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ORIGINAL ARTICLE

Performance Assessment of HSE Management Systems: A Fuzzy Approach in a Steel Manufacturing Company

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ABSTRACT

Organizations and companies have realized the significance of Health, Safety and Environmental (HSE) management as an integral and vital part of modern factories and organizations. Developing HSE processes requires performance assessment, for which defining appropriate indicators is a necessity. Because of the non-deterministic nature of performance indicators, assessments are prone to influence from personal judgments by the assessors. Many HSE management system indices are uncertain. Fuzzy approaches can reduce the effects of assessor judgments as well as uncertainty. The aim of the study was to present an HSE management system performance assessment model in a fuzzy environment. A questionnaire was used to conduct the study in one of the largest steel companies in Iran. The results revealed that, in the areas of health, safety, and environment, control of disease, fire hazards, and air pollution were of paramount importance, with coefficients of 0.057, 0.062, and 0.054, respectively. Furthermore, health and environment indicators were the most common causes of poor performance. Many performance health indicators had remained unchanged which were also due to the long-term nature of health indicators. Finally, it was shown that HSE management systems could affect the majority of safety indicators the short run, whereas health and environment indicators require longer periods.

KEYWORDS:*Noise, Hearing loss, Otoacoustic emissions, DPOAE, Rat*

INTRODUCTION

Executives in modern industries are fully aware of the importance of Health, safety and Environmental (HSE) systems. Many organizations and companies have realized that HSE management is an integral and vital part of modern factories and organizations [1]. Developing HSE processes requires evaluation, for which defining appropriate indicators is a necessity, so that the process is not assessed solely based on one criterion – often-financial [2]. Many developing countries may incur large accident costs caused by lack of proper facilities.

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Nonetheless, weaknesses can be identified and resolved through performance assessment systems [3]. Therefore, it is essential that the environment and workforce be protected since they are indispensable to economic prosperity [4]. In order to increase productivity as well as prevent health-, safety-, and environment-related incidents, a HSE Management System (HSE-MS) with an efficient structure is required. This type of management moves toward sustainable development, cost reduction, and efficiency by preventing health, safety, and environmental injuries. In addition, health and safety of employees and others affected by the current activities of the organization are taken into account [5]. With the advancement of technology and the increased use of machines, the risk of accidents in industrial environments is now very important. Historically, accidents caused irreparable damage. Today, however, regulating safety, health and environment measures have reduced the frequency and severity of accidents [6]. The HSE-MS system needs to be in line with organizational policies. Furthermore, detailed and accurate plans are required to achieve its goals. The success of an activity is judged based on how its feedback is evaluated; therefore, assessing HSE performance is essential [7-8]. Despite the numerous benefits of HSE-MS systems, they also have weaknesses, such as the need for constant auditing in order to prevent performance deviation [9].

Performance assessment of management systems is a major concern for managers, to which HSE-MS is not an exception. Managers need to ensure proper functionality and performance in all the aspects of the deployed HSE-MS. Moreover, the impact of the HSE-MS must be measured against established expectations. A large number of studies focus on performance assessment systems. Omidvari and Lashghary studied the effects of personal judgments and qualitative assessments in HSE performance assessment systems, and concluded that mathematical and engineering structures can increase performance assessment accuracy [2]. In addition, Omidvari and Ghandehari discuss assessing the performance quality of environmental management in urban management systems [10]. They refer to the impact of personal judgments based on inappropriate indicators on assessment. The application of decision-making models in fuzzy environments can help resolve this issue. The most important environmental defined indices were air pollution, solid waste, noise pollution and recycling [10-11]. A study on assessing the performance of HSE units also pointed to the qualitative nature and impact of personal opinions by evaluators on the evaluation process. To assess accurately performance, a model that represents performance in the business processes is required [12]. In this regard, Santos et al. provide a conceptual model to assess performance. The study of Santo et al., also refers to a conceptual model for accurate performance assessment [13]. Further, Nouri et al. highlight the need for a performance assessment model for environmental issues. The most important indices were defined in this study environmental risk [14].

In many practical situations, decision-makers judgments are uncertain and cannot be explained by exact numerical values. Thus, to deal with the complexity of these decision-making problems, it is necessary to use new interdisciplinary approaches. The fuzzy approach is often used to study information uncertainty and incompleteness. Its application in the mathematical analysis of systems with incomplete information follows a growing trend [15]. The fuzzy expert system has been successfully used in in identifying the characteristics of safety management system of a company at a certain point and its performance [16]. Many safety management system indicators were identified as being uncertain; the fuzzy approach is suitable for assessment in these situations [17].

Nikoomaram calculated performance and efficiency of the health, safety and environment system in a petrochemical complex using a fuzzy method. She argued that indicators of performance assessment were qualitative and uncertain and a fuzzy system was required to rectify the problem. The management believes to safety issues and resource, facilities, and Realized HSE funds were the most important HSE indices that she was defined [18].

Under uncertain condition, the fuzzy approach establishes a comprehensive approach for evaluating HSE performance using weights assigned by experts' weights is established. A performance assessment of HSE management system in Fuzzy environmental was designed to receive a comprehensive and objective evaluation result [19-20]. The HSE performance indicators are qualitative therefore the fuzzy approach is recommended, which can reduce the effects of assessor judgment during the assessment process [19]. A major challenge in assessing the performance of safety management systems is the fact that judgments are influenced during the assessment process. Using fuzzy systems, one can increase the accuracy of data collection and calculation [21].

Focusing on safety limitations and health problems, an adequate infrastructure for constant assessment and monitoring of health and safety issues can be established through controlling the activities of the safety and HSE management system [22-23]. Tajoddini found a significant relationship between HSE culture and performance improvement of this unit. In order to create a unified HSE culture, performance assessment is vital [24]. In another study, an HSE-MS system is considered as an essential management tool to effectively monitor and verify the health, safety and environment policies in any organization and factory. Regular performance assessment of this sector is also emphasized. Performance assessment is essential in improving safety and needs to be taken seriously [25]. One of the most important effects of hazardous agents is loss of performance. Steel industries are among the most hazardous industries. Thus, HSE-MS is very important in these industries. The most critical safety system management indices include safety culture and safety risk. The worker perspective and their participation in safety directly affect the performance of safety system performance. The steel manufacturing industry is inherently extremely "unsafe"; thus, it is vital that employees identify and control extant hazards [26].

The objective of this paper was to present an HSE-MS performance assessment model in the steel industry. We seek to identify factors that affect the system.

Moreover, for each factor, the extent of impact on HSE management system performance in the organization was determined.

MATERIALS AND METHODS

Fig.1 presents the steps of the study. As indicated, initially, the study aimed to gain an understanding of the environment.

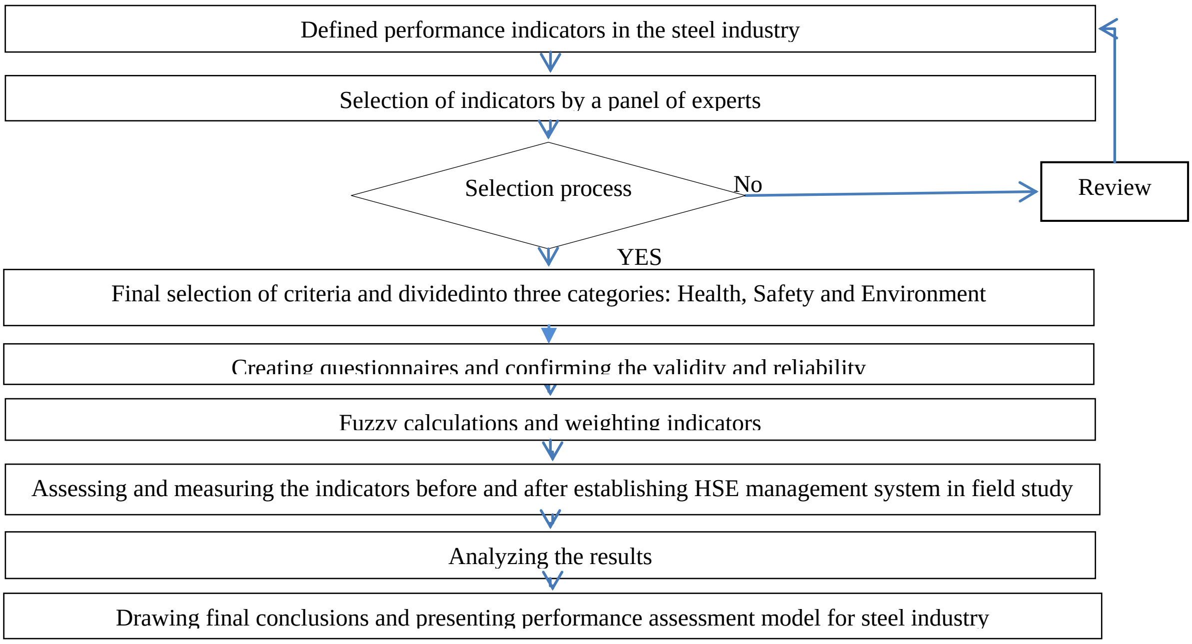

Fig.1. Main steps of the study

All HSE management system performance indicators in steel industry were defined according to available resources (scientific articles) and standards (HSE-MS & OHSAS-18001), [26]. The indicators were selected by experts in Delphi method. We define an expert as an individual with at least 10 years of experience in the steel industry, whose qualifications include at least an undergraduate degree and a complete understanding of the performance assessment process as well as the concepts fuzzy logic. The population of the study consisted of 30 experts including university professors, senior staff of HSE unit of Isfahan Steel Company, and technical personnel of different production units of the plant.

A questionnaire was used for collecting data, While reliability of questionnaire was established by Cronbach's alpha ($a_{cronbach}$=0.798).

Answers were given on a five-point Likert scale ranging from very weak to excellent. Based on the questionnaire as well as expert opinion, performance indicators in the areas of safety, health and environment were categorized for agglomeration, steelmaking and casting units. To quantify weights of performance indicators, a fuzzy method was employed. Using the indicators defined in the questionnaire, prepared a checklist to gather information. Then, the indicators were then studied and calculated in the field study by the checklist was prepared.

The weights were determined using statistical methods by comparing indicators, obtained from available documents, before and after the implementation of the HSE system. This was followed by a pair t-test analysis. Accordingly, a significant relationship was found between indicators and the HSE unit performance.

This research was conducted in the Steel Manufacturing Company for three consecutive years (2012 to 2015). The HSE-MS was implemented in 2012. Data pertaining to the HSE tasks and performance were collected through site visits and investigating case study documents. Next, a questionnaire was developed to identify performance indicators. Measurements were taken in the first year prior to the implementation of the HSE-MS system and the third year, i.e. 3 years after the HSE-MS had been implemented.

In this study, two main sections of the steel manufacturing company (i.e. agglomeration, steel making and casting) were considered. Furthermore, through collecting data related to the performance of sponcefirm's HSE unit, the relationships between HSE performance assessment and a series of performance indicators were investigated. The items covered the firm’s HSE performance in terms of safety, health, and environment. Essentially, performance refers to the ratio of inputs to outputs in a system [27]. Therefore, in this study a series of the same input parameters are considered for the three categories of health, safety, and environment. Furthermore, a number of distinct output indicators were defined in each respective area, as shown in Table 1.

In most checklists and questionnaires, optionsare oftenqualitative, which need to be quantified before being processed. First, using the appropriate scale, qualitative alternatives are converted to fuzzy numbers. As described below, the obtained fuzzy numbers are then converted to absolute values. The first step often requires the use of appropriate fuzzy scales, which are chosen according to the number and nature of the alternatives. To convert normal numbers (i.e. numbers whose x values range from 0 to 1), to absolute values, a maximum and a minimum function are defined as follows.Equation.1.

Equation 1:

$$\text{Max}(x) = \begin{cases} X & 0 \le x \le 1 \\ 1 & \text{Otherwise} \end{cases} \qquad \text{Min}(x) = \begin{cases} 1-x & 0 \le x \le 1 \\ 0 & \text{Otherwise} \end{cases}$$

After defining the functions above, the maximum is cut with the right tolerance of the fuzzy number, and minimum with the left tolerance of the fuzzy number. Thus, the left and right score values of the fuzzy number are obtained. This is the importance level of the fuzzy numbers ((x) м) at the intersection points. The left and right points are represented with ((x) μ_r) and (μ_L (x)), respectively. Fig. 2 shows the defined fuzzy domains. Fuzzy equivalents of the options of questionnaire items are presented in Table 2.

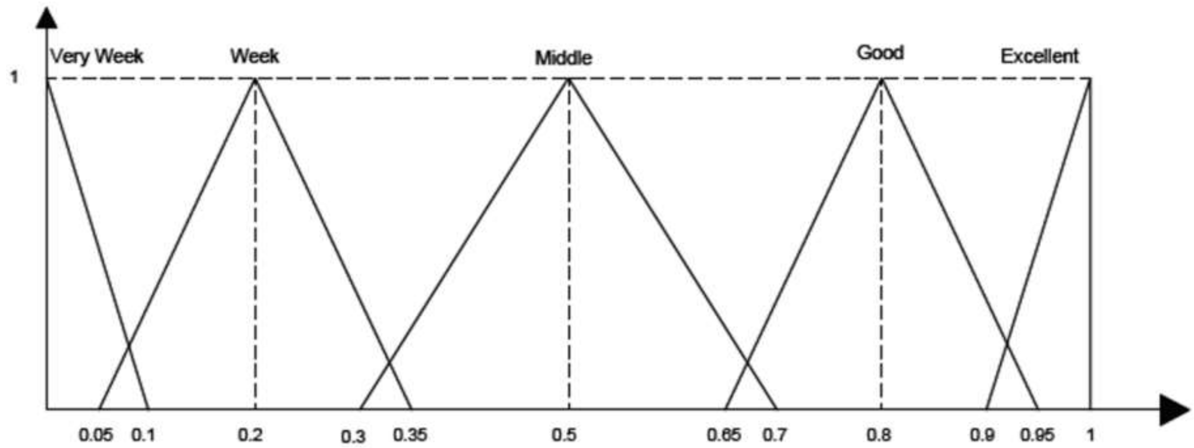

Fig.2. Domains of fuzzy numbers

Expert opinionswere then averaged using the following expressions as Equation (2).

Equation 2:

$$\left(\frac{a}{7},\frac{b}{7},\frac{c}{7}\right) = \left(\frac{\sum_{i=1}^{7}(a_i)}{7},\frac{\sum_{i=1}^{7}(b_i)}{7},\frac{\sum_{i=1}^{7}(c_i)}{7}\right)$$

To calculate the total score the following formula was used:

Equation 3:

$$\mu_T(x) = \frac{\mu_R(x) + (1 - \mu_L(x))}{2}$$

Consideringthe triangular fuzzy number as (m, α, β), the left and right domain values are determined. Therefore, using (m, α, β), the qualitative options can be quantified. Furthermore, the values can be easily calculated using the following formula.

Equation 4:

$$\mu_T(x) = \frac{m+\beta}{2(1+\beta)} + \frac{m}{2(1+\alpha)}$$

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Once the weight of each indicator is determined, a normalization occurs so that the sum of the weights equals zero. In order to normalize the weights, the following formulas are used.

Equation 5:

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n} \, \overline{x_\iota} = \frac{x_i}{\bar{X}}$$

To measure the effectiveness of HSE management system, the performance safety indices were measured in before and after system implementation. The results of this study step were compared by pair *t* test statistical analysis. Ultimately, the unit's performance is assessed based on the significance of the changes in the indicator; in case of realization, the weight shows the importance of the indicator and is taken into account to determine the rate of the input and output. The total weight of input and output indicators was considered in calculating performance. This methodology focused on the overall performance of the HSE-MS in the organization. The performance of the organization is evaluated according to the weights derived from a case study based on the following equation:

Equation 6:

$$\mathrm{p} = \frac{\sum_{i=1}^{7} x_{i\ output}}{\sum_{i=1}^{19} x_{i\ input}}$$

Table 1. Performance indicators defined in this study

No.	Group	Indicator		Definition
1	Input	Number of individuals	HSE	The number of experts in HSE in each unit (The ratio of number of staff to HSE officer)
2		Dedicated funds	HSE	Appropriated funds for the HSE department dedicated to performance management activities, particularly compensation and rewarding
3		Resources and facilities	HSE	Adequacy of financial resources for the implementation of HSE-MS programs
4		Realized HSE funds	HSE	Approved funds for the measures envisaged in the field of HSE
5		Pertinent instructions	HSE	Comprehensive HSE instructions for daily activities
6		Personal protection equipment	HSE	Realized percentage of the anticipated personal protection equipment
7		Annual funds	HSE	The annual funds dedicated to HSE activities
1	Output	Continuous inspection of public places	H	Percentage of continuous inspection of public places according to HSE indicators
2		Notifications and public awareness	H	Increasing staff information and public awareness regarding the dangers of consumables
3		Work-related diseases	H	Percentage of employees suffering from work-related diseases
4		Staff examinations	H	Percentage of general medical examinations among staff
5		Job-specific examinations	H	Number of job-specific medical tests
6		Ergonomic conditions	H	Extent of improvements in the ergonomic conditions of the unit
7		Individual incidents at work	S	Number of individuals who sustain injuries while working - Accident Frequency Rate (AFR)
8		Controlled risks	S	Percentage of controlled risks that lead to accidents
9		Fire hazards	S	Percentage of controlled risks resulting in fire
10		Controlled fire sources	S	Increase in the percentage of controlled fire sources
11		Power protection systems	S	Percentage of the electricity systems with power protection systems
12		Personal Accident Severity Rate (ASR)	S	Percentage of employees injured while working
13		Waste water pollution load	E	The reduction of BOD pollution of unit's waste water
14		Air pollution	E	Percentage of Air Pollution Index (API) caused by agglomeration
15		Pollution caused by waste water	E	Percentage of pollution caused by waste water
16		Solid waste	E	Volume percent of solid waste
17		Recycling solid waste	E	The percentage of recycled solid waste in the plant
18		Soil pollution	E	Percentage of soil pollution caused by plant activities
19		Noise pollution	E	Percentage of reduction in the level of noise pollution

H, S, E: indicators in all the three areas of health, safety and environment
H: Indicators in the area of health
S: Indicators in the area of safety
E: Indicators in the area of environment

Table 2. Fuzzy equivalents of the options of questionnaire items [10]

Row	Scale	Domain
1	Very weak	(0,0,0.1)
2	Weak	(0.05,0.2,0.35)
3	Average	(0.3,0.5,0.7)
4	Good	(0.65,0,8,0.95)
5	Excellent	(0.9,1,1)

RESULT

This study was conducted in a large steel company, with 16000 personnel from 7 sections: two main manufacturing sectors; three auxiliary sectors; and two non-manufacturing sectors. Only the main manufacturing sectors (agglomeration and steelmaking - casting units) were considered. The weight of HSE performance indices is showed in Table 3.

Table 3. The defined performance indicators weight

Row	Group	Index	HSE	Weight
1	Input	Number of HSE officer (The ratio of number of staff to HSE officer)	HSE	0.079
2		Dedicated funds	HSE	0.085
3		Resources and facilities	HSE	0.102
4		Realized HSE funds	HSE	0.243
5		Pertinent instructions	HSE	0.145
6		Personal protection equipment	HSE	0.114
7		Annual funds	HSE	0.232
		Sum		1.000
1	Output	Continuous inspection of public places	H	0.053
2		Notifications and public awareness	H	0.054
3		Work-related diseases	H	0.058
4		Staff examinations	H	0.052
5		Job-specific examinations	H	0.048
6		Ergonomic conditions	H	0.043
7		Individual incidents at work	S	0.057
8		Controlled risks	S	0.063
9		Fire hazards	S	0.062
10		Controlled fire sources	S	0.065
11		Power protection systems	S	0.051
12		Personal Accident Severity Rate (ASR)	S	0.053
13		Waste water pollution load	E	0.052
14		Air pollution	E	0.054
15		Pollution caused by waste water	E	0.043
16		Solid waste	E	0.051
17		Recycling solid waste	E	0.047
18		Soil pollution	E	0.056
19		Noise pollution	E	0.045
		Sum		1.000

H, S, E: indicators in all the three areas of health, safety and environment
H: Indicators in the area of health
S: Indicators in the area of safety
E: Indicators in the area of environment

The results showed no significant difference between HSE performance input indicators in the main manufacturing units (agglomeration and steelmaking - casting units) in the steel industry. The weights of the input indicators measured using the defined fuzzy system and expert opinion can be seen in Table 3. Input indicators of the performance model were analyzed in the agglomeration unit. The results are shown in Table 4. Pair-*t*.testrevealed a significant difference between the values of input indicators before and after the implementation of HSE-MS (*P*-values <0.05).

Table 4. Results from performance input indicators in the agglomeration unit

Row	Indicator	BeforeHSE-MS	After of HSE-MS		
			2013	2014	2015
1	Number of individuals	10	10		14
2	Dedicated funds (Rial/year)	8000000	90000000	92000000	97600000
3	Number of financial Resources per year	155	170	180	188
4	Percentage of HSE funds Realized	35%	65%	67%	74%
5	Pertinent instructions	257	280	300	302
6	Personal protection equipment	67%	70%	72%	73%
7	Annual funds	$10^{9} \times 27.2$	$10^{9} \times 70.2$	77.1	$10^{9} \times 88.1$

Table 5 Presents measured values for the health and safety performance indicator in the agglomeration unit.

Table 5. Measured values for safety and health performance indicators in the agglomeration unit

Row		Indicator	Before HSE-MS	After HSE-MS
1	Safety	Reduction of the number of individual incidents at work - AFR	27	18
2		Individual injuries (ASR)	15	8
3		Controlled risks	122	177
4		Fire hazards	32	55
5		Controlled fire sources	71	123
6		Power protection systems	26	41
7	Health	Notifications and public awareness	36%	58%
8		Continuous inspection of public places	104	209
9		Work-related diseases	104	88
10		Staff examinations	63%	77%
11		Job-specific examinations	23%	44%
12		Ergonomic conditions	77%	83%

As specified in Table 6, there was a significant difference for "number of incidents at work" before and after the implementation of HSE-MS. This is also shown in the statistical results (*P*-values <0.05).

Results of measuring performance indicators of health and safety in steel-making and casting units are shown in Table 6. The staff examinations index was not significantly different before and after HSE-MS implementation, as demonstrated by the statistical results (*P*-values>0.05). Furthermore, other than "continuous inspection of public places", no statistically significant differences were observed for health performance indicators before and after the establishment of HSE-MS system.

Table 6. Results of measuring performance indicators of health and safety in steel-making and casting units

Row		Index	Before HSE-MS	After HSE-MS
1	Safety	Reduction of the number of individual incidents at work - AFR	33	17
2		Individual injuries ASR	17	13
3		Controlled risks	114	198
4		Fire hazards	29	48
5		Controlled fire sources	78	112
6		Power protection systems	29	55
7	Health	Notifications and public awareness	35.5%	52%
8		Continuous inspection of public places	102	211
9		Work-related diseases	108	66
10		Staff examinations	88%	93%
11		Job-specific examinations	44%	62%
12		Ergonomic conditions	52%	69%

Measurements of environmental performance indicators in the agglomeration, steel making, and casting are shown in Fig. 3. Pair *t* test results showed no significant difference between the environmental indicators before and after the implementation of the HSE-MS system in the agglomeration, steel making, and casting. However, a substantial reduction (20%) is observed for air pollution, which is also confirmed in the statistical results (*P*-values > 0.05).

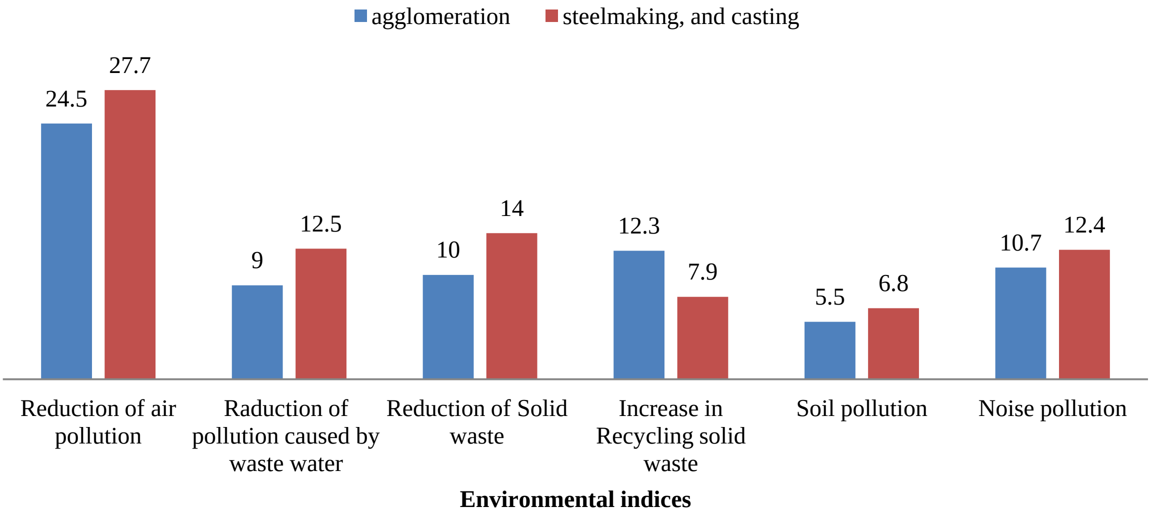

Fig.3. Measurements of environmental performance indicators in the agglomeration, steelmaking, and casting unit

The results of the model regarding performance assessment showed that the agglomeration unit had a score of 0.442 in output and of 1 in input, according to which agglomeration unit performance is ultimately equal to 0.442. In the steel and casting units the output was 0.543 and the input was 1, thus the efficiency of steel and casting unit is equal to 0.543.

DISCUSSION

The objective of this study was to determine the HSE unit performance assessment in steel manufacturing in Iran. Our findings showed that HSE systems affect accident indicators, as there was a significant difference between accident rates before and after the implementation of the HSE-MS. This finding was similar to the result of another study [2]. One of the most important HSE indices in safety was fire hazard and controlled fire source. This finding was contrary to the finding of Omidvari and Lashghary study [2]. The main reason was the difference in the type of field study. This study was done in steel industry but their study was in metro [2]. In steel industry, fire and fire source control is very important but in metro company, safety training is very important.

Documentation is very important in HSE management system. This result is in line with our results [19]. In addition, HSE-MS can be effective in enhancing HSE performance in organizations [16]. There results were similar to ours. The result of our study showed a significant difference between the values of HSE indicators before and after the implementation of HSE-MS. As such, the HSE-MS does indeed affect health, safety and environmental indices [16].

An important finding of this study was that the environmental indicators in steel manufacturing were weak. The problem could be reducing the performance of the safety management system. The main reason for this is that management does not believe in these areas. Azadeh et al. point out the low performance of organizations in the field of environment. They noted that managers tend to make the smallest investments in the field of environment and occupational health track [21]. Our findings are in line with those of Mohammadfam et al who identified health and safety as the most important aspects of efficiency in HSE. Furthermore, the authors assert that the environmental issues are the weakest area of HSE, as pointed out in this study [28]. The management system played a very important role in safety performance [29]. In addition, top management should involve safety committee to review the effectiveness of the safety program. Employees must be familiar with the basic safety policies and objectives. Safety meetings, including all levels of the employees should be regularly held. Adequate safety staffing should exist to carry out effective safety programs. Their findings were in line with our finding [29]. The important items of HSE performance were HSE culture, regular learning courses, environmental pollution management wastewater treatment management and systematic risk analyses. These indices were similar with our indices in our study. In both of study, risk management was the most important of HSE performance [30]. This suggests the importance of risk management in the process of HSE performance assessment system.

The most important limitation of this study was a shortage of experts and lack convenient access to information.

CONCLUSION

HSE systems affect accident indicators, as there was a significant difference between accident rates before and after the implementation of HSE management system, which could be mainly attributed to the medium-term influence of the HSE systems. Many performance health indicators remained unchanged which is also due to the long-term nature of health indicators. Reviewing results over a long time could demonstrate the effect of HSE systems on the performance of health indicators. Air pollution control has the highest performance among environmental indicators; the most important reason is emphasis law.

For future study, HSE management system performance can be obtained using mathematical methods for example Data Envelopment Analysis (DEA).

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