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Identifying and prioritizing the factors influencing industrial waste management using Fuzzy Analytical Hierarchy Process (FAHP)

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Abstract: Over the past few decades, human societies have faced one of the most significant consequences of industrial development. That is the improper transportation and disposal of hazardous and industrial-specific waste, which accounts for a large share of the total pollution of the environment, and its destructive effects on creating environmental crises are quite evident. The plating industry is one of the main consumers of toxic chemicals used for different applications. However, because of the lack of a comprehensive model, hazardous waste management has not yet met the current needs, and its principles still require more development. This study was carried out using tools and standards including Multi-Criteria Decision Support Systems (MCDSS) and Fuzzy Analytical Hierarchy Process (FAHP) to rank the contributions of effective components to the plating industry in a case study conducted and implemented in *Paitakht* Industrial District of Tehran. In order to realize this objective, after extracting 10 components effective in optimizing the management of industrial wastes, questionnaires were used to survey experts to verify the components. The factors were identified using the Delphi method through the analysis of frequency carried out using a second questionnaire based on the results of the analysis of the data extracted from the first questionnaire. The results showed that components contributing to the optimal management of industrial waste included leadership and management, policy, strategy, technology and mode of collection and transportation, economic factors, policy making, expertise, culture, education, and the amount and composition of waste, in that order.
Keywords: FAHP (Fuzzy Analytical Hierarchy Process), Multi-Criteria Decision Support Systems (MCDSS), Plating Industrial Waste Management, Effective Components of Industrial Waste Management.

1. Introduction

Rapid population growth, industrial development, technological advancement, and human inclination to increase consumption, and, ultimately, the growth of solid waste are among the issues that have recently resulted in serious crises in human societies (Aivalioti et al, 2014; Chalise, 2014). In recent decades, achieving goals such as public health and environmental quality has become important for societies and governments (Fataei et al., 2005). The term 'industrial waste' refers to all types of waste produced by industrial operations or generated as by-products of manufacturing processes (Musin et al, 2016). Industries have traditionally managed their waste products by discharging them into the environment without prior treatment. This practice resulted in an increase in pollution, and produced an adverse environmental impact. However, the requirement for environmental quality resulted in the transformation of the whole concept of pollution control (Yavuz and Ögütveren, 2017). The history of Industrial Waste Management goes back to the ratification of the Resource

Conservation Recovery Act in the United States in 1976 (Safarzadeh et al, 2019). The first laws and regulations pertaining to hazardous waste management were implemented in member countries of the Common Market in 1980 in Europe (Karami et al, 2011). The chemical industry plays an important role in the industrial development of the countries (Koolivand et al, 2017). A wide range of materials used in the intermediate and end-use activities are in some way dependent on the efficient operation of chemical industries (Li et al, 2016). In line with the policy of sustainable development, a sustainable chemical industry can be considered as a counterpart of sustainable industrial development when the functioning of these industries does not entail irreparable harms to the environment (Hogland and Stenis, 2000). Certainly, in the chemical industry, a number of waste materials are produced that require coherent management. Hazardous waste management is one of the most important components of environmental management, which has been extensively explored by professionals in recent years (Soler et al, 2017). The use of various chemicals, including hazardous chemicals, and non-sanitary and imprecise disposal of these substances will lead to widespread hazards (Capón-García et al, 2014). Over the past few decades, human societies have faced one of the most serious consequences of industrial development. That is the improper transportation and disposal of hazardous and industrial waste, which accounts for a large share of the total pollution of the environment, and its destructive effects on creating environmental crises are quite evident (Russell, 2008). Many countries have tried to provide appropriate technological and scientific methods for the management of hazardous waste, including industrial wastes. However, because of the lack of a comprehensive model, hazardous waste management has not yet met the current needs, and its principles require more development (Bugallo et al, 2012). Various experiences in a number of developed countries indicate that eliminating the harmful effects of hazardous waste discharges and the purification of the contaminated environment is far more costly than the proper management for preventing it (Babu and Ramakrishna, 2000). The sources generating dangerous wastes are very diverse. Industrial waste is one of the most important hazardous wastes (Zamorano et al, 2011). Achieving a balanced development and the realization of developmental goals will require the reconciliation of the industry and the environment (Ndiaye et al, 2010). One of the most important problems in Iran is the lack of proper management of industrial waste, especially specific industrial waste. In this regard, it should be noted that about 16,600 authorized industrial units are operating in Tehran Province, producing about 800 to 1000 tons of industrial waste on a daily basis. About 450 tons of industrial waste has been recorded by the Environment Directorate of Tehran during the process of the environmental monitoring of industrial units, of which about 90 tons of hazardous industrial waste is produced each day. Therefore, disposing of this amount requires the adoption and implementation of special management approaches (Mohammadi et al, 2005). The main objective of this study is to focus on identifying and ranking the factors influencing industrial waste management by using the Fuzzy Analytical Hierarchy Process, identifying main challenges, and proposing a waste management framework for industries.

2. Materials and Methods

The current study is a descriptive and inferential one based on deducing the results of data analysis that was carried out in two stages with the aim of evaluating the status of waste management through a case study in the plating industry located in Tehran metropolitan area. In order to realize the research objectives, the inductive logic and the inductive method have been utilized for assessing the optimal management of industrial waste. Accordingly, the information and statistics related directly or indirectly to the topic of the study were extracted from relevant specialized books, scientific research articles, dissertations and theses in different fields inside and outside the country, and the results of research reports published inside and outside the country. Then, the results of studies on the utilized methods and the list of components influencing industrial waste management in relevant studies carried out inside and outside the country were used to conduct the current study. Subsequently, questionnaires were developed to elicit the opinions of experts (specialists) for verification of the selected components and criteria. Afterward, tools and standards including Multi-Criteria Decision Support Systems (MCDSS) were utilized in order to determine the significance and ranking of identified components through quantitative analysis in industrial waste management based on the principles and concepts of Multi-Criteria Decision Making Systems (MCDM) and the Fuzzy Analytical Hierarchy Process (FAHP). Then, using a checklist of components, a survey was carried out in the form of Questionnaire 1 based on the Delphi Method with the aim of screening and collecting the research data. It is worth noting that 30 questionnaires were distributed among 30 identified experts as the statistical population of the study. The experts' comments were summarized in Questionnaire 1 based on the Delphi method (common sense) and analyzed based on frequency. It should be noted that the items in the questionnaire had three response choices, i.e., agree, disagree, and not sure, for each of the components and criteria influencing industrial waste management. Subsequently, data analysis was performed using Questionnaire 2 based on the results of the analysis of the data extracted from Questionnaire 1 by determining the adequacy of the accepted data and based on the hourly method utilized for the corresponding numerical verbal wording. Due to the necessity of reducing the uncertainty of the desired results in terms of the research objectives, the fuzzy analytical hierarchy process technique was used to clear up ambiguities in the verbal method, where fuzzy sets are more consistent with the verbal method, and according to Han-Zing (1999), they can increase the possibility of long-term prediction of decision making in the real world. Chang's development analysis method has been used in analyzing the data (S. Safavian and Fataei, 2017), in which the numbers used are based on fuzzy triangles. To this end, a hierarchical chart was first created to compare the level of the elements relative to each other so that the relative importance of the elements can be investigated using fuzzy numbers. Then, the fuzzy numbers were defined for the purpose of pairwise comparison, and the paired comparison matrix was constructed using fuzzy numbers (Shcherbina et al, 2010).

$$\widetilde{D} = \begin{bmatrix} 1 & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & 1 & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \dots & 1 \end{bmatrix} \tag{1}$$

Table 1: Realistic numerical values based on the Chang method for fuzzification using fuzzy triangle method

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1,1,1	**1,2,3**	**2,3,4**	**3,4,5**	**4,5,6**	**5,6,7**	**6,7,8**	**7,8,9**	**8,9,9**
L,M,U	L,M,U	L,M,U	L,M,U	L,M,U	L,M,U	L,M,U	L,M,U	L,M,U
Not significant	Negligible significance	little significant	little significant to significant	significant	Significant to very significant	very significant	very significant to significant	Fully significant

L: low level, M: medium level, U: upper level

After providing a pairwise comparison matrix, the Si value for each of the rows of the paired comparison matrix, which is a triangular fuzzy number, is calculated using the following equation, and the values of Si are compared to each other (Moeenaddini, 2011).

$$\sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \tag{2}$$

In this equation, i represents the row number and j represents the column number, M_{gi}^{j} signifies the triangular fuzzy numbers of the pair comparison matrices, and l_i ,m_i, and u_i, represent the first, second, and third components of the fuzzy numbers, respectively.

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j \,, \sum_{j=1}^{m} m_j \,, \sum_{j=1}^{m} u_j\right) \tag{3}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i \,, \sum_{i=1}^{n} m_i \,, \sum_{i=1}^{n} u_i\right) \tag{4}$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (5)$$

In the next step, the values of Si are calculated from each other using the following equations, and the magnitude of the triangular fuzzy number is calculated from other triangular fuzzy numbers.

$$V\ (M_2 \geq M_1) = \text{hgr}\ (M_1 \cap M_2) = \mu_{M_2}(d) = M1, M2 \quad (6)$$

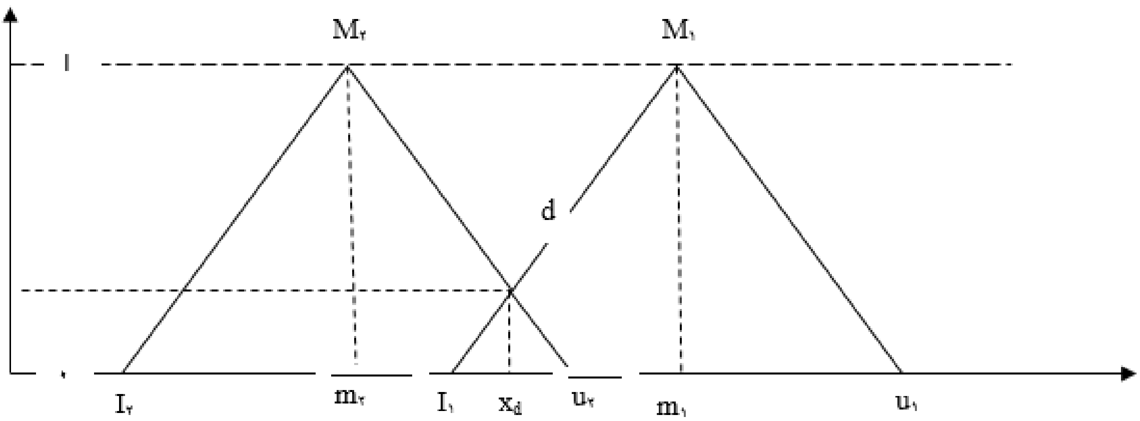

Figure 1: The magnitude of two fuzzy numbers relative to each other

$$V\ (M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M1) \text{and} (M \geq M2) \text{ and} \ldots (M \geq Mk)] = \text{Min } V(M \geq Mi) i = 1,2,\ldots,k \quad (7)$$

Finally, the weight of the criteria in the pairwise matrices and the final weight vector were obtained using the following equations, and the final weights were determined for each of the components.

K= 1, 2,3,…, n , k≠i $S_{k)}$ d' (D_i)= Min V (S_i≥ (8)

Not-Normalized Weight Vector:

W'= (d' (D1), d' (D2),… , d' (Dn))T Di (i=1,2, …,n) (9)

Finalized Weight Vector:

W= (d (D1), d (D2),… , d (Dn))T (10)

W'= (d' (D1), d' (D2),… , d' (Dn))T Di (i=1,2, …,n)

3. Results

A. Identification of Waste Management Factors

The MCDM criteria are typically extracted from previous studies and screened using the Delphi method (Üsküdar et al, 2019; Dožić, 2019; Hasanzadeh et al, 2013; Jozi et al, 2010). As noted earlier, in this study, a checklist of criteria was compiled extracted from the results of the surveys, the review of the available sources including books, theses, and articles inside and outside the country, research reports and the like using the first-round survey of checklists from the experts, as shown in Table 2.

B. Assigning Scores to the Plating Waste Management Criteria

Based on the Delphi and Fuzzy AHP results, a total of 10 criteria were found to contribute to waste management in the plating industry. These can be used to present a comprehensive model of waste management in the plating industry. Pertinent scores are shown in Tables 3 and 4

Table 2: First-round Survey of checklists from the experts

Component		Agreed		Disagreed		Abstentions	
		amount	%	amount	%	amount	%
General	Leadership and Management	100	30	0	0	0	0
	Policy	97	29	1	3	0	0
	Strategy	97	29	0	0	1	3
	Economics	97	29	1	3	0	0
	Policy Making	90	27	2	7	1	3
	Cultural	76	23	5	17	2	7
	Education	100	30	0	0	0	0
Technical	Expertise	83	25	4	14	1	3
	Technology and Mode of Collection and Transportation	100	30	0	0	0	0
	Amount and Composition of Waste	83	25	3	10	2	7

The results of the first round showed that all criteria were approved by the experts with a majority of votes (% of agreement over 50%). Then, in the second stage, based on 30 questionnaires completed by relevant experts (Questionnaire No. 1), using the Mode Statistics based on the Delphi method, and the results of the survey of the experts, the qualitative-descriptive data, including the components and criteria, were obtained based on analyzing the data from Questionnaire 2, which was based on the results of the analysis of the data extracted from Questionnaire 1, which was developed based on the principles and rules of the fuzzy hierarchy process analysis technique and distributed between 30 experts, as described in Table 3. Ultimately, Weight Vectors of Effective Components in Optimal Management of Industrial Wastes were calculated using the following equations, and the priority of the components was determined according to Table 4.

Total rows of (SSr)= (313.42 ،352.73 ،392.58)

Table 3: (12)

Normalized weights of all rows: $\frac{1}{SSr_i}$ = (0.0025, 0.0028, 0.0032) (13)

SSr multiplied by $\frac{1}{SSr_i}$ =Si (14)

S_1 =(56.1 ،62 ،68.3) × (0.0025 ،0.0028 ،0.0032) =(0.1403 ،0.1736، 0.2186)
S_2 =(49.2 ،54.8، 61.2) × (0.0025 ،0.0028 ،0.0032) =(0.1229 ،0.1536 ،0.1958)
S_3 =(43.3 ،49.6 ،55.8) ×(0.0025 ،0.0028 ،0.0032) =(0.1048 ،0.1390 ،0.1786)
S_4 =(34 ،38 ،42) ×(0.0025 ،0.0028 ،0.0032) =(0.0850 ،0.1065 ،0.1345)
S_5 =(25.5 ،27.2 ،29) ×(0.0025 ،0.0028 ،0.0032) =(0.0637 ،0.0762 ،0.0929)
S_6 =(35.7 ،40 ،43.2) ×(0.0025 ،0.0028 ،0.0032) =(0.0893 ،0.1119 ،0.1384)
S_7 =(24.2 ،26.8 ،29.8) ×(0.0025 ،0.0028 ،0.0032) =(0.0604 ،0.0752 ،0.0955)
S_8 =(14.6 ،16 ،17.5) ×(0.0025 ،0.0028 ،0.0032) =(0.0364 ،0.0448 ،0.0561)
S_9 =(11.6 ،15.2 ،17.8) ×(0.0025 ،0.0028 ،0.0032) =(0.0289 ،0.0427 ،0.0569)
S_{10} =(11.1 ،14.2 ،17.5) ×(0.0025 ،0.0028 ،0.0032) =(0.0277 ،0.0397 ،0.0559)

The magnitude of the values of weights of (S_i)s relative to each other

$$V(M_2>M_1)=hgr(M_1\cap M_2)=\mu_{M_2}(d)=\begin{cases} 1 & if\ m_2 \geq m_1 \\ 0 & if\ l_1 \geq u_2 \\ \frac{(l_1-u_2)}{(m_2-u_2)-(m_1-l_1)} & otherwise \end{cases} \quad (15)$$

Table 3: Fuzzification of Weight Values of Effective Factors in the Optimal Management of Industrial Waste

	A	B	C	D	E	F	G	H	I	J
A	(1,1,1)	(2.6.2.8.3.7)	(2.4،2.6،2.8)	(2.8،3.7،4.7)	(3.7،4.7،5.7)	(5.9،6.1،6.3)	(4.7،5.7،5.9)	(7.2،7.7،8.3)	(6.1،6.3،7.2)	(5.7،5.9،6.1)
B	(0.27.0.36.0.38)	(1,1,1)	(2.6،3.8،5.1)	(2.5،2.6،3.8)	(2.4،2.5،2.6)	(5.1،5.4،5.5)	(3.8،5.1،5.4)	(5.4،5.5،6.3)	(5.5،6.3،7.1)	(6.3،7.1،7.2)
C	(0.36.0.38.0.42)	(0.2.0.26.0.38)	(1،1،1)	(2.1،3.7،4.5)	(2،2.1،3.7)	(3.7،4.5،4.6)	(4.5،4.6،4.7)	(6.5،7.3،7.7)	(4.6،4.7،6.5)	(6.5،6.9،7.3)
D	(0.21.0.27.0.36)	(0.26.0.38.0.4)	(0.22،0.27،0.48)	(1،1،1)	(3.9،4،6.1)	(3.5،3.9،4)	(2.9،3.2،3.5)	(2.6،2.9،3.2)	(6.1،6.2،6.3)	(3.2،3.5،3.9)
E	(0.17.0.21.0.27)	(0.38,0.4,0.42)	(0.27،0.48،0.5)	(0.16،0.22،0.26)	(1،1،1)	(3،3.1،3.3)	(3.7،3.9،4.3)	(3.1،3.3،3.6)	(3.9،4.3،4.7)	(2.9،3،3.1)
F	(0.15.0.16.0.17)	(0.18.0.19.0.2)	(0.21،0.22،0.27)	(0.25،0.26،0.28)	(0.3،0.32،0.33)	(1،1،1)	(4.1،4.8،5.5)	(5.5،6.1،6.3)	(5.5،6.3،7.4)	(4.8،5.5،6.1)
G	(0.16.0.17.0.21)	(0.18.0.19.0.26)	(0.21،0.22،0.23)	(0.29،0.31،0.34)	(0.23،0.25،0.27)	(0.18،0.21،0.24)	(1،1،1)	(3.9،4.3،4.7)	(4.3،4.7،5.5)	(3.5،3.9،4.3)
H	(0.12,0.13,0.14)	(0.16.0.18.0.19)	(0.13،0.14،0.15)	(0.31،0.34،0.38)	(0.28،0.3،0.32)	(0.15،0.16،0.18)	(0.21،0.23،0.25)	(1،1،1)	(2.7،2.8،2.9)	(2.8،2.9،3.8)
I	(014.0.15.0.16)	(0.14.0.15.0.18)	(0.15،0.21،0.22)	(0.15،0.16،0.17)	(0.21،0.23،0.25)	(0.14،0.16،0.18)	(0.18،0.21،0.23)	(0.34،0.36،0.37)	(1،1،1)	(1.5،3،4.6)
J	(0.16.0.17.0.18)	(0.13.0.14.0.16)	(0.14،0.15،0.16)	(0.26،0.28،0.31)	(0.32،0.33،0.34)	(0.16،0.18،0.21)	(0.23،0.26،0.29)	(0.26،0.34،0.36)	(0.22،0.33،0.66)	(1،1،1)

A: Leadership and Management; B: Policy; C: Strategy; D: Economics; E: Policy Making; F: Cultural; G: Education; H: Expertise; I: Technology and Mode of Collection and Transportation; J: Amount and Composition of Waste

Table 4: Component Ranking Based on Weight and Rank

Component	Not-normalized weight	Normalized weight	Rank
Leadership and Management	1,000	0.23	1
Policy	0.735	0.169	2
Strategy	0.525	0.121	4
Economics	0.445	0.102	6
Policy Making	0.207	0.047	7
Cultural	0.144	0.033	9
Education	0.129	0.03	10
Expertise	0.165	0.038	8
Technology and Mode of Collection and Transportation	0.534	0.123	3
Amount and Composition of Waste	0.466	0.107	5
Total	4.35	1	

4. Discussion

The rapid propagation and development of industry in recent decades has confronted human societies to one of the most dangerous environmental issues; so that inexact management of dangerous waste materials, especially industrial wastes have played a major role in the environmental pollution as its destructive effects are clearly evident in the creating environmental crises. So, many countries have attempted to present an appropriate technology and scientific methods for management of dangerous waste materials (including industrial wastes of various industries). However, due to the lack of a comprehensive management model for this type of dangerous wastes, especially in the plating industry, the necessity of systematic management based on scientific principles is developing significantly. Considering the set of mentioned issues, it can be concluded that the main problem in achieving a comprehensive model for management of industrial wastes, especially dangerous wastes, is due to the different methods used in the metal plating industry. Therefore, variables including used raw materials and the waste (that is result of their preparation) to enter the processing stage, wastes of materials processing stage to produce the product and the wastes of the stage of storage of products and their consumption by users in the form of liquid wastes (sewage), which their management altogether requires the comprehensive model, from the entry of materials into the production system to the exit and consumption of plant product, which it is the basic issue in these industries and the other similar industries. This research has been performed to solve the mentioned problem. So, in this research the main and effective factors of industrial waste management (especially plating industry) were identified and the experts prioritized that by using FAHP based on Delphi method. Based on the obtained prioritization, the factors with higher weight value should be prioritized in the industrial waste management and the management strategies should be identified and used in this regard.

5. Conclusions

Questionnaires have been used as a tool to learn about the management of wastes in industrial areas, and other types of waste (Abduli, 1996; Asadi et al., 1996; El-Fadel et al., 2001; Monahan, 1990). The results of the current study attempt to evaluate the overall industrial waste management in the plating industry in Iran; however, the waste management of the plating industry is not comprehensively assessed in the current study. The use of questionnaires to obtain data regarding the production, characterization, and management of industrial wastes should also be accompanied by other studies concerning the type of industrial activity in the research area. Nonetheless, the study identified the 10 main influential components for optimizing the management of industrial waste, including the leadership and management component with a weight of 0.23 (ranked first), the component of policy with a weight of 0.169 (ranked second), the technology and mode of collection and transportation component with a weight of 0.123 (ranked third), the component of the strategy with a weight of 0.121 (ranked fourth), the amount and composition of waste with a weight of 0.107 (ranked fifth), the economic component with a weight of 0.102 (ranked sixth), the component of policy making with a weight of 0.047 (rank seventh), the component of expertise with a weight of 0.038 (ranked eighth), the cultural component with a weight of 0.033 (ranked ninth), and the education component with a weight of 0.03 (ranked tenth). These were the ten main factors (components) that were effective in optimizing the management of industrial waste. Therefore, in order to optimize industrial waste management, the focus should be on general components including management and leadership, policy, strategy and technology used, and then on the technical factors and components, even those related to the composition of the waste and their transportation.

6. ADDITIONAL INFORMATION AND DECLARATIONS

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Competing Interests

The author declare there is no competing interests, regarding the publication of this manuscript

Author Contributions

Mina Moeeni, Ghasemali Omrani, Nematallh Khorasani, and Reza Arjomandi prposed the plan, conceived the experiments, analyzed the data, revised drafts of the paper, and approved the final draft.

Ethics Statement

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