{12}	ζ_{12}	F_{1j}	ζ_{1j}		...	F_{1n}	ζ_{1n}	
Factor 2	v_2	F_{21}	ζ_{21}	F_{22}	ζ_{22}	F_{2j}	ζ_{2j}		...	F_{2n}	ζ_{2n}	
.....									...			
Factor i	v_i	F_{i1}	ζ_{i1}	F_{i2}	ζ_{i2}	F_{ij}	ζ_{ij}		...	F_{in}	ζ_{in}	
.....									...			
Factor m	v_m	F_{m1}	ζ_{m1}	F_{m2}	ζ_{m2}	F_{mj}	ζ_{mj}		...	F_{mn}	ζ_{mn}	

Evaluation of all parameters according to workplaces		ζ_1		ζ_2		ζ_j	...		ζ_n	$\zeta_p = \frac{\sum_{j=1}^{n} \zeta_j}{n}$

Real load of the working environment by the safety factors we can express in following relation $\zeta_{ij} = v_i \cdot F_{ij}$.

Where: ζ – real load by the safety factors, v_i – normalised value of the vector weight, F_{ij} – measured normalised value of the safety factors.

The average value of the load by individual indicators ζ_p, which is the indicator of the average load of the whole working environment we can state as follows

$$\zeta_p = \frac{\sum_{j=1}^{n} \zeta_j}{n}$$

Where: ζ_j – are the elements of the column vector.

Overall load of the working environment is then given by $\zeta = \sum_{j=1}^{n} \zeta_j$.

Actual work-loading are given in Table 3.

Table 3

Actual loading of the working environment (1 workstation or 1 worker)

Factor	Normalised value	Normalised value of the weight vector	Actual load
F1 (noise)	0,5	0,5462	0,2731
F2 (dust)	0,54	0,2323	0,12544
F3 (lighting)	0,6	0,1377	0,08262
F4 (vibration)	0,48	0,0837	0,04017
Overall load ζ			**0,5213**

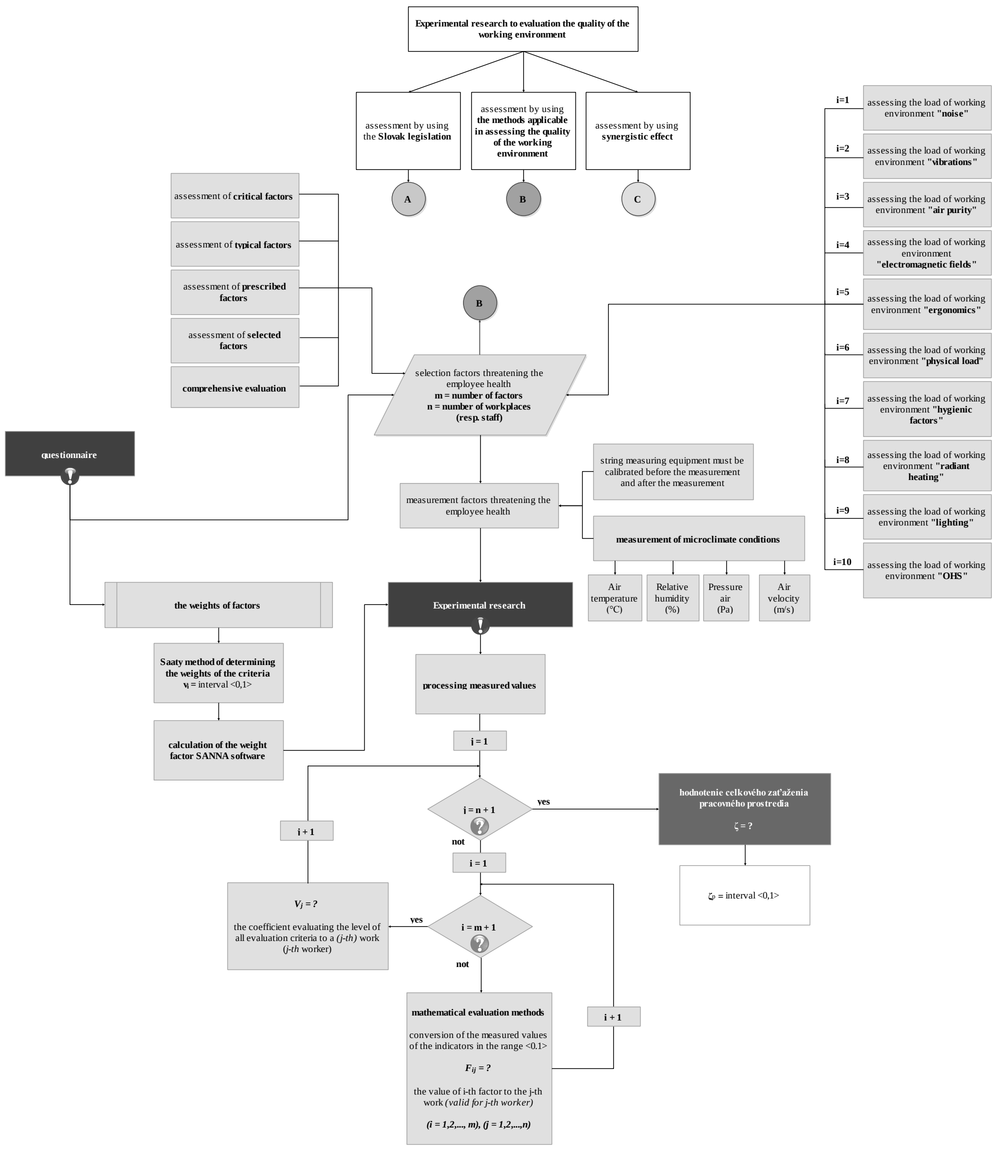

Figure 1

Procedure of the calculation of the working environment factor values at the n-workplace

Conclusion

Comprehensive evaluation of the environmental quality is a new innovative approach for assessing the effects on humans. Computation of the final evaluation factor level work environment in workplace is real work load value equal to 0.5213. It should be noted that this issue is complicated and therefore there are many approaches to its solution. The methodology presented in this paper describes the authors' idea about how to resolve this issue. The presented results are based on past experience in the field of measurement and evaluation of environmental factors, the authors actually perform.

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