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A GREY-BASED DECISION-MAKING APPROACH TO THE IMPROVEMENT OF OHS MANAGEMENT SYSTEM

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Abstract: The objective of this paper is to present and verify the approach, using which it is possible to rank management system elements according to the decision-making criteria adopted by decision-makers, in order to reduce incoherence levels within the frameworks of the decision-making process concerning targeting of the system improvement measures. This approach makes use of the grey systems concept and properties of grey numbers. The following three cost-based parameters were used as assessment criteria of the particular elements of the system in terms of improvements: meeting requirements, performance costs, and performance time. This approach was verified in a furniture manufacturing company, based upon the work health and safety management system according to PN-N 18001, which was in place in this company. By using the proposed approach, it was possible to rank all the assessed elements of the system, and to identify those elements that could be improved in the first sequence, taking into account the adopted assessment criteria. This paper makes up for shortages in using the grey system theory to improve work health and safety management systems, and constitutes an original application of this concept in the area of work health and safety management systems. The approach presented herein may constitute a significant tool of improving not only health and safety management systems, but also other management systems as well.

Key words: management system, OHS, enterprises, MCDM, Grey theory

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Introduction

The management system improvement process is aimed at improving its efficiency by introducing desired changes in the proper place and at the proper time. Such improvement measures may take the form of both small refinements being made to the selected elements of the system on a regular basis, and far-reaching changes made to the entire system (Denton, 1982; Law et al., 2006; Oláh et al., 2018). For the improvement process, it is significant that such changes are based upon a well-thought-out assessment of the situation, using the appropriate information and data, i.e., that they result from properly conducted assessment of the management system (CEN, 2009). Due to the need to assess the management system, various methods and tools have been systematically developed (see Cadieux and Desmarais, 2006; and Granerud and Rocha, 2011). There are plentiful examples of method used to assess work health and safety management systems available in literature, e.g.:

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the Universal Assessment Instrument (Redinger and Levine, 1998), the Safety Element Method (Alteren, 1999), the Safety Self-Checking Tool (Roy et al., 2005), the Tripod Delta (Cambon et al., 2006), the Climate / Safety Culture Questionnaire (EU-OSHA, 2011), the ILO-OSH 2001 Audit Matrix (ILO, 2013), and a number of questionnaire tools (e.g. Fernández-Muñiz et al., 2009; Nja and Fjelltun, 2010; Vinodkumar and Bhasi, 2010; Chen and Chen, 2012). At the same time, search has been going on for methods and tools from outside the classical area of research. At the moment, special attention is paid towards multi-criteria decision-making (MCDM) methods and tools (see TOPSIS in Behzadian et al, 2012; VIKOR in Mardani et al., 2016; PROMETHEE in Behzadian et al., 2010; ELECTRE in Govindan and Jepsen, 2016, and much more in Zanakis et al., 1998). Although the multi-criteria decision-making process constitutes an integral part of the work health and safety management system, the use of tools that support this process is still rarely practiced, and poorly described in the work health and safety literature (see Zavadskas and Turskis, 2011).
The objective of this paper is to propose and verify the approach used to rank management system elements according to the criteria adopted by decision-makers, in order to reduce incoherence levels within the frameworks of the decision-making process concerning targeting of the management system improvement measures. Application of the Simos procedure and the grey system theory, as presented in this paper with reference to work health and safety management system improvements, is original in nature.

Key Elements of the Proposed Approach

The Simos procedure, as a ranking tool and a criteria weight identifying tool, is used in many different areas (see Shanian et al., 2008; Fontana et al., 2011; Marzouk et al., 2013; Siskos and Tsotsolas, 2015). This procedure is based upon using the concept of arranging "cards" according to some pre-determined principles. One set of cards corresponds to the criteria that should be ranked; these cards are usually described with criteria names. The other set of cards is the so-called "Blank Cards" which are not described, and whose task is to reflect the difference in significance levels between the particular criteria. Criteria cards are arranged in ascending order, from the lowest to the highest rank, and then "Blank Cards" are inserted in between them in such a way as to account for the difference in significance between the two successive criteria. One "Blank Card" means a difference of two measures, two „Blank Cards" means a difference of three measures, and so on, i.e. the more "Blank Cards" in between the criteria, the bigger the difference in significance between the successive criteria. In this way, the ranking of the analyzed criteria can be accomplished. Another operation within the frameworks of the Simos procedure is conversion of the ranks of the criteria into the weights of the criteria. Simos proposed the following stages of conversion of the ranks into weights (Figueira and Roy, 2002):

- Identify the position of each criterion card and each “Blank Card”, assuming that the least important criterion card receives Rank 1, the next card receives Rank 2, and so on;
- For each criterion card (bearing a determined rank), calculate its non-normalized weight by dividing its ranks total by the number of the criteria that bear such rank;
- For each criterion, calculate its normalized weight by dividing the non-normalized weight of a given criterion by the total sum of non-normalized weights of all the criteria, without taking into account any “Blank Cards”, though.

In this way, weights can be obtained for all the analyzed criteria. Within the approach proposed herein, the Simos procedure was used to rank management system elements (alternatives) according to their significance for the system.

At the same time, the proposed approach makes use of the grey system theory (GST), which, although formulated as long ago as in the 80s of the previous century, is still the most recent methodology of analyzing and evaluating systems within the conditions whereby information concerning these systems is incomplete and uncertain. By using the grey system theory, it is possible to skip plentiful necessary assumptions that occur in case of statistical, fuzzy, and rough methods, and results obtained using grey numbers are much more accurate than in any other approach (Liu et al., 2016). The basic operations involving grey numbers take place according to the following formulas:

$$\otimes G_1 + \otimes G_2 = [\underline{G_1} + \underline{G_2}, \overline{G}_1 + \overline{G}_2]$$

$$\otimes G_1 - \otimes G_2 = [\underline{G_1} - \overline{G}_2, \overline{G}_1 - \underline{G_2}]$$

$$\otimes G_1 \times \otimes G_2 = [\min(\underline{G_1}\underline{G_2}, \underline{G_1}\overline{G}_2, \overline{G}_1\underline{G_2}, \overline{G}_1\overline{G}_2), \max(\underline{G_1}\underline{G_2}, \underline{G_1}\overline{G}_2, \overline{G}_1\underline{G_2}, \overline{G}_1\overline{G}_2)]$$

$$\otimes G_1 \div \otimes G_2 = [\underline{G_1}, \overline{G}_1] \times \left[\frac{1}{\underline{G_2}}, \frac{1}{\overline{G}_2}\right]$$

The proposed approach makes use of the concept of comparing grey numbers according to the formula:

$P\{\otimes G_1 \leq \otimes G_2\} = \frac{max(0, L^* - \max(0, \overline{G}_1 - \underline{G_2}))}{L^*}$, where: $L^* = L(\otimes G_1) + L(\otimes G_2)$; and the lenght of a grey number: $L(\otimes G) = \left|\overline{G} - \underline{G}\right|$.

W wyniku porównania dwóch szarych liczb możliwe są następujące przypadki (Li et al., 2007):

- $If\ \underline{G_1} = \underline{G_2}\ and\ \overline{G}_1 = \overline{G}_2\ that \otimes G_1 = \otimes G_2, then\ P\{\otimes G_1 \leq \otimes G_2\} = 0.5$,
- $If\ \underline{G_2} > \overline{G}_1\ that \otimes G_2 is\ larger\ than \otimes G_1, then\ P\{\otimes G_1 \leq \otimes G_2\} = 1$,
- $If\ \overline{G}_2 < \underline{G_1} that \otimes G_2 is\ smaller\ than \otimes G_1, then\ P\{\otimes G_1 \leq \otimes G_2\} = 0$.

The grey system theory is used in many disciplines of engineering, medical, and social sciences, as evidenced by the systematically growing number of publications concerning its practical applications. Especially fast is growth in the use of the

GST theory in both classical and contemporary multi-criteria decision-making tools (Tzeng and Huang, 2011).

Methodology

Implementation of the proposed approach to rank management system elements according to criteria adopted by decision-makers takes place according to the following procedure:

1) Identify the weights of the particular management system elements as per the Simos procedure.

2) Evaluate the decision-making criteria using linguistic variables.

3) Determine decision-making criteria significance levels, and aggregate these evaluations using a selected method (e.g. the arithmetic mean method):

$$\otimes W_j = \frac{1}{K}\left[\otimes W_j^1 + \otimes W_j^2 + \cdots + \otimes W_j^K\right] \textit{ where: } \otimes W_j^K = \left[\underline{W}_j^K, \overline{W}_j^K\right] \tag{1}$$

4) Evaluation of the particular management system elements by experts using linguistic variables, and aggregation of these evaluations using a selected method (e.g. the arithmetic mean method):

$$\otimes G_{ij} = \frac{1}{K}\left[\otimes G_{ij}^1 + \otimes G_{ij}^2 + \cdots + \otimes G_{ij}^K\right] \tag{2}$$

where: $\otimes G_{ij}^K, (i = 1,2,\ldots,m; j = 1,2,\ldots,n)$ made an assessment of the criterion by the k^th decision-maker, which is represented by a grey number : $\otimes G_{ij}^K = \left[\underline{G}_{ij}^K, \overline{G}_{ij}^K\right]$.

5) Build the grey decision-making matrix:

$$D = \begin{bmatrix} \otimes G_{11} & \otimes G_{12} & \cdots & \otimes G_{1n} \\ \otimes G_{21} & \otimes G_{22} & & \otimes G_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes G_{m1} & \otimes G_{m2} & \cdots & \otimes G_{mn} \end{bmatrix} \tag{3}$$

6) Build the normalized decision-making matrix:

$$D^* = \begin{bmatrix} \otimes G_{11}^* & \otimes G_{12}^* & \cdots & \otimes G_{1n}^* \\ \otimes G_{21}^* & \otimes G_{22}^* & & \otimes G_{2n}^* \\ \vdots & \vdots & \ddots & \vdots \\ \otimes G_{m1}^* & \otimes G_{m2}^* & \cdots & \otimes G_{mn}^* \end{bmatrix} \tag{4}$$

Perform normalization for the profit-type criterion:

$$\otimes G_{ij}^* = \left[\frac{\underline{G}_{ij}}{G_j^{max}}, \frac{\overline{G}_{ij}}{G_j^{max}}\right] \textit{ where: } G_j^{max} = max_{1\le i\le m}\{\underline{G}_{ij}\} \tag{5}$$

Perform normalization for the loss-type criterion:

$$\otimes G_{ij}^* = \left[\frac{\underline{G}_{ij}}{G_j^{max}}, \frac{\overline{G}_{ij}}{G_j^{max}}\right] \textit{ where: } G_j^{max} = \max_{1\le i\le m}\{\underline{G}_{ij}\} \tag{6}$$

7) Build the weighted normalized decision-making matrix:

$$D_W^* = \begin{bmatrix} \otimes V_{11} & \otimes V_{12} & \cdots & \otimes V_{1n} \\ \otimes V_{21} & \otimes V_{22} & & \otimes V_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes V_{m1} & \otimes V_{m2} & \cdots & \otimes V_{mn} \end{bmatrix}, \text{where: } \otimes V_{ij} = \otimes G_{ij}^* \times \otimes W_j \quad (7)$$

8) Identify the best alternative in line with the assumption that for the set m of possible alternatives A = {A_1, A_2, A_3, …A_m}, the ideal alternative A^{max} is defined as follows:

$$A^{max} = \{\otimes G_1^{max}, \otimes G_2^{max}, \dots, \otimes G_n^{max}\} \quad (8)$$

$$A^{max} = \left\{\left[\max_{1\le i\le m} \underline{V}_{i1}, \max_{1\le i\le m} \overline{V}_{i1}\right], \left[\max_{1\le i\le m} \underline{V}_{i2}, \max_{1\le i\le m} \overline{V}_{i2}\right], \dots, \left[\max_{1\le i\le m} \underline{V}_{in}, \max_{1\le i\le m} \overline{V}_{in}\right]\right\} \quad (9)$$

9) Calculate the possibility degree between the compared alternatives A and the ideal alternative A^{max}, using the formula:

$$P\{A_i \le A^{max}\} = \frac{1}{n}\sum_{j=1}^{n} P\{\otimes V_{ij\le} \otimes G_j^{max}\} \quad (10)$$

10) Rank the P values in the ascending order.

The adopted approach was verified in a furniture manufacturing company, based upon the work health and safety management system according to PN-N 18001, which was in place in this company. The work health and safety management system based upon the PN-N 18001 Standard is the system that is most frequently used in Poland (Klimecka-Tatr and Niciejewska, 2016). Two questionnaire tools were prepared for our studies: the first one concerned assessment of the ranks of the particular work health and safety management system elements, while the second one concerned assessment of these elements from the point of view of selected decision-making criteria, as well as assessment of significance levels of the criteria themselves. Three experts: PLE (a proxy of the board for the work health and safety management system), AUD (internal auditor of the work health and safety management system), and SUPA (external auditor of the work health and safety management system) assessed the following three cost-based decision-making criteria (the lower the value, the better): C1- Meeting requirements, C2- Performance costs and C3- Performance time, and 24 components (i.e. work health and safety management system areas): A1- General systemic requirements, A2- Top management commitment, A3- Work health and safety policies, A4- Participation of employees, A5- General planning requirements, A6- Legal and other requirements, A7- General and detailed objectives, A8- Planning activities, A9- Structure, rights and responsibilities, A10- Providing for resources, A11- Training, awareness, competence, and motivation, A12- Communication, A13- Work health and safety management system documentation, A14- Occupational risk management, A15- Organizing works and activities associated with serious hazards, A16- Prevention, preparedness and reacting to accidents at work and serious failures, A17- Purchases, A18, Subcontracting, A19- Monitoring, A20- Investigating accidents at work, occupational diseases and near-misses, A21-

Auditing, A22- Non-conformances and corrective measures, A23- Management review, A24- Continuous improvements. In order to assess significance levels of the three decision-making criteria, experts used the prepared, seven-degree linguistic assessment scale ranging from *insignificant* to *highly significant*. Linguistic assessments were assigned relative grey numbers in the following form: *insignificant* [0.0, 0.1], *low* [0.1, 0.3], *medium-low* [0.3, 0.4], *medium* [0.4, 0.5], *medium-significant* [0.5, 0.6], *significant* [0.6, 0.9] and *highly significant* [0.9, 1.0]. On the other hand, the particular work health and safety management system areas were assessed for each criterion C1, C2, and C3 according to three separate assessment scales. Table 1 contains description of a scale used to make such assessments, together with their corresponding grey numbers.

Table 1. List of linguistic assessment scales used in criteria assessments

A seven-level linguistic scale of grade			Grey number
(C1) Meeting the requirements	(C2) Cost of implementation	(C3) Delivery time	
(CW) Completly wrong	(VL) Very low	(VS) Very short	[0.0, 1.0]
(VP) Very poorly	(L) Low cost	(S) Short time	[1.0, 3.0]
(P) Poor	(MSm) Medium-small	(MSh) Medium-short	[3.0, 4.0]
(M) Medium	(AC) Average cost	(AT) Average time	[4.0, 5.0]
(W) Well	(MLa) Medium-large	(MLo) Medium-long	[5.0, 6.0]
(VG) Very good	(H) High cost	(L) Long time	[6.0, 9.0]
(P) Perfect	(VH) Very high	(VL) Very long	[9.0, 10.0]

Results

PLE, AUD and SUPA experts assessed the ranks of main and detailed alternatives, using the especially prepared questionnaire. Based upon their assessments, the particular alternatives were ranked (Table 2).

Table 2. Ranking of the alternatives according to the Simos procedure

Main alternatives	(A5-A8) P (A9-A18) R (A23) P (A19-A22) P (A2-A4) R (A24) P (A1)
Alternatives A2-A4	(A3) P (A4) P (A2)
Alternatives A5-A8	(A6) P (A7) R (A8) P (A5)
Alternatives A9-A18	(A11) R (A14) P (A12) P (A10) R (A9) P (A15) R (A16) P (A13) P (A17) R (A18)
Alternatives A19-A22	(A20) P (A19) P (A21) R (A22)

P – Alternative preferred; R – Equivalent alternatives

Main alternatives and alternatives in groups (A2-A4), (A5-A8), (A9-A18), and (A19-A22) were arranged in sequence from the most preferred alternative to the least preferred one. The situation in which the alternatives were equivalent was identified as “R”. Questionnaires were also used to identify the number of “Blank Cards”, i.e. to show the difference in significance between the two successive alternatives. Depending on the dispersion degree of assessments of a given alternative’s rank by our experts, either one “Blank Card” or two “Blank Cards” were inserted (no extreme cases were noted). The ranks of alternatives were converted into weights according to the measures as proposed by Simos. Table 3 lists calculations of non-normalized weights for the particular main alternatives and alternatives in groups.

Table 3. Values of non-normalized weights for the particular alternatives in Simos procedure

Main Alternatives	Number of cards	Item	Weight
(A1)	1	1	1
Blank Card	1	2	-
(A2-A4); (A24)	2	3; 4	3.5
Blank Card	2	5; 6	-
(A19-A22)	1	7	7
Blank Card	2	8; 9	-
(A9-A18); (A23)	2	10; 11	10.5
Blank Card	1	12	-
(A5-A8)	1	13	13

Alternatives (A9-A18)	Number of cards	Item	Weight
A17; A18	2	1; 2	1.5
Blank Card	2	3; 4	-
A13	1	5	5
Blank Card	1	6	-
A15; A16	2	7; 8	7.5
Blank Card	2	9; 10	-
A10; A9	2	11; 12	11.5
Blank Card	1	13	-
A12	1	14	14
Blank Card	1	15	-
A11; A14	2	16; 17	16.5

Alternatives (A2-A3)	Number of cards	Item	Weight
A2	1	1	1
Blank Card	2	2; 3	-
A4	1	4	4
Blank Card	1	5	-
A3	1	6	6

Alternatives (A19-A22)	Number of cards	Item	Weight
A21; A22	2	1; 2	1.5
Blank Card	2	3; 4	-
A19	1	5	5
Blank Card	1	6	-
A20	1	7	7

Alternatives (A5-A8)	Number of cards	Item	Weight
A5	1	1	1
Blank Card	1	2	-
A7; A8	2	3; 4	3.5
Blank Card	2	5; 6	-
A6	1	7	7

Following that, based upon non-normalized weights, normalized weights were calculated for the alternatives. Normalized weights were obtained by dividing the non-normalized weight by the total sum of non-normalized weights. Normalized weights for main alternatives were respectively: (A1)- 0.02, (A2-A4)- 0.07, (A5-A8)- 0.27, (A9-A18)- 0.21, (A19-A22)- 0.15, (A23)- 0.21, (A24)- 0.07. In case of alternatives in groups, the aggregation process was also conducted, which consisted in multiplication of the normalized weight of the determined alternative from the group by the weight of the relative main alternative – Table 4.

Table 4. Values of normalized and aggregated weights for alternatives in Simos procedure

Alternatives	Normalized Weight	Agregated Weight	Alternatives	Normalized Weight	Agregated Weight
A2	0.09	0.01	A13	0.05	0.01
A3	0.54	0.04	A14	0.18	0.04
A4	0.36	0.02	A15	0.08	0.02
A5	0.07	0.02	A16	0.08	0.02
A6	0.47	0.13	A17	0.02	0.00
A7	0.23	0.06	A18	0.02	0.00
A8	0.23	0.06	A19	0.33	0.05
A9	0.12	0.02	A20	0.47	0.07
A10	0.12	0.02	A21	0.10	0.02
A11	0.18	0.04	A22	0.10	0.02
A12	0.15	0.03			

As follows from the above analysis, work health and safety management system elements that achieved the highest significance levels were: (A23) Management review, (A6) Legal and other requirements, (A24) Continuous improvements, and (A20) Investigating accidents at work, occupational diseases, and near-misses.
Following that, based upon the second questionnaire, linguistic assessments of significance levels of the three analyzed criteria C1, C2, and C3, and linguistic assessments of the particular alternatives (work health and safety management system elements) were received from experts, and then such assessments were assigned their corresponding grey numbers. Table 5 lists grey criteria assessments and the aggregated assessment obtained after using formula (1), i.e. the formula of aggregation using the arithmetic mean method.

Table 5. List of criteria C significance assessments by our expert

Criteria	Expert Assessment			Weight
	PLE	AUD	SUPA	
C1	[0.6, 0.9]	[0.9, 1.0]	[0.4, 0.5]	[0.63, 0.80]
C2	[0.9, 1.0]	[0.4, 0.5]	[0.5, 0.6]	[0.60, 0.70]
C3	[0.3, 0.4]	[0.6, 0.9]	[0.4, 0.5]	[0.43, 0.60]

Linguistic assessments of the particular alternatives A1-A24 (Table 6) were assigned their corresponding grey numbers, as in Table 1. As a result of aggregation of assessments of the particular alternatives according to formula (2), input data were obtained, required to build the grey decision-making matrix, according to formula (3) – Table 6.
Arrangement of linguistic assessments of criteria C1, C2, and C3 in Table 6 pertains to indications received successively from PLE, AUD, and SUPA.

Table 6. List of assessments of alternatives A made by our PLE, AUD, and SUPA experts for the particular criteria C1, C2, and C3

	Linguistic Assessments (PLE, AUD, SUPA)			Aggregated Grey Assessments		
	C1	C2	C3	C1	C2	C3
(A1)	P, VG, M	MLa, MSm, MLa	MSh, MLo, AT	[6.33, 8.00]	[4.33, 5.33]	[4.00, 5.00]
A2	M, W, M	AC, MSm, AC	AT, S, MSh	[4.33, 5.33]	[3.67, 4.67]	[2.67, 4.00]
A3	VG, W, M	AC, MLa, L	MSh, MLo, AT	[5.00, 6.67]	[3.33, 4.67]	[4.00, 5.00]
A4	M, P, VG	L, MSm, MLa	MLo, AT, L	[4.33, 6.00]	[3.00, 4.33]	[5.00, 6.67]
A5	W, P, M	L, AC, L	MSh, S, S	[4.00, 5.00]	[2.00, 3.67]	[1.67, 3.33]
A6	VG, M, W	MSm, MLa, L	AT, AT, MLo	[5.00, 6.67]	[3.00, 4.33]	[4.33, 5.33]
A7	P, M, VG	MSm, AC, L	MLo, S, AT	[5.67, 8.00]	[2.67, 4.00]	[3.33, 4.67]
A8	M, VG, W	MLa, MSm, L	AT, MSh, MLo	[5.00, 6.67]	[3.67, 4.67]	[4.00, 5.00]
A9	W, W, VG	AC, AC, MSm	MLo, AT, S	[5.33, 7.00]	[3.67, 4.67]	[3.33, 4.67]
A10	W, W, P	AC, AC, H	L, AT, VL	[6.33, 7.33]	[4.67, 6.33]	[6.33, 8.00]
A11	W, VG, M	MLa, AC, AC	MSh, AT, VL	[5.00, 6,67]	[4.33, 5.33]	[5.33, 6.33]
A12	P, P, P	L, MLa, MSm	S, L, AT	[4.33, 6.00]	[3.00, 4.33]	[3.67, 5.67]
A13	M, VG, W	AC, MSm, AC	AT, L, AT	[5.00, 6.67]	[3.67, 4.67]	[4.67, 6.33]
A14	VG, W, W	H, MLa, AC	AT, AT, L	[5.33, 7.00]	[5.00, 6.67]	[4.67, 6.33]
A15	M, P, M	L, MSm, MLa	MSh, AT, S	[3.67, 4.67]	[3.00, 4.33]	[2.67, 4.00]
A16	P, W, M	AC, AC, H	MSh, MLo, MSh	[4.00, 5.00]	[4.67, 6.33]	[3.67, 4.67]
A17	P, P, M	L, L, MSm	MSh, AT, MSh	[3.33, 4.33]	[1.67, 3.33]	[3.33, 4.33]
A18	P, P, M	L, MSm, AC	MSh, MSh, MSh	[3.33, 4.33]	[2.67, 4.00]	[3.00, 4.00]
A19	P, W, M	AC, H, AC	MLo, AT, AT	[6.00, 7.00]	[4.67, 6.33]	[4.33, 5.33]
A20	M, M, W	MSm, MSm, AC	AT, AT, L	[4.33, 5.33]	[3.33, 4.33]	[4.67, 6.33]
A21	W, M, P	MSm, L, MSm	AT, MLo, MSh	[4.00, 5.00]	[2.33, 3.67]	[4.00, 5.00]
A22	P, W, M	AC, L, MLa	MSh, MLo, AT	[4.00, 5.00]	[3.33, 4.67]	[4.00, 5.00]
(A23)	M, P, W	L, MSm, AC	AT, MSh, MLo	[4.00, 5.00]	[2.67, 4.00]	[4.00, 5.00]
(A24)	M, P, M	AC, MSm, H	MSh, AT, MSh	[3.67, 4.67]	[4.33, 6.00]	[3.33, 4.33]

Due to the fact that the adopted criteria were all cost-based in nature, values from the grey decision-making matrix were normalized using formula (6), and data were obtained, required to build the normalized grey decision-making matrix, and, after using formula (7) values required for the weighted normalized grey decision-making matrix were obtained. At this stage, weights of alternatives obtained according to the Simos procedure were used.

Table 7. List of assessments of the grey normalized and grey weighted decision-making matrix

	Normalizes Grey Assessments			Weighted Grey Assessments		
	C1	C2	C3	C1	C2	C3
(A1)	[0.42, 0.53]	[0.31, 0.39]	[0.33, 0.42]	[0.26, 0.42]	[0.19, 0.27]	[0.14, 0.25]
A2	[0.62, 0.77]	[0.36, 0.46]	[0.42, 0.63]	[0.39, 0.61]	[0.21, 0.32]	[0.18, 0.38]
A3	[0.50, 0.67]	[0.36, 0.50]	[0.33, 0.42]	[0.31, 0.53]	[0.21, 0.35]	[0.14, 0.25]
A4	[0.56, 0.77]	[0.39, 0.56]	[0.25, 0.33]	[0.35, 0.61]	[0.23, 0.39]	[0.11, 0.20]
A5	[0.67, 0.83]	[0.46, 0.84]	[0.50, 1.00]	[0.42, 0.67]	[0.27, 0.58]	[0.22, 0.60]
A6	[0.50, 0.67]	[0.39, 0.56]	[0.31, 0.39]	[0.31, 0.53]	[0.23, 0.39]	[0.13, 0.23]
A7	[0.42, 0.59]	[0.42, 0.63]	[0.36, 0.50]	[0.26, 0.47]	[0.25, 0.44]	[0.15, 0.30]
A8	[0.50, 0.67]	[0.36, 0.46]	[0.33, 0.42]	[0.31, 0.53]	[0.21, 0.32]	[0.14, 0.25]
A9	[0.48, 0.62]	[0.36, 0.46]	[0.36, 0.50]	[0.30, 0.50]	[0.21, 0.32]	[0.15, 0.30]
A10	[0.45, 0.53]	[0.26, 0.36]	[0.21, 0.26]	[0.29, 0.42]	[0.16, 0.25]	[0.09, 0.16]

A11	[0.50, 0.67]	[0.31, 0.39]	[0.26, 0.31]	[0.31, 0.53]	[0.19, 0.27]	[0.11, 0.19]
A12	[0.56, 0.77]	[0.39, 0.56]	[0.29, 0.46]	[0.35, 0.61]	[0.23, 0.39]	[0.13, 0.27]
A13	[0.50, 0.67]	[0.36, 0.46]	[0.26, 0.36]	[0.31, 0.53]	[0.21, 0.32]	[0.11, 0.21]
A14	[0.48, 0.62]	[0.25, 0.33]	[0.26, 0.36]	[0.30, 0.50]	[0.15, 0.23]	[0.11, 0.21]
A15	[0.71, 0.91]	[0.39, 0.56]	[0.42, 0.63]	[0.45, 0.73]	[0.23, 0.39]	[0.18, 0.38]
A16	[0.67, 0.83]	[0.26, 0.36]	[0.36, 0.46]	[0.42, 0.67]	[0.16, 0.25]	[0.15, 0.27]
A17	[0.77, 1.00]	[0.50, 1.00]	[0.39, 0.50]	[0.48, 0.80]	[0.30, 0.70]	[0.17, 0.30]
A18	[0.77, 1.00]	[0.42, 0.63]	[0.42, 0.56]	[0.48, 0.80]	[0.25, 0.44]	[0.18, 0.33]
A19	[0.48, 0.56]	[0.26, 0.36]	[0.31, 0.39]	[0.30, 0.44]	[0.16, 0.25]	[0.13, 0.23]
A20	[0.62, 0.77]	[0.39, 0.50]	[0.26, 0.36]	[0.39, 0.61]	[0.23, 0.35]	[0.11, 0.21]
A21	[0.67, 0.83]	[0.46, 0.72]	[0.33, 0.42]	[0.42, 0.67]	[0.27, 0.50]	[0.14, 0.25]
A22	[0.67, 0.83]	[0.36, 0.50]	[0.33, 0.42]	[0.42, 0.67]	[0.21, 0.35]	[0.14, 0.25]
(A23)	[0.67, 0.83]	[0.42, 0.63]	[0.33, 0.42]	[0.42, 0.67]	[0.25, 0.44]	[0.14, 0.25]
(A24)	[0.71, 0.91]	[0.28, 0.39]	[0.39, 0.50]	[0.45, 0.73]	[0.17, 0.27]	[0.17, 0.30]

Then, according to formulas (8) and (9), the ideal solution, i.e. the best alternative, was identified in the form of [0.48, 0.80] [0.30, 0.70] [0.22, 0.60]. Using the principle of comparing two grey numbers and formula (10), a list of P_C values was obtained for all alternatives – Table 8.

Table 8. List of final results

	P_{C1}	P_{C2}	P_{C3}	P_C	W_{SIMOS}
(A1)	1.00	1.00	0.94	0.98	0.02
A2	0.75	0.96	0.73	0.81	0.01
A3	0.90	0.91	0.94	0.91	0.04
A4	0.77	0.84	1.00	0.87	0.02
A5	0.67	0.60	0.50	0.59	0.02
A6	0.90	0.84	0.98	0.91	0.13
A7	1.00	0.76	0.85	0.87	0.06
A8	0.90	0.96	0.94	0.93	0.06
A9	0.96	0.96	0.85	0.92	0.02
A10	1.00	1.00	1.00	1.00	0.02
A11	0.90	1.00	1.00	0.97	0.04
A12	0.77	0.84	0.90	0.84	0.03
A13	0.90	0.96	1.00	0.95	0.01
A14	0.96	1.00	1.00	0.99	0.04
A15	0.59	0.84	0.73	0.72	0.02
A16	0.67	1.00	0.89	0.85	0.02
A17	0.50	0.50	0.84	0.61	0.00
A18	0.50	0.76	0.79	0.68	0.00
A19	1.00	1.00	0.98	0.99	0.05
A20	0.75	0.90	1.00	0.88	0.07
A21	0.67	0.68	0.94	0.76	0.02
A22	0.67	0.91	0.94	0.84	0.02
(A23)	0.67	0.76	0.94	0.79	0.21
(A24)	0.59	1.00	0.84	0.81	0.07

$$P\{A_5 \leq A^{max}\} = 0.59\,; P\{A_{10} \leq A^{max}\} = 1.00$$

In line with guidelines of stage 10 of the calculation procedure, the following final ranking of work health and safety management system elements was compiled:

$$A_5 > A_{17} > A_{18} > A_{15} > A_{21} > (A_{23}) > (A_{24}) > A_2 > A_{22} > A_{12} > A_{16} > A_7 > A_4 > A_{20} > A_6 > A_3 > A_9 > A_8 > A_{13} > A_{11} > (A_1) > A_{19} > A_{14} > A_{10}$$

As follows from our ranking of elements (stage 10 of the calculation procedure), for such adopted assessment criteria, and for such established relation between these criteria, the following alternatives turned out to be the closest to the ideal alternative: A5- General planning requirements, A17- Purchases, and A18- Subcontracting. Table 8 also lists the weights of the particular elements obtained using the Simos procedure, which makes it easier to select the work health and safety management system element with the relative lowest P value, as well as its corresponding highest significance level within the system (see: A23 and A24).

Conclusion

The key problem we faced in our work was to decide on how to identify the weights of the assessed alternatives, and how to identify significance levels of the assessment criteria. The solution that has been most frequently used so far is arbitrary identification of weights by a decision-maker, or a solution based upon the maximum deviation method. Our approach proposes to use the Simos procedure, which is available in literature, at the stage of identifying weights of the particular work health and safety management system elements, and the arithmetic mean method at the assessment aggregation stages. It is also possible to use another, simpler aggregation process, e.g. using the weighted average, which makes it possible to assign varying weights to assessments obtained from the particular experts (e.g. to assign the highest weight to the assessment obtained from the SUPA external auditor, or to assign the highest weight to the criterion C1 – Meeting requirements). It is also important to clearly determine the nature of the particular assessment criteria (cost-based only, profit-based only, or mixed), i.e., to determine the purpose of the obtained hierarchy of elements of the system. In the given situation, the adopted assessment criteria are all cost-based in nature (the lower the value, the better), which follows from assessment model we have adopted; although some other model could have been adopted as well. The development of work health and safety management systems and the tendency to integrate them with the remaining management systems within the company create some serious requirements for the assessment of their performance. Analysis of the reliable data and information received from the system is helpful in proper identification of improvement targets and is conducive to more effective decisions.
Due to the fact that any management system is an intrinsically complicated system that cannot be described using a single parameter only, the most recommended approach in the area of studies concerning the functioning of the system is using the multi-dimensional analysis approach, and, in consequence, multi-dimensional (multi-criteria) methods. The approach as proposed herein, i.e. the approach based

on the grey system theory, is beneficial in situations of imprecise or uncertain information, which we have to do with in case of work health and safety management systems. These studies as described above confirm that the approach we have developed is useful as a multi-criteria decision-making tool in the area of work health and safety management systems, in terms of streamlining elements of the management system in connection with the need to improve it. Practical application of the approach as presented herein will make it possible to reduce uncertainty levels that tend to occur while making decisions concerning focusing of the improvement measures upon those elements of the system, which are important from the decision-maker's point of view. This paper describes an original application of the GST concept in the area of management system improvements, including work health and safety management system improvements. The further research will be focused upon developing new hybrid, multi-criteria assessment methods, which will link together some well-elaborated basic multi-criteria decision-making methods within the frameworks of the grey system theory.

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PODEJŚCIE DO DOSKONALENIA SYSTEMU ZARZĄDZANIA BHP OPARTE NA PODEJMOWANIU SZARYCH DECYZJI

Streszczenie: Celem artykułu jest przedstawienie i zweryfikowanie podejścia za pomocą, którego można uporządkować elementy systemu zarządzania według przyjętych przez decydentów kryteriów decyzyjnych, co pozwoli na zmniejszenie niespójności w ramach podejmowania decyzji o ukierunkowaniu działań doskonalących system. W podejściu wykorzystano koncepcję szarych systemów oraz właściwości szarych liczb. Jako kryteria oceny, poszczególnych elementów systemu pod kątem doskonalenia, wykorzystano trzy parametry o charakterze kosztowym: spełnienie wymagań, koszty realizacji oraz czas realizacji. Podejście zostało zweryfikowane w firmie z branży produkcji mebli, na bazie funkcjonującego w tym przedsiębiorstwie systemu zarządzania bhp wg PN-N 18001. Wykorzystanie zaproponowanego podejścia umożliwiło uszeregowanie wszystkich elementów ocenianego systemu oraz zidentyfikowanie tych, które można udoskonalić w pierwszej kolejności, uwzględniając przyjęte kryteria oceny. Niniejszy artykuł uzupełnia braki w zakresie wykorzystania teorii szarych systemów do doskonalenia systemów zarządzania bhp i stanowi oryginalne zastosowanie tej koncepcji w ramach zarządzania bezpieczeństwem i higieną pracy. Zaprezentowane podejście może stanowić istotne narzędzie w ramach doskonalenia systemów zarządzania, nie tylko dedykowanych bhp.

Słowa kluczowe: system zarządzania, BHP, przedsiębiorstwa, wielokryterialne podejmowanie decyzji, teoria szarych systemów

基于灰色决策改进安全管理体系的探讨

摘要:本文的目的是提出并验证该方法，借助于该方法，您可以根据决策者采用的决策标准组织管理系统的要素，这将有助于减少决策制度改进的不一致性。该方法使用灰色系统的概念和灰色数字的属性。作为评估标准，系统的各个要素在改进方面，使用了三个成本参数:要求的实现，实施的成本和完成的时间。根据PN-N 18001，该方法已经在家具行业的公司中得到验证，该公司基于在该公司运营的OHS管理系统。使用所提出的方法使得有可能对所评估系统的所有要素进行排序，并在考虑所采用的评估标准的情况下，首先确定可以改进的系统。本文补充了使用灰色系统理论改进健康和安全管理系统的不足，并且是这一概念在职业健康和安全管理框架中的原始应用。所提出的方法可以成为改进管理系统的重要工具，而不仅仅是专注的健康和安全。

关键词:管理体制，职业健康安全，企业，多标准决策，灰色系统理论