IJOH INTERNATIONAL JOURNAL OF OCCUPATIONAL HYGIENE
Copyright © 2008 by Iranian Occupational Health Association (IOHA)
2008-5435/14/63-1-8

**ORIGINAL ARTICLE**

# The Performance of HSE Management System Using Fuzzy Data Envelopment Analysis (FDEA) Model in the Smelting Industry

AZIN SHAMAII[1], MANOUCHEHR OMIDVARI[2*], *FARHAD HOSSEINZADEH LOTFI* [3]

[1]*Department of Environmental Management, Science and Research Branch, Islamic Azad University, Tehran, Iran*
[2]**Industrial and Mechanical Engineering Faculty, Islamic Azad University, Qazvin, Iran*
[3] *Department of Mathematics, Islamic Azad University, Science and Research Branch, Tehran, Iran*

Received September 05, 2019; Revised October 19, 2019; Accepted October 16, 2019

This paper is available on-line at *http://ijoh.tums.ac.ir*

## ABSTRACT

An accurate assessment of performance of Health, Safety, and Environment (HSE) system allows managers to identify strengths and weaknesses in the HSE system. This paper mainly was aimed to assess the performance of HSE management system using Fuzzy Data Envelopment Analysis (FDEA) model in the smelting industry. The indices of performance evaluation of process HSE management systems of smelting industries were weighted and ranked by Fuzzy System. Then, based on the weights of performance indices and data collected in the case study, performance was evaluated via DEA. The FDEA model was solved using a network model with constant returns to scale. According to the results, environment was the most important index of efficiency. Number of HSE Expert (0.16) and annual HSE Budget per employee (0.17) were the most important input indices in HSE performance system. Ergonomic risk control (0.08), Fire source control (0.08), and waste water quality (0.08) were the most important output indices in HSE performance system, respectively. The different performance criteria or safety performance with varying levels of significance can be used in each step of the assessment process. Budget of HSE was ranked the most important of HSE performance input indicators. This index affects other input indicators. Risk control in the three areas of safety, health, and the environment was one of the most important indicators of performance appraisal output. To evaluate systems safety, a performance evaluation system based on multiple inputs and multi-outputs was more applicable than other systems.

**KEYWORDS:** *Performance Assessment; FDEA; HSE; Fuzzy; Network Models*

## INTRODUCTION

Nowadays, many companies and factories understand the necessity to integrate Health, Safety, and Environment (HSE) management into their activities. Assessment is an essential part of HSE development processes in which the indices require appropriate definition [1]. HSE Management System (HSE-MS) refers to a process composed of planning, execution, assessment, and review steps. Assessment

***Corresponding author: Manouchehr Omidvari***
***E-mail:*** Omidvari88@yahoo.com

is a vital step which helps to identify the strengths and weaknesses of the system [2]. In order to prevent HSE accidents, leading to increased efficiency as well as improved health and safety of employees, contractors, and other individuals, an effective HSE-MS needs to be in place. The proliferation of advanced production technologies has increased accidents possibilities in industrial areas. The severity and frequency of such incidents are controllable by applying HSE measures [3]. In order to increase human productivity and avoid incidents, a HSE Management System (HSE-MS) with an efficient structure was required. These systems may prevent accidents, enhance sustainable development, and reduce costs. It should be noted that the employees' health and safety were influenced by the activities of the organization [4]. With an ascending trend in technology advances and increased use of machines, risk of accidents in industrial environments is now higher than before. Although, the frequency and severity of incidents may reduce significantly with establishment a safety, health and environment management system but occupational accidents are inevitable in the industrial areas [5].

Performance evaluation is one of the most important methods to improve systems performance. The correlation evaluation may able to identify and correct the weaknesses of the systems. In many systems, only the input-output ratio is defined as performance while the process of converting inputs and outputs is also of particular importance. Furthermore, the system's inefficiency detector establishment can be an effective method to define strategies to improve the performance of organizations. HSE-MS must be deployed to support organizational policies and must be planned accurately to achieve its goals. Along with other activity, performance assessment is critical in determining the success of the HSE-MS [6]. Essentially, performance assessment involves identifying the strengths and weaknesses of an individual or a team in performing a task. Therefore, HSE management in a company should periodically monitor and audit HSE affective elements to identify the strengths and weaknesses [7]. Accordingly, the environmental performance of a company must be assessed based on the HSE-MS which allows the company to coordinate its environmental plans, programs, HSE budget, facilities, and policies as its first priority [8]. In various studies, several indicators have been introduced to evaluate the performance of safety systems. Omidvari and Lashgari in a study mentioned one of the most important indicators. A large number of parameters and factors contributed to the assessment of a HSE-MS in numerous studies. The most important indices of HSE management system included personal protection systems, workplace safety according to the HSE policies, legal requirements, HSE training, and business strategies [1]. Nouri et al. identified HSE risk assessment, HSE documentation, accident reporting, and management consulting as the most important indices of HSE-MS. In this study, the performance evaluation indicators determined as the main elements of the HSE management system [9].

It could be concluded that the performance assessment is a significant step to establish a structured management system. Different studies just focused on conceptual, descriptive, analytical, and statistical methods of HSE performance assessment, so far. Although qualitative and quantitative methods almost proposed for assessing environmental performance but a comprehensive model which able to unify various aspects of performance assessment was remain [10]. In 2014, Omidvari et al. studied the impact of personal judgments and qualitative evaluations in HSE performance assessment and concluded that using mathematical and engineering constructs may improve the accuracy of assessments [1]. Furthermore, Omidvari and Ghandehari found that personal judgments created a biased urban HSE-MS. The authors recommended the use of fuzzy decision-making models [11]. Chiou and Tzeng suggested that environmental performance criteria could be ranked based on fuzzy weights and fuzzy synthetic utility values. In their study, the environmental risk control was introduced as indicators of performance appraisal [12]. Literatures review also pointed the impact of personal judgments on how HSE performance is assessed. Consequently, the application of a fully expressive model recommended [13]. Nouri et al. also underscored the necessity for an environmental assessment model with higher accuracy and the ability to identify weaknesses in the system [9]. In many practical conditions, decision-making indicators were uncertain and cannot be described with exact numerical values. Thus, to deal with such problem, it was necessary to use new hybrid approaches in fuzzy environment. The fuzzy approach often used to check the uncertainty and incompleteness of the information using a mathematical analysis system [14]. For example, safety management systems performance evaluating in companies [15]. In a study conducted by Shamaii, many HSE management system indicators were uncertain and the fuzzy approach was suitable for assessment in these situations. In this study, the HSE department budget, HSE facilities, and HSE risk control were introduced as the most common indicators of performance appraisal [16].

Safety culture and safety risk as one of the HSE-MS indices should be followed in the hazardous industries such as steel industries. In order to improve safety performance, it is better that the employees effectively engaged in safety performance. The steel industry is inherently “unsafe”; thus, hazards identification and control is vital [17].

The quantitative methods unable to measure all costs and benefits accurately. Moreover, some measurement models use weak variables, which cause inputs and outputs to be unreliable. Consequently, quite often, there are parameters which cannot be controlled effectively [18-19]. Different unrealistic judgments negatively affect the safety management performance assessment and known as one of major challenge during the assessment process. Fuzzy systems may increase the accuracy of data calculation [20]. The first problem is typically addressed using a Data Envelopment Analysis (DEA) model known as the Hertzsprung–Russell diagram, while extended models, capable of simultaneously dealing with certain and uncertain factors are employed to resolve the other issues [21]. DEA provide an appropriate model to analysis and get purposes in organizational and factory settings. In this method, the inputs and outputs of a unit were measured and analyzed in a specific time zone to assess its performance and efficiency [22]. Different researchers purposed a data envelopment analysis method application to assess plot-level efficiency in environmental issues [23].

The current study was aimed to assess the HSE management system performance using FDEA model in the smelting industry. In this research, in order to obtain better results, a strong mathematical DEA model was used as an alternative to traditional linear models.

## MATERIALS AND METHODS

This study was conducted in one of the biggest smelting companies during 2012 to 2015. The steps of the study have been presented in Figure 1.

The first step involved analyzing and understanding the company. Accordingly, the unit's functions and performance information was collected, then a questionnaire was developed to determine performance indices. Based on this questionnaire and expert's opinions, performance indices in areas of health, safety, and the environment was determined to provide more accurate analyses. In the DEA model, all stages of planning, implementation, evaluation and review were divided into input, output and process indicators [19]. The input and output indices have been shown in Table 1. The indices were defined based on the experts’ responses and available references [1-8-9-16-24-25]. In this paper, five main smelting industry units including coke making, agglomeration, steel making and casting unit, blast furnace, and hot milling unit were observed. All of the performance indicators were defined in a brainstorming meeting using experts’ opinion. The Delphi method was applied to determine the accuracy and correctness of these indicators. The HSE managers’ approved the output and input performance relevancy between the case study as well as expert consensus.

In the present paper, the relationship between the identified indices and HSE performance data were collected from the Isfahan Steel Company. The statistical population was included 30 experts comprising university professors, executive managers, senior HSE personnel, and technicians from different units at Isfahan Steel Company. In this study, experts were selected among graduated employees, with at least ten years of experience in the smelting industries, ability to understand the assessment process and the concept of fuzziness. The data collection instrument was designed based on a three sectional questionnaire composed of health, safety, and environment. The Cronbach’s alpha coefficient was calculated 0.7 which was adequate reliable.

The ratio of outputs to inputs demonstrates the performance. In this study, a set of similar input and output indices regarding health, safety, and environment was considered. The majority of checklists and questionnaires were determined qualitative measures which should be first quantified before being processed. In the first step, using an appropriate scale, the alternatives defined based on the fuzzy set; the resulting values are then converted into deterministic values as follow: Quite often, fuzzy scales were applied to convert qualitative alternatives to fuzzy values. The appropriate scale was selected according to the number and nature of the alternatives. Consequently, in this paper, a fuzzy system was used to determine the performance indices. A maximum and minimum interval function was defined to convert normal values (values between 0 and 1), into deterministic ones as follow [1-9]

$$\text{Max}(x)=\mu \begin{cases} X & 0 \leq x \leq 1 \\ 1 & \text{Otherwise} \end{cases}$$

$$\text{Min}(x)=\mu \begin{cases} 1-x & 0 \leq x \leq 1 \\ 0 & \text{Otherwise} \end{cases}$$

The inputs, process, and outputs indices were defined as DMUs and have been presented in Table 2.

The processing indices were defined using experts' opinion and available references and have been shown in Table 3 [1-9-25].

Based on DEA, a number of input and output indices were defined. The outputs were in fact a set of expectations determined by the inputs.

Assume a set of DMUs iff each DMU has M input and generate S output. Also, let $Xj=\{x1j,x2j,\ldots,xmj\}$ and $Yj=\{y1j,y2j,\ldots,ymj\}$ denote input and output factors, respectively, where;

$Yj \neq 0,\ yj \geq 0,\ Xj \neq 0,\ xj \geq 0.$

Banker, Charles, and Cooper proposed the BCC model for performance assessment as follows [26]:

$$\text{Min } \theta$$

$$\begin{aligned} &\textstyle\sum_{j=1}^{n} \lambda_j x_{ij} + s_{i^-} \quad, i = 1, \ldots, m \\ &\textstyle\sum_{j=1}^{n} \lambda_j y_{rj} - s_{r^+} \quad, r = 1, \ldots, s \qquad (1) \\ &\textstyle\sum_{j=1}^{n} \lambda_j = 1 \quad, j = 1, \ldots, n \\ &\lambda_j \geq 0 \ ,\ S^- \geq 0 \ ,\ S^+ \geq 0 \end{aligned}$$

The values of θ and λ were calculated using Model 1. The optimal solution for Equation 1 was denoted by $\theta^*$ which was the relative productivity $DMU_p$ and falls between 0 and 1. The variable represents a portion of the inputs used to generate the output. The reduction in input values was measured using Equation 2 [22].

$$X_p - \theta^* X_p = (1-\theta^*) X_p \qquad (2)$$

Where; $(1-\theta^*)$ is the reduction coefficient. [22]

The coefficient for $DMU_j$ is represented by $\lambda_j$, which helps the virtual DMU to determine the assessed DMU. According to the third constraint of this model, each $\lambda_j$ takes a value between 0 and 1, where a value of 0 implies that DMU modification does not impact assessment. The value of λ is larger than 0 [22]

$S^+$ and $S^-$ denotes slack variable vectors for the reduction of inputs and increase in outputs, respectively. If all variables decrease at the same rate, some inputs may be overused; this may result $S^-$ elimination [22]

In this paper, a total of five DMUs were considered: agglomeration, steel making and casting, coke making, blast furnace, and hot milling, denoted by $DMU_1$ through $DMU_5$, respectively. All DMUs share the same input indices $I_1$ through $I_7$.

The process and output indices were divided into three sections: health, safety, and environment consisting of 15, 15, and 14 indices respectively. There were six output indices for each of the three areas. Each DMU had three SUB DMUs: health, safety, and environment. In other words, in order to study and evaluate HSE units deeply, the performance of each unit was studied in three mentioned areas.

Once the preceding functions are defined, the maximum and the minimum are cut with the right and left tolerance of the fuzzy number, respectively. This yields the right and left scores for the fuzzy number. The value represents the importance level of the fuzzy number (i.e. $\mu(x)$) at the intersection points. It follows that the right and left scores are denoted by $\mu_R(x)$ and $\mu_L(x)$. The defined fuzzy domains have been shown in Figure 2 [27].

The weighted indices were determined using a set of domains identified by experts in the form of lingual terms then converted into deterministic numbers. The obtained fuzzy numbers were used to determine the weight of each index. The assigned weights were then used in DEA. The equivalent fuzzy values for each of the lingual terms can be seen in Table 3.

Next, expert opinions were averaged according to Equation 3.

$$Ave(a,b,c) = \left(\frac{\sum_{i=1}^{7}(a_i)}{7}, \frac{\sum_{i=1}^{7}(b_i)}{7}, \frac{\sum_{i=1}^{7}(c_i)}{7}\right) \quad (3)$$

Total score was calculated using Equation 4 [27]

$$\mu_T(x) = \frac{\mu_R(x)+(1-\mu_L(x))}{2} \quad (4)$$

Given a triangular fuzzy number (m, α, β), the left and the right domains can be determined. Thus, based on the values, for each qualitative option, a deterministic quantitative value was obtained as follows [16-28]:

$$\mu_T(x) = \frac{m+\beta}{2(1+\beta)} + \frac{m}{2(1+\alpha)} \quad (5)$$

In the next step, a normalization process occurs so that the sum of input and output index weights equals 1. Normalization was performed using Equation 6 [16-28].

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad \bar{x_i} = \frac{x_i}{\bar{X}} \quad (6)$$

For each DMU, the input, process, and output indices have several finer parameters which increase the accuracy of calculations [28].

It should be noted that, in this study, index weights were given by executives and HSE professionals. As mentioned earlier, all DMUs share the same input indices, namely $I_1$ through $I_7$. The process and output indices were divided into three categories included health, safety, and environment (as shown in Tables 1 and 2). The efficiency of each unit and subunit was then determined using the weights of indices. The efficiency of each SUB DMU was given by the following equation. Finally, overall HSE efficiency was obtained using Equation 7 which is a function of output weights (i.e. UY) and inputs (i.e. VX).

$$\theta = \frac{UY}{VX} \quad (7)$$

In order to study system's efficiency more accurately, the system was divided into different parts. The inputs were represented by $V_x$ while the outputs were classified as health, safety, and environment. A schematic representation of the network DEA of the study was illustrated in Figure 3.

$$S1 = \frac{\sum W_{FESini} wixi}{Vx} \quad (8)$$

$$S^{2-1} = W_{FESpro2-1}\frac{U2-1Y2-1}{W2-1Z2-1} \quad (9)$$

$$S^{2-2} = W_{FESpro2-2}\frac{U2-2Y2-2}{W2-2Z2-2} \quad (10)$$

$$S^{2-3} = W_{FESpro2-3}\frac{U2-3Y2-3}{W2-3Z2-3} \quad (11)$$

Based on the individual efficiency equations, the overall efficiency model was proposed as a fractional network DEA with constant returns to scale.

$$Max\ ^{Z} = \frac{\sum W_{FESouti} UiYi}{Vx}$$

$$\text{s.t} \quad \frac{w1z1 + w2z2 + w3z3}{Vx} \le 1 \qquad j = 1, \dots, n$$

$$\frac{U2-1Y2-1}{w2-1Z2-1} \le 1 \qquad j = 1, \dots, n$$

$$\frac{U2-2Y2-2}{W2-2Z2-2} \le 1 \qquad j = 1, \dots, n$$

$$\frac{U2-3Y2-3}{W2-3Z2-3} \le 1 \qquad j = 1, \dots, n$$

$$U2-1, U2-2, U2-3, W2-1, W2-2, W2-3, V \ge 0$$

$$S2 = W_{FES2}\frac{U1Y1+U2Y2+U3Y3}{W1Z1+W2Z2+W3Z3} \quad (12)$$

$$\text{S overall} = \frac{\sum W_{FESouti} UiYi}{Vx} \quad (13)$$

$W_{FESout}$ and $W_{FESin}$ were calculated by expert's opinion in a fuzzy environment. The fuzzy term was defuzzified using Equation 14.

$$W_{FESi} = \frac{a+2b+c}{4} \quad (14)$$

Using Charnes-Cooper modifications, the fractional model was linearized as below [22]:

$$Max\ z = \sum_r u_r^1 y_{rp}^1 + \sum_g u_g^2 y_{gp}^2 + \sum_h u_h^3 y_{hp}^3 \quad (15)$$

$$s.t \qquad \sum_{i=1}^{m} v_i x_{ip} = 1$$

$$\sum_t w_t^1 z_{tj}^1 + \sum_f w_f^2 z_{fj}^2 + \sum_s w_s^3 z_{sj}^3 - \sum_i v_i x_{ij} \le 0$$

$$\sum_r^n u1_r y1_{rj} - \sum_t w1_t z1_{tj} \le 0 \qquad j = 1, \dots, n$$

$$\sum_g^n u2_g y2_{gj} - \sum_f w2_f z2_{fj} \le 0 \qquad j = 1, \dots, n$$

$$\sum_h^n u3_h y3_{hj} - \sum_t w3_s z3_{sj} \le 0 \qquad j = 1, \dots, n$$

In DEA model, efficient DMUs have an efficiency value of 1 whereas inefficient DMUs have smaller values. The DEA defines two modes for evaluated systems: efficient and inefficient. The closer the efficiency of a system is to 1, the more efficient it is. Therefore, the efficiency of DMUs was defined in comparison with each other [22]. The conceptual model of unit performance was illustrated in Figure 4.

This study was conducted in one of the largest smelting factories in Iran, with over 16000 personnel and seven sectors; two main manufacturing; three auxiliary and two on manufacturing. In this paper, five main units of the factory including agglomeration, steel making and casting, coke making, casting area, and hot milling area were considered. Furthermore, the five main units were defined as DMUs:

- $DMU_1$ : Agglomeration unit
- $DMU_2$ : Steel making and casting unit
- $DMU_3$ : Coke making unit
- $DMU_4$ : blast furnace unit
- $DMU_5$ : Hot milling area unit

In order to improve accuracy, three categories of indices (i.e. health, safety, and environment) were considered (as shown in Tables 1 and 3). To assess the validity of the pattern, DMUs were also reviewed by experts and the results were compared with the obtained pattern results. So that, the results obtained from the model were same as expected results of the experts. The results obtained from the model showed that some units have low performance and experts also evaluate those units as low performance.

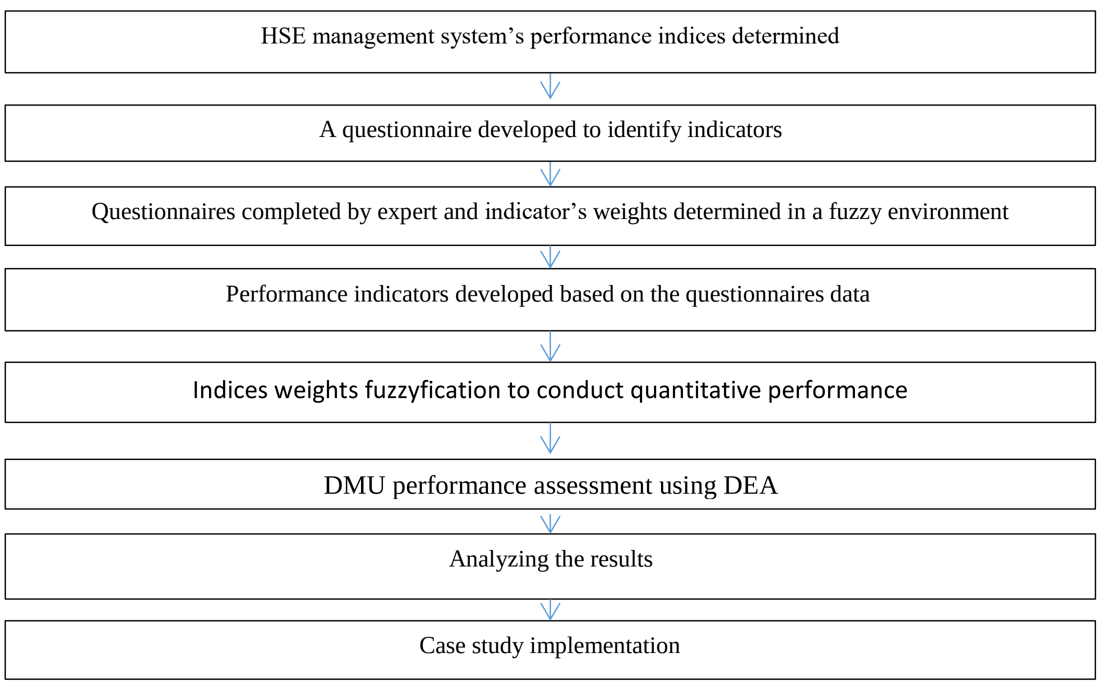


***Fig. 1.*** The steps' of the Study

***Table 1.*** Input and output indices

| No. | Group | Index | | Definition |
|---|---|---|---|---|
| 1 | Input | Number of experts [16] | HSE | The number of HSE experts in each unit |
| 2 | | Performance specific budget (Rate of Reward) [16] | HSE | The HSE department budget for the implementation of performance management activities, particularly appreciation and rewards |
| 3 | | Number of Resources and facilities [9] | HSE | Adequacy of resources and facilities for the implementation of HSE-MS programs |
| 4 | | Realized HSE budget (Rate of HSE budget) [9,16] | HSE | The budget approved for the measures envisaged in the field of HSE |
| 5 | | Pertinent instructions [16,24] | HSE | Comprehensive HSE instructions for daily activities |
| 6 | | Personal protection equipment (%) [1] | HSE | The realized percentage of the anticipated personal protection equipment |
| 7 | | Annual budget of HSE [16] | HSE | The annual budget dedicated to HSE activities |
| 8 | | Number of HSE training [1] | HSE | The number of HSE courses organized in one year |
| 1 | Output | Continuous inspection [9] | H | Continuous inspection of public places based on the HSE indicators |
| 2 | | Notifications and public awareness [9] | H | Increasing staff information and public awareness regarding the dangers of consumables |
| 3 | | Occupational illnesses [16] | H | The percentage of employees suffering from work-related diseases |
| 4 | | Staff checkups [16] | H | Percentage general health assessment among staff |
| 5 | | Job-specific checkups [25,16] | H | The number of job-specific medical tests |
| 6 | | Ergonomic conditions [16] | H | Extent of improvements in ergonomic conditions of the unit |
| 7 | | Individual accidents at work [1] | S | The Accident Frequency Rate (AFR) is used as the number of individual injuries while working |
| 8 | | Controlled risks (unsafe condition) [25] | S | Percentage of controlled risks that lead to accidents |
| 9 | | Risks resulting in fire [25] | S | Percentage of controlled risks resulting in fire |
| 10 | | Controlled fire sources [25] | S | Increase in the percentage of controlled fire sources |
| 11 | | Power protection systems [25] | S | Percentage of the electricity systems with power protection systems |
| 12 | | Personal Accident Severity Rate (ASR) [1] | S | Percentage of employees injured while working |
| 13 | | Waste water pollution load [25] | E | The reduction of BOD (Biological Oxygen demand) pollution of unit's wastewater |
| 14 | | Air pollution [25] | E | Air Pollution Index (API) caused by agglomeration |

| | | | |
|---|---|---|---|
| 15 | Pollution caused by waste water [25, 16] | E | Percentage of pollution caused by wastewater |
| 16 | Solid waste [25,16] | E | Solid waste volume (percentage) |
| 17 | Recycling solid waste [25] | E | The percentage of recycled solid waste in the factory |
| 18 | Soil pollution [25] | E | Percentage of soil pollution caused by factory activities |
| 19 | Noise pollution [16] | E | Reduction in the level of noise pollution (%) |
| 20 | Per capita green space [16] | E | The rate of green space per each person |

*H, S, E: indices in all the three areas of health, safety and environment*
*H: Indices in the area of health*
*S: Indices in the area of safety*
*E: Indices in the area of environment*

***Table 2.*** Defined DMUs in this study

| No. | DMU | Definition |
|---|---|---|
| 1 | DMU1 | Agglomeration unit |
| 2 | DMU2 | Steel making and casting unit |
| 3 | DMU3 | Coke making unit |
| 4 | DMU4 | Blast furnace unit |
| 5 | DMU5 | Hot milling area unit |

***Table 3.*** Defined process performance assessment indices [1-9-8-25].

| No | Group | Index | Definition |
|---|---|---|---|
| 1 | | Instructions, training courses, and seminars may improve employee knowledge of HSE [16-9] | HSE trainings, conferences, and seminars can change employees' HSE behavior and enhance their HSE knowledge |
| 2 | | Responsibilities and authority of HSE personnel [25-9] | To what extent the HSE personnel (managers) were authorized and responsible for their-self and other employees training |
| 3 | | Allocation of time for participation of managers [9] | Sufficient time is allocated by managers to participate in HSE activities |
| 4 | | Reevaluation of performance goals [9-25] | To what extent the performance goals in each unit were measured and evaluated periodically and documented if necessary |
| 5 | | Documentation of accidents, threats, and problems [1-8] | The quality of accident and illness documentations |
| 6 | | Training programs establishment to deploy management systems and environmental assessment [9-25] | Inclusion of training programs on deployment of management systems and environmental assessment |
| 7 | | Expert participation [9] | To what extent the HSE employees were involved in planning and making change and maintenance instructions |
| 8 | Process | Individual and environmental monitoring records [9-8] | The quality of records regarding personal and environmental monitoring as well as employee training records were maintained |
| 9 | | Emergencies [8-8] | The plans that were prepared in HSE emergencies situations |
| 10 | | Work environment emergencies[25] | Identification of factors that may lead to harm on work (i.e. physical, chemical, ergonomic, biologic, and psychological factors). |
| 11 | | Performance indices [25-9] | Performance indices were identified by senior manager to support HSE programs |
| 12 | | Intermittent monitoring (documentation, personnel, and work environment) [25] | Planning for intermittent monitoring (documentation, personnel, and work environment) should be a part of the activities by the HSE unit |
| 13 | | Periodic assessment and evaluation to determine performance and status [9-25] | To what extent the periodic assessment and evaluation were carried out to determine performance and status |
| 14 | | Periodic assessment of organizational goals effectiveness [9-25] | To what extent the organizational goals were periodically assessed by the executives in terms of effectiveness |
| 15 | | Rewards and appreciation [1-9-8] | To what extent each employee was rewarded for his/her HSE efforts |

*H, S, E: indices in all the three areas of health, safety and environment*
*H: Indices in the area of health*
*S: Indices in the area of safety*
*E: Indices in the area of environment*

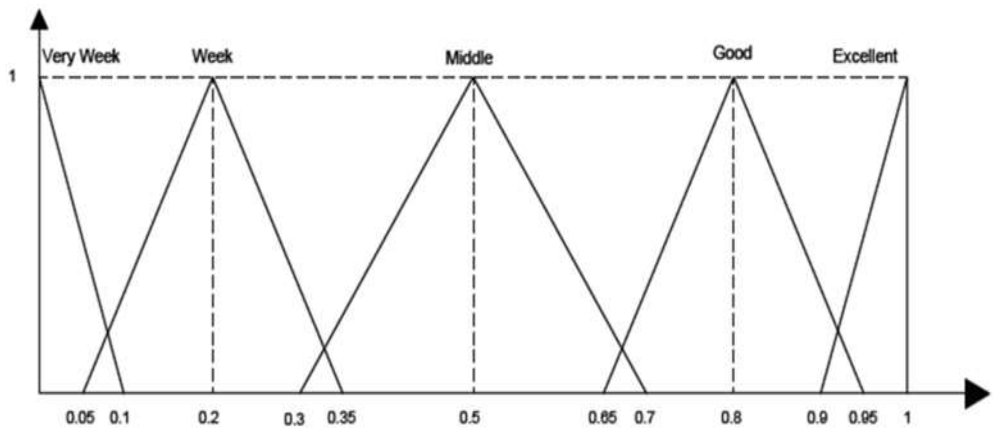


***Fig. 2.*** Domains of fuzzy numbers

***Table 4.*** Domain definitions [27]

| Row | Linguistic Term | The scale domain |
|---|---|---|
| 1 | low Effective | (0,0,0.1) |
| 2 | Effective | (0.05,0.2,0.35) |
| 3 | Average | (0.3,0.5,0.7) |
| 4 | Good effective | (0.65,0,8,0.95) |
| 5 | High effective | (0.9,1,1) |

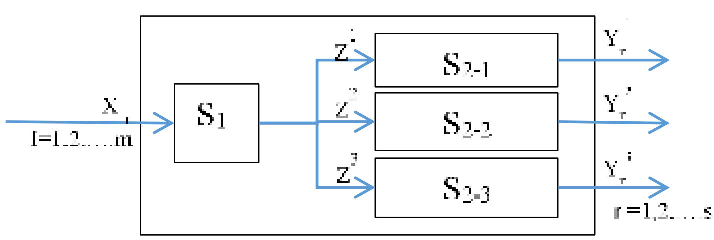


***Fig. 3.*** DEA network model

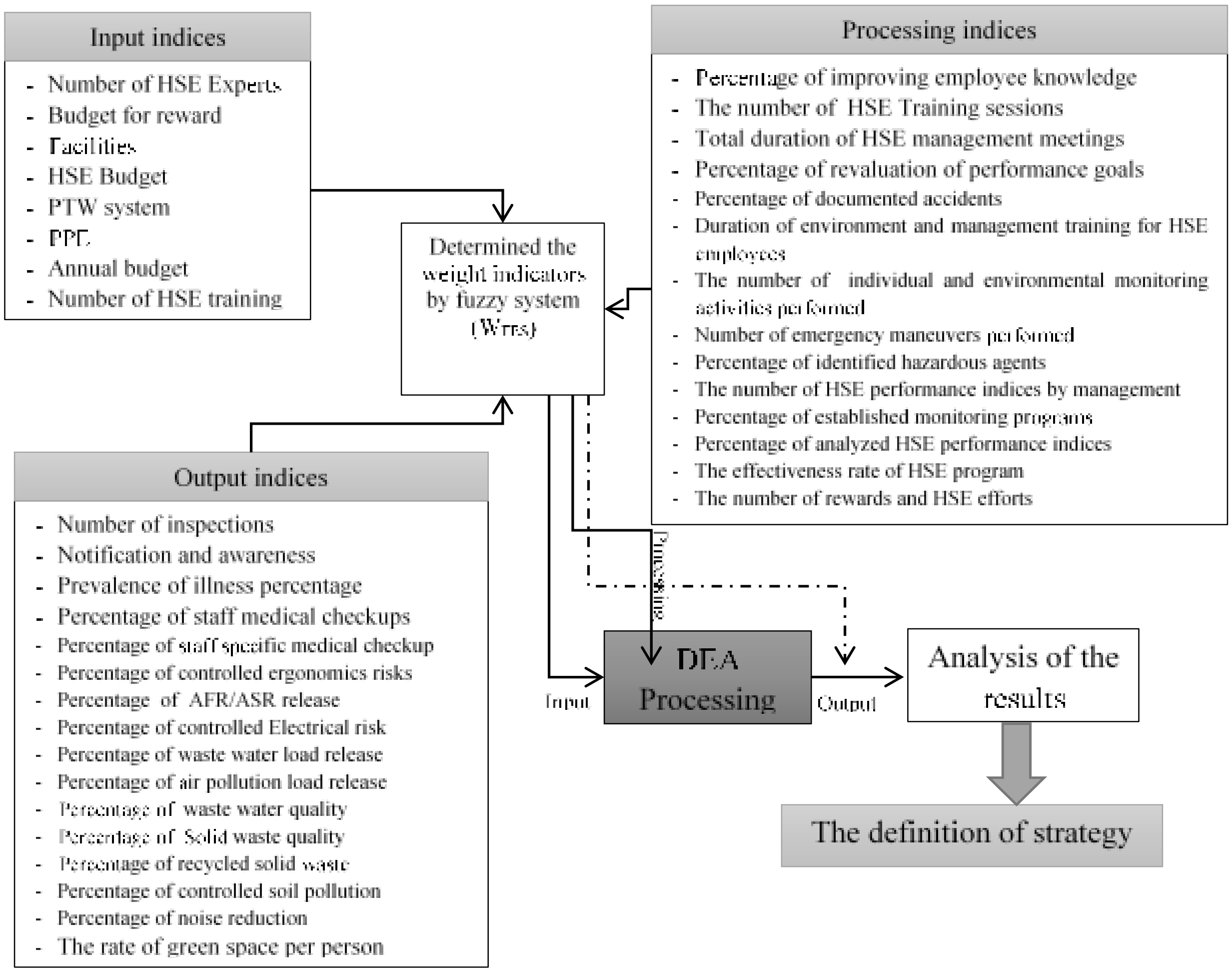


***Fig. 4.*** The conceptual model of HSE unit performance

## RESULTS

As mentioned in the conceptual model, in the DEA method, all stages of planning, execution, evaluation and review were divided into input, output and process indicators, so the results were classified based on input, output and process indicators. The executives and HSE professionals weighted indexes have been presented in Table 4. Based on the results obtained in this section of the study, the most important input indices were found to be the number of HSE experts, budget per employee, and annual budget. With respect to output, percentage of general health checkups, percentage of controlled ergonomics risks, percentage of controlled electrical risks, percentage of controlled fire sources, and percentage of solid waste quality were the most important indices Finally, man-hours of HSE training, percentage of documented accidents, the number of individual and environmental monitoring activities and percentage of identified hazardous agents were identified as the most important processing indices.

The results for all of units have been shown in Table 5. All of the DMUs were audited and their indices were measured (through inspection and reviewing documents) by researchers and experts.

Based on the number of DMUs and SUB class of DMUs as well as the number of indices, a network DEA with constant returns to scale was employed in this study, which enables detailed analysis of individual units. The remaining indices act generally for all of the units. Measurement results have been shown in Tables 6. As evident, the DMUs are ranked with respect to input, output, and process. The efficiency of each unit was represented by a number ranging from 0 to 1. $DMU_4$ was found to be the most efficient.

The results of units' comparison showed that the blast furnace was the only efficient unit in terms of input. After network model application with constant returns based on the scales, the DMUs were ranked as follows:

1. $DMU_4$ (blast furnace)
2. $DMU_1$ (agglomeration)
3. $DMU_2$ (steel making and casting)
4. $DMU_3$ (coke making)
5. DMU5 (hot milling area)

The results showed that four out of the five examined units were efficient in terms of health and safety. Whereas, only one unit was environmentally efficient.

With respect to the output indices, as shown in Table 4, only the agglomeration and blast furnace units were efficient. Finally, considering the inputs and outputs in all three areas of health, safety, and environment, the blast furnace unit was the only efficient unit in the factory. The results proved experts' findings and the validity of this study pattern.

***Table4.*** The weight of HSE management system indices

| Input Indices | WFESIn | Output indices | WFESout | Processing indices | WFESpro. |
|---|---|---|---|---|---|
| - Number of HSE Experts<br>- Budget for reward<br>- Facilities<br>- budget per employee<br>- PTW system<br>- PPE<br>- Annual budget<br>- Number of HSE training sessions<br>- | 0.16<br>0.1<br>0.11<br>0.17<br>0.06<br>0.12<br>0.16<br>0.12 | - Number of inspections<br>- Notification & awareness<br>- Prevalence of illness percentage<br>- Percentage of general health checkup<br>- Percentage of staff specific medical checkup<br>- Percentage of controlled ergonomics risk s<br>- Percentage of AFR/ ASR release<br>- Percentage of controlled electrical risk<br>- Percentage of | 0.04<br>0.03<br>0.06<br>0.07<br>0.06<br>0.08<br>0.06<br>0.07<br>0.08<br>0.06<br>0.06<br>0.05<br>0.08<br>0.05<br>0.04<br>0.07<br>0.04 | - Percentage of improving employee knowledge<br>- Man-hours of HSE training<br>Total duration of HSE management meetings<br>- Percentage of reevaluation of performance goals<br>- Percentage of documented accidents<br>- Duration of environment and management training for HSE employees<br>- The number of individual and environmental monitoring activities performed<br>- Number of emergency | 0.06<br>0.09<br>0.06<br>0.05<br>0.09<br>0.07<br>0.09<br>0.07<br>0.1<br>0.06<br>0.07<br>0.07<br>0.06<br>0.06 |

| | | | | | |
|---|---|---|---|---|---|
| | | controlled fire sources<br>- Percentage of waste water load release<br>- Percentage of air pollution load release<br>- Percentage of waste water quality<br>- Percentage of solid waste quality<br>- Percentage of recycled solid waste<br>- Percentage of controlled soil pollution<br>- Percentage of noise reduction<br>- The rate of green space per person | | maneuvers performed<br>- Percentage of identified hazardous agents<br>- The number of HSE performance indices by management<br>- Percentage of established monitoring programs<br>- Percentage of analyzed HSE performance indices<br>- The effectiveness rate of HSE program<br>- The number of rewards and HSE efforts | |
| Sum | 1 | | 1 | | 1 |

***Table 5.*** General indices of performance measured at factory DMUs

| No. | Group | Index | $W_{FES}$ | DMU 1 | DMU 2 | DMU 3 | DMU 4 | DMU 5 |
|---|---|---|---|---|---|---|---|---|
| **1** | **Input** | Number of HSE Experts | 0.16 | 55 | 57 | 55 | 53 | 55 |
| **2** | | Performance specific budget (Rate of Reward) (million Rials) | 0.10 | 48 | 46 | 47 | 52 | 47 |
| **3** | | Number of resources and facilities | 0.11 | 51 | 49 | 48 | 46 | 49 |
| **4** | | Allocated budget per employee (millions of Rials) | 0.17 | 55 | 56 | 54 | 55 | 55 |
| **5** | | Established pertinent instructions (%) | 0.06 | 45 | 48 | 44 | 42 | 43 |
| **6** | | Personal protection equipment (%) | 0.12 | 85 | 89 | 88 | 84 | 85 |
| **7** | | Annual HSE budget | 0.16 | 144 | 148 | 144 | 146 | 146 |
| **8** | | Number of HSE training sessions for employees | 0.12 | 21 | 23 | 22 | 21 | 24 |
| **1** | **Output** | Number of inspections | 0.04 | 81 | 83 | 84 | 80 | 84 |
| **2** | | Notification & awareness | 0.03 | 25 | 21 | 22 | 25 | 27 |
| **3** | | Prevalence of illness percentage | 0.06 | 40 | 43 | 47 | 50 | 45 |
| **4** | | Percentage of staff medical checkups | 0.07 | 25 | 21 | 19 | 22 | 26 |
| **5** | | Percentage of staff specific medical checkups | 0.06 | 66 | 64 | 65 | 61 | 56 |
| **6** | | Percentage of controlled ergonomics risks | 0.08 | 32 | 31 | 33 | 32 | 30 |
| **7** | | Percentage of AFR/ASR release | 0.06 | 29 | 32 | 34 | 31 | 28 |
| **8** | | Percentage of controlled fire sources | 0.08 | 52 | 44 | 45 | 51 | 39 |
| **9** | | Percentage of controlled electrical risks | 0.06 | 82 | 70 | 76 | 81 | 78 |
| **10** | | Percentage of waste water load release | 0.06 | 33 | 32 | 27 | 27 | 32 |
| **11** | | Percentage of air pollution load release | 0.05 | 45 | 44 | 43 | 41 | 41 |
| **12** | | Percentage of waste water quality | 0.08 | 19 | 21 | 23 | 18 | 25 |
| **13** | | Percentage of recycled solid waste | 0.05 | 8 | 9 | 7 | 7 | 6 |
| **14** | | Percentage of controlled soil pollution | 0.04 | 10 | 12 | 12 | 13 | 11 |
| **15** | | Percentage of noise reduction | 0.07 | 5 | 6 | 5 | 4 | 5 |
| **16** | | The rate of green space per person | 0.04 | 1 | 1.1 | 1.3 | 1.2 | 1.3 |
| **1** | **Process** | Percentage of improving employee knowledge | 0.06 | 70 | 72 | 70 | 75 | 73 |
| **2** | | Man-hours of HSE Training | 0.09 | 18 | 21 | 19 | 18 | 20 |
| **3** | | Total duration of HSE management meetings (h/year) | 0.06 | 66 | 66 | 66 | 66 | 60 |
| **4** | | Percentage of reevaluation of performance goals | 0.05 | 10 | 12 | 13 | 12 | 12 |
| **5** | | Percentage of documented accidents | 0.09 | 90 | 92 | 95 | 93 | 91 |
| **6** | | The time of environment and management training for HSE employees | 0.07 | 16 | 16 | 18 | 16 | 12 |
| **7** | | The number of individual and environmental monitoring activities performed | 0.09 | 12 | 12 | 12 | 11 | 11 |
| **8** | | Number of emergency maneuvers performed | 0.07 | 5 | 6 | 6 | 5 | 5 |
| **9** | | Percentage of identified hazardous agents | 0.10 | 80 | 85 | 87 | 88 | 80 |
| **10** | | The number of accepted HSE performance indices by management | 0.06 | 35 | 43 | 45 | 45 | 46 |
| **11** | | Percentage of established monitoring programs | 0.07 | 76 | 75 | 76 | 77 | 75 |
| **12** | | Percentage of analyzed of HSE performance indices | 0.07 | 86 | 87 | 89 | 88 | 85 |
| **13** | | The effectiveness rate of HSE program | 0.06 | 65 | 66 | 66 | 65 | 65 |
| **14** | | The number of rewards and HSE efforts | 0.06 | 3 | 3 | 4 | 4 | 2 |

***Table 6.*** DMU rankings

| DMU | OVERALL | Remaining indices as network DEA model (fig 3) | | | | |
|---|---|---|---|---|---|---|
| | | **S1** | **S2** | **S2-1** | **S2-2** | **S2-3** |
| DMU1 | 0.94644723 | 0.94644723 | 1.00000000 | 1.00000000 | 1.00000000 | 1.00000000 |
| DMU2 | 0.94288103 | 1.00000000 | 0.99999990 | 1.00000000 | 0.97359234 | 0.96845577 |
| DMU3 | 0.93437969 | 1.00000000 | 0.99985322 | 1.00000000 | 0.95968544 | 0.97377413 |
| DMU4 | 1.00000000 | 1.00000000 | 1.00000000 | 1.00000000 | 1.00000000 | 1.00000000 |
| DMU5 | 0.88942295 | 1.00000000 | 0.95882616 | 0.97281609 | 0.95882684 | 0.99448338 |

## DISCUSSION AND CONCLUSION

It can be concluded that the DEA was an applicable model to assess quantitative performance factors based on health, safety, and environment criteria. It was consistent with Azadeh et al. finding which considered the three areas collectively. In this study, the most important factor in increasing the efficiency of HSE systems is the participation of personnel in HSE programs, which is inconsistent with the results of our findings. In the present study, the level of management support and investment in HSE programs were the most important factor in increasing the performance of HSE systems [29].

Abbaspour et al. proposed an HSE-MS assessment model using BCC; however, in their study, only DMU performance was investigated, without considering the SUB class of DMUs or their impacts on each other. In this study, the most important performance evaluating indicator of HSE were management system and risk assessment system, which was inconsistent with the results of the present study. In the current study, HSE annual budget indicators per employee and the number of HSE experts were defined as the most important performance indicators. The main reason for this difference was due to Abbaspour's study was conducted in the petrochemical industry and the present study in the steel industry [30].

Shamaii el al. examined performance indicators in a study conducted in the steel industry. In this study, the effect of HSE systems on the performance of different units was investigated, which concluded that the greatest impact was on the safety system and the least effective in health and environmental field of different units. On the other hand, they found that the fire control and HSE investment indicators had the highest weight. Having considered all above results, the budget of the HSE unit was significantly important and there were a lot of HSE unit's experts in the current study which is not mentioned in Shamaii study. The reason for the difference in this section was the results of the difference in the methodology [31].

Different factors improve an organization health efficiency including rigorous standards and regulations, periodic inspections, continual presence of HSE authorities in the units, and intermittent tests of all employees. Four out of the five DMUs were sufficiently efficient. Therefore, strict regulations and periodic checks increase personal and work safety. Additionally, access to safe equipment has led four out of the five units to be efficient in terms of safety. In contrary, the highest level of inefficiency was observed for environmental issues. Different units of the factory constantly cause various types of pollution such as air, water, and soil. Air pollution was particularly problematic in the coke making, blast furnace, steel making, and hot milling areas. The units also cause severe water pollution. A portion of the pollution has been controlled since the factory was mandated to install wastewater and air purification equipment in the agglomeration and blast furnace units. Thus, two units were become environmentally efficient. The remaining units, however, need to be managed with appropriate mechanisms and measures. The result regarding the efficiency of the blast furnace, the inherent sensitivity of the unit and the large volume of environmental pollution were the reasons behind the higher degree of attention to environmental issues in this unit.

## ACKNOWLEDGEMENT

The authors are grateful to the Islamic Azad University Tehran Research and Science Branch for their efforts to help in conducting this study.

## CONFLICT OF INTEREST

There is no conflict of interest for any of the authors.

## REFERENCES


1 Omidvari M., Lashgary Z. Presenting a model for safety program performance assessment using grey system theory, Grey Systems: *Theory and Application*, 2014; 4(2): 287-296.

2 Keeley D., Turner SH., Harper H. Management of the UK HSE failure rate and event date, *Journal of Loss Prevention in the Process Industries*, 2011; 24(3): 237-241

3 Wang Yu., Mingbang T., Dongbo W., Qiang Zh., Shihui Sh., Shuhuang L. Study on HSE Management at construction site of oil and gas Processing Area, *Procedia Engineering*, 2012; 45: 231-234.

4 Harris JR., Richard SC. Machine Safety: New & Updated Consensus Standards. *Prof Saf*. 2012; 57(5): 50-57.

5 Fang D., Jiang Z., Zhang M., Wang H. An experimental method to study the effect of fatigue on construction workers safety performance, *Safety Science*, 2015; 73: 80-91.

6 Chakraborty AB. Hilistic Approach to HSE Performance Assessment,Monitoring and Management in an Integrated Upstream Oil/Gas corporation. SPE 86744, *Health, Safety and Environment in Oil and Gas Exploration and Production*, 2004; Cadana.

7 Honkasalo A. Occupational health and safety and environmental management systems. *Environmental Science and Policy*, 2000; 3(1): 39–45.

8 May PH., Dabbs AW., Fernández-Dávila PD., Vinha V., Zaidenweber N. A corporate approach to social monitoring and assessment for development in a fragile environment. *Environmental Monitoring and Assessment*, 2002; 76(1): 125–134.

9 Nouri J., Abbaspour M., Roayaei E., Nikoomaram H. Comparison of environmental performance—HSEQ management system, regarding the international and Iranian oil and gas general contractors. *American Journal of Applied Sciences*, 2005; 2(1): 447–451.

10 Maclean R. Superior Environmental, Health and Safety Performance; What is it?, *Journal of Environmental Quality Management*, 2003; 13(2): 13-20.

11 Omidvari M., Ghandehari M. Urban Environmental Management Performance Assessment by Fuzzy Analytical Hierarchy Processing (FAHP). *Journal of Environmental Accounting and Management*, 2014; 2(1): 31-41.

12 Chiou H-K., Tzeng G-H. Fuzzy Multiple-Criteria Decision-Making Approach for Industrial Green Engineering. *Environmental Management*, 2002; 30(6): 816–830.

13 Yang Y., MacLean R. A template for assessing corporate performance: Benchmarking EHS organization. *Journal of Environmental Quality Management*, 2004; 13(3), 11–23.

14 Dong G., Yamaguchi D., Nagai M. A grey-based decision-making approach to the supplier selection problem", *Math. Comp. Model*, 2006; 46(3): 573-581.

15 Kang J., Zhang J., Gao J. Improving performance evaluation of health, safety and environment management system by combining fuzzy cognitive maps and relative degree analysis. *Safety Science*, 2016; 87: 92–100.

16 Shamaii A., Omidvari M., Hosseinzadeh Lotfi F. Health, safety and environmental unit performance assessment model under uncertainty (case study: steel industry), *Journal of Environment monitoring and Assess*, 2017; 189(1): 42.

17 Nordlöf H., Wiitavaara B., Winblad U., Wijk K., Westerling R. Safety culture and reasons for risk-taking at a large steel-

manufacturing company: investigating the worker perspective. *Safety Science*, 2015; 73: 126-135.

18 Zhou P., Ang B W., Poh K L. A survey of data envelopment analysis in energy and environmental studies. *European Journal of Operational Research*, 2008; 189(1): 1–18.

19 Wang J., Zhao T., Zhang X. Environmental assessment and investment strategies of provincial industrial sector in China – Analysis based on DEA, *Environmental Impact Assessment Review*, 2016; 60: 156-168.

20 Li W., Liang W., Zhang L., Tang Q. Performance assessment system of health, safety and environment based on experts' weights and fuzzy comprehensive evaluation, *Journal of Loss Prevention in the Process Industries*, 2015; 35: 95-103.

21 Jahanshahloo GR., Memariani A., Hosseinzadeh Lotfi F., Shoja N. A feasible interval for weights in data envelopment analysis. *Applied Mathematics and Computation*, 2005; 160(1): 155–168.

22 Charnes A., Cooper WW., Rhodes E. Measuring the efficiency of decision making units. *European Journal of Operational Research*, 1978; 2(6):429–444.

23 Susaeta A., Adams DC., Carter DR., Dwivedi P. Climate Change and Ecosystem Services Output Efficiency in Southern Loblolly Pine Forests, *Environmental Management*, 2016; 58(3): 417–430.

24 Mohammadfam I., Mahmoudi S., Kianfar A. Development of the Health, Safety and Environment Excellence Instrument: a HSE-MS Performance Measurement Tool, *Procedia Engineering*, 2012; 45: 194-198.

25 American Petroleum Institute, Model environmental, health and safety (EHS) management system. API Publication, 1998; report no. 9100A.

26 Banker R D., Charnes A., Cooper W W. Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, 1984; 30(9): 1078–1092.

27 Lee SH. Using Fuzzy AHP to develop Intellectual Capital evaluation model for assessing their performance contribution in a University. *Expert Systems with Applications*, 2010, 37, 4941–4947.

28 Beriha G.S., Patnaik B., Mahapatra S S., Padhee S. Assessment of Safety Performance in Indian Industries using Fuzzy approach. *Journal of Expert System with applications*, 2012; 39(3); 3311-3323.

29 Azadeh A., Hasani Farmand A., Jiryaei Sharahi Z. Performance assessment and optimization of HSE management systems with human error and ambiguity by an integrated fuzzy multivariate approach in a large conventional power plant manufacturer, *Journal of Loss Prevention in the Process Industries*, 2012; 25(3); 594–603.

30 Abbaspour M., Hosseinzadeh Lotfi F., Karbasi A R., Roayaei E., Nikoomaram H. Development of a model to assess environmental performance, concerning HSE-MS principles. *Journal of Environment monitoring and Assess*, 2010: 165(1); 517-528.

31 Azin Shamaii, A., Manouchehr Omidvari M., Hosseinzadeh Lotfi F. Health, safety and environmental unit performance assessment model under uncertainty (case study: steel industry), *Environment Monitoring and Assess*, 2017: 189(42); 1-12