CzOTO 2019, volume 1, issue 1, pp. 18-25

FUZZY TOPSIS IN THE ASSESSMENT OF OHS MANAGEMENT SYSTEM

doi: 10.2478/czoto-2019-0003
Date of submission of the article to the Editor: 26/11/2018
Date of acceptance of the article by the Editor: 16/01/2019

Joanna Tabor – *orcid id: 0000-0002-7746-2970*
Czestochowa University of Technology, **Poland,** *joanna.tabor@wz.pcz.pl*

Abstract: Occupational health and safety (OHS) management is a cycle of decision-making processes, many of which are in fact multi-criterion processes in nature. Therefore, it is important to look for and develop tools to support decision-makers in their actions aimed at improving work safety levels. The objective of this paper is to propose and verify the fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method applied to compare and assess the ways OHS management systems function in different companies. The fuzzy TOPSIS method has already been used for a number of years in assessments of alternative solutions in many different areas, but the application that uses ordered fuzzy numbers is quite original in nature. It is especially beneficial to use the fuzzy approach in OHS management systems, as it makes it possible for experts to assess different criteria using most frequently used linguistic variables. The adopted approach was verified in the study of OHS management systems in four furniture manufacturing companies. Assessment criteria were requirements of the PN-N 18001: 2004 Standard. Thanks to the ordered fuzzy TOPSIS method, the analysed OHS management systems were streamlined from the point of view of 24 assessment criteria, and the best and the worst functioning system was identified. The approach presented here may constitute a significant tool for improving OHS management systems.
Keywords: management system, OHS, enterprise, MCDM, fuzzy TOPSIS

1. INTRODUCTION

There are plentiful examples of OHS management system assessment methods in the literature, e.g.: the Safety Element Method (Alteren, 1999), the Universal Assessment Instrument (Redinger and Levine, 1998), the Occupational Health and Safety Self-Checking Tool (Roy et al., 2005), Tripod Delta (Cambon et al., 2006), the Climate / Culture Safety Questionnaire (EU-OSHA, 2011), the Audit Matrix ILO-OSH 2001 (ILO, 2013), as well as many examples of questionnaire tools (e.g. Fernández-Muñiz et al., 2009; Nja and Fjelltun, 2010; Vinodkumar and Bhasi, 2010; Chen and Chen, 2012). These methods and tools have been systematically developed, as there exists a clear need to assess management systems. At the same time, researchers seek methods and tools outside the classical fields of interest. At the moment, special attention is paid towards multi-criterion decision-making methods and tools (MCDM).

Multi-criterion decision-making processes constitute an integral part of OHS management, but application of tools that support this process (e.g. AHP, TOPSIS, VIKOR, PROMETHEE) is still insufficiently practiced and rarely described in work health and safety literature. The objective of this paper is to propose and verify applications of the fuzzy TOPSIS method using ordered fuzzy numbers, to compare and assess the ways OHS management systems function. The TOPSIS method is a tool that is used in the decision-making process for linear arrangement of variants (Hwang and Yoon, 1981). The method is based upon using the measure of relative distance from the best solution, which constitutes the pattern, and from the worst solution, which constitutes the anti-pattern. The main objective of TOPSIS is to identify an alternative, which would be characterised by the maximum relative proximity level to the pattern and the minimum relative proximity level to the anti-pattern. At the moment, the method that is most frequently used is the fuzzy TOPSIS method (Chen and Hwang, 1992). On the other hand, the ordered fuzzy numbers model was proposed by W. Kosiński, P. Prokopowicz, and D. Ślęzak in 2002 (Kosiński et al., 2003). The ordered fuzzy number (OFN) is an orderly pair of continuous functions $A = (f_A , g_A),\ where\ f_A, g_A: [0,1] \to \mathbb{R}$ .The individual functions of OFN are respectively: f_A – rising part (*UP*) and g_A – falling part (*DOWN*), which has certain limits: $UP_A = (l_A, 1_A^-)$ and $DOWN_A = (1_A^+, p_A)$. Membership function of OFN is determined as follows:

$$\mu_A(x) = \begin{cases} 0, & when\ x \notin [l_A, p_A] \\ f_A^{-1}(x), & when\ x \in UP_A \\ 1, & when\ x \in [1_A^-, 1_A^+] \\ g_A^{-1}(x), & when\ x \in DOWN_A \end{cases}$$

Which means that the ordered fuzzy number can be represented using 4 elements: $A = (l_A\ 1_A^-\ 1_A^+\ p_A)$. Some of the fundamental advantages of the ordered fuzzy numbers model include the possibility to go through plentiful operations without losing accuracy, and the possibility of retroactive interference. As presented in this paper, application of the TOPSIS method using ordered fuzzy numbers, and with reference to work health and safety management systems, is original in nature.

2. METHODOLOGY OF RESEARCH

It is especially beneficial to use the fuzzy approach in safety management processes, as it makes it possible for experts to assess different criteria using most frequently used linguistic variables. Modern OHS management systems are intrinsically complicated, therefore the number of criteria being assessed in such a system can be very high (Holubová, 2016). The paper makes use of the assessment blurring method by extending assessment ranges to include fuzzy uncertainty ranges, which makes the calculations simpler. This approach was comprised in the following procedure:
(1) Creating a fuzzy decision-making matrix *X* using ordered fuzzy numbers:

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1N} \\ x_{21} & x_{22} & \dots & x_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ x_{M1} & x_{M2} & \dots & x_{MN} \end{bmatrix} \tag{1}$$

Where:
$x_{ij} = \left(l_{ij}\ \ 1_{ij}^{-}\ \ 1_{ij}^{+}\ \ p_{ij}\right)\ (i = 1, 2, \ldots M; j = 1, 2, \ldots N)$ are ordered fuzzy numbers. The fuzzy decision-making matrix is constructed based upon replacing sharp assessments x_{ij}^{*} with assessments expressed using ordered fuzzy numbers x_{ij}.
(2) Creating a normalized fuzzy decision-making matrix *Z*:

$$Z = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1N} \\ z_{21} & z_{22} & \cdots & z_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ z_{M1} & z_{M2} & \cdots & z_{MN} \end{bmatrix},\ where: \qquad (2)$$

$$z_{ij} = \begin{cases} \left(\dfrac{l_{ij}}{\max\limits_{i} p_{ij}}\ \dfrac{1_{ij}^{-}}{\max\limits_{i} p_{ij}}\ \dfrac{1_{ij}^{+}}{\max\limits_{i} p_{ij}}\ \dfrac{p_{ij}}{\max\limits_{i} p_{ij}}\right) when\ C_j - \text{"profit"} - type\ criterion \\ \left(\dfrac{\min\limits_{i} p_{ij}}{l_{ij}}\ \dfrac{\min\limits_{i} p_{ij}}{1_{ij}^{-}}\ \dfrac{\min\limits_{i} p_{ij}}{1_{ij}^{+}}\ \dfrac{\min\limits_{i} p_{ij}}{p_{ij}}\right) when\ C_j - \text{"loss"} - type\ criterion \end{cases} \qquad (3)$$

(3) Creating a weighted normalized fuzzy decision-making matrix *V*:

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1N} \\ v_{21} & v_{22} & \cdots & v_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ v_{M1} & v_{M2} & \cdots & v_{MN} \end{bmatrix}, where: v_{ij} = z_{ij} \times w_j\ \ (i = 1, 2, \ldots M; j = 1, 2, \ldots N) \qquad (4)$$

(4) Calculating weights w_j of the particular criteria, according to the maximum deviations method (Yingming, 1997):

$$w_j = \frac{H_j}{\sum_{j=1}^{n} H_j}, where: H_j = \sum_{i=1}^{m} H_{ij} \qquad (5)$$

$$and: H_{ij} = \sum_{k=1}^{m} d(a_{ij}, a_{kj}), where: i \in \{1, 2, \ldots, m\}, j \in \{1, 2, \ldots, n\} \qquad (6)$$

Hence, the scalar weight vector $w = [w_1, w_2, \ldots w_N]$, where $w_N \in \mathbb{R}\ (w_N > 0, n = 1, 2, \ldots N)$ constitutes the weight of the n^th^ criterion, whereas $w_1 + w_2 \ldots + w_N = 1$.
(5) Finding the pattern A^{+} and the anti-pattern A^{-} for assessments against each criterion, whereas:

$$A^{+} = (v_1^{+}, v_2^{+}, \ldots v_N^{+}), \qquad (7)$$

$$\text{where: } v_j^{+} = \left(\max_i l_{v_{ij}}\ \ \max_i 1_{v_{ij}}^{-}\ \ \max_i 1_{v_{ij}}^{+}\ \ \max_i p_{v_{ij}}\right), j = 1, 2, \ldots, N$$

$$A^{-} = (v_1^{-}, v_2^{-}, \ldots v_N^{-}), \qquad (8)$$

$$\text{where: } v_j^{+} = \left(\min_i l_{v_{ij}}\ \ \min_i 1_{v_{ij}}^{-}\ \ \min_i 1_{v_{ij}}^{+}\ \ \min_i p_{v_{ij}}\right), j = 1, 2, \ldots, N$$

(6) Calculating distances of assessments of the particular variants from the pattern and from the anti-pattern, using the following relations:

$$d_i^{+} = \sum_{j=1}^{N} d\left(v_{ij}, v_j^{+}\right) \quad and \quad d_i^{-} = \sum_{j=1}^{N} d\left(v_{ij}, v_j^{-}\right) \quad for\ i = 1, 2, \ldots M \qquad (9)$$

$$\text{where: } d(A,B) = \sqrt{¼[(l_A - l_B)^2 + (1_A^- - 1_B^-)^2 + (1_A^+ - 1_B^+)^2 + (p_A - p_B)^2]}, \quad (10)$$

$$\text{when: } A = (l_A \;\; 1_A^- \;\; 1_A^+ \;\; p_A) \; and \; B = (l_B \;\; 1_B^- \;\; 1_B^+ \;\; p_B)$$

(7) Determining the synthetic variant assessment measure CC_i using relative proximity of assessment variants to the pattern and the anti-pattern:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-}, i = 1, 2, \dots M \quad (11)$$

The lower the distance of the variant assessment from the pattern, and, at the same time, the higher the distance from the anti-pattern, the closer the value of the measure to 1.

(8) Creating a ranking for M variants based upon linear arrangement of synthetic measures CC_i, where $i = 1, 2, \dots M$.

The adopted approach was verified in the study of work health and safety management systems used in four furniture manufacturing companies: S1, S2, S3, and S4. Assessment criteria were requirements of the PN-N 18001: 2004 Standard. Four experts (from an external company) assessed the particular criteria on a seven-grade linguistic scale from bad to excellent in each company separately; and then, in case there were high discrepancies in some assessments, they were agreed upon at a separate meeting. The following 24 requirements were adopted as assessment criteria: C1- General requirements, C2- Commitment of top management, C3- OHS policy, C4- Employee participation, C5- General requirements (planning), C6- Legal and other requirements, C7- General and specific objectives, C8- Planning activities, C9- Structure, responsibilities and accountabilities, C10- Provision of resources, C11- Training, awareness, competence and motivation, C12- Communication, C13- Documentation of the management system, C14- Occupational risk management, C15- Organizing work and activities related to significant hazards, C16- Prevention, preparedness and responding to accidents at work, C17- Acquisition, C18- Subcontracting, C19- Monitoring, C20- Accident investigation, occupational diseases and potentially accidental events, C21- Auditing, C22- Incompatibilities, corrective and prevention actions, C23- Management review and C24- Continuous improvement. Linguistic assessments obtained were assigned their relative fuzzy assessments: *Wrong* (W)- (1)- [0.0, 0.5, 1.5, 2.0], *Very poor* (VP)- (2)- [1.0, 1.5, 2.5, 3.0], *Poor* (P)- (3)- [2.0, 2.5, 3.5, 4.0], *Medium* (M)- (4)- [3.0, 3.5, 4.5, 5.0], *Good* (G)- (5)- [4.0, 4.5, 5.5, 6.0], *Very good* (VG)- (6)- [5.0, 5.5, 6.5, 7.0], *Excellent* (E)- (7)- [6.0, 6.5, 7.5, 8.0].

3. RESULTS

Table 1 lists linguistic assessments of the particular criteria C1-C24 for the analysed OHS management systems S1, S2, S3, and S4.

Table 1
Linguistic assessments of criteria C for the analysed systems S1, S2, S3 and S4

C	**Alternatives**				**C**	**Alternatives**				**C**	**Alternatives**			
	S1	**S2**	**S3**	**S4**		**S1**	**S2**	**S3**	**S4**		**S1**	**S2**	**S3**	**S4**
C1	G	P	M	VG	C9	M	G	G	M	C17	VP	P	P	VP
C2	M	M	P	P	C10	M	G	G	M	C18	VP	P	P	VP

C3	M	P	M	G	C11	G	P	M	M	C19	M	G	P	VG
C4	VP	G	VP	P	C12	VP	VP	M	VG	C20	P	M	M	P
C5	VP	P	VP	M	C13	G	M	P	P	C21	P	VP	P	VP
C6	P	M	P	G	C14	VG	M	M	G	C22	M	P	VP	VP
C7	P	G	P	VG	C15	VP	P	VP	P	C23	VP	M	VP	P
C8	G	M	M	P	C16	M	P	M	VP	C24	VP	P	VP	P

Based upon input data, using formula (1), a fuzzy decision-making matrix was created, which contained ordered fuzzy values of alternative assessments against the criteria. Then, using formulae (2) and (3), a normalised fuzzy decision-making matrix was constructed. On the other hand, criterion weights were calculated using formulae (5) and (6). The scalar weight vector of the assessed criteria C1-C24 adopted the following form: w = [0.062, 0.025, 0.037, 0.062, 0.044, 0.044, 0.068, 0.037, 0.025, 0.044, 0.037, 0.088, 0.044, 0.044, 0.025, 0.044, 0.025, 0.025, 0.062, 0.025, 0.025, 0.044, 0.044, 0.025]. Using the normalized decision-making matrix and the calculated weights, according to formula (4), the weighted normalized decision-making matrix was obtained. The calculation procedure was repeated for the remaining three systems S2, S3, and S4. Table 2 lists fuzzy criteria assessments for the OHS management system S1.

Table 2
List of fuzzy criteria assessments for the OHS management system S1

	Fuzzy assessments	**Normalized fuzzy assessments**	**Weighted normalized fuzzy assessments**
C1	[4.0, 4.5, 5.5, 6.0]	[0.571, 0.643, 0.786, 0.857]	[0.035, 0.040, 0.049, 0.053]
C2	[3.0, 3.5, 4.5, 5.0]	[0.600, 0.700, 0.900, 1.000]	[0.015, 0.018, 0.023, 0.025]
C3	[3.0, 3.5, 4.5, 5.0]	[0.500, 0.583, 0.750, 0.833]	[0.019, 0.022, 0.028, 0.031]
C4	[1.0, 1.5, 2.5, 3.0]	[0.167, 0.250, 0.417, 0.500]	[0.010, 0.016, 0.026, 0.031]
C5	[1.0, 1.5, 2.5, 3.0]	[0.200, 0.300, 0.500, 0.600]	[0.009, 0.013, 0.022, 0.026]
C6	[2.0, 2.5, 3.5, 4.0]	[0.333, 0.417, 0.583, 0.667]	[0.015, 0.018, 0.026, 0.029]
C7	[2.0, 2.5, 3.5, 4.0]	[0.286, 0.357, 0.500, 0.571]	[0.019, 0.024, 0.034, 0.039]
C8	[4.0, 4.5, 5.5, 6.0]	[0.667, 0.750, 0.917, 1.000]	[0.025, 0.028, 0.034, 0.037]
C9	[3.0, 3.5, 4.5, 5.0]	[0.500, 0.583, 0.750, 0.833]	[0.013, 0.015, 0.019, 0.021]
C10	[3.0, 3.5, 4.5, 5.0]	[0.429, 0.500, 0.643, 0.714]	[0.019, 0.022, 0.028, 0.031]
C11	[4.0, 4.5, 5.5, 6.0]	[0.667, 0.750, 0.917, 1.000]	[0.025, 0.028, 0.034, 0.037]
C12	[1.0, 1.5, 2.5, 3.0]	[0.143, 0.214, 0.357, 0.429]	[0.013, 0.019, 0.031, 0.038]
C13	[4.0, 4.5, 5.5, 6.0]	[0.667, 0.750, 0.917, 1.000]	[0.029, 0.033, 0.040, 0.044]
C14	[5.0, 5.5, 6.5, 7.0]	[0.714, 0.786, 0.929, 1.000]	[0.031, 0.035, 0.041, 0.044]
C15	[1.0, 1.5, 2.5, 3.0]	[0.250, 0.375, 0.625, 0.750]	[0.006, 0.009, 0.016, 0.019]
C16	[3.0, 3.5, 4.5, 5.0]	[0.600, 0.700, 0.900, 1.000]	[0.026, 0.031, 0.040, 0.044]
C17	[1.0, 1.5, 2.5, 3.0]	[0.250, 0.375, 0.625, 0.750]	[0.006, 0.009, 0.016, 0.019]
C18	[1.0, 1.5, 2.5, 3.0]	[0.250, 0.375, 0.625, 0.750]	[0.006, 0.009, 0.016, 0.019]
C19	[3.0, 3.5, 4.5, 5.0]	[0.429, 0.500, 0.643, 0.714]	[0.027, 0.031, 0.040, 0.044]
C20	[2.0, 2.5, 3.5, 4.0]	[0.400, 0.500, 0.700, 0.800]	[0.010, 0.013, 0.018, 0.020]
C21	[2.0, 2.5, 3.5, 4.0]	[0.500, 0.625, 0.875, 1.000]	[0.013, 0.016, 0.022, 0.025]
C22	[3.0, 3.5, 4.5, 5.0]	[0.600, 0.700, 0.900, 1.000]	[0.026, 0.031, 0.040, 0.044]
C23	[1.0, 1.5, 2.5, 3.0]	[0.200, 0.300, 0.500, 0.600]	[0.009, 0.013, 0.022, 0.026]
C24	[1.0, 1.5, 2.5, 3.0]	[0.250, 0.375, 0.625, 0.750]	[0.006, 0.009, 0.016, 0.019]

Based upon weighted normalized fuzzy decision-making matrix, using formulae (7) and (8), the pattern and the anti-pattern was identified – Table 3. Then, using formulae (9) and (10), particular assessments' distances from the pattern and from the anti-pattern were calculated – Table 4, and then, based upon formula (11), synthetic assessment measures CC_1 were calculated for the particular systems S1, S2, S3, and S4, which were, respectively: for S1- 0.357, for S2- 0.496, for S3- 0.285, and for S4- 0.594.

Table 3
Fuzzy assessments of the pattern and the anti-pattern

	Pattern	**Anti-pattern**
C1	[0.044, 0.049, 0.058, 0.062]	[0.018, 0.011, 0.031, 0.035]
C2	[0.015, 0.018, 0.023, 0.025]	[0.010, 0.013, 0.018, 0.020]
C3	[0.025, 0.028, 0.034, 0.037]	[0.012, 0.015, 0.022, 0.025]
C4	[0.041, 0.047, 0.057, 0.062]	[0.010, 0.016, 0.026, 0.031]
C5	[0.026, 0.031, 0.040, 0.044]	[0.009, 0.013, 0.022, 0.026]
C6	[0.029, 0.033, 0.040, 0.044]	[0.015, 0.018, 0.026, 0.029]
C7	[0.049, 0.053, 0.063, 0.068]	[0.019, 0.024, 0.034, 0.039]
C8	[0.025, 0.028, 0.034, 0.037]	[0.012, 0.015, 0.022, 0.025]
C9	[0.017, 0.019, 0.023, 0.025]	[0.013, 0.015, 0.019, 0.021]
C10	[0.031, 0.035, 0.041, 0.044]	[0.019, 0.022, 0.028, 0.031]
C11	[0.025, 0.028, 0.034, 0.037]	[0.012, 0.015, 0.022, 0.025]
C12	[0.063, 0.069, 0.082, 0.088]	[0.013, 0.019, 0.031, 0.038]
C13	[0.029, 0.033, 0.040, 0.044]	[0.015, 0.018, 0.026, 0.029]
C14	[0.031, 0.035, 0.041, 0.044]	[0.019, 0.022, 0.028, 0.031]
C15	[0.013, 0.016, 0.022, 0.025]	[0.006, 0.009, 0.016, 0.019]
C16	[0.026, 0.031, 0.040, 0.044]	[0.009, 0.013, 0.022, 0.026]
C17	[0.013, 0.016, 0.022, 0.025]	[0.006, 0.009, 0.016, 0.019]
C18	[0.013, 0.016, 0.022, 0.025]	[0.006, 0.009, 0.016, 0.019]
C19	[0.044, 0.049, 0.058, 0.062]	[0.018, 0.022, 0.031, 0.035]
C20	[0.015, 0.018, 0.023, 0.025]	[0.010, 0.013, 0.018, 0.020]
C21	[0.013, 0.016, 0.022, 0.025]	[0.006, 0.009, 0.016, 0.019]
C22	[0.026, 0.031, 0.040, 0.044]	[0.009, 0.013, 0.022, 0.026]
C23	[0.026, 0.031, 0.040, 0.044]	[0.009, 0.013, 0.022, 0.026]
C24	[0.013, 0.016, 0.022, 0.025]	[0.006, 0.009, 0.016, 0.019]

Table 4
Distances from the pattern and from the anti-pattern

	Distances from the pattern				**Distances from the anti-pattern**			
	S1	**S2**	**S3**	**S4**	**S1**	**S2**	**S3**	**S4**
C1	0.009	0.027	0.018	0.000	0.018	0.000	0.009	0.027
C2	0.000	0.000	0.005	0.005	0.005	0.005	0.000	0.000
C3	0.006	0.013	0.006	0.000	0.006	0.000	0.006	0.012
C4	0.031	0.000	0.031	0.021	0.000	0.031	0.000	0.010
C5	0.018	0.009	0.018	0.000	0.000	0.009	0.000	0.018
C6	0.015	0.007	0.015	0.000	0.001	0.008	0.001	0.015
C7	0.029	0.010	0.029	0.000	0.000	0.020	0.000	0.029
C8	0.000	0.006	0.006	0.013	0.012	0.006	0.006	0.000
C9	0.004	0.000	0.000	0.004	0.000	0.004	0.004	0.000
C10	0.013	0.000	0.006	0.013	0.000	0.013	0.006	0.000
C11	0.000	0.013	0.006	0.006	0.012	0.000	0.006	0.006

C12	0.050	0.050	0.025	0.000	0.000	0.000	0.025	0.050
C13	0.000	0.007	0.015	0.015	0.015	0.007	0.000	0.000
C14	0.000	0.013	0.013	0.006	0.013	0.000	0.000	0.006
C15	0.007	0.000	0.007	0.000	0.000	0.006	0.000	0.006
C16	0.000	0.009	0.000	0.018	0.018	0.009	0.018	0.000
C17	0.007	0.000	0.000	0.007	0.000	0.006	0.006	0.000
C18	0.007	0.000	0.000	0.007	0.000	0.006	0.006	0.000
C19	0.018	0.009	0.027	0.000	0.009	0.018	0.000	0.027
C20	0.005	0.000	0.000	0.005	0.000	0.005	0.005	0.000
C21	0.000	0.007	0.000	0.007	0.006	0.000	0.006	0.000
C22	0.000	0.009	0.018	0.018	0.018	0.009	0.000	0.000
C23	0.018	0.000	0.018	0.009	0.000	0.018	0.000	0.009
C24	0.007	0.000	0.007	0.000	0.000	0.006	0.000	0.006
Sum	0.244	0.190	0.270	0.154	0.136	0.187	0.108	0.226

As follows from the final ranking of systems (stage 8 of the calculation procedure), with such adopted assessment criteria and such determined relation of their significance, the best functioning work health and safety management system is system S4, since S4 > S2 > S1 > S3.

4. DISCUSSION

The key problem as part of this work was to decide on how to determine the weights of the assessed criteria. The most frequently used solution is to use the weights that have been arbitrarily determined by the decision-maker, or to use averaged expert opinions, as part of procedures that are available in the literature. Contrary to the above, this work makes use of the solution that is based upon the maximum deviations method. It is assumed in this method that in case a determined criterion adopts very different values depending on the alternative, then such a criterion plays a very important role in the selection process of the best solution, and thus should have a high weight; on the other hand, in case there is only a small difference in values of a given criterion between the alternatives, then such a criterion is of low significance and has a low weight. At the same time, it should be noted that all the adopted assessment criteria are identical in nature, i.e. they are all stimulants (the more of them, the better), which follows from the adopted system functioning assessment model that can be different as well.

5. CONCLUSION

This work offers an original application of ordered fuzzy numbers and the TOPSIS method in work health and safety management system assessments. The approach proposed here is beneficial in the face of unclear and uncertain information (e.g. in case of expert linguistic assessments). Thanks to the approach as proposed herein, work health and safety management systems used in four companies were compared and streamlined, which made it possible to identify the best and the worst functioning system. Benchmarking of the ways work health and safety management systems function constitutes an important tool of their improvement. Although the TOPSIS method used in the proposed approach is not the only streamlining method, it is the method that is most widely known and best described. On the other hand, the use of ordered fuzzy numbers has extended the range of applications of the TOPSIS method to include the areas that have been insufficiently represented so far, such as, for instance, the area of work health and safety management systems. At the same time, this paper may offer some inspiration to search for further applications of the fuzzy TOPSIS method, both in the above-said area, and to search for further applications of ordered fuzzy numbers within the frameworks of many other multi-criterion decision-making methods.

REFERENCES

Alteren, B., 1999. *Implementation and evaluation of the Safety Element Method at four mining sites,* Safety Science, 31(3), 231-264, DOI: 10.1016/S0925-7535(98)00069-1

Cambon, J., Guarnieri, F., Groeneweg, J., 2006. *Towards a new tool for measuring safety management system performance*, [In:] E. Rigaud, E. Hollnagel (Eds.) Proceeding of the Second Resilience Engineering Symposium, Less Press, Paris, France, 53-62.

Chen, C.-F., Chen, S.-F., 2012. *Scale development of safety management system evaluation for the airline industry*, Accident Analysis & Prevention, 47, 177-181, DOI: 10.1016/j.aap.2012.01.012

Chen, S. J., Hwang, C. L., 1992. *Fuzzy Multiple Attribute Decision Making: Methods and Applications*, Springer, Berlin.

EU-OSHA, 2011. *Occupational Safety and Health Culture Assessment – A Review of Main Approaches and Selected Tools*, Bilbao, Spain.

Fernández-Muñiz, B., Montes-Peón, J. M., Vázquez-Ordás, C. J., 2009. *Relation between occupational safety management and firm performance*, Safety Science, 47, 980-991, DOI: 10.1016/j.ssci.2008.10.022

Holubová, V., 2016. *Integrated Safety Management Systems*, Polish Journal of Management Studies, 14(1), DOI: 10.17512/pjms.2016.14.1.10

Hwang, C. L., Yoon, K., 1981. *Multiple Attribute Decision Making. Methods and Applications,* Springer, Berlin Heidelberg.

ILO, 2013. *Audit Matrix for the ILO Guidelines on Occupational Safety and Health Management Systems (ILO-OSH 2001),* ILO, Switzerland 2013, 115-116.

Kosiński, W., Prokopowicz, P., Ślęzak, D., 2003. *Ordered fuzzy numbers*, Bulletin of the Polish Academy of Sciences Mathematic, 52(3), 327-339.

Nja, O., Fjelltun, S.H., 2010. *Managers' attitudes towards safety measures in the commercial transport sector,* Safety Science, 48, 1073-1080, DOI: 10.1016/j.ssci.2010.02.005

Redinger, C. F., Levine, S. P., 1998. *Development and evaluation of the Michigan occupational health and safety management system assessment instrument: a universal OHSMS performance management tool*, American Industrial Hygiene Association Journal, 59(8), 572-581, DOI: 10.1080/15428119891010758

Roy, M., Desmarais, L., Cadieux, J., 2005. *Ameliorer la performance en SST: les resultats vs les predicteurs*, Perspectives interdisciplinaires sur le travail et la sante, 7(2), [http://pistes.uqam.ca/ v7n2/articles/v7n2a10.htm].

Vinodkumar, M.N., Bhasi, M., 2010. *Safety management practices and safety behaviour: assessing the mediating role of safety knowledge and motivation*, Accident Analysis & Prevention, 42, 2082-2093, DOI: 10.1016/j.aap.2010.06.021

Yingming, W., 1997. *Using the method of maximizing deviation to make decision for multi-indices,* Journal of Systems Engineering and Electronics, 8(7), 21-26.