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AN IMPROVING THE PROCESS OF RISK ASSESSMENT OCCUPATIONAL FOR INDUSTRY

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Purpose: The aim was improving the process of risk assessment occupational for industry, by implemented in this process the fuzzy scale (and the Fuzzy Analytic Hierarchy Process, FAHP).
Design/methodology/approach: The FAHP method was integrated with the PN-N-18002 method.
Findings: It was demonstrated that implemented the FAHP method in PN-N-18002 method allows on more precise an assessment of the root of threats on the workplace.
Research limitations/implications: This method can be used to risk assessment of each workplaces, by integrating the FAHP with any methods of occupational risk assessment.
Practical implications: The assumption was to improve the method of risk assessment occupational for industry, in which as was shown the number of accidents in work was the highest. Test of the proposed method was carried out for the operator's position of a floating excavator KG-2.5 in one of Podkarpacie enterprise extracting aggregate.
Social implications: This method can be helped to the entity performing the occupational risk assessment in precise identify the root of threats on the workplaces. This will ensure a safe workplace.
Originality/value: The originality of the proposed method is to achieve more precise an assessment of the root of threats in the workplace than by using the traditional risk assessment methods.

Keywords: risk assessment occupational, production engineering, mechanical engineering, PN-N-18002, FAHP.

Category of the paper: research paper.

1. Introduction

Providing a safe workplace is the basis for the functioning of each organization. As part of these actions is making the risk assessment occupational, for example, Risk Score method, FTA method (Fault Tree Analysis) or ETA method (Event Tree Analysis). Another often practice method of risk assessment occupational is the PN-N-18002 method (PN-N-18002:2011), which belongs to the PN-N-18002 series of occupational health and safety standards (Bajdur, and Idzikowski, 2012; Karkoszka, 2009; Woźny, and Pacana, 2013). As part of the literature review was shown that the actions, which have the aim to improve the process of risk assessment occupational were made. For example, the models of improving the risk assessment occupational and the way of reporting results were proposed (Aagedal et al., 2002). Also, was integrated the risk assessment occupational methods in the context of meeting the legal requirements of assessment the OHS, environment and quality management (Karkoszka, 2009; Karkoszka and Szewieczek, 2007). However, in the context of improving the process of risk assessment occupation was not tried to reduce the inconsistencies in assessments resulting from using a traditional number scale. Because this issue was not analyzed yet, it was considered for the research gap.

Therefore, it was justified to improving the process of risk assessment occupational as part of reducing the inconsistencies in the grades by implemented the fuzzy scale in process of risk assessment occupational, and then making the calculation adequate for it FAHP method (Fuzzy Analytic Hierarchy Process) (Chen et al., 2020; Gil, and Gonzalez-Rodriguez, 2012; Siwiec et al., 2020). It was founded that it is beneficial to implementing the Saaty scale in the PN-N-18002 method (Duda, and Juzek, 2018). The choice was resulting from preferring to using the PN-N-18002 method in risk assessment occupational in industry, in which the number of accidents in work was the highest in Poland, i.e. 28 212 accidents in the 2019 year (GUS, 2020). Therefore, the aim was improving the process of risk assessment occupational for industry, by implemented in this process the Saaty scale (and the Fuzzy Analytic Hierarchy Process, FAHP). The analysis was made as part of risk assessment occupational for the workplace in one of Podkarpacie enterprise extracting aggregate.

2. Method

The proposed method was a combination of the method of risk assessment occupational with Fuzzy Analytic Hierarchy Process (FAHP) (Pacana et al., 2020; Pacana, and Siwiec, 2020). This integration consisted of a combination of assessments obtained from risk assessment with assessments in fuzzy scale, and then on carrying out calculations the risk assessment by the FAHP method. The premise of integrating these methods was definition in a precise manner the root of threats on workplace, by which this precision relates to reduction of the occurring inconsistencies of assessments (which was obtained by applying the fuzzy scale). This method was presented in three main steps (Fig. 1).

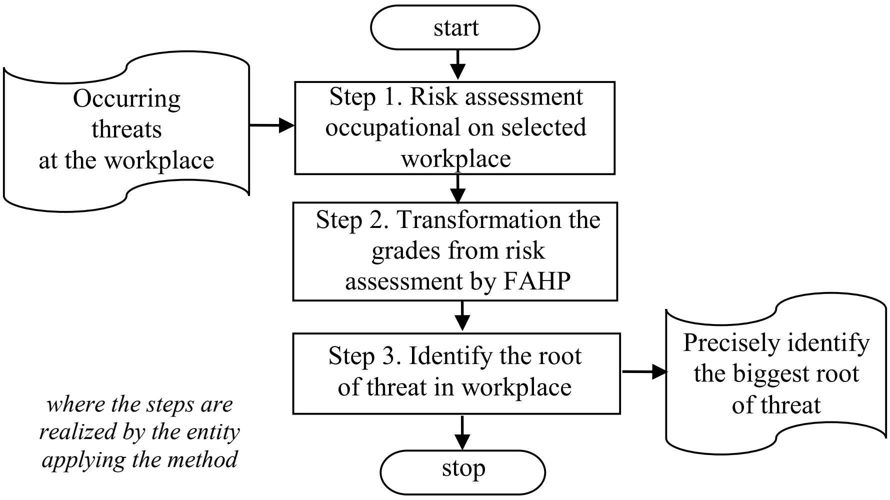

Figure 1. Algorithm of risk assessment occupational supporting by FAHP method.

The first step is to make a risk assessment for the selected workplace. Risk assessment occupational can be realized by any method in depending on the threats on workplace and needs of enterprise (Pacana, 2019).

The second step is the transformation of grades from risk assessment obtained in traditional number scale on triangular, fuzzy scale, i.e. 1-5, 1-7 or 1-9, according to the article (for example: Tsai et al., 2020). If the root of threats has more than one assessment, it is necessary to choose maximum assessment from all of the assessments for this root of threat.

The third step is making calculations by the Fuzzy Analytic Hierarchy Process (FAHP) with aim of assessing the root of threats in the workplace. This step including the reduction of inconsistency in the assessments given as part of the performed risk assessment occupational (step 1). This process is made based on transformed the grades from risk assessment occupational on triangular, Saaty scale (step 2). Then, the fuzzy comparison matrix is created in which the assessments in a fuzzy scale are comparison in pair. Then on the diagonal of the matrix there are values equal to the grade 1, i.e. in the triangular fuzzy grade scale 1,1,1. The relative fuzzy weight value is then calculated and expressed as (1) (Chang, 1996; Łuczak, 2012; Pacana et al., 2020; Tsai et al., 2020):

$$W_i = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}} \; where \; i,j = 1 \sim n \tag{1}$$

where:

a_{ij} – the Tringular Fuzzy Number located at row *i* and column *j* in the parawise comparision matrix,

W_i – the fuzzy weight of row *i*.

Subsequently, the degree of possibility is calculated by the formula (2) (Chang, 1996; Łuczak, 2012; Pacana et al., 2020; Tsai et al., 2020):

$$V(\widetilde{W_i} \geq \widetilde{W_j}) = \mu_{\widetilde{W_i}}(d) = \begin{cases} 1, & for \quad m_{ij} \geq m_{ji} \\ 0, & for \quad l_{ji} \geq u_{ij} \\ \dfrac{(l_{ji} - u_{ij})}{(m_{ij} - u_{ij}) - (m_{ji} - l_{ji})} & for\ others. \end{cases} \tag{2}$$

where the degree of possibility is determined for all compared fuzzy numbers, assuming that $\widetilde{W_i} = (l_{ij}, m_{ij}, u_{ij})$ and $\widetilde{W_j} = (l_{ji}, m_{ji}, u_{ji})$. Successively, it is possible to find the smallest degree of possibility with respect to the fuzzy numbers (3), weight vector (4) and normalized weight vector (5) (Chang, 1996; Łuczak, 2012; Pacana et al., 2020; Tsai et al., 2020):

$$V(\widetilde{W}_i \geq \widetilde{W}_j | j = 1, \ldots, n; i \neq j) = \min_{\substack{j \in (1,\ldots,n) \\ j \neq i}} V(\widetilde{W}_i \geq \widetilde{W}_j) = \mu_{\widetilde{W}_i}(d) = \mu_{\widetilde{W}_j}(d); i = 1, 2, \ldots, n \tag{3}$$

$$W' = \left(min_1 V(\widetilde{W}_i \geq \widetilde{W}_j), \ldots, min_n V(\widetilde{W}_i \geq \widetilde{W}_j)\right) \tag{4}$$

$$W'_N = \left(\frac{\mu_{\widetilde{W}_i}(d)}{\sum minV}, \frac{\ldots}{\ldots}, \frac{\mu_{\widetilde{W}_n}(d)}{\sum minV}\right)^T = (w_j, \ldots, w_n), \text{where i} = 1, 2, \ldots \text{n; j} = 1, 2, \ldots, \text{n} \tag{5}$$

The maximum value of the normalized weight vector is the greatest source of risk at the analyzed workplace.

3. Results

A test of the proposed method was made for one of Podkarpacie industry enterprises which was extracting aggregate. The choice the analyze in context of the extracting aggregate was conditioned one of the highest numbers of accidents at work, which was noted for mining and quarrying plants (i.e. 2407 accidents in 2019 year) (GUS, 2020; Siwiec, and Pacana, 2018). In mentioned the industry enterprises (and in mining and quarrying plants) one of the most practice methods for risk assessment occupational is the PN-N-18002 method (Duda, and Juzek, 2018). This method is also practiced to the risk assessment in enterprise extracting aggregate, which was selected to analyze. Therefore, as part of the test proposed method, it was reasonable to integrate the FAHP method with the PN-N-18002 method. The workplace which was subject to occupational risk assessment by the PN-N-18002 method was the workplace of KG-2,5 floating excavator operator. It resulted from a relatively high assessment of the occupational risk obtained for this job (i.e.: 4.57 – low risk according to PN-N-18002) compared to the remaining job positions of the analyzed enterprise.

The operator of floating excavator KG-2,5 of selected enterprise makes the jobs on water bodies to 30 meters from the water table, and also brings out among others gravel, sand and clay. The results of risk assessment by the PN-N-18002 method for the operator of floating excavator KG-2,5 are shown in Table 1.

Table 1.
The results of risk assessment by the PN-N-18002 method for the operator of floating excavator KG-2,5

The root of the threat	Threat	Protection	Risk category adopted	Total points in the group
Machine	Noise during plant inspection	Applied noise reduction measures below 85 dB (A)	4	4
		Exceeding NDN, noise above 85 dB, hearing protectors are used	-	
		Noise above 85 dB - hearing protectors are not used	-	
		Equivalent sound L level A [dB]	68,4 dB	
		Multiplicity	0,5417	
Machines, production process	Vibration	General vibration	4	4
		Local vibration	-	
		No mechanical vibrations	-	
		Vector mean sum	0,169	
		Multiplicity of the limit value	0,21	
Production process	Petroleum vapors	Possibility of diesel spill	3	3
		No oil can spill	-	
		Failure to apply security	-	
Electric lighting of the workplace	Electric shock	Applied efficient fire protection	4	4
		Failure to apply or ineffective fire protection	-	
Work at height	Fall from a height	Use of personal protective equipment against falls from a height	5	5
		Failure to use personal protective equipment	-	
Work in forced position	Fatigue	Use of facilities and auxiliary equipment	-	4
		Failure to use auxiliary equipment	4	
Machines, stationary and auxiliary tools	Hit, fall, slip	Possibility of hitting moving parts of the machine (without guards)	1	1
		Hazards related to sharp and protruding parts	2	2
		Hazards related to the movement of people and equipment (drowning)	3	3
		Hazards related to the physical properties of the material (weight, sharp edges, slippery surfaces, etc.)	2	2
		Electric shock hazard inadequate electrical installation	2	2
		Work in open space	6	6
		Burn hazard	1	1
		Risk of a person falling	4	4
Sum				45

Achieved assessments from the risk assessment occupational for the root of threats on the operator of floating excavator KG-2,5 were transformed on a triangular fuzzy scale (i.e. scale from 1 to 5). By which, for the root of threat i.e. machines, stationary and auxiliary tools, was achieved more than one assessment (in total points in the group). Therefore, it was chosen the maximum assessment from these threats, it was the work in open space (with 6 points).

As part of analyzing the root of threats were named in symbolic from T1 to T7, where: T1 – machines, T2 – machines, production process, T3 – production process, T4 – electric lighting of the workplace, T5 – work at height, T6 – work in forced position, T7 – machines, stationary and auxiliary tools. Subsequently, the calculations were carried out in accordance with the FAHP method, the results of which are presented in Table 2.

Table 2.
Results from the FAHP analysis

No.	**Fuzzy assessment**	**Fragment of the fuzzy matrix pairwise comparisons**			**Relative fuzzy weight value**	**Normalized weight vector and ranking**	
	l_{ij}, m_{ij}, u_{ij}	**T1**	**T2**	**T3**	**Wi**	**Wn'**	**Ranking**
T1	3; 4; 5	1,0; 1,0; 1,0	0,6; 1,0; 1,7	0,8; 1,3; 2,5	0,1; 0,1; 0,3	0,13	4
T2	3; 4; 5	0,6; 1,0; 1,7	1,0; 1,0; 1,0	0,8; 1,3; 2,5	0,0; 0,1; 0,4	0,14	3
T3	2; 3; 4	0,4; 0,8; 1,3	0,4; 0,8; 1,3	1,0; 1,0; 1,0	0,0; 0,1; 0,3	0,12	5
T4	3; 4; 5	0,6; 1,0; 1,7	0,6; 1,0; 1,7	0,8; 1,3; 2,5	0,0; 0,1; 0,4	0,14	3
T5	4; 5; 6	0,8; 1,3; 2,0	0,8; 1,3; 2,0	1,0; 1,7; 3,0	0,0; 0,2; 0,4	0,15	2
T6	3; 4; 5	0,6; 1,0; 1,7	0,6; 1,0; 1,7	0,8; 1,3; 2,5	0,1; 0,2; 0,4	0,15	2
T7	5; 6; 7	1,0; 1,5; 2,3	1,0; 1,5; 2,3	1,3; 2,0; 3,5	0,0; 0,2; 0,5	0,17	1

After calculations, it has been shown that the greatest source of threat at the position of the KG-2.5 excavator operator is the threat conventionally designated as T7 – the root of threat about the machines, stationary and auxiliary tools. This hazard reached the maximum value of the normalized weight vector (i.e. 0.17). Next (the second position in the ranking, weight 0,15) were the work at height (T5) and work in forced position (T6). Then (the third position in the ranking, weight 0,14) were the machines, production process (T2) and electric lighting of the workplace (T4). The fourth position in ranking (weight 0,13) was the root of threat about the machine (T1), and the last position in the ranking (weight 0,12) was the root of threat about the production process (T3).

4. Summary

The risk assessment occupational is basic to functional each enterprise. In Poland, the largest number of accidents in work was noted in production enterprises (28 212 accidents in the 2019 year), and also in enterprises of mining and quarrying (2407 accidents). Therefore, it was justified to analyze the way of making the risk assessment occupational in the mentioned production enterprises. It was shown, that the most often used method is PN-N-18002, but this method (as other methods of risk assessment occupational), was not improved in the context of reducing inconsistent grades. Therefore, the aim was to improve the process of risk assessment in industry enterprises by integrated the PN-N-18002 method with the FAHP method (Fuzzy Analytic Hierarchy Process). The method was tested in an enterprise localized in Podkarpacie (which was extracting aggregate), on position the operator of floating excavator KG-2,5. After analysis, it has been shown that the greatest source of threat at the position of the KG-2.5 excavator operator is a threat about the machines, stationary and auxiliary tools. According to the context of the proposed method, it was concluded that there results from the implemented method allows for precise risk assessment occupational. The main benefit of the proposed method is an assessment of the root of threats to the workplace by reducing the inconsistent grades by fuzzy scale. This method can be used to assess the threats on other workplaces, by integrated the FAHP method with any method of occupational risk assessment.

References

1. Aagedal, J. et al. (2002). *Model-based Risk Assessment to Improve Enterprise Security*. IEEE, Proceedings of the Fifth International Enterprise Distributed Object Computing Conference, pp. 51-62, September 17-20, 2002, Lausanne, Switzerland.
2. Bajdur, W., and Idzikowski, A. (2012). Analiza i ocena ryzyka zawodowego wybranych stanowisk pracy w zakładzie odkrywkowym dolomitu. *PTZP*, pp. 691-702. Available online http://ptzp.org.pl/files/konferencje/kzz/artyk_pdf_2012/p062.pdf, 21.11.2020.
3. Chang, D.Y. (1996). Application of the extent analysis method on fuzzy AHP. *Eur. J. Oper. Res*., 95(3), pp. 649-655.
4. Chen, T. et al. (2020). Multistage Decision Framework for the Selection of Renewable Energy Sources Based on Prospect Theory and PROMETHEE. *International Journal Of Fuzzy Systems, 22(5),* pp. 1535-1555. DOI: 10.1007/s40815-020-00858-1.
5. Duda, A., and Juzek, T. (2018). Ocena ryzyka zawodowego podczas czynności związanych z drążeniem przzodka I zabudową obudowy. *Systemy wspomagania w inżynierii produkcji. Górnictwo – perspektywy i zagrożenia. Węgiel, tania czysta energia i miejsca pracy, 7, 1,* pp. 329-340.
6. Gil, M.A., and Gonzalez-Rodriguez, G. (2012). *Fuzzy vs Likert scale in Statistics. In Combining Experimentation and Theory.* Springer-Verlag, pp. 407-420. DOI: 10.1007/978-3-642-24666-1_27.
7. GUS (2020). *Wypadki przy pracy w 2019 r. – dane wstępne,* 03.11.2020.
8. Karkoszka, T. (2009). Improvement of the chosen process based on the occupational health and safety criterion. *Journal of Achievements in Materials and Manufacturing Engineering, 37(20),* pp. 735-742.
9. Karkoszka, T., and Szewieczek, D. (2007). Risk of the processes in the aspect of quality natural environment and occupational safety. *Journal of Achievements in Materials and Manufacturing Engineering, 20(1-2),* pp. 539-542.

10. Łuczak, A. (2012). Ocena ważności czynników strategicznych w gminie wiejskiej z wykorzystaniem rozmytego analitycznego procesu hierarchicznego. *Journal of Agribusiness and Rural Development, 4(26),* pp. 43-56.
11. Pacana, A. (2019). *Systemy zarządzania bezpieczeństwem i higieną pracy zgodne z ISO 45001:2018.* Rzeszów: Oficyna Wydawnicza Politechniki Rzeszowskiej.
12. Pacana, A., and Siwiec, D. (2020). Improving the process of analysing the causes of problem by integrating the Ishikawa diagram and FAHP method. *Scientific Papers of Silesian University of Technology. Organization and Management Series, 143,* pp. 247-257. DOI: 10.29119/1641-3466.2020.143.20.
13. Pacana, A., Siwiec, D., and Bednárová, L. (2020). Method of Choice: A Fluorescent Penetrant Taking into Account Sustainability Criteria. *Sustainability, 12,* p. 5854. DOI: https://doi.org/10.3390/su12145854.
14. PN-N-18002:2011. *Systemy zarządzania bezpieczeństwem i higieną pracy – Ogólne wytyczne do oceny ryzyka zawodowego*.
15. Siwiec, D., Bednarova, L., and Pacana, A. (2020). Metoda doboru penetrantów dla przemysłowych badań nieniszczących. *Przemysł Chemiczny, 99(5),* pp. 771-773. DOI: DOI: 10.15199/62.2020.5.18.
16. Tsai, H.-C. et al. (2020). An Application of the Fuzzy Delphi Method and Fuzzy AHP on the Discussion of Training Indicators for the Regional Competition, Taiwan National Skills Competition, in the Trade of Joinery. *Sustainability, 12(10),* p. 4290. DOI: https://doi.org/10.3390/su12104290.
17. Woźny, A., and Pacana, A. (2013). *Ocena ryzyka zawodowego: teoria i przykłady*. Oficyna Wydawnicza Politechniki Rzeszowskiej, ISBN: 8371999054.