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Original

Identification and Ranking of Noise Control Solutions by Using Fuzzy Delphi approach, Fuzzy Analytic Hierarchy Analysis (FAHP) and Fuzzy Vikor in an Oil Refinery

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Abstract

Background: The study aimed of this study was to identify and ranking noise control solutions by using fuzzy Delphi approach and Fuzzy Analytic Hierarchy Analysis (FAHP) and Fuzzy Vikor method in an oil refinery. **Methods:** This descriptive-analytical study was conducted in the catalytic conversion unit in an oil refinery. First, noise measurement was performed based on the standard to identify the sources of noise generating factors. Second, the criteria and initial solutions were identified by reviewing the texts and conducting interviews with experts and the most significant criteria and solutions for noise control were selected using the fuzzy Delphi method. Then, the criteria were weighed using the fuzzy analytic hierarchy method. Finally, the control solutions were prioritized using fuzzy Vikor method. **Results:** The results of FAHP method indicated that cost with final weight (0.27) had the highest weight and non-interference in the process with final weight (0.11) had the lowest weight among the identified criteria. The ranking of noise control solutions with fuzzy Vickor method indicated that the construction of an acoustic room for workers exposed to weights (Q = 0) as the most appropriate solution for noise control and the method of modifying or changing the work process with the final weight (Q = 1) is the last noise control solution among the solutions identified in the studied refinery. **Conclusion:** The use of multi-criteria decision-making methods in selecting the appropriate solution for noise control can overcome the uncertainties in making an appropriate decision for selecting the best solution for noise control. In this study, a decision model was introduced for selecting the most appropriate noise control solution based on different criteria and this model can be used in other industries which should select a noise control solution.

Keywords: Noise control; Prioritization; Catalytic conversion unit; Fuzzy AHP; Fuzzy Vikor

Introduction

Noise is one of the most significant and common pollutants in the workplace and is caused by human activities. Developments in technology and the expansion of different industries have made a large number of people in the exposure of unwanted noise.[1] Exposure to noise can result in a range of adverse physiological and psychological effects such as hearing loss, hypertension,

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cardiovascular diseases, sleep disturbance, irritation, and distraction among the exposed individuals.[2, 3] Exposure to unwanted noise exists in many different occupations including steel, textile, power plant, and oil industry.[4, 5] A study by Mousavi and Dehghan indicated that there is noise pollution in some refinery units and the need for noise control should be regarded for preventing the adverse effects.[6, 7] The need to have a noise control program in the workplace is felt due to the high costs and adverse consequences of exposure to noise.[8, 9] In order to control noise, different control solutions such as controlling the noise at the source, controlling the noise at the source path, and controlling the noise at the receiving point have been recommended. In different conditions, some of these measures have a better efficiency, but a combination of these measures are often used for reducing the noise pressure level to the recommended standard range.[10, 11]

Making decision on to select the best noise control solution is one of the most fundamental issues which has always been considered by experts and professional safety and health experts. Due to the limited organizational resources and diverse noise control solutions, selecting a noise control solution from several solutions is highly significant. The use of multiple criteria decision models (MCDM) is suggested for selecting one solution from several existing solutions.[12] Analytical hierarchy process is one of the most widely used multi-criteria decision making methods, helping decision makers to set priorities based on their goals, knowledge, and experience and fully considering their feelings and judgments.[13] Since decision makers cannot often express definite judgments on priorities due to their fuzzy nature and uncertainty, using fuzzy logic in the hierarchical analysis method was formed.[14] Vikor means multi-criteria optimization and compromise solution and was introduced for the first time in 1998 by Oprikovich. This method was developed by Zheng in 2002 for the multi-criteria optimization of complex systems. VIKOR focuses on categorizing and selecting from a set of options and determines solutions for a problem with conflicting criteria, so that it can help decision makers made the final decision.

Using this method during the recent years has been considered as a method of solving multiple decision-making problems and used in various studies.[15, 16] Due to the significance of noise control to prevent its adverse consequences in individuals, it is necessary to adopt an appropriate noise control solution.[11] Since it is not possible to test all control solutions and making decisions on the selection of the best noise control solution by considering all criteria and solutions due to the variety of technical and economic criteria effective in choosing a noise control solution, thus it is beneficial to use multi-criteria decision making methods for selecting a noise control strategy. Thus, this study aimed to identify and prioritize noise control solutions using fuzzy Delphi method and FAHP-fuzzy vikor method in an oil refinery.

Methods

The present study was a descriptive-analytical study being conducted in 2019 in the catalytic conversion unit of an oil refinery in southern Iran. This study was a type of problem solving and multi-criteria decision making based on group decision making. At the beginning of the study, a list including 25 available academic and industrial experts was prepared. In this study, academic experts with a doctoral degree in occupational health and mechanics with a history of research related to noise control, as well as academic experts among industrial experts with more than 10 years of experience in noise control methods in the industry were selected. Then, seven criteria and 12 control solutions which can be used in the refinery were extracted by reviewing the texts and conducting interviews with available experts. Then, fuzzy Delphi method was used for determining the final criteria and solutions.[17] Determining criteria and solutions for noise control using fuzzy Delphi method

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Steps of fuzzy Delphi method are shown in figure 1. First, an anonymous questionnaire was sent to the team of experts who were asked to show the relevance of the identified initial criteria with the main research subject. The screening and the importance of each factor using the linguistic variables are shown in Table 1.

Table 1. Linguistic expressions used in the fuzzy Delphi method and their range of importance

Score of the range of importance	Linguistic expressions
1	Very low
2	Low
3	Average
4	High
5	Very high

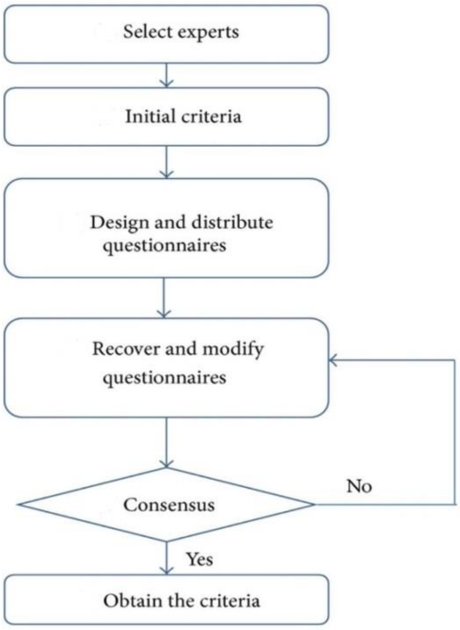

Figure 1. Steps of fuzzy Delphi method

In order to aggregate the experts' opinions, the mathematical relations governing fuzzy numbers were used. It is assumed that the linguistic expression of criterion j from the point of view of expert i is number i among n experts Wij = [aij, bij, cij] that the value of j equals j = 1, 2,3,… m and the value of i equals i = 1,2,3,… m.

Thus, the fuzzy value of the criterion j is calculated from the following equation, which equals Wj = [aj, bj, cj].

aj= min Equation (1)

$bj = \frac{1}{n}\sum_{i=1}^{n} bj$ Equation (2)

cj=max Equation (3)

Then, Eq. 4 was used for defuzzification.

$Sj=\frac{aj+bj+cj}{3}$ i=1 ,2, 3 ,…m Equation (4)

A number of 18 questionnaires were completed by experts and calculations were conducted based on the participation of 18 experts in the study. In addition, the condition of consensus or agreement of experts was realized when 70% of the experts gave the same answer to one of the options for each criterion.[18]

Determining the weight of criteria using the fuzzy analytic hierarchy analysis

In order to determine the weight of the criteria specified in this study, the fuzzy analytic hierarchy was used. The analytic hierarchy analysis was presented for the first time by Chang.[19] In this method, decisions were made on a specific case in order to aggregate the experts' opinions and also weighing was perfumed using a series of triangular fuzzy numbers. In order to weigh the opinion of experts and make comparisons between the criteria, linguistic terms and triangular fuzzy numbers presented in Table 2 were used. A questionnaire was provided to the experts and they were asked to compare the criteria in pairs and determine the degree of importance of the two criteria in relation to each other using linguistic terms.

Table 2. Linguistic scale and its corresponding fuzzy numbers used in pairwise comparisons

triangular fuzzy numbers	Linguistic term of relative importance	Degree of importance
(8, 9, 10)	Perfect	8
(7, 8, 9)	Absolute	7
(6, 7, 8)	very good	6
(5, 6, 7)	Fairly Good	5
(4, 5, 6)	preferable	4
(2, 3, 4)	Not bad	3
(1, 2, 3)	weak advantage	2
(1, 1, 1)	Equal	1

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Table 3. Linguistic variable and its corresponding numerical value used in Vikor method

Row	Linguistic variable	numerical value
1	Very poor	(1,1,2)
2	poor	(2,3,4)
3	Relatively good	(4,5,6)
4	good	(6,7,8)
5	perfect	(8,9,10)

In order to combine the experts' opinions, the geometric averaging technique was used, the output of which was a comparison matrix which was the result of experts' judgments (K= number of experts) based on Eq. 5.

$$a_{ij} = (\prod_{k=1}^{k} \tilde{a}_{ijk})^{\frac{1}{k}} \quad k = 1.2 \ldots . k \qquad \text{Equation (5)}$$

Then, Si which represents a triangular fuzzy number was calculated using Eq. 2 for each row of pairwise comparisons.

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=l}^{n} \sum_{j=l}^{m} M_{gi}^{j}\right]^{-1} \quad \text{Equation (6)}$$

In this equation, i represents the number of row, j represents the column number, and M_{gi}^{j} represents the fuzzy numbers of pairwise matrices. Values of $\left[\sum_{i=l}^{n} \sum_{j=l}^{m} M_{gi}^{j}\right]^{-1}$, $\sum_{i=l}^{n} \sum_{j=l}^{m} M_{gi}^{j}$, $\sum_{j=1}^{m} M_{gi}^{j}$ were calculated using Eqs. 7, 8, and 9.

$$\sum_{j=1}^{m} M_{gi}^{j} = (\sum_{j=1}^{m} l_j . \sum_{j=1}^{m} m_j . \sum_{j=1}^{m} u_j) \quad \text{Equation (7)}$$

$$\sum_{i=l}^{n} \sum_{j=l}^{m} M_{gi}^{j} = (\sum_{j=1}^{n} l_j . \sum_{j=1}^{n} m_j . \sum_{j=1}^{n} u_j) \quad \text{Equation(8)}$$

$$\left[\sum_{i=l}^{n} \sum_{j=l}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i} . \frac{1}{\sum_{i=1}^{n} m_i} . \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad \text{Equation (9)}$$

After that, the degree of magnitude of the Si obtained in the previous step was calculated relative to each other using Eq. 10.

$$V(M_2 \geq M_1) = \text{hgt}(M_1 \cap M_2) =$$

$$\mu_{M_2}(d) = \begin{cases} 1 & if\ m2 \geq m1 \\ 0 & if\ l1 \geq u2 \\ \frac{l1-u2}{(M_2-u2)-(m1-l1)} & other\ wise \end{cases} \quad \text{Equation (10)}$$

Then, the non-normalized weight of the criterion was calculated using Eqs. 11 and 12 of and finally the final normalized weight was calculated using Eq. 13.[20]

$$\acute{d}(A_i) = \text{Min V } (S_{i \geq} S_k) \ \text{k= 1,2,....,n , k≠i} \quad \text{Equation(11)}$$

$$w \acute{=} (\acute{d}(A_l). \acute{d}(A_l) \ldots . \acute{d}(A_n))^T \ A_l = (\text{i= 1,2,....,n}) \quad \text{Equation(12)}$$

$$w = d(A_l). d(A_l) \ldots . d(A_n))^T \quad \text{Equation (13)}$$

Selecting the most appropriate noise control solution using fuzzy Vikor method

After determining the weight of the criteria by using FAHP, the fuzzy Vikor method was used for prioritizing and selecting the most appropriate noise control solution.[21] At this step, the experts were asked to express their opinions on the extent to which each criterion was met by a specified solution based on linguistic terms.

The evaluation matrix was formed using the average opinions of experts and the values of the best and worst values for each positive index (profit) were determined.

$$i = 1,2, \ldots, n \ \tilde{f}_j = Max_i \ \tilde{f}_{ij} \quad \text{Equation (14)}$$

$$i = 1,2, \ldots ., n \quad f_j^{\sim\circ} = Min_i \ \tilde{f}_{ij} \quad \text{Equation (15)}$$

If $f_j^{\sim *} = (l_j^{\circ}, m_j^{\circ}, r_j^{\circ})$ and $f_j^{\sim\circ} = (l_j^{\circ}, m_j^{\circ}, r_j^{\circ})$ are two fuzzy numbers for normalizing the positive index of profit, Eq. 16 was used while Eq. 17 was used for the negative index (cost).

$$\tilde{d}ij = \frac{f_j^{\sim *} \ominus f_j^{\sim}}{r_j^{*} - l_j^{\circ}} \quad \text{Equation (16)}$$

$$\tilde{d}ij = \frac{f_{ij}^{\sim} \ominus f_j^{\sim *}}{r_j^{\circ} - l_j^{*}} \quad \text{Equation (17)}$$

Then the values of Sj (utility size) and Rj (effect size) for all solutions were calculated using Eqs. 18 and 19.

$$\tilde{S}_i = \sum_{j=1}^{j} (\tilde{w}j \otimes \tilde{d}ij) \quad \text{Equation (18)}$$

$$Ri = max_j \, (\tilde{w}j \otimes \tilde{d}ij) \quad \text{Equation (19)}$$

Finally, the final value of Vikor index was calculated using Eq. 20.

$$\tilde{Q}_i = v \frac{(\tilde{s}_j \ominus \tilde{s}^*)}{s^{\circ r} - s^{*l}} \oplus (1-v) \frac{(\tilde{R}_j \ominus \tilde{R}^*)}{R^{\circ r} - R^{*l}} \qquad \text{Equation (20)}$$

In the above equation, Qj represents the value of the Vikor index and the value of Vikor for the j-th option. v represents a weight for the maximum group utility solution, being usually equal to 0.5.[22] The solutions were prioritized based on the increase of Qj. As the Qj value is lower, the solution is in priority.[23]

Results

The results of fuzzy Delphi method indicated that five criteria and nine noise control solutions could achieve 70% of the consensus of experts and could be considered as the final criteria and solutions for noise control in the present study Table 4.

The criteria were identified by the fuzzy analytic hierarchy analysis and it was determined that executive cost and cost-effectiveness of the method with a normalized weight of 0.2796 were among the most effective criteria in selecting a noise control solution among the criteria. Other criteria and control solutions as well as the relative and normal weight of each criterion are presented in Table ۵.

The weight of the criteria obtained by the fuzzy analytic hierarchy process was used for calculating the final weight of the solutions using the fuzzy Vikor method. The results of Vikor method indictaed that the use of acoustic chamber for the individuals exposed to noise as the first priority, the building acoustic chambers on noise generating sources as the second priority, and installing the silencer on airjets as the third priority are among the studied solutions.

Table 4. Criteria and solutions for noise control identified by fuzzy Delphi method

Criterion	Nature of criterion	Percentage of consensus	Noise control solution
Efficiency of method in noise level reduction	Positive	0.88	Using hearing protection devices
Executive cost and cost-effectiveness of the method	Negative	0.90	Controlling the exposure time
Being executable	Positive	0.75	Repairing the defective parts of devices
non-interference in the process	Positive	0.82	Replacing new devices with old ones
Being secure	Positive	0.71	Building an acoustic chamber on noise generating sources
			Installing the silencer on the airjets
			Using vibration dampers to control the vibration of noise generating sources
			Modifying or changing the work process to reduce the steam egression rate
			Building an acoustic chamber for individuals exposed to noise

Table 5. Abnormal and normal weight of the criteria based on weighting with fuzzy analytic hierarchy process

Criterion	Abnormal weight	Normal weight
Being executable	0.8744	0.2445
Executive cost and cost-effectiveness of the method	1.0000	0.2796
Being secure	0.4007	0.1120
non-interference in the process	0.3959	0.1107
Efficiency of method in noise level reduction	0.9053	0.2531

Table 6. Final results of Vikor method and prioritization of noise control solutions based on Q value

Solution	S value			R value			Q value	priority
Using hearing protection devices	0.72	0.61	11.6	0.24	0.24	11	0.98	7
Controlling the exposure time	0.52	0.41	11.4	0.19	0.20	11	0.97	6
Repairing the defective parts of devices	0.83	0.71	11.7	0.24	0.24	11	0.993	5
Replacing new devices with old ones	0.90	0.91	11.8	0.25	0.25	11	0.998	8
Building an acoustic chamber on noise generating sources	0.60	0.46	5.97	0.21	0.18	5.5	0.498	2
Installing the silencer on the airjets	0.68	0.58	6.08	0.21	0.18	5.5	0.503	3
Using vibration dampers to control	0.73	0.62	6.12	0.21	0.20	5.5	0.505	4
Modifying or changing the work process to reduce the steam egression rate	0.94	0.95	11.8	0.27	0.27	11	1	9
Building an acoustic chamber for individuals exposed to noise	0.10	0.12	0.12	0.06	0.06	0.06	0	1

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Discussion

Few studies have been conducted on weighting and prioritizing noise control solutions in Iran and other countries and the use of multi-criteria decision-making methods in solving noise-related decision-making problems is a new subject which has been considered. In this study, fuzzy analytic hierarchy method was used for weighing the criteria for noise solution selection and fuzzy Vikor method was used for prioritizing noise control solutions. Vikor method is an effective tool in the multi-criteria decision-making process, when decision makers cannot accurately express their priorities due to inability or lack of knowledge, using this method is regarded highly efficient.[24] In fact, the main goal of Vikor method is to be closer to the ideal answer and also the prioritization of solutions is based on this goal.[25] The results of fuzzy Vikor method showed that building an acoustic chamber for the individuals exposed to the final weight (Q = 0) and building an acoustic chamber on noise generating sources with the final weight (Q = 0.49) were identified as the second priority. Due to the open environment of the catalytic conversion unit and the wide range of noise generating sources, it is not possible to enclose all noise generating sources. Thus, according to experts, building an acoustic chamber for the exposed individuals was superior to building an acoustic chamber on noise generating sources.

The solutions such as repairing old devices, replacing new devices with old ones, and changing the process due to high costs were among the last priorities of decision makers, indicating the effect of cost in selecting the method of noise control in industry. According to the experts, using personal protection equipment and time management is less effective than other methods in the field of noise control. The results of fuzzy analytic hierarchy method showed that cost with a final weight of 0.2796 and efficiency of the method with a final weight of 0.1077 had a role in selecting decision makers. Moradi et al. in their research entitled "Selecting the most appropriate noise control solution in an oil refinery using fuzzy analytic hierarchy method" concluded that the two criteria of cost and efficiency had the maximum relative weight among the considered criteria.". In addition, a study by Zare and Shirali indicated that there is a direct linear relationship between efficiency and cost while cost increases with increasing efficiency.[26, 27] In this study, cost with the final weight of (0.2796) and the efficiency of method with the final weight of (0.2531) were considered as two criteria with relative weight higher than other criteria, indicating the importance of these two criteria in selecting the noise control method. Eshaghi in his study that was conducted for selecting the best noise control solution in a glass factory used the AHP method. The results indicated that efficiency had the maximum relative weight or the most important criterion and cost had the minimum relative weight or in other words the least important criterion among the studied criteria.[28] In a similar study conducted by Sekhavati in the cement industry, initial investment cost was determined as the most significant criterion for selecting the noise control method.[29]

In both studies, exact words were used in the AHP method for performing pairwise comparisons between the criteria. An important disadvantage for the conventional hierarchical analysis method is that experts and decision-makers cannot clearly and conclusively express their opinion about the superiority of one criterion over another due to uncertainty and fuzzyness and using accurate numbers to make pairwise comparisons increase the possibility of errors in pairwise comparisons. Thus, using fuzzy analytic hierarchy technique as a powerful and scientific tool can be recommended for correcting possible errors in pairwise comparisons.[30, 31] Nasiri indicated that the confinement of noise generating sources

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significantly reduces the pressure level, but the limitations of this method should be considered.[8] A study by Golmohammadi et al. revealed that building an acoustic chamber on noise generating sources can reduce noise exposure.[32] In this study, it was found that building acoustic chambers on noise generating sources is one of the most effective solutions for noise control in the catalytic conversion unit. The results of a study by Moradi et al. conducted in the distillation unit of an oil refinery indicated that building a chamber for noise control is the first priority among the current control solutions that is consistent with the present study.[26] The limitation of the present study was that the internal relationship among the criteria was neglected and it was assumed that the weight of criteria would be calculated and compared to the results of the present study using multi-criteria decision making methods such as ANP which can analyze the internal relationships among the criteria.

Conclusion

This study proposed a decision-making model based on multi-criteria decision models which can be used as a scientific method for selecting the most appropriate noise control solution in the industry, considering different criteria and strategies. This model can be used for selecting a noise control solution in other industries where there is exposure with a noise higher than the allowed limit and require control solutions.

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