Multi-Criteria Assessment of Ergonomic Conditions of Work. Case Study

doi:10.2478/mape-2021-0002
Date of submission to the Editor: 04/2021
Date of acceptance by the Editor: 05/2021
MAPE 2021, volume 4, issue 1, pp. 14-22

Zygmunt Korban
ORCID ID: 0000-0003-4312-847X
Silesian University of Technology, **Poland**

INTRODUCTION

The approach to the issue of occupational health and safety is based on the assumption that occupational safety is a resultant of:

- psychophysical predisposition, qualifications and experience of the employees, as well as their behavior;
- material and social environment.

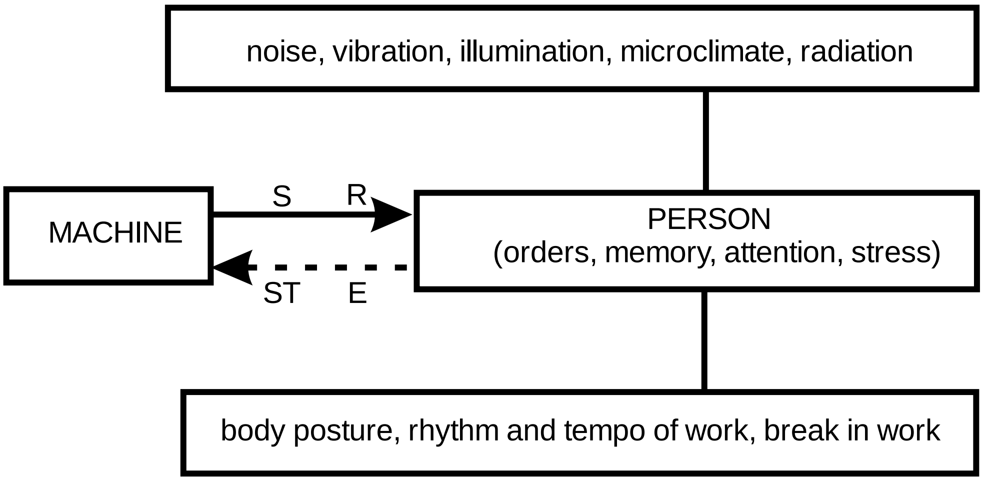
The first element involves the so-called socio-organizational aspect (human aspect) - it comprises inattention or attitude that is in conflict with applicable legal regulations, and non-compliance with the adopted technological and organizational arrangements, which are often the main causes of accidents and material losses. According to Danielson, 30-35% of failures are effected by incorrect human behavior (Danielson, 1987), according to Meister, 23-45% of electronic system failures occur due to human causes (Meister, 1973) and according to Niczyporuk, about 50% of failures in the mining industry result from improper operation of mining machines (Niczyporuk, 1994). Therefore, when we perceive employees (operators or users) as the perpetrators of all activities, special attention should be paid to their motivations, attitudes and behavior, since such elements significantly affect the employees' involvement in the work process and have impact on their work performance. The said elements have been researched by both psychologists and sociologists, but they also constitute the essence of occupational health and safety management.

In the case of the material environment, we are faced with the so-called energy impact conditions of the hazard factor at workstation (physical conditions). The issue is typical for the mining industry, in which, apart from technospheric hazards (hazards resulting from the complexity of technological processes), there are also natural hazards associated with the work environment itself. Although the essence of such hazards and the mechanisms of their triggering have been recognized, and despite the technical and technological progress that has been taking place and which allows for a progressively more effective combating of such hazards, accidents caused by natural threats are still

Contact address: zygmunt.korban@polsl.pl

occurring. Therefore, the conditions in which the employees perform work tasks are being analyzed together with the circumstances in which dysfunctions may occur in the work process (in parallel with the examination of the causes and circumstances of the occurring accidents (failures), also the so-called hazard potential is analyzed).

The external environment, due to its character and occurrence intensity, affects the employees' behavior and state of health (the relations in the biotechnical system "human-technology-environment" are presented in Fig. 1).



S - signaling devices; ST - control devices; R - receptors; E - effectors

Fig. 1 "Human-technology-environment" system

Source: (Koradecka, 1997, Wieczorek, 2008)

In this system, a person (operator, user) performs the subjective role and is the most sensitive element. Therefore, the main problem is to provide him with conditions in which their level of reliability will be the highest and in which they can make the most of their professional aptitudes and qualifications. The occurrence of human errors is a derivative of inappropriate working conditions – the effect of the impact of the following factors:

- natural (resulting from the geospheric work environment);
- technical;
- organizational;
- psychological.

Information about working conditions and the way in which work is carried out is a basis for proper and effective functioning of any economic organization and is essential to ensure efficient management. As part of the overall model of the management system, we can distinguish (Sienkiewicz, 1988):

- decision-making subsystem SD defined by the dependence

$$SD = \langle M^D, R^D \rangle \quad (1)$$

where:

M^D – a set of decision makers;

R^D – a set of connections between decision making elements;

- information subsystem SI defined by the dependence

$$SI = \langle M^I, R^I \rangle \quad (2)$$

where:

M^I – a set of information elements;

R^I – a set of relations between information elements (the so-called information structure),

and it is important that the information determining the shape of the SI subsystem should be (Grabiński, 1995, Nowak, 1990):

- reliable (should reflect the actual state of the examined phenomenon);
- accurate (the measurement of variables should not exceed the specified error rate);
- comparable (information should be standardized while taking into account differences in units and in measuring methods of phenomena);
- adequate (compliance of the features with their substantive meaning should be maintained);
- complete (full availability of data should be ensured involving the values of the objects' features in the examined period of time).

Based on the collected information, a set of diagnostic variables is defined. Due to the complexity of the studied problems, and thus due to the number of diagnostic variables, synthetic measures, which are one-dimensional images of complex phenomena, are often used in decision-making processes. They allow not only to replace the entire set of diagnostic features describing objects with one aggregate variable, but also to organize them in terms of the character of the investigated phenomenon (Müller-Frączek, 2017).

One of the most widespread and most commonly used methods to generate a synthetic final measure is the Simple Additive Weighting method (SAW).

SIMPLE ADDITIVE WEIGHTING (SAW) – DESCRIPTION OF THE METHOD

The Simple Additive Weighting method belongs to the group of single-criterion synthesis methods, which creates a ranking of the examined objects basing on the linear combination of the weight vector *W* [k x 1] and the decision matrix *D* [m x k] (*m* – object, *k* – criterion) (Afshari et al., 2010, Alinezhad et al., 2014, Chen, 2012, Churchman and Ackoff, 1954, Deni et al., 2013, Goodridge, 2016, Huang et al., 2013, Hwang and Yoon, 1981, Janssen, 1996, Koffka and Goodridge, 2015, Kumar et al., 2013, Memariani et al., 2009, Mokhtari et al., 2016, Putra and Punggara, 2018, Simanaviciene and Ustinovichius, 2010, Tahyudin et al., 2018, Trzaskalik, 2014). The weight vector W can be filled arbitrarily (subjective weights), or using mathematical methods (objective weights), and regardless of the determination method of the weights, the values of the coefficients determining the degree of impact of the *k*-th criterion on the final decision should be in the range of ⟨0;1⟩. In the SAW method it is required to specify the nature of each of the criteria: cost criterion or qualitative criterion (in the case of the first of these, it is desirable to minimize the obtained values, in the case of the second - to maximize the obtained values). In turn, the decision matrix *D* is made up by real numbers d_{ij} corresponding to the numerical value adopted by a given criterion for a selected object. To ensure the comparability of the values obtained by the objects under *k* criteria, a linear rescaling of the decision matrix *D* should be made (Trzaskalik red., 2014):

- in the case of the so called cost criterion:

$$v_{ij} = \frac{d_j^{max} - d_{ij}}{d_j^{max} - d_j^{min}} \tag{3}$$

- in the case of the so called qualitative criterion:

$$v_{ij} = \frac{d_{ij} - d_j^{min}}{d_j^{max} - d_j^{min}} \tag{4}$$

which gives a new decision matrix *V* [m x k]. By multiplying this matrix and the weight vector *W* [k x 1], we can determine the ranking vector *R* [m x 1]: the best object is the one that reaches the highest value of ranking coefficient.

EXEMPLARY APPLICATION OF SAW METHOD IN THE PROCESS OF ERGONOMIC ASSESSMENT OF THE SELECTED ELEMENTS OF THE MATERIAL WORK ENVIRONMENT

The assessment involved five miner's work stations in the dog headings being excavated. The characteristics of mining faces are presented in Table 1.

Table 1 Characteristics of mining faces subjected to assessment

Object m	Characteristics of the object
1	• planned (target) length of the heading about 520 m; • separate combined ventilation; • mining with the AM-50 roadheader, possible mining/loosening blasting before the header; • lining ŁP 10/V29/4/A; • other elements of the equipment: belt conveyors Gwarek-1000, suspended monorail KSP-32.
2	• planned (target) length of the heading approx. 610 m; • separate combined ventilation; • mining with the AM-50 roadheader; • lining ŁP 10/V29/3A; • other elements of the equipment: belt conveyors PTG 1000; suspended monorail KSP-32.
3	• planned (target) length of the heading approx. 240 m; • separate combined ventilation; • mining with the roadheader AM-50z-w/Bz; • lining ŁP 10/V29/3A; • other elements of the equipment: scraper conveyor SKAT E-180, belt conveyors PTGm-50/1000, MIFAMA; suspended monorail KSP-32; electric drills ER-61 and impact drills WUP.
4	• planned (target) length of the heading approx. 275 m; • separate forced ventilation; • mining by means of blasting works; • steel lining V-36/12, V-29/12; • other elements of the equipment: ŁBS loader; belt conveyors PTG 1000; suspended monorail KSP-16; air impact drills; • and electric impact drills.

5	• planned (target) length of the heading approx. 340 m; • separate forced ventilation; • mining by means of blasting works (drilling of blast holes with a VVH-1U gadding car); • steel lining V-32/12/4; • other elements of the equipment: side-discharge loaders type SPH-1D; scraper conveyor GROT 67B, belt conveyors PTG 1000.

Source: Own study based on technical and operational documentation

As part of the assessment, a set of eight features describing the ergonomic conditions of the miner's work in the mining face was identified (Table 2).

Table 2 Summary of describing features (evaluation criteria)

k	Describing feature
1	energy expenditure [kJ/shif]
2	oxygen content [%]
3	methane content [%]
4	total dust concentration [mg/m^3] with the content of SiO_2 = 6.0 [%]
5	respirable dust concentration [mg/m^3] with the content of SiO_2 = 6.0 [%]
6	illuminance [lx]
7	noise exposure level for 8h $L_{Ex,\,8h}$ [dB]
8	$a_{ws,eq,8h}$ for local vibrations [m/s^2] for directional components X, Y, Z

Source: Own study

The averaged results of control measurements for the miner's workstation employed in the headings $m \in \langle 1 \div 5 \rangle$ are presented in Table 3.

Table 3 Summary of the averaged measurement results at the miner's workstation employed in selected dog headings – input data

	k							
m	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	6250	19.3	0.3	3.2	0.7	9	85.4	0.54
2	6390	18.9	0.2	2.9	0.4	9	84.2	0.51
3	6210	18.7	0.4	2.9	0.4	9	84.9	0.61
4	6595	19.1	0.5	3.1	0.5	8	85.3	0.63
5	6220	18.9	0.9	2.7	0.4	10	85.8	0.62

Source: Own study

The scaled decision matrix V is presented in Table 4.

Table 4 Scaled decision matrix *V*

	k							
m	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	0.896	1.000	0.857	0.000	0.000	0.500	0.250	0.750
2	0.532	0.333	1.000	0.600	1.000	0.500	1.000	1.000
3	1.000	0.000	0.714	0.600	1.000	0.500	0.562	0.167
4	0.000	0.667	0.571	0.200	0.667	0.000	0.313	0.000
5	0.974	0.333	0.000	1.000	1.000	1.000	0.000	0.083

Source: Own study

Using the method based on Shannon entropy (Kobryń, 2014), the entropy vector was determined, and then the vector of objective criteria weights (Table 5).

Table 5 Entropy vector *E* and weight vector *W*

k	E	W
1	0.999	0.008
2	0.999	0.006
3	0.930	0.764
4	0.998	0.018
5	0.987	0.145
6	0.998	0.023
7	0.999	0.006
8	0.997	0.031

Source: own study

Ranking vector *R* [m x 1] is contained in Table 6.

Table 6 Ranking vector *R*

m	r	Ranking place of the object
1	0.704	3
2	0.974	1
3	0.729	2
4	0.543	4
5	0.197	5

Source: own study

The obtained results demonstrate that the most favorable ergonomic assessment, being a resultant of both the way the work was performed and the conditions in which the work process was carried out, was obtained for the miner's workstation m = 2, for which the coefficient r was 0.974. For that workstation we recorded the lowest methane concentration (0.2%), the lowest (ex aequo with m = 3 and m = 5) respirable dust concentration (0.4 mg/m^3), the lowest noise exposure level for 8h $L_{Ex, 8h}$ (84.2 dB) and the lowest acceleration value aws, eq, 8h for local vibrations (0.51 m/s^2).
The assessments of the two subsequent workstations (m = 3 and m = 1) are at a similar level: their coefficients r were: 0.729 and 0.704 respectively.
In the case of the workstation which was second in the ranking (m = 3), we recorded the lowest value of the employee’s energy expenditure (6210 kJ) and one of the lowest (among the assessed workstations) respirable dust concentrations (0.4 mg/m^3). Only at this workstation (and workstation No. 2) the recorded noise exposure level for 8h $L_{Ex, 8h}$ was below the permissible value, i.e. 85 dB.
In the case of the last two workstations in the ranking (m = 4 and m = 5), the coefficients r were: 0.543 and 0.197, respectively. The workstation No. 4 is characterized, among others, by the highest energy expenditure of the miner (6595 kJ), the lowest level of illuminance (8 lx) and the highest acceleration value $a_{ws, eq, 8h}$ for local vibrations (0.63 m/s^2). In turn, the workstation 5 has the highest methane content (0.9%) and the highest noise exposure for 8h $L_{Ex, 8h}$ (85.8 dB).

CONCLUSIONS

In the process of broadly understood assessment, synthetic measures determined on the basis of multivariate statistics methods are becoming increasingly important. Although these methods differ in the way they treat the criteria taken into account (setting interdependence thresholds, unifying the field of the compared criteria), their application offers an option to replace the entire set of features describing the object with one variable being an aggregate. The Simple Additive Weighting (SAW) method used in the article belongs to the so-called discrete multi-criteria decision-making methods, and it consists in determining for each of the diagnosed objects (variants) a linear combination of standardized elements of the decision matrix and the elements of the weight vector. As part of the provided example, ergonomic conditions at 5 workstations in underground dog headings being mined were assessed, taking into account 8 assessment criteria: employee's energy expenditure (a criterion being one of the elements of physical work load assessment), and 7 factors of physical material work environment. The averaged measurement results were used to build the decision matrix *D* [5 x 8], with the criteria 1, 3, 4, 5, 7 and 8 being cost criteria, and the criteria No. 2 and 6 had the character of qualitative criteria. The method based on Shannon entropy was used to determine the weight vector *W*, which made it possible to objectify the criteria weights.

The assessed workstations were located in headings having similar characteristics (dog headings with separate ventilation). The differences concerned only the applied method of excavation (headings 1, 2 and 3 were excavated using roadheader technology and in the case of heading No. 1, blasting works were carried out sporadically before the mining with roadheader, and in headings No. 4 and 5 explosives were used) and the method of ventilation (in the case of headings No. 1, 2 and 3 combined ventilation was used (suction – forced air), and in the case of the other two – forced ventilation).

The first three places in the final ranking were taken by workstations located in the headings were roadheader technology was applied. In the headings No. 1-3, as many as 6 criteria had the most favorable values in terms of the measured parameters (k = 1 – energy expenditure, k = 2 – oxygen content, k = 3 – methane content, k = 5 – respirable dust concentration, k = 7 – noise exposure level for 8h $L_{Ex,\ 8h}$ and k = 8 – $a_{ws,\ eq,\ 8h}$ for local vibrations), with the workstation No. 2 (r = 0.974) having the most favorable parameters in as many as 4 of the above criteria (k = 3, k = 5, k =7 and k = 8).

In the author's opinion, the Simple Additive Weighting method is a helpful diagnostic tool that allows the decision-maker to carry out, among others, a comprehensive assessment of occupational health and safety conditions. This method can be used at the planning stage of preventive actions aimed at improving the conditions of safety and/or work comfort, and thus, it can be a practical tool in the process of testing the hazard potential.

REFERENCES

Afshari, A., Mojahed M. and Yusuff R. (2010). Simple Additive Weighting approach to personnel selection problem. International Journal of Innovation and Technology Management, 1(5), pp. 511-515.

Alinezhad, A., Sarrafha, K. and Amini, A. (2014). Sensitivity analysis of SAW technique: the impact of changing the decision making matrix elements on the final ranking of alternatives. Iranian Journal of Operations Research, 5(1), pp. 82-94.

Chen, T.Y. (2012). Comparative analysis of SAW and TOPSIS based on interval-valued fuzzy sets: discussions on score functions and weight constraints. Expert Systems with Applications, 39(2), pp.1848-1861.

Churchman, C.W. and Ackoff, R.L. (1954). An approximate measure of value. Journal of Operations Research Society of America, 2(1), pp. 172-187.

Danielson, B. (1987). Study of maintenance problems in Swedish mines, Study Raport. Idhammar Konsult AB.

Deni, W., Sudana, O. and Sasmita, A. (2013). Analysis and implementation fuzzy multi-attribute decision making SAW method for selection of high achieving students in faculty level. International Journal of Computer Science, 10(1), pp. 674-680.

Grabiński, T. (1995). Informacyjne aspekty statystyki międzynarodowej. Wiadomości Statystyczne, 9, pp. 31-36.

Goodridge, W. S. (2016). Sensitivity analysis using Simple Additive Weighting method. International Journal of Intelligent Systems and Applications, 8(5), pp. 27-33

Huang, Y.S., Chang, W.C., Li, W.H. and Lin, Z.L. (2013). Aggregation of utility-based individual preferences for group decision-making. European Journal of Operational Research, 229(2), pp. 462-469.

Hwang, C.L. and Yoon, K. (1981). Multiple attribute decision making methods and application. New York: Springer.

Janssen, R. (1996). Multiobjective decision support for environmental management. Dordrecht: Kulwer Academic Publishers.

Kobryń, A. (2014). Wielokryterialne wspomaganie decyzji w gospodarowaniu przestrzenią. Warszawa: Difin.

Koffka, K. and Goodridge, W. (2015). Fault tolerant multi-criteria multi-path routing in wireless sensor networks. International Journal of Intelligent Systems and Applications, 7(6), pp. 55-63.

Koradecka, D. (red.) (1997). Bezpieczeństwo pracy i ergonomia. Warszawa: Centralny Instytut Ochrony Pracy.

Kumar, M., Jayaswal, P. and Kushwah K. (2013). Exploring fuzzy SAW method for maintenance strategy selection problem of material handling equipment. International Journal of Current Engineering and Technology, 3(2), pp. 600-605.

Meister, D. (1973). A critical review of human performance reliability predictive methods. IEEE Transactions of Reliability, 22(3), pp. 116-123.

Memariani, A., Amini, A. and Alinezhad, A. (2009). Sensitivity analysis of simple additive weighting method (SAW): the results of change in the weight of one attribute on the final ranking of alternatives. Journal of Industrial Engineering, 4, pp. 13-18.

Mokhtari, E., Khamehchian, M., Montazer, G. and Nikudel, M. (2016). Landfill site selection using Simple Additive Weighting (SAW) method and artificial neural network method; a case study from Lorestan province, Iran. International Journal of Geography and Geology, 5(10), pp. 209-223.

Müller-Frączek, I. (2017). Propozycja miary syntetycznej. Przegląd Statystyczny, 4, pp. 421-436.

Niczyporuk, Z. T. (1994). Role of technical diagnostics in improvements of safety in coal mines. In: Proceedings of an International Conference on Condition Monitoring. Swansea, 21st-24th March 1994.

Nowak, E. (1990). Problem informacji w modelowaniu ekonometrycznym. Warszawa: Państwowe Wydawnictwo Naukowe.

Putra, D.W.T. and Punggara A.A. (2018). Comparison analysis of simple additive Weighting (SAW) and weigthed product (WP) in decision support systems. In: MATEC Web of Conferences. [on line] 215(1), pp. 1003. Available at: https://pdfs.semanticscholar.org/705b/2d3c3ba9e882f113f53c83ec185f7aef6425.pdf?_ga=2.165226936.624443085.1618500084-257788093.1618500084 [Accessed 25 Jan. 2021].

Sienkiewicz, P. (1988). Inżynieria systemów kierowania. Warszawa: Państwowe Wydawnictwo Ekonomiczne.

Simanaviciene, R. and Ustinovichius, L. (2010). Sensitivity analysis for multiple criteria decision making methods: TOPSIS and SAW. Social and Behavioral Sciences, 2(6), pp. 7743-7744.

Tahyudin, I., Rosyidi, R., Ahmar, A.S. and Haviluddin, H. (2018). Comparison of the Simple Additive Weighting (SAW) with the Technique for Others Reference by Similarity to Ideal Solution (TOPSIS) methods. International Journal of Engineering and Technology, 7(2.2), pp. 87-89.

Trzaskalik, T. (2014). Wielokryterialne wspomaganie decyzji. Przegląd metod i zastosowań. Zeszyty Naukowe Politechniki Śląskiej, 74, pp. 239-263.

Trzaskalik, T. (red.) (2014). Wielokryterialne wspomaganie decyzji. Metody i zastosowania. Warszawa: Polskie Wydawnictwo Ekonomiczne.

Wieczorek, S. (2008). Ergonomia. Kraków – Tarnobrzeg: TARBONUS Sp. z o.o.

Abstract: The supervision of OHS conditions (working conditions and the realization of work tasks) is one of the basic obligations of the employer. The number and variety of describing elements (and thus being subject to assessment) means that synthetic measures (measures that are one-dimensional images of complex phenomena) are more and more frequently applied to solve problems of that type. Although the methods of multivariate statistics used for this purpose differ in the way they treat assessment criteria (defining mutual dependency thresholds, unifying the field of compared criteria), the final effect of their application always offers the option to replace the entire set of features describing a given object with one variable (aggregate). The article presents a potential applicability of one of the so-called discrete multi-criteria decision-making methods (Simple Additive Weighting), which allows to determine a linear combination of normalized elements of the decision matrix and the elements of weight vector. As part of the article, the working conditions at 5 workstations were assessed (a miner's workstation in 5 underground mine workings being excavated), taking into account 8 assessment criteria (6 were cost criteria and 2 – criteria of qualitative character). In effect of the application of the Simple Additive Weighting method, we could determine the ranking vector R, which allowed to order the examined objects and to carry out a comprehensive assessment of OSH conditions occurring in them.

Keywords: discrete multi-criteria decision, OHS