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ORIGINAL ARTICLE

Environmental risk management in order to energy efficiency in automaker industries (Case study: pre-paint Part of Iran Khodro Company (IKCO)

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ABSTRACT

Despite abundant resources, the automotive industry is reported to adversely impact the environment owing to the use of heavy machinery, diverse and governmental management policies for car production per hour, remarkable employed labor force, production cycle timing, etc. For this purpose, many studies involving environmental risk management have been conducted. To this aim, the present study has been carried out in pre-paint part No. 2 of IKCO (preparation process). In this regard, using FUZZY FMEA and VIKOR methods, the identified risks were assessed and reformative measures and solutions were classified, respectively. A total of 15 individuals considered HSE experts of IKCO were selected as a statistical sample size according to the Morgan table. Consequently, the high-level risks were identified and appropriate solutions were suggested to reduce the environmental effects. According to achieved scores, "torch adjustments based on compliance report" was selected as the compromise solution. IKCO should consider torch adjustment based on compliance report actions as its first priority.

KEYWORDS: *Risk management; Automobiles; Industry, paint*

INTRODUCTION

The automotive industry is usually associated with high rates of raw material consumption and pollution during the production process, added to which road vehicles are consistent targets of criticism because of their gas emissions, involvement in accidents, the cause of noise pollution, and so on [1].

Iran has a remarkable number of old maintained cars, added to which, the water, air, soil, and noise pollution released by these industries make identification of potential risks along with optimal management strategies extremely important. The results can be applied to decision-making and management of control and reduction of risk consequences. It is worth mentioning that investigating the environmental risks of the automotive industry is aimed at providing better

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environmental risk management and assessment of the said industry has not been done so far. The environmental hazard risks could include pollution emission, natural disasters, use of dangerous technologies, and assessment of their probable accidents, as well as determination of adverse effects of environmental risks on human life and the ecosystem [2].

The automotive industry is experiencing many challenges that affect its sustained growth [3]. The effects of environmental risks on the automotive industry have long been of interest to many researchers [4-6]. In the car manufacturing process, there are processes and treatments with high potential risks, including the pre-paint Hall [7]. Due to the use of chemical materials, color coating, etc. in the painting process, the occurrence of air, noise, and soil pollution is unavoidable. However, there has not been a thorough review of this process yet, making it necessary to pay attention to these types of risks.

Managing environmental risks is one of the best ways to achieve sustainable development goals. The management of environmental risk can be used as a planning tool to guide the implementation of projects in line with environmental laws and regulations [8]. To reduce the environmental risks, it is very important to identify potential risk sources and manage their occurrence and severity [6].

Previous research focused on methods for identifying and managing environmental risks to reduce environmental and human health risks. For example, FMEA methods especially in fuzzy environment are used repeatedly to identify the inherent risk factors in automotive industries where pollutants are released [9].

Fuzzy Failure Mode and Effect Analysis (FMEA)

FMEA is recognized as an effective risk analysis technique recommended by international standards such as MIL-STD-1689A. This method has been widely used for identifying and removing the main causes of failure and the relevant consequences before the event, thus improving the reliability of production or processes [10].

In this method, each failure mode is evaluated by three factors, including severity, occurrence, and the ability of detection. In traditional assessment, by multiplying these three factors, the Risk Priority Number (RPN) is achieved, i.e. RPN= S×O×D [11-12]. Then, RPN is classified to find failure modes with the highest risk [13].

The risk priority number has shown some problems as mentioned below: [4, 13-18]

- Relative importance of three risk factors, including risk occurrence, risk detection, and risk severity were not considered. They were accepted with similar importance.
- Multiple combinations of S, O, and D might create similar RPN. Hence, a similar importance for every three factors is usually supposed.
- Precise determination of S, O, and D parameters is very difficult.

In order to overcome these problems, some researchers [19-21] used Fuzzy logic to assess reliability and risk in FMEA method.

The Fuzzy FMEA procedure provides a tool to achieve the results through a better method, using inaccurate data and definitions [22, 3].

In addition, the mentioned procedure was applied in multiple studies in order to assess risk. Chin et al. (2008) suggested an assessment procedure in FUZZY FMEA to define production. To this aim, they declared a primary model of system called EPDS-1 which assists new users in FMEA to improve quality and reliability, evaluate replaced plans and evaluate costs as well. Xu et al. (2002) presented a FMEA method based on Fuzzy logic to evaluate motor systems. To facilitate FMEA in a Fuzzy environment, Tay et al. (2006) suggested a general method with fewer rules for users applied to modeling Fuzzy risk priority number (FRPN). Afterwards, they evaluated the suggested method by three studied items. Furthermore, Wang et al. (2009) carried out risk analysis using FMEA combined with Fuzzy geometric mean weight. A failure ranking using intuitive Fuzzy ranking method was presented by Chang et al. (2010). Yang et al. (2010) suggested a new FMEA based on Fuzzy theory applied to computer numerical control (CNC). Results showed that Fuzzy FMEA procedure applied to CNC machines is an acceptable method in production and assists in creating a reliable model to support a production control program. Bukowski and Feliks (2005), based on FMEA and FMECA presented a method to assess risk in a designed system which simultaneously omits disadvantages of both methods. In this regard Tay et al. (2008) developed an accident updating model according to Fuzzy logic for FMEA process. Moreover Liu et al. (2011) proposed a new procedure of FMEA using Fuzzy Evidential Reasoning (FER). Mandal and Maiti (2014) suggested applying Fuzzy evidential reasoning as an estimation number of Fuzzy Risk Priority according to expert opinions [11, 17, 23, 25-29].

• *VIKOR*

Firstly, the VIKOR method was presented in 2002 [30] and developed in 2007 [31]. Liu et al. (2012) applied the VIKOR method to analyze failure modes in Fuzzy condition [18].

The VIKOR method may be considered a suitable tool in decision-making, particularly during difficulties arising due to incompatible indices. A compromise solution, achieved in the VIKOR method, has been agreed upon by decision-makers because the mentioned procedure presented the maximum group desirability and minimum individual efforts and attempts to select the best optimal alternative, closest to the ideal answer. The above studied method insists on classification and selection of a set of alternatives along with determination of a compromise solution considering undesirable standards, which assist decision-makers in making an ultimate decision [31]. So, in this study, this method was used for prioritization of corrective actions.

The present study was carried out in order to assess and manage environmental risk of pre-painted Part of IKCO. To this aim, FUZZY FMEA and VIKOR methods were applied to evaluate potential failure modes and ranking of reformative measures, respectively. Furthermore, this study was done in order to answer the questions: 1) which of the identified factors have higher risks in pre-painted Part of IKCO; and 2) which of the corrective actions identified is the best action with respect to safety, facility, cost, satisfaction, efficiency and persistence, and duration of the effected aspects.

MATERIALS AND METHODS

The Iran-Khodro Industrial Group is located 14 km off the Karaj Highway, with the production factories and principal activity center established at the core of the enterprise. The company, stretched in an area of 3375613 sq. m, is composed of eight production parts as follows: press part, body part, paint part, iron and aluminum casting part, motor part, gearbox part, axle part, and decorating part.

The paint part (which includes the pre-paint part) is one of the most important processes in the Iran-Khodro Co. that poses a considerable health risk. In this part, various processes are conducted in order to paint the automotive body correctly. In this section, the pre-treatment process as carried out in the pre-paint part is the first process consisting of three main stages (degreasing, phosphate wash, and washing with deionized water). Later, the electrodeposition step is used to spray the paint in an electrochemical manner on the vehicle-body. After completion of these processes, quality control of paint and process conduction is carried out [3].

This study is descriptive-analytic in terms of method and functional in terms of objective. The present research was done in two steps as shown in Figure 1.

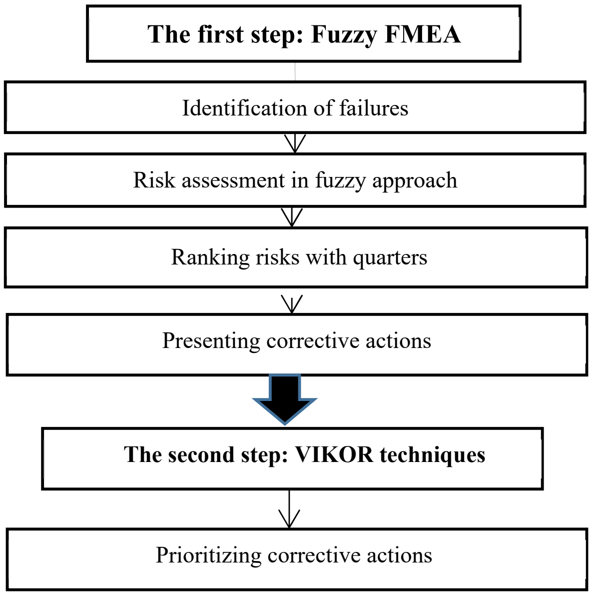

Figure 1. The main steps of this study

Table 1. Environmental risk assessment using fuzzy criteria

Severity			occurrence		extent		crisps
Lingual variable	**Triangular number**	**crisps**	**Lingual variable**	**Triangular number**	**Lingual variable**	**Triangula r number**	
impossible	0,0,2	2	Monthly	0,0,2	Station	0,2,2	1
Very low	1.33,1.66, 3.33	3	Weekly	4,5,6	company	4.5,5,6	2
Low	2.66, 3.33, 4.66	4	Daily	8,10,10	Out of company	9,10,10	3
average	4,5,6	5					
Relatively high	5.33,6.66,7.33	6					
High	6.66, 8.33, 8.66	7					
Very high	8,10,10	8					

Table 2. Classification of risk levels

Risks classification	Risk domains
VL	$X \leq 8$
L	$8 < X \leq 17.1$
M	$17.1 < X \leq 24.3$
H	$X > 24.3$

The first step: Fuzzy FMEA

After reviewing the literature, visiting the process, interviewing with the responsible HSE and employees of the pre-paint part, and using the Delphi technique, the potential failure modes and consequences were identified.

The expert team included 15 persons from the HSE unit (according to the Morgan table) who were people with at least five years of experience in the automotive industry and had familiarity with the surface preparation process. They also had a Bachelor's degree in the field of HSE.

In this regard, the environmental risk assessment factors related to the Iran-Khodro Company were classified with respect to the current situation into four categories, including severity (S), extent of the risk (E), and occurrence of the risk (O).

- Occurrence: risk occurrences within a specified period
- Extent: risk domain or number of risk centers
- Severity: degree of injuries due to the risk

These factors were defined by linguistic values and converted to crisp numbers, which then underwent fuzzy logic using certain hypotheses and MATLAB software. In this regard, triangular membership functions were used. The hypotheses are as follows:

- Severity numbers are classified into eight categories from fuzzy numbers (2, 0, 0), which represent no risk to fuzzy numbers (10, 10, 8), which are considered dangerous.
- Occurrence Number is classified into six categories from fuzzy numbers (2, 0, 0), which are unlikely to represent fuzzy numbers (10, 10, 8), which represents too much.
- Extent Number is classified into six categories from fuzzy numbers (2, 0, 0) which represent the level of activity within the company and fuzzy numbers (10, 10, 9) which represent the external environment of the company.

It is worth noting that these hypotheses were defined using some references [14-16].

The results of applying triangular membership functions are described in Table 1.

After environmental risk assessment in Fuzzy Logic, the RPN numbers were defuzzified based on Equation 1.

$$Merits\ (M) = \frac{W1\ (a) + W2\ (b) + W3\ (c)}{W1 + W2 + W3} \tag{1}$$

The given weights were considered based on the probability of occurrence and the suggestion of Nahook and Eftekhari (2013) for numbers a, b, and c considered as 1, 4, and 1, respectively [32].

Then, the identified risks classes were classified based on analysis in Excel 2010 into four categories (high, medium, low, and very low). To do this, the first, second, and third quarters were calculated. The classification of risk levels is shown in Table 2.

The second step: VIKOR method

Based on the VIKOR technique, corrective actions were prioritized and finally a compromise strategy was presented. To perform this procedure, six criteria were identified based on expert opinion, following which a screening questionnaire was prepared to prioritize corrective actions. Its validity and reliability were calculated by the experts' consensus and Cronbach's alpha coefficient, respectively. Then, the Shannon entropy method was used for weighting the criteria [36,37]. The steps of the Shannon entropy method are as follows:

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}} \quad (2)$$

Identification of entropy for each criterion

$$E = -\frac{1}{Ln\,(m)} \sum_{i=1}^{m} \sum_{i=1}^{m} P_{ij}\, Ln(p_{ij}) \quad (3)$$

M= the number of alternatives (in this study is equivalent to 15 experts)

Identification of unreliability or standard deviation for each criterion (d)

$$d_j = 1 - E_j \quad (4)$$

Determination of weight for each criterion (Wj)

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (5)$$

In the next step, the decision-making matrix, using a 5-point Likert spectrum and experts' surveys (according to criteria to assess the importance of alternatives), was prepared and eventually, the VIKOR technique was conducted as follows:

The development of the VIKOR technique starts with the following LP form:

$$1 \le p \le \infty, j = 1,2, \ldots . j \quad (6)$$

$$L_{Pj} = \{\sum_{i=1}^{n} [w_i\ (f_i^* - f_{ij})\ |(f_i^* - f_i^-)]^p\}^{\frac{1}{p}}$$

Descaling, in order to normalize the decision-making matrix (4)

$$X_{ij}^* = X_{ij} / (X_{ij\,MAX}) \quad \text{for positive criteria} \quad (7)$$

$$X_{ij}^* = (Xij_{MIN}) / X_{ij} \quad \text{for negative criteria} \quad (8)$$

- Determine the best f_j^* and the worst f_j^- values of all criterion ratings, j=1,2,…,n

$$f_j^* = \text{Max}\ f_{ij}\ , i=1,2,....,m. \quad (9)$$

$$f_j^- = Min\ f_{ij\ ,j=1,2,.....n}$$

Compute the values S_i and R_i, i=1,2,…,m, by the relations

$$S_i = \sum_{j=1}^{n} \frac{w_j (f_j^* - x_j)}{f_j^* - f_j^-}, \quad (10)$$

$$R_i = \max_i \left(\frac{w_j (f_j^* - x_j)}{f_j^* - f_j^-} \right). \quad (11)$$

Where, w_j is the weight of criteria, expressing their relative importance.

- Compute the clause Q_i, i=1,2,…,m, by relation

$$Q_i = v \left[\frac{S_i - S^*}{S^- - S^*}\right] + (1 - v) \left[\frac{R_i - R^*}{R^- - R^*}\right] \quad (12)$$

where, $S^* = \min_i S_i, S^- = \max_i S_i, R^* = \min_i R_i, R^- = \max_i R_i$, and υ is introduced as a weight for the strategy of maximum group utility, whereas $1 - \upsilon$ is the weight of the individual regret. The value of υ is set to 0.5 in this study.

- Rank the alternatives, sorting by the values S, R, and Q in ascending order. The results are listed as three rankings.
- Propose the alternative $(A^{(')})$ as a compromise solution, which is the best ranked by the measure Q (minimum) if the following two conditions are satisfied.

C1: Acceptable advantage: $Q(A^{(')}) - Q(A^{('')}) \ge DQ$, where $A^{(')}$ is the alternative with second position in the ranking list by Q; $DQ = 1/(m-1)$.

C2: Acceptable stability in decision-making: The alternative $A^{('')}$ must also be the best ranked by S or/and R. This compromise solution is stable within a decision-making process, which could be the strategy of maximum group utility (when $\upsilon > 0.5$ is needed), or "by consensus" $\upsilon \approx 0.5$, or "with veto" $(\upsilon < 0.5)$. Here, υ is the weight of decision-making strategy of the maximum group utility.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

- Alternatives $A^{('')}$ and $A^{(')}$ if only the condition C2 is not satisfied,

Table 3. All identified activities regarding environmental aspects

Coding	consequence	Environmental aspects	Environmental activities	Activities performance place	Definitions
1Aa	Air pollution	Metax emissions to the environment	Primary washing of body	Pre-cleaning	manual washing by Metax (alkaline solution)-body washing by ring or hot water ring (to clean Metax solution)
1Ab	Water pollution	Discharge of solution rinse wastewater			
1Ba	Water pollution	Discharge of consumed water during the process	Hot water ring		
2Aa	Water pollution	Overflow of solution from tank	Primary and second degreasing	Primary and second degreasing	Degreasing material is sprayed on body. Physical conditions are similar, but tank volume and as a result, concentration of the materials are different.
2Ab	Water pollution	Risk of tanks overflow to zero			
2Ac	Water pollution	Discharge of degreasing solution and entrance to the environment			
2Ba	Water pollution	Discharge of wastewater	Washing charge tanks of degreasing		
3Aa	Water pollution	Discharge of the wastewater containing hazardous chemicals and entry into the environment	Washing degreasing solvents	Phosphate and degreasing	Sulfuric acid solution is sprayed on body to create a layer of phosphate crystal for better adhesion of paint
3Ab	Water pollution	risk of losing added materials during charge	Phosphate		
3Ac	Water pollution	Solution overflow			
3Ad	Soil pollution	Disposal of sediments from the press filter			
4Aa	Water pollution	Discharging contaminated water into the environment	Body rinsing	Rinse	In this step, grease materials are cleaned from the body surface
4Ab	Water pollution	Risk of foam overflow from tank to zero level			
4Ac	Water pollution	Overflow of tank containing water and foam maker into the environment			
4Ad	Water pollution	Overflow of waste-water into the environment			
4Ba	Water pollution	risk of materials loss	Activation		
5Aa	Water pollution	overflow from tanks into the environment	Rinsing of phosphate body	Phosphate rinse	Washing salts and acidic solution as well as body pollution by industrial water
5Ab	Water pollution	discharge of consuming solution			
6Aa	Water pollution	discharge of effluents	Fixation operation	Fixation	Use of Hexafluorozirconic acid as a fixer to for filling the pores left unfilled by phosphate crystals
6Ab	Water pollution	overflow from tanks			
7Aa	Air pollution	emission of paint solvent into the atmosphere	electrophoresis dock	Electro deposition	In this step, electric flow is used to protect the body metal by creating an intermediate cover. This process is carried out in an electrophoresis dock containing water solution. After primary and second rinsing, the body is baked in a furnace at 90 °C
7Ba	Water pollution	Draining of cleaning solution	Washing tanks of electrophoresis dock		
7Ca	Water pollution	Overflow of cleaning solution	Body washing		
7Cb	Water pollution	Discharge of cleaning solution			
7Da	Water pollution	Leakage of body-cleaning solution	Drip-making of paint		
7Ea	Air pollution	Emission of pollutant gases due to furnace gas torches	Bake in an electrophoresis furnace		

Table 4. High level risks

RPN	consequence	Environmental risk	activity	coding
625.3	Air pollution	Emission of pollutant gases due to gas torches	Paint baking in the electrophoresis oven	7Ea
90.4	Water pollution	Overflow water	Body rinse	4Ad
90.4	Water pollution	Overflow of water and deformer of tank	Body rinse	4Ac

Table 5. Weighting criteria using Shannon entropy method

F	E	D	C	B	A	Index
0.168	0.169	0.168	0.163	0.168	0.168	*W*

Table 6. Identification of VIKOR parameters and presentation of compromise solution

Number of corrective action	S	R	Q
A1	0.8196	0.1684	0.9492
A2	0.4836	0.1698	0.6981
A3	0.263	0.156	0
A4	0.393	0.1683	0.5623
Ranking	$A_3>A_4>A_2>A_1$	$A_3>A_4>A_1>A_2$	$A_3>A_4>A_2>A_1$
Compromise Solution	A_3	A_3	A_3

Or

- Alternatives $A^{(''')}, A^{(')}, \ldots, A^{(M)}$ if the condition C1 is not satisfied; $A^{(M)}$ is determined by the relation $Q(A^{(M)}) - Q(A^{(''')}) < DQ$ for maximum M (the positions of these alternatives are "in closeness") (Liu et al., 2012)

RESULT

After visiting the paint preparation process in the pre-paint part, interviewing the responsible workers in each part of the process, HSE unit, and investigation of HSE unit documents, all the activities, risks, and their consequences were identified and coded (Table 3).

According to the presented classification, the high-level risks were determined as shown in Table 4. The emission of pollutant gases owing to furnace gas torches has been classified as the highest risk. This type of risk is significantly much higher than all the other risks, quantitatively. Therefore, in this study, corrective actions for this specific result were taken and prioritized.

In relation to the risk of pollutant emissions caused by gas torches, many corrective actions can be considered. In the present study, the most appropriate one was determined using the VIKOR technique. In this regard, certain criteria were considered and weighted with the Shannon entropy method (Table 5).

A: Safety of corrective action
B: Facility in applying the corrective action
C: Personnel satisfaction
D: Cost of investment and implementation
E: Efficiency in risk control
F: Persistence and duration of the effect

According to the above-mentioned table, efficiency in risk control with a total weight of 0.169 was identified as the most important corrective action criterion, followed by safety of corrective action and persistence and duration of effect, each with final weights of 0.168 showing less importance.

To manage the risk of emission of pollutant gases caused by gas torches, appropriate corrective actions were selected for each risk as follows:
A1: Reforming of CO_2
A2: Reduction of fossil fuel consumption
A3: Torch adjustment based on compliance report
A4: Catalyst installation and greenhouse gas reduction
The results of the VIKOR technique are shown in Table 6. The suitable value (S), regret value ®, and VIKOR index (Q) for each alternative were determined (Table 6) (Coefficient = 0.5 was considered representing a compromise view of the experts).
Based on Table 10, Q $(A^{(4)})$ – Q $(A^{(3)})$ = 0.562 > 0.333 as a condition is established as an acceptable advantage (Condition 1). Condition 2 is also established as acceptable stability. Based on the results, the corrective action for torch adjustment based on compliance report has the highest priority in terms of safety, facility, cost, satisfaction, efficiency and persistence, and duration of the effect's aspects. Later, the corrective action of

catalyst installation and greenhouse gases reduction has been put in second priority.

DISCUSSION

The various stages of chemical treatment, baking oven, etc. involved in the automotive color process of the pre-painting part have consequences that can cause adverse impacts on the environment with irreparable damage. Given the lack of research in this field, the present study was done in order to identify and assess risks involved in processes carried out in the pre-paint part of IKCO. The results showed that the risks of emission of pollutant gases due to gas torches as well as the overflow water from the body rinse have the highest priority among all the risks.

These results are similar to those of previous studies, e.g. Khezri et al. (2014), in a research on color contamination in the Saipa automobile industry, determined the most important environmental risk to be the emission of pollutants into the atmosphere [33]. Moreover, Jeste et al., in a study in 2013, showed that the emission of pollutants into the combustion atmosphere during the baking process of sealers in the oven along with the provision of heating and cooling energy were considered as the highest risks, respectively, causing air and soil pollution [34]. Those results are consistent with the results of this study.

Chang et al. (2010) used a fuzzy FMEA method in risk assessment of process [26]. The present study also considered this method as a substitute for the FMEA method. It should be noted that in Chang et al.'s study, this method is used only in assessment of injury to individuals while the present research is about environmental risks thus Chang's study differs from the present study.

Another aspect of difference between the present research and other research is the use of decision-making methods, including VIKOR, to prioritize corrective actions. These have not been considered in any of the other investigations so far.

CONCLUSION

Regarding the results and ranking of corrective actions, it is suggested that IKCO, with the objective of reducing air pollution, should consider torch adjustment based on compliance report actions as its first priority.

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ETHICAL ISSUES

The authors hereby certify that all data collected during the study are as stated in IKCO, and no data from the study has been or will be published separately elsewhere.

COMPETING INTERESTS

The authors declare that they have no conflict of interest.

AUTHOR'S CONTRIBUTIONS

The authors contributed and were involved in the problem suggestion, experiments design, data collection, and manuscript approval.

REFERENCES

1. Xun D, Hao H, Sun X, Liu Z, Zhao F. End-of-life recycling rates of platinum group metals in the automotive industry: Insight into regional disparities. J Clean Prod. 2020:121942. https://doi.org/10.1016/j.jclepro.2020.121942
2. Wells P, Wang X, Wang L, Liu H, Orsato R. More friends than foes? The impact of automobility-as-a-service on the incumbent automotive industry. Technol Forecast Soc Change. 2020;154:119975. https://doi.org/10.1016/j.techfore.2020.119975
3. Rivera JL, Reyes-Carrillo T. A Framework for Environmental and Energy Analysis of the Automobile Painting Process. Procedia CIRP. 2014;15:171-5. https://doi.org/10.1016/j.procir.2014.06.022
4. Bowles JB, editor An assessment of RPN prioritization in a failure modes effects and criticality analysis. Annu Reliab Maintainability Symp, 2003; 2003: IEEE. https://doi.org/10.1109/RAMS.2003.1182019
5. Rafie M, Namin FS. Prediction of subsidence risk by FMEA using artificial neural network and fuzzy inference system. Int J Min Sci Technol. 2015;25(4):655-63. https://doi.org/10.1016/j.ijmst.2015.05.021
6. Harris P, Viliani F. Strategic health assessment for large scale industry development activities: an introduction. Environ Impact Assess Rev. 2018;68:59-65.
7. Pescaroli G, Wicks RT, Giacomello G, Alexander DE.Increasing resilience to cascading events: The M.OR.D.OR.scenario. Safety Science. 2018;110:131-40.
8. Salokolaei DD,Esmaili SM.A Hybrid Approach Based on AHP and FMEA Approaches for Risk Assessment of Refinery Construction Projects.World. 2019;8(4):35-41.
9. Delic M,Eyers DR.The effect of additive manufacturing adoption on supply chain flexibility and performance: An empirical analysis from the automotive industry.Int J Prod Econ. 2020;228:107689.
10. Tazi N,Châtelet E,Bouzidi Y.Using a hybrid cost-FMEA analysis for wind turbine reliability analysis.Energies. 2017;10(3):276.
11. Chin K-S, Chan A, Yang J-B. Development of a fuzzy FMEA based product design system. Int J Adv Manuf Technol. 2008;36(7-8):633-49. https://doi.org/10.1007/s00170-006-0898-3
12. Zhang Z, Chu X. Risk prioritization in failure mode and effects analysis under uncertainty. Expert Syst Appl. 2011;38(1):206-

14.
13. Kutlu AC, Ekmekçioğlu M. Fuzzy failure modes and effects analysis by using fuzzy TOPSIS-based fuzzy AHP. Expert Syst Appl. 2012;39(1):61-7.
14. Braglia M, Bevilacqua M. Fuzzy modelling and analytical hierarchy processing as a means of quantifying risk levels associated with failure modes in production systems. Technol Law Insur. 2000;5(3-4):125-34.
15. Braglia M, Frosolini M, Montanari R. Fuzzy criticality assessment model for failure modes and effects analysis. Int J Qual Reliab Manag. 2003.
16. Chang CL, Liu PH, Wei CC. Failure mode and effects analysis using grey theory. Integr Manuf Syst. 2001.
17. Wang Y-M, Chin K-S, Poon GKK, Yang J-B. Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean. Expert Syst Appl. 2009;36(2):1195-207.
18. Liu H-C, Liu L, Bian Q-H, Lin Q-L, Dong N, Xu P-C. Failure mode and effects analysis using fuzzy evidential reasoning approach and grey theory. Expert Syst Appl. 2011;38(4):4403-15.
19. Gargama H, Chaturvedi SK. Criticality assessment models for failure mode effects and criticality analysis using fuzzy logic. IEEE Trans Reliab. 2011;60(1):102-10.
20. Grassi A, Gamberini R, Mora C, Rimini B. A fuzzy multi-attribute model for risk evaluation in workplaces.Safety Science. 2009;47(5):707-16.
21. Zalewski P. Risk assessment of LNG carrier systems failure using fuzzy logic. Zeszyty Naukowe/Akademia Morska w Szczecinie. 2011:77-85.
22. Petrović DV, Tanasijević M, Milić V, Lilić N, Stojadinović S, Svrkota I. Risk assessment model of mining equipment failure based on fuzzy logic. Expert Syst Appl. 2014;41(18):8157-64.
23. Xu K, Tang LC, Xie M, Ho SL, Zhu M. Fuzzy assessment of FMEA for engine systems. Reliab Eng Syst Saf. 2002;75(1):17-29.
24. Tay KM, Lim CP. Fuzzy FMEA with a guided rules reduction system for prioritization of failures. Int J Qual Reliab Manag. 2006.
25. Yang Z, Xu B, Chen F, Hao Q, Zhu X, Jia Y, editors. A new failure mode and effects analysis model of CNC machine tool using fuzzy theory. The 2010 IEEE International Conference on Information and Automation; 2010: IEEE.
26. Chang K-H, Cheng C-H, Chang Y-C. Reprioritization of failures in a silane supply system using an intuitionistic fuzzy set ranking technique. Soft Comput. 2010;14(3):285.
27. Bukowski L, Feliks J, editors. Application of fuzzy sets in evaluation of failure likelihood. 18th International Conference on Systems Engineering (ICSEng'05); 2005: IEEE.
28. Tay KM, Teh CS, Bong D, editors. Development of a Fuzzy-logic-based Occurrence Updating model for Process FMEA. 2008 International Conference on Computer and Communication Engineering; 2008: IEEE.
29. Mandal S, Maiti J. Risk analysis using FMEA: Fuzzy similarity value and possibility theory based approach.Expert Syst Appl. 2014;41(7):3527-37.
30. Tzeng G-H,Teng M-H,Chen J-J,Opricovic S.Multicriteria selection for a restaurant location in Taipei.Int J Hosp Manag. 2002;21(2):171-87.
31. Opricovic S, Tzeng G-H. Extended VIKOR method in comparison with outranking methods. Eur J Oper Res. 2007;178(2):514-29.
32. Nahook HN, Eftekhari M. A feature selection method based on∩-fuzzy similarity measures using multi objective genetic algorithm. Complement. 2013;11(S12):S13.
33. Shahabi H, Khezri S, Ahmad BB, Hashim M. Landslide susceptibility mapping at central Zab basin, Iran: a comparison between analytical hierarchy process, frequency ratio and logistic regression models. Catena. 2014;115:55-70.
34. Jeste DV, Savla GN, Thompson WK, Vahia IV, Glorioso DK, Martin AvS, et al. Association between older age and more successful aging: critical role of resilience and depression. Am J Psychiatry. 2013;170(2):188-96.
35. Boroun R, Mosavianasl Z, Tahmasbi Birgani Y, Shirali GA. Fuzzy Logic in HEART and CREAM 36.Methods to Assess Human Error and Find an Optimum Method Using a Hierarchical Fuzzy System: A Case Study in a Steel Factory. Int J Occup Hyg. 2021;13(2).
36. Jafari B. Shift work and work ability index in nurses: A case study of an educational hospital in Ahvaz. Int J Occup Hyg. 2021;13(2).