

THE USE OF THE DEVELOPMENT INDEX IN THE ASSESSMENT OF OCCUPATIONAL HEALTH AND SAFETY CONDITIONS - CASE STUDY

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Research article

Abstract: Both one- and multi-criteria tasks can be distinguished depending on the number of criteria being considered. Illustrated with an example of seven selected underground workplaces, each described by the set of 10 elements, this article discusses the possibilities to use the development index m_i for determination of the workplaces which, in the light of the multi-criteria evaluation, are characterised by the worst and most favourable working conditions.

Keywords: Occupational health and safety conditions, multidimensional analysis, development index.

Introduction

In the work environment, especially the underground environment, the complexity in the decision-making process is to a large extent related to the nature of activities, which results from, but is not limited to, the impact of the work environment and the reactions of employees to this impact. In this meaning, the problem concerns both the natural environment (natural hazards) and the way in which and conditions under which the work tasks are executed (environmental exposures). The location of the above-mentioned elements in the process of shaping safe working conditions is presented in Fig. 1.

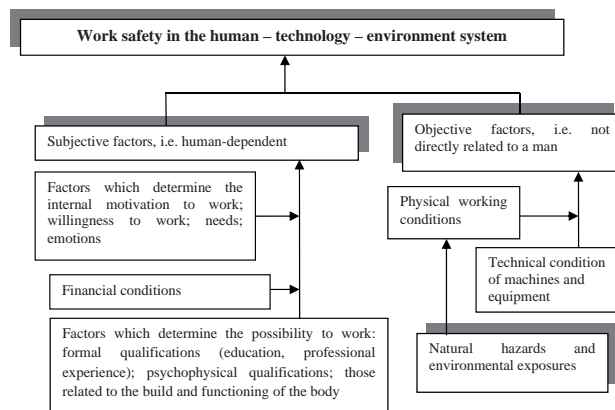


Fig. 1 “Location” of the natural hazards and environmental exposures in the process of shaping safe working conditions (Korban, 2009)

Thus, it can be assumed that in the diagnostic process for the assessment of working conditions we deal with the observation matrix:

$$X = [x_{ij}]$$

where

$i = 1, 2, \dots, n$ n - number of objects;

$j = 1, 2, \dots, m$ m - number of characteristics;

$t = 1, 2, \dots, k$ k - number of time spans.

Materials and methods

Development index - essence, assumptions

Due to the complexity, objects are more and more often described (assessed) with the use of synthetic measures that allow the entire set of diagnostic characteristics (partial ratings) to be replaced by one variable, which is an aggregated (synthetic) quantity (Gordon, 1981; Gordon, 1999; Milligan, 1989; Wedel and Kamakura, 1998). The use of such a solution is essential insofar as it allows, but is not limited to, the organisation of the above-mentioned objects subject to evaluation (ranking).

In the event when the development index is used, first of all the evaluation criteria (goodness criteria) should be determined. To this end, the abstract point P_0 is defined, which illustrates the model solution and whose coordinates $\{x_{01}, x_{02}, \dots, x_{0m}\}$ meet the following conditions (Chmiela and Przybyła, 1997):

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$$x_{0j} = \max_i x_{ij} \quad \text{if } j \in S$$

$$x_{0j} = \min_i x_{ij} \quad \text{if } j \in D$$

where

- S set of stimulants (stimulants - the ratings whose increments in absolute values are considered positive);
- D set of destimulants (destimulants - the ratings whose increments in absolute values are considered negative).

The distance between the individual points P_i and the point P_0 is determined from the following formula:

$$C_{i0} = \sqrt{\sum_{j=1}^m \alpha_j (x'_{ij} - x'_{0j})^2}$$

where

- x'_{ij} normalised coordinates of the point P_i ;
- α_j importance (rank) of the j^{th} partial characteristic, determined based on the experts' opinion survey.

The basic precondition for determination of the above-mentioned measure is the normalisation of output variables. This normalisation is to make variables with different denominations comparable and to standardise the nature of characteristics. For the needs of normalisation it is necessary to distinguish characteristics which are stimulants, destimulants or nominants (for characteristics which are nominants the ranges within which they behave as stimulants and ranges within which they behave as destimulants should be indicated). The following can be used in the normalisation process (Mynarski et al., 1992; Milligan, 1989; Wedel and Kamakura, 1998):

- standardisation of variables:

$$x'_{ij} = \frac{x_{ij}}{s}$$

$$x'_{ij} = \left(\frac{x_{ij}}{s} \right)^2$$

$$x'_{ij} = \frac{x_{ij} - \bar{x}}{s}$$

where

- s standard deviation of variable (for $s \neq 0$),

- quotient transformations:

$$x'_{ij} = \frac{x_{ij}}{\max_{ij} x_{ij}} \quad \text{for stimulants,}$$

$$x'_{ij} = \frac{\min_{ij} x_{ij}}{x_{ij}} \quad \text{for destimulants,}$$

- ranking of variables, which consist in replacing the diagnostic variables by digits/numbers (ranks) resulting from the organisation of observation in accordance with increasing values of variables,
- unitarisation:

$$x'_{ij} = \frac{x_{ij}}{B}$$

$$x'_{ij} = \frac{x_{ij} - \bar{x}}{B}$$

$$x'_{ij} = \frac{x_{ij} - \min_j x_{ij}}{B}$$

$$x'_{ij} = \left(\frac{x_{ij} - \min_j x_{ij}}{B} \right)^2$$

$$x'_{ij} = \sqrt{\frac{x_{ij} - \min_j x_{ij}}{B}}$$

where

- B empirical area of changeability.

If there are quality characteristics within the set, they should be previously quantified (given the numerical values)¹. The essence of the location of assessed solutions in relation to the ideal solution (graphic interpretation) is presented in Fig. 2.

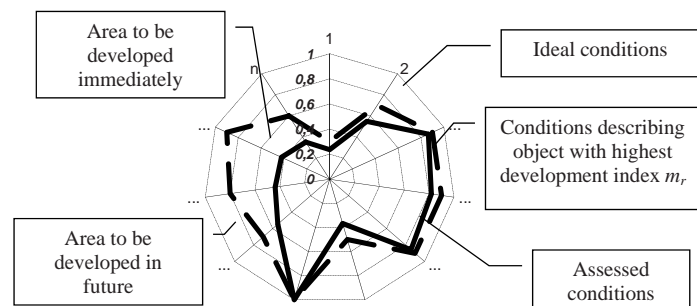


Fig. 2 The essence of the location of solutions - graphic interpretation (Przybyła and Korban, 2007)

¹ In the assessment of quality characteristics, it is possible to use other methods, e.g. Analytic Hierarchy Process (AHP) (Trzaskalik, 2008).

The value of the development index m_i is determined from the following formula:

$$m_i = 1 - \frac{C_{i0}}{\max_i C_{i0}}$$

where

$m_i \in [0;1]$ the more developed an object is the more its measure value approaches 1.

Results

The use of the development index on the example of occupational health and safety diagnostics at selected underground workplaces

The subject of the assessment was seven workplaces located in seven different dog headings where reconstructions were being conducted. The results of measurements of environmental factors are presented in Tab. 1.

Tab. 1 The results of measurements of environmental factors at selected workplaces

	$i = 1$	$i = 2$	$i = 3$	$i = 4$	$i = 5$	$i = 6$	$i = 7$
$j = 1$	7467	7850	6550	7235	7550	6895	6952
$j = 2$	2.4	4.7	3.4	2.5	2.1	3.9	4.2
$j = 3$	0.6	0.9	0.8	0.7	0.7	0.8	0.9
$j = 4$	9	8.5	10	11	10	12.5	9
$j = 5$	0.5	0.4	0.5	0.4	0.5	0.5	0.4
$j = 6$	24.5	28.3	23.2	28.2	27.3	26.8	27
$j = 7$	14.6	11.4	13.6	10.5	11.5	12	11.8
$j = 8$	85.3	87.4	85	83.2	82.6	85.2	86.2
$j = 9$	0.55	0.55	0.61	0.55	0.61	0.58	0.55
$j = 10$	0.51	0.52	0.57	0.51	0.57	0.45	0.53

* Source: own study based on the results of environmental measurements at the "Jan" Coalmine.

The objects (workplaces) put to analysis ($i = 1, 2, \dots, n$) in the following sequence were the faceman workplaces located in:

- the coalgate of longwall 41, bed 508, at the KSP overground railway unloading station level - 32; ($i = 1$);
- the tailgate of longwall 2, bed 620, at the PZS upper drive level ($i = 2$);
- the heading to bed 621, at the pumping station level ($i = 3$);

- the westward research inclined drift, at the KWS battery level ($i = 4$);
- the haulage roadway in bed 508 ($i = 5$);
- the driven coalgate of longwall 17, bed 620 ($i = 6$);
- the tailgate of longwall 45, bed 508, in the area of crossway with the circular cross heading at the level of 645 m ($i = 7$).

For reconstructions no. 1, 2, 4 and 5, the works were carried out using hand drills and explosives. For reconstructions no. 3 and 6 the works were carried out using side-spill loaders LBT - 1200 EH, while for reconstruction no. 7 - using caterpillar loader LG - A 10.10.

The characteristics, i.e. the diagnosed elements of the material working environment ($j = 1, 2, \dots, m$), included:

- energy expenditure [kJ/shift] ($j = 1$);
- total inhalable dust concentration [mg/m^3] at SiO_2 content = 6.0 [%] ($j = 2$);
- respirable dust concentration [mg/m^3] at SiO_2 content = 6.0 [%] ($j = 3$);
- illumination [lx] ($j = 4$);
- luminance uniformity ($j = 5$);
- dry air temperature T_s [$^{\circ}\text{C}$] ($j = 6$);
- air cooling intensity K_w [$\text{mcal}/\text{cm}^2\text{s}$] ($j = 7$);
- noise exposure level for 8 h $L_{Ex,8h}$ [dB] ($j = 8$);
- $a_{ws,eq,8h}$ for local vibrations [m/s^2] for direction components X, Y, Z ($j = 9$);
- $a_{ws,eq,8h}$ for local vibrations [m/s^2] for direction components X, Y, Z (predominating value) ($j = 10$).

For characteristics $j = 4, j = 5, j = 7$ we say about the nature of simulants, while in other cases - about the nature of desimulants.

The rank values assigned to the individual characteristics², determined by the experts' survey (the experts were assumed to be the employees of OHS Department at the "Jan" Coalmine), are as follows:

- = 0.9;
- = 0.9;
- = 0.9;
- = 0.7;
- = 0.5;
- = 0.7;
- = 0.6;
- = 0.8;
- = 0.8;
- = 0.8.

² The range of rank variation is from [0.1, 1.0].

In one-criterion assessment (separately for the energy expenditure, total inhalable dust concentration, respirable dust concentration, illumination, luminance uniformity and dry air temperature), the faceman workplace in the tailgate of longwall 620, bed 620 ($i = 2$) is characterised by as many as six worst environmental results in the group of assessed workplaces - the best results (the most favourable from the point of view of occupational health and safety conditions) in the group of assessed workplaces are presented in Tab. 2.

Tab. 2 Exposure factors - one-criterion assessment

Object (i)	Assessment criterion	The best working conditions	
		Characteristic	Measured parameter (the co-ordinates of point the P_o)
1	2	3	4
1	Energy expenditure [kJ/shift]	$j = 3$	6560
2	Total inhalable dust concentration [mg/m ³] at SiO ₂ content = 6.0 [%]	$j = 5$	2.1
3	Respirable dust concentration [mg/m ³] at SiO ₂ content = 6.0 % [%]	$j = 1$	0.6
4	Illumination E_{sr} [lx]	$j = 6$	12.5
5	Luminance uniformity δ	$j = 1, j = 3, j = 5, j = 6$	0.5
6	Dry air temperature T_s [°C]	$j = 3$	23.2
7	Air cooling intensity K_w [mcal/cm ² s]	$j = 1$	11.5
8	Noise exposure level for 8 h $L_{Ex,8h}$ [dB]	$j = 5$	82.6
9	$A_{ws,eq,8h}$ for local vibrations [m/s ²] for direction components X, Y, Z	$j = 1, j = 2, j = 4, j = 7$	0.55
10	$A_{ws,eq,8h}$ for local vibrations [m/s ²] for direction components X, Y, Z (predominating value)	$j = 6$	0.45

Aiming at determination of one synthetic rating (multi-criteria rating) using the quotient transformations, first of all the values of characteristics describing the individual objects were normalised (Tab. 3).

Tab. 3 Normalisation of the values of characteristics

0.877	0.834	1.000	0.905	0.868	0.950	0.942
0.875	0.447	0.618	0.840	1.000	0.538	0.500
1.000	0.667	0.750	0.857	0.857	0.750	0.667
0.720	0.680	0.800	0.880	0.800	1.000	0.720
1.000	0.800	1.000	0.800	1.000	1.000	0.800
0.947	0.820	1.000	0.823	0.850	0.866	0.859
1.000	0.781	0.932	0.719	0.788	0.822	0.808
0.968	0.945	0.972	0.993	1.000	0.969	0.958
1.000	1.000	0.902	1.000	0.902	0.948	1.000
0.882	0.865	0.789	0.882	0.789	1.000	0.849

Based on the results of multi-criteria assessment, the most favourable working conditions in the group of assessed objects should be considered those at the reconstruction conducted in the coalgate of longwall 41, bed 508, at the KSP overground railway unloading station level - 32 ($i = 1$). The measure of solution goodness for this object was 0.585. Slightly worse conditions were recorded at the reconstruction conducted in the haulage roadway in bed 508 ($i = 5$), for which the development index was 0.485, and at the reconstruction conducted in the westward research inclined drift, at the KWS battery level ($i = 4$), for which $m_i = 0.465$. Definitely, the worst results were obtained at the reconstruction conducted in the tailgate of longwall 45, bed 508, in the area of crossway with the circular cross heading at the level of 645 m ($i = 7$) and in the tailgate of longwall 2, bed 620, at the PZS upper drive level ($i = 2$) - in the first of the above-mentioned headings the development index was 0.095 and in the latter - 0.000.

The values of distance measures are presented in Tab. 4.

Tab. 4 Distance measures

0.310	0.748	0.512	0.400	0.385	0.534	0.677
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The measures of solution goodness are summarised in Tab. 5.

Tab. 5 Measures of solution goodness

0.585	0.000	0.315	0.465	0.485	0.287	0.095
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Conclusion

Functioning within the “man - technology - environment” (M - T - E) system, a man to a large extent deals with uncertain, complex and dynamic situations described by multi-element sets of parameters (characteristics). When assessing these situations, one can formulate both one- and multi-criteria tasks and thus either obtain n results for n assessments conducted under n one-criteria tasks or try to obtain one synthetic value under one multi-criteria task. Based on the values of material working environment factors recorded at workplaces (dustiness, lighting, thermal conditions, noise, vibrations) and the values of energy expenditure characterising the dynamic physical load, 10-element sets of characteristics (Tab. 1) representing the output data for multi-criteria assessment were determined. This assessment was made using the development index. Based on the obtained results, it can be found that for a workplace of a faceman employed in the coalgate of longwall 41, bed 508, at the KSP overground railway unloading station level - 32 ($i = 1$) we deal with the most favourable working conditions among the seven assessed workplaces - the measure of solution goodness in this case was 0.585. Talking about the most favourable working conditions, it need to be borne in mind that these are not the ideal conditions - this reservation concerns especially the physical load (the energy expenditure runs at approx. 7500 kJ/shift, which

means that we deal with a hard work) and noise level (the noise exposure level for 8 h $L_{Ex,8h}$ is 85.3 dB, thus exceeding the permissible value of 85 dB).

Definitely, the worst working conditions were recorded in the tailgate of longwall 2, bed 620, at the PZS upper drive level ($i = 2$). The destimulant characteristics describing this workplace (energy expenditure, total inhalable and respirable dusts, air temperature and noise level) were assessed highest in the group of all the assessed elements as many as five times, exceeding the permissible limits for dry air temperature, total inhalable dust concentration and noise exposure level for 8 h $L_{Ex,8h}$. In addition, in case of stimulant characteristics the luminance uniformity was also lowest among the recorded values. The improvement in working conditions at the said workplace should be sought in a partial work mechanisation, which is confirmed, for instance, by the energy expenditure values recorded for people employed at the reconstruction of the heading to bed 621 ($i = 3$), in the driven coalgate of longwall 17, bed 620 ($i = 6$) or at the reconstruction of the tailgate of longwall 45, bed 508 ($i = 7$), where the works were carried out with use of loaders. Also, the shortening of the work shift (at present, the personnel is employed on a full-time basis, i.e. 7.5 hours) will allow not only to reduce the physical load, but should also contribute to the reduction in exposure to noise and dust generated especially during the drilling works.

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