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Research Article

Evaluation of optimal waste management in the plating industry based on the Delphi Method and Fuzzy Analytic Hierarchy Process (Case Study: Paitakht Industrial District of Tehran)

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Abstract
The plating industry is one of the main toxic chemicals consumers, which uses various chemicals, including solvents, acids, bases, cleansers, sophisticated organic ingredients, and metal salts of cadmium, nickel and chromium. Due to the growing production of industrial waste in spite of actions related to these wastes' management, no comprehensive pattern was introduced at different levels. This research uses equipment and standards, including techniques such as Multi-Criteria Decision Supporting System and Fuzzy Analytic Hierarchy Process, to rank and prioritize the participation contribution of the factors that are effective in optimizing the management of waste from the plating industry in a case study, implementing the model on *Paitakht* Industrial District of Tehran. In order to evaluate waste management situation in the metal plating industry, an integrated empirical model with principles and concepts of Balanced Scorecard Method was used, and factors were identified using the Delphi method. Variation range related to total score based parameters were calculated by the scalographic method, and the significance of the linear relationship between them was analyzed using linear regression in order to determine industrial waste management at three levels, including weak, moderate, and appropriate, presentingthe final pattern. The results showed that waste management in the plating industry, as a sample of special waste and residue, was at a low level. Considering to outputs from the represented pattern, to improve industrial waste management in first priority considered, item interpretation and proceeding to medium-term strategic planning were provided to eliminate the limitations and mentioned issues.

Keywords: Balanced Scorecard Method, Delphi Method, Empirical Modeling, Plating Industrial Waste management.

Introduction

Rapid population growth, industrial development, technological advancement, and human inclination to increase consumption and, ultimately, the growth of solid waste are among the

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issues that have recently created massive crises in human societies (Aivalioti et al, 2014; Chalise, 2014). Over the past years, many parts of the world have witnessed a remarkable evolution in the management of industrial waste management, from open dumping on the land and indiscriminate burning, to integrated systems incorporating waste processing, recycling, and treatment. This progress made public's growing awareness of the need to protect human health and the environment and the importance of resource and energy conservation. Governments, businesses, and individuals now recognize, and in many cases embrace, the adoption of sustainable practices in many aspects of daily life, including the management of solid waste. Improper industrial and municipal waste management can lead to many forms of contamination, such as groundwater contamination, air quality deterioration, and greenhouse gas emissions (Usapein and Chavalparit 2014). Industrial waste is the waste produced by industrial activity which includes conventional wastes and hazardous waste. Currently, industrial activities are the main sources of world's hazardous waste production (Al-Qaydi 2006).

Today, most manufacturing plants are in need of detailed analysis of their waste management system at all stages of production. Those who have already studied waste streams within the company and who have identified opportunities for recovery and resource saving usually find that there are large economic as well as environmental benefits to be gained when appropriate waste management is implemented (McDougall, et al. 2008). Industries generate complex wastes, a complexity not only due to the quantity of wastes but also to their composition (Wei & Huang, 2001). The term industrial waste refers to all wastes produced by industrial operations or derived from manufacturing processes (Abduli, 1996).

Industries have traditionally managed their waste products by discharging them into the environment without previous treatment. This practice resulted in an increase of pollution and produced an adverse environmental impact. The requirement for environmental quality resulted in a change of the whole concept of pollution control (Vigneswaran,et.al., 1999). Industrial Waste Management history returns to approval of Resource Conservation Recovery Act in United States in 1976. The first laws and regulations pertaining to hazardous waste management have been implemented in member countries of the Common Market in 1980, Europe. The establishment and development of the industries pursue economic and social development and seek goals such as increasing domestic production, creating jobs, and improving quality of life, which are among the developmental indicators of countries (Karami et al, 2011). The chemical industry plays an important role in the industrial development of countries (Koolivand et al, 2017). Industrial waste is the waste produced by industrial activities, which includes conventional wastes and hazardous waste (Ko et al, 2016). Currently, industrial activities are the main sources of the world's hazardous waste production (Musin et al, 2016).

Inappropriate transportation and disposal of hazardous and industrial waste, which accounts for a large portion of the total pollution of the environment, and its destructive effects are quite evident in creating environmental crises (Russell, 2008). Today, most manufacturing plants need a detailed analysis of their waste management system at all stages of production. The expansion of factories and industrial units, despite the industrial progress and economic profitability of the country, increases the input of industrial pollution into soil resources and the climate of the human environment (Wang and Yang, 2016).

The creation of waste and industrial waste containing heavy metals and its penetration into the living environment and the human food cycle are the most important part of industrial pollution (Yavuz and Ögütveren, 2017). Industrial waste management is one of the most important parts of environmental management, which has been taken more and more into considerations by experts in recent years (Usapein and Chavalparit, 2014; Koolivand et al, 2017). The use of various chemicals, including hazardous chemicals, and the non-sanitary and inadequate disposal of these substances will lead to widespread hazards (Singh et al, 2017). Disposal of materials and the remaining waste from consumed products and harmful and hazardous substances from the outputs of factories and manufacturing industries are among the most important problems of today's world (Rabbani et al, 2017). In line with sustainable development policy, we can involve the sustainable industrial sector in the existing complex of industries only when the performance of these industries does not impose irreparable problems on the environment (MehriAhmadia et al, 2013; Liu et al, 2017).

Certainly, in industries dealing with chemicals, produced waste materials require coherent management. Hazardous material waste management is one of the most important parts of environmental management, which has been taken more and more into considerations by experts in recent years (Padash et al, 2015; Yetis et al, 2017). Sewage and effluent from the industry may contain toxic substances and high amounts of heavy metals, which, by discharging these wastes into the agricultural run-offs, large amounts of these metals enter into the environment (Dong et al, 2016). In the metal plating industry, various chemicals are used. These materials include solvents, acids, alkalis, detergents, complex organic materials, and metal salts such as cadmium, nickel and chromium salts.

The metal plating industry is one of the largest consumers of toxic chemicals. Wastewater purification of plating industries is of significant importance because of the large volume of pollutants in the wastewater of these industries (Soler et al, 2017). The metal plating industry produces a wide range of metal components, such as metal cans, hand tools, hardware, and many construction products. It accounts for the production and manufacturing of a large portion of industries such as automotive, electronics, defense, aerospace, hardware, heavy equipment, communications, and jewelry (Dobes, 2013). The sewage produced by the metal plating industry contains chemical compounds and metal particles. Regarding the different and diverse quantities of chemicals and consumables, the produced sewage contains a wide range of pollutants. including metals, organic wastes, hovering solids, phosphates, fluorides. Phosphate and fluoride are important parameters whose effects on the environment have been identified, and regulations have been set to control them. Hovering solids are old control parameters in the purification and disposal of toxic organic and inorganic parameters (Zamorano et al, 2011). The aim of this research is to model waste management in the plating industry to determine their environmental situation. Therefore, numerous studies and investigations have been carried out in accordance with national and international standards.

Material and Methods

This research is descriptive and inferential research based on deducing the results of data analysis that was carried out in four stages with the aim of providing a model for evaluating the status of waste management through a case study in the plating industry located in Tehran metropolitan area of Iran. The research was conducted using the Delphi method and based on the MCDM approach by applying the Fuzzy Analytical Hierarchy Process (FAHP) method (Ahadi and Ghazanfari, 2012; Wang et al., 2020; Intharathirat and Salam, 2020; Parveen and Kamble, 2020; Yücenur et al., 2020; Padash and Ataee, 2019). In order to achieve the research objectives, the logic and inductive method was implemented in the field of evaluation of the optimal management of industrial waste in the *Paitakht* Industrial Town of Tehran. For this purpose, the Delphi method was used to screen the factors, and the FAHP technique was used to rank them

(Wang et al, 2008; Chatterjee, and Mukherjee, 2010; Kheybari et al., 2020; Prato, 2020; Li et al., 2020; Di Cesare et al., 2020; Padash, 2017; Chen and Honda, 2020; Tran et al., 2020; Musyoki et al., 2020; Kumar et al., 2020). Initially, a comprehensive review of extant literature was conducted, and the information and statistics directly or indirectly related to the research generals and the subject were extracted from relevant specialized books, scientific and promotional research papers published in specialized journals, Ph.D. and Master's dissertations from different fields, and the results of research reports to extract a list of potential criteria. In the second step, a checklist of the factors was compiled and submitted to domain experts to be screened using the Delphi method. Given the use of a convenience population, the availability of experts was used to determine the number of surveyed experts. Furthermore, item reliability was established through Cronbach's alpha coefficient. It is noteworthy that it was not necessary to examine the validity since expert opinions were harnessed to obtain the items. The third step involved the statistical analysis of the data provided by the participants. By applying the Mod statistic, a second questionnaire was developed to rank the criteria by using Fuzzy AHP.

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

Since the FAHP technique has been used in this study to increase the certainty of the results, the result of the fuzzification of the numerical values of the components based on the scale method (fuzzy triangle method) was used in accordance with Table 1.

Table 1. Realistic numerical values based on the Chang method for fuzzification using the fuzzy triangle method (Habibi et al, 2004)

1	2	3	4	5	6	7	8	9
1.1.1 L,M,U insignificant	1.2.3 L,M,U negligible significance	2.3.4 L,M,U little significance	3.4.5 L,M,U little significance to significant	4.5.6 L,M,U significant	5.6.7 L,M,U significant to very significant	6.7.8 L,M,U very significant	7.8.9 L,M,U very significant to significant	8.9.9 L,M,U absolutely significant

L: Low level, M: Medium level, U: Upper level

In cases where several decision-makers are involved in decision making, the entries of comprehensive pairwise comparison matrices used in the fuzzy hierarchical analysis method should be a triangular fuzzy number, so that from left to right, its first component is the minimum scale or spectrum of polls, the second component is the average of polls, and the third component is the maximum number of polls.. In order to calculate S_i for each row of the pairwise comparison matrix, which itself is a triangular fuzzy number, the following equation is used:

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

Where i is the row number, and j is the column number, M_{gi}^{j}, in which the triangular fuzzy numbers are pairwise comparison matrices, and to calculate other values, the following equations are used:

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

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

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

In which l_i, m_i and u_i are the first, second, andthird entries of fuzzy numbers, respectively. The next step was to calculate the magnitude of S_is relative to each other. Let $M_1= (l_1, m_1, u_1)$ and $M_2= (l_2, m_2, u_2)$ be two triangular fuzzy numbers, the magnitude of M_1 relative to M_2 is defined as follows:

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

On the other hand, the magnitude of a triangular fuzzy number of another K triangular fuzzy number is obtained by the following equation:

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

The weighting of criteria in the pairwise comparison matrices was calculated by the following equation:

$$d' (D_i)= Min\ V (S_i \geq S_k) \qquad K= 1, 2,3,\ldots, n \quad , \quad k \neq i \quad (8)$$

Therefore, the non-normalized weight vector was obtained as follows:

$$W'= (d' (D1), d' (D2),\ldots, d' (Dn))\ T \quad Di\ (i=1,2, \ldots, n) \quad (9)$$

Finally, the final weight vector was calculated and normalized through the following equation:

$$W= (d (D1), d (D2),\ldots, d (Dn))\ T \quad (10)$$

Lastly, after determining the final weights of the factors, the entries were ranked.

$$W'= (d' (D1), d' (D2),\ldots, d' (Dn))\ T \quad Di\ (i=1,2, \ldots, n) \quad (11)$$

Finally, in order to assess the industrial waste management status, individual scores were calculated. The model was generated using a balanced scoring approach with 1000 scores equally distributed among the criteria (according to the numbers). Waste management score in the plating industry was calculated as follows:

$$(WMS)i = (Wi)\ (Si) \quad (12)$$

Where $(WMS)i$ is the waste management score, Wi represents the normalized weights, and Si denotes factor scores. It should be noted that Relation (13) yields the total score to determine environmental performance in plating waste management.

$$WMS=\Sigma(Wi)(Si) \quad (13)$$

In which the normalized weight of each factor (Wi) was calculated using Fuzzy AHP by summing the balanced scores. To assess waste management, the normalized weights yielded by Fuzzy AHP were multiplied by 1000 to determine the weighted score of each criterion (Wi). Finally, the percentages of the final factor weights were calculated to find the domains of indicator scores (Si). As a result, upper and lower bounds were established for each waste management factor.

Results and discussion

A. Identification of waste management factors

MCDM criteria, as factors were 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). In this research, as mentioned, a checklist of criteria was compiled using the First-round Survey of checklists from the experts, as shown in Table 2.

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

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 exploited to present a comprehensive model of waste management in the plating industry. Pertinent scores are shown in Tables 3 and 4.

C. Determination of the variation domains of factors scores

Domain variations of the waste management factors are shown in Table 5. According to the results, waste management in the plating industry can be measured in eight levels: very poor, fairly poor, poor, medium, fairly good, good, very good and excellent.

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	

Table 5. The evaluation results of the status of waste management in the plating industry based on the evaluation of effective factors

Factor	Range of scores							
	very poor	fairly poor	poor	medium	Fairly good	good	very good	excellent
Leadership and management	0-25	25-50	50-75	75-100	100-125	125-150	150-175	175-200
Policy	0-15	15-30	30-45	45-65	65-85	85-105	105-125	125-150
Technology and Mode of Collection and Transportation	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-100
Strategy	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-100
Amount and Composition of waste	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-100
Economic	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-100
Policy making	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-50
Expertise	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-50
Cultural	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-50
Education	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-50
Total score	0-100	100-200	200-300	300-405	405-510	510-615	615-720	720-950

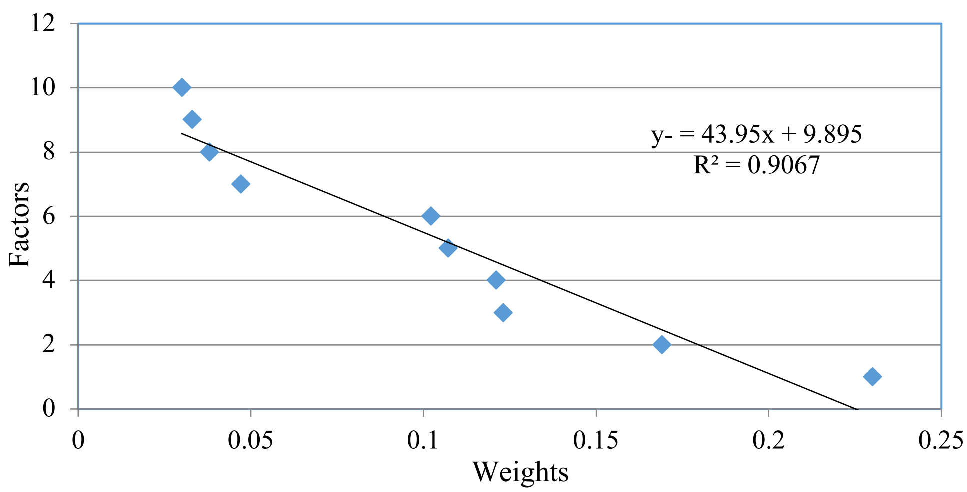

Figure 1. Scalographic pattern of relationships between factors (linear equation)

D. waste management status results in the studied center

Since the model is a semi-structured model using the FAHP technique based on the MCDM approach,, the implementation of the third stage of modeling i.e., the sensitivity of the model, is dependent on the final (normalized) weight of each factor. Consequently, considering the weight of each factor in Table 4, the model is sensitive to existing factors, respectively. In order to validate the model, according to the research carried out in the Paitakht Industrial district of Tehran (Abbas Abad), the model was implemented in plating units. The result of the validation of the model was carried out based on field observations and interviews with experts and specialists in the field of plating and waste management industry by using randomized sampling. Based on the results obtained in the above evaluation tables, the status of waste management of the plating industry was evaluated from the viewpoint of the ten factors, taking into account the range of points taken from the four classes and subclasses, as described in Table 6. Hence, considering the total assessment scores of the 10 factors, the equivalent of 950, and the total score of the current status evaluation of the waste management of the plating industry was equivalent to a score of 277, indicating a poor status in the unit, which means that there is no systematic approach to the management of industrial waste with respect to identified factors. In other words, approaches are not convergent and are not in line with industrial waste management.

Table 6. The evaluation results of the status of waste management in the plating industry based on the evaluation of effective factors

Factor	Status	Score
Leadership and management	Fairly poor	45
Policy	poor	40
Technology	medium	35
Strategy	Fairly poor	15
Amount and Composition of waste	medium	35
Economic	medium	37
Policymaking	poor	12
Expertise	medium	17
Cultural	Fairly good	23
Education	medium	18
Total		277

Conclusion

According to the results of this research to evaluate the overall industrial waste management of plating industry in Iran, and since in this model, the waste management of plating industry is not comprehensively assessed, the model introduced in this research (with emphasis on main factors) can be used to evaluate the waste management of plating industries in the country.Thus, by using this model, while it is possible to determine the existing waste management status by examining and measuring the factors that have been evaluated, necessary actions are taken to address the weaknesses in improving the status of the waste management of the plating industry. In other words, the model has the capacity to achieve the applied strategies for improving the waste management status of industries and is an effective tool for managing change towards being “eco-friendly”. Accordingly, with regards to the implementation of the evaluation model presented for the Paitakht Industrial Town located in Tehran, the final score of that was 277, which according to Table 5, is in the range of 200 to 300, and it is possible to assess the performance status of the industry as “poor,” based on the final score. Finally, considering the outputs of the proposed model, it is recommended, in the first priority, to take into consideration the presented items as described (causes of poor status) to improve the industrial waste management status, and to take the necessary actions with regard to strategic mid-term planning in the context of eliminating the limitations and the issues mentioned earlier in this research. Since eliminaing all of the limitations and the issues related to industrial waste management are based on the ten factors obtained in the research, it is suggested that, given the outputs from the implementation of the proposed model, in the first place, actions should be taken through short-term planning to remove items related to factors with low scorecard. It is recommended to test the model in other industries in the form of a research program to validate it and eliminate possible limitations and to complete the model as the output of the current research, and in order to generalize the model, the presented model is recommended to be adopted in future researches.

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