Improving the Performance in Occupational Health and Safety Management in the Electric Sector: An Integrated Methodology Using Fuzzy Multicriteria Approach

Genett Jimenez-Delgado[1](✉), Alexa Senior-Naveda[2], Freddy Marín-Gonzalez[2], Jesus García-Guiliany[3], Lina Fontalvo-Molina[1], Miguel Ruiz-Muñoz[1], Hugo Hernández-Palma[4], and Bertha Santos-Hernandez[5]

[1] Department of Engineering in Industrial Processes, Engineering Faculty, Institucion Universitaria ITSA, Soledad, Atlántico, Colombia
{gjimenez,linapfontalvo,mjruiz}@itsa.edu.co

[2] Faculty of Human and Social Sciences, Universidad de la Costa CUC, Barranquilla, Colombia
{asenior,fmarin}@cuc.edu.co

[3] Faculty of Administration and Business, Universidad Simón Bolívar, Barranquilla, Colombia
jesus.garcia@unisimonbolivar.edu.co

[4] Economic Sciences Faculty, Program, Corporación Universitaria Latinoamericana CUL, Barranquilla, Colombia
hugoghernandezpalma@gmail.com

[5] Department of Business Administration and Marketing, Universidad Tecnologica del Retoño, Aguascalientes, Mexico
bertha.santos@utr.edu.mx

Abstract. The electric sector is fundamental for the economic and social development of society, impacting on essential aspects such as health, education, employment generation, industrial production, and the provision of various services. In addition to the above, the growing trend in energy consumption worldwide could increase, according to expert estimates, up to 40% by 2030, which in turn increases the efforts of the public and private sector to meet increasing demands and increase access to energy services under requirements of reliability and quality. However, the electricity sector presents challenges and complexities, one of which is the reduction of health and safety risks for workers, service users, and other stakeholders. In many countries, this sector is classified as high risk in occupational safety and health, due to its complexity and the impact of accidents and occupational diseases on the health of workers, in infrastructure, in operating costs and competitiveness of the energy sector. Worldwide, there are rigorous regulations for the electricity sector, from local and national government regulations to international standards to guarantee health and safety conditions. However, it is necessary to develop objective and comprehensive methodologies for evaluating occupational safety and health performance that provides solutions for the electricity sector, not only to comply with standards and regulations also as a continuous improvement tool that supports the decision-making processes given the complexity of the industry and the multiple criteria that are taken into account when evaluating and establishing improvement strategies. In scientific

V. G. Duffy (Ed.): HCII 2020, LNCS 12199, pp. 130–158, 2020.
https://doi.org/10.1007/978-3-030-49907-5_10

literature, different studies focus on the analysis of accident statistics, the factors that affect accidents and occupational diseases, and the risk assessment of the sector. Despite these considerations, studies that focus directly on the development of hybrid methodologies for the evaluation and improvement of performance in occupational safety and health in the electrical sector, under multiple criteria and uncertainty are mostly limited. Therefore, this document presents an integrated methodology for improving the performance in occupational health and safety in the electric sector through the application of two techniques of Multi-criteria Decision Methods (MCDM) uses in environments under uncertainly. First, the fuzzy Analytic Hierarchy Process (FAHP) is applied to estimate the initial relative weights of criteria and sub-criteria. The fuzzy set theory is incorporated to represent the uncertainty of decision-makers' preferences. Then, the Decision-making Trial and Evaluation Laboratory (DEMATEL) used for evaluating the interrelations and feedback among criteria and sub-criteria. FAHP and DEMATEL are later combined for calculating the final criteria and sub-criteria weights under vagueness and interdependence. Subsequently, we applied the proposed methodology in a company of the energy sector for diagnosis of performance in OHS to establish improvement proposals, the work path, and implementation costs. Finally, we evaluate the impact of the strategies applied in the improvement of the performance of the company.

Keywords: Fuzzy analytical hierarchy process · Fuzzy AHP · Multicriteria decision making · MCMD · DEMATEL · Occupational health and safety · ISO 45001 · Electric sector · Performance evaluation

1 Introduction

According to the World Bank (2018), the energy sector is a driver of investments, technological development, innovation, and new industries, with an impact on job creation, economic, social growth and the contribution to the Development Goals Sustainable UN 7 - affordable and non-polluting energy, 8 - decent work and economic growth, 9 - industry, innovation and infrastructure, and 11 - Sustainable cities and communities [1]. The energy sector faces new challenges such as a 30% growth in energy demand and, therefore, in the generation, transmission and distribution capabilities of operating companies, the search for new and better sources of energy, the decrease of environmental impacts and occupational health and safety risks for interested parties [2]. Regarding occupational safety and health, it is of high relevance for the competitiveness of the sector due to the complexity in their operations, the regulation, and control of the government, customers, and other stakeholders involved in the energy chain. In this sense, the energy sector is considered as high risk at the Occupational health and safety level, due to the potential risk of accidents and occupational diseases and the seriousness of the damage caused. Given that the circumstances surrounding this type of accident can have an impact on the welfare and health of workers and interested parties, on infrastructure, operational costs and the results of companies in the sector [3].

Following the International Labor Organization, aggregate statistics indicate a general increase in the number of people who died by causes attributable to work from

2.33 million in 2014 to 2.78 million in 2017. In the energy sector, electrical accidents represent a high number of worldwide [4–7]. This situation increases in countries in Africa and Latin America. In Colombia, for example, the energy sector registered for 2017 the fourth-highest accident rate, with an average of 7.33 accidents. Among the leading causes attributable to accidents in the energy sector, there are insecure behaviors [8], deficiencies in training, training, and awareness in safety and self-help culture and shortcomings in the implementation of comprehensive management systems focused on prevention and in the welfare of workers [9–13].

In the literature review, different studies have been carried out to contributes to the analysis, development, and implementation of methodologies and techniques focused on the prevention of accidents and occupational diseases in the energy sector. In this regard, we found different works oriented to analysis of personal factors and consequences of electrical occupational accidents [3], time series analysis of occupational accidents and the assessment of risks applied to the energy and construction industry [14], the longitudinal descriptive study of occupational accidents and their causes [15] as well as the analysis of occupational safety and health in hydroelectric plants [16], photovoltaic industry [17] and energy supply companies [18]. Although several efforts have been made to address this problem, the evidence base is still scant and with scarce information, especially in the develop of integrated multicriteria decision-making methodologies to evaluate and improve the performance in the prevention of accidents and occupational diseases in energy sector, where previous studies have been found in the logistics industry [19].

This paper bridges this gap by extending the multi-criteria decision-making approach adopted in land cargo transportation [19] to improve the performance in Occupational Health and Safety Management in the energy sector. First, the fuzzy Analytic Hierarchy Process (FAHP) is applied to estimate the initial relative weights of criteria and sub-criteria. The fuzzy set theory is incorporated to represent the uncertainty of decision-makers' preferences. Then, the Decision-making Trial and Evaluation Laboratory (DEMATEL) is used for evaluating the interrelations and feedback among criteria and sub-criteria. FAHP and DEMATEL are later combined for calculating the final criteria and sub-criteria weights under vagueness and interdependence. Subsequently, we applied the proposed methodology in a company of the energy sector for diagnosis of performance in OHS to establish improvement proposals, the work path, and implementation costs. Finally, we evaluate the impact of the strategies applied in the improvement of the performance of the company.

A real case study considering four criteria, 23 sub-criteria, six decision-makers, and an instrument for the diagnosis of the occupational health and safety management is presented to validate the proposed approach. The results revealed that the criteria planning (58.9%), improvement (15.0%), and application (14.3%) have the most significant weight in the evaluation of occupational health and safety performance in the context of the energy company. Also, we found strong interrelations among criteria and sub-criteria with an impact on the performance evaluation in the adoption of the OHS management. On the other hand, we evaluated the changes and improvement of the company between the initial diagnosis, and the implementation of the action plans one year later. The outcomes of this evaluation evidenced a significant increase in the level of compliance in occupational health and safety management, going from 14% to 88% compliance, with an impact on the reduction in the indicators of accidents and absenteeism in work company results, increasing its sales by 43.8%. Considering the previous results, this integrated methodology facilitates the decision-making process managers in the energy sector for the improvement in the management of occupational health and safety.

2 Approaches of MCDM for Occupational Health and Safety Performance Evaluation in Electric Sector: A Literature Review

Occupational health and safety (OHS) is a multidisciplinary activity that focuses on the analysis of improving the conditions of workers in their workplaces, to reduce the number of accidents and occupational diseases, increase productivity, the commitment of workers and the competitiveness of companies [20, 21]. The previous implies that companies must adopt different standards and methodologies to manage health and safety in their work environments. Concerning the implementation of standards in OHS, for the electricity sector, it is even more relevant, given their complexity and the high risk that this industry poses in the safety and health of workers, users, and other stakeholders.

One of the critical elements in occupational safety and health management is related to performance evaluation, which according to ISO 45001 [22], is performance related to the effectiveness of the prevention of injuries and deterioration of health for workers and the provision of safe and healthy workplaces. In this sense, performance evaluation includes aspects such as compliance with legal requirements, risk and risk assessment, progress in achieving objectives, goals, and indicators in OHS, and the effectiveness of operational controls.

Concerning the evaluation of performance in OHS, it is in itself a complicated process, where different stakeholders intervene with their needs, expectations, and judgments (workers, managers, clients, government, suppliers, among others) multiple criteria to the time to evaluate, and uncertainty environments that make it difficult to establish the most appropriate actions in the prevention of accidents and occupational diseases. In this sense, there are different qualitative and qualitative methodologies that companies can use to identify gaps in performance, their causes and establish improvement actions, such as the cause-effect or Ishikawa diagram, the 5 W and 2H technique, the time series analyses, the risk assessment matrices, among others. However, multi-criteria decision-making (MCDM) based approaches can help companies in the electricity sector to learn about the evaluation of their performance, in real environments, with multiple criteria, and under uncertainty environments in organizations.

Regarding the object of this research, we found in the literature review evidence of studies oriented to apply the Multicriteria Decision Methods (MCDM) in occupational health and safety management (OHS). In this regard, we found a study that develops a critical state-of-the-art review of OHS risk assessment studies using MCDM-based approaches, includes fuzzy versions of MCDM approaches applied to OHS risk assessment [20]. The results of this study, which analyzed a total of 80 papers cited in high-impact journals, demonstrated the growing trend in the use of MCDM in the evaluation of risks, especially in the use of FAHP-based approaches, with application mainly in the industrial sector. On the other hand, the study identifies that methods such as VIKOR, PROMETHEE, ELECTRE, and DEMATEL remain superior methods in risk assessment and management due to their flexibility.

Bibliographic research has shown interesting articles written on the application of support systems for decision-making in occupational safety and health (OHS). Still, little has been published on the evaluation of integral performance in the management of OSH and the complex context of the electrical sector, as seen in Table 1, with the studies found related to an assessment in OHS and the MDCM techniques used.

The articles found focus on the application of MCDM techniques for the evaluation of risks, safety and health conditions, the satisfaction of workers concerning the OHS, but few articles focused on the integral assessment of performance in OHS, that consider the international standard ISO 45001. Besides, the main application sectors of MCDM techniques are mining, and construction, and the literature presents a limited development in the application of the MCDM models applied towards performance evaluation in OHS in the electric sector.

At the level of MDCM techniques, the literature review shows that the most used methods are related to the AHP technique and its extensions, such as Fuzzy AHP, Pythagorean Fuzzy AHP, and Intuitionistic Fuzzy AHP. Besides, the AHP methods can be used in combination with other techniques such as TOPSIS, VIKOR, ELECTRE, and DEMATEL, which gives researchers an open field for the use of hybrid MCDM methodologies according to the reality of the industries.

Concerning to the hybrid MCDM approaches, the combination of different methods allows overcoming the limitations of several techniques to obtain better outcomes [35]. Notably, the AHP method has the disadvantage of the phenomenon known as "reversal rank" related to the change of preference or order after an alternative is added or removed [36]. Concerning other methods such as the Technique for Order Preference by Similarity to Ideal Solution" (TOPSIS) do not provide an explicit procedure to allocate the relative importance of criteria and sub-criteria [37]. Due to the considerations mentioned above, it is necessary to apply a hybrid decision-making model that can consider inaccuracy, uncertainty, and lack of consensus in the judgments of the experts regarding the weights of the criteria and sub-criteria and that analyzes the interrelationships between the evaluation factors.

The novelty of the present study is based on the integration of the FAHP, as an extension of the AHP multi-criteria method with the DEMATEL method to evaluate the performance in occupational health and safety in the electric sector to provide a robust framework for evaluation and improvement in OHS. FAHP was chosen due to its capability of calculating the relative importance of criteria and sub-criteria under uncertainly. On the other hand, we proposed the integration of the DEMATEL method to FAHP. DEMATEL is applied to evaluate interrelations be-tween criteria and sub-criteria [38], helping decision-makers identify the interdependencies between decision factors, receiving and dispatching factors, which allows the design of comprehensive improvement plans.

Therefore, this research contributes to the scientific literature and provides a hybrid methodology for overall performance evaluation in occupational health and safety management and provides to managers procedures and techniques to generate a culture of prevention and healthy environments, through strategic alignment, driving the behavior and performance of people towards the achievement of the strategic objectives of electric sector.

Table 1. Performance evaluation in OHS based in MDCM approaches

Authors (Year)	Sector	Application	Objective	MDCM applied/Other
Inan UH, Gul S, and Yılmaz H. (2017) [21]	Mining, construction, ports	OHS performance	It integrates Simo's procedure and the VIKOR technique to build a multi-criteria decision-making model for OHS performance in companies, considering the OHSAS 18001: 2007 standard	Simo's procedure, VIKOR
Adema, A., Çolak, A., Dağdeviren, M. (2018) [23]	Energy sector	Risk evaluation in OHS	It proposes a methodology for the classification of labor risks for the wind turbine production stages	SWOT and Hesitant fuzzy linguistic term
Efe, B., Kurt, M., and Efe, F. (2017) [24]	Textile sector	Risk evaluation in OHS	It provides an integrated IFAHP-IFVIKOR approach for risk evaluation under group decision making	Intuitionistic fuzzy AHP (IFAHP)-intuitionistic fuzzy VIKOR (IFVIKOR)
Badria, A., Nadeaua, S., and Gbodossoub, A. (2012) [25]	Industrial projects	Risk evaluation in OHS	It proposes a risk-factor-based analytical approach for integrating occupational health and safety into project risk evaluation	AHP, risk evaluation
Jiangdong, B., Johansson, J., and Zhang, J. (2017) [26]	Mining	Employee satisfaction in OHS	It provides an analytic method of Evaluation on Employee Satisfaction of mine Occupational Health and Safety Management System based on improved AHP and 2-Tuple Linguistic Information,	Improved AHP 2-tuple linguistic information
Sadoughi et al. (2012) [27]	Government	Evaluation of performance indicators in OHS	It proposes a comprehensive approach for decision-makers to evaluate and prioritize of performance indicators of health, safety, and environment using Fuzzy TOPSIS	Fuzzy AHP
Gul, M., and Ak, M. (2018) [28]	Mining	Risk assessment in OHS	Provide a novelty and comparative methodology to quantify risk classifications in the assessment of occupational health and safety risks	Pythagorean fuzzy analytic hierarchy process (PFAHP), Fuzzy TOPSIS
Hatami-Marbini et al. (2013) [29]	Hazardous Waste Recycling	Safety and health assessment	Propose a multi-criteria decision making (MCDM) model based on an integrated fuzzy approach in the context of Hazardous Waste Recycling (HWR)	Fuzzy logic, ELECTRE

(*continued*)

Table 1. (*continued*)

Authors (Year)	Sector	Application	Objective	MDCM applied/Other
Ilbahara, E et al. (2018) [30]	Construction	Risk assessment in OHS	Propose a novel approach to risk assessment for occupational health and safety	Pythagorean fuzzy AHP, fuzzy inference system
Koulinas, G et al. (2019) [31]	Construction	Risk assessment in OHS	Propose a risk analysis and assessment in the worksites using the fuzzy-analytical hierarchy process and a quantitative technique	Fuzzy AHP, Proportional Risk Assessment Technique (PRAT)
Sukran Seker, S., and Zavadskas, E. (2017) [32]	Construction	Risk assessment in OHS	Application of Fuzzy DEMATEL Method for Analyzing Occupational Risks on Construction Sites	Fuzzy DEMATEL
Basahel, A., and Taylan, O (2016) [33]	Construction	Safety conditions assessing	Use of Fuzzy AHP and Fuzzy TOPSIS for Assessing Safety Conditions at Worksites	Fuzzy AHP and Fuzzy TOPSIS
Zheng, G., Zhu, N., Tian, Z., Chen, Y., and Sun, B (2012) [34]	Mining	Safety evaluation	Application of a trapezoidal fuzzy AHP method for work safety evaluation and early warning rating of hot and humid environments	Fuzzy AHP

3 Proposed Methodology

The proposed approach aims to evaluate the performance in occupational health and safety management in the electric sector by the integrated methodology using FAHP and DEMATEL. In this regard, the methodology is comprised of four phases (refer to Fig. 1):

– **Phase 1 (Design of the model for performance evaluation OHS FAHP/DEMATEL):** A decision-making group is chosen based on their experience in occupational health and safety in the electric sector. The experts will be invited to be part of the decision-making process through FAHP and DEMATEL techniques. Subsequently, the criteria and sub-criteria are established to set up a decision hierarchy considering the opinion of the expert decision-makers, the literature review, and regulations in occupational health and safety management [19, 35, 38]. Then, the surveys for the application of the FAHP and DEMATEL methods were designed.
– **Phase 2 (FAHP application):** In this step, FAHP is used to estimate the global and local weights of criteria and sub-criteria under uncertainty in the ponderation. In this phase, the experts were invited to perform pairwise comparisons, which are subsequently processed following the FAHP method, as detailed in Sect. 3.1.

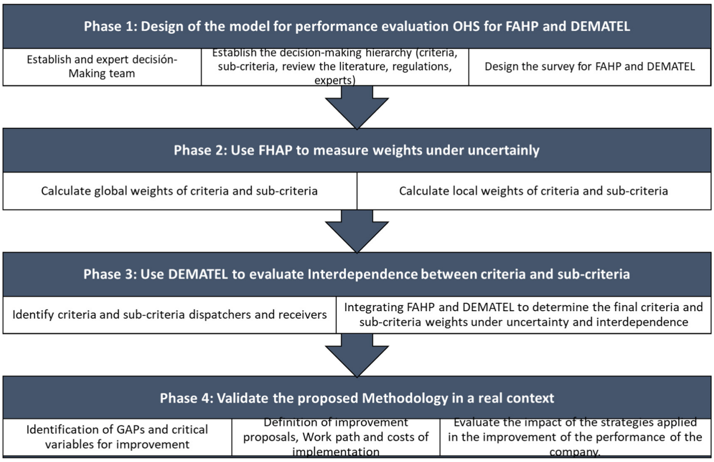


Fig. 1. The methodological approach for evaluating the performance in occupational health and safety management in the electric sector

- **Phase 3 (DEMATEL application):** In this phase, DEMATEL is implemented to determine the interdependence and interrelations between criteria and sub-criteria (described in Sect. 3.2) as well as identify the receivers and dispatchers. Additionally, it is used to assess the strength of each influence relation [35]. Then, FAHP and DEMATEL are combined to obtain the criteria and sub-criteria weights with the basis of interdependence.
- **Phase 4 (Validation of the proposed methodology**): In this step, GAPs and critical variables were identified to improve the performance in OHS management [10, 19, 39]. Subsequently, were defined the improvement proposals, the schedule, and the costs of implementation of strategies. Finally, was evaluated the impact after the implementation of the strategy in the improvement of the performance in OHS, their statistics or accidents, and the revenue of the company.

3.1 Fuzzy Analytic Hierarchy Process (FAHP)

Fuzzy AHP is a derived method of Analytic Hierarchy Process (AHP) proposed by Thomas L. Saaty as combined technique between AHP and fuzzy logic with the purpose of improve the decision-making process due that the AHP method does not consider vagueness of human judgments, the fuzzy logic theory was introduced due to its capability of representing imprecise data [38, 40].

In FAHP, the paired comparisons are represented in a matrix using fuzzy triangular numbers [41] as described below (Refer to Table 2). Considering the findings from the literature review, a reduced AHP scale has been adopted by the decision-makers when making comparisons [38].

The steps of the FAHP algorithm as follows:

- Step 1: Perform pairwise comparisons between criteria/sub-criteria by using the linguistic terms and the corresponding fuzzy triangular numbers established in Table 2.

Table 2. Linguistic terms and their fuzzy triangular numbers

Reduced AHP scale	Definition	Fuzzy triangular number
1	Equally important	[1, 1, 1]
3	More important	[2–4]
5	Much more important	[4–6]
1/3	Less important	[1/4, 1/3, 1/2]
1/5	Much less important	[1/6, 1/5, 1/4]

With this data, a fuzzy judgment matrix $\tilde{A}^k(a_{ij})$ is obtained as described below in Eq. 1:

$$\tilde{A}^K = \begin{bmatrix} \tilde{d}_{11}^k & \tilde{d}_{12}^k & \ldots & \tilde{d}_{1n}^k \\ \tilde{d}_{21}^k & \tilde{d}_{22}^k & \ldots & \tilde{d}_{2n}^k \\ \ldots & \ldots & \ldots & \ldots \\ \tilde{d}_{n1}^k & \tilde{d}_{n2}^k & \ldots & \tilde{d}_{nn}^k \end{bmatrix} \tag{1}$$

$\tilde{d}_{ij}^k$ indicates the *kth* expert's preference of *ith* criterion over *jth* criterion via fuzzy triangular numbers.

- Step 2: In the case of a focus group, the judgments are averaged according to Eq. 2, where K represents the number of experts involved in the decision-making process. Then, the fuzzy judgment matrix is updated, as shown in Eq. 3.

$$\tilde{d}_{ij} = \frac{\sum_{k=1}^{K} \tilde{d}_{ij}^k}{K} \tag{2}$$

$$\tilde{A} = \begin{bmatrix} \tilde{d}_{11} & \ldots & \tilde{d}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{d}_{n1} & \ldots & \tilde{d}_{nn} \end{bmatrix} \tag{3}$$

- Step 3: Calculate the geometric mean of fuzzy judgment values of each factor by using Eq. 4. Here, $\tilde{r}_i$ denotes triangular numbers.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{1/n}, i = 1, 2, \ldots, n \tag{4}$$

- Step 4: Determine the fuzzy weights of each factor ($\tilde{w}_i$) by applying Eq. 5.

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \ldots \oplus \tilde{r}_n)^{-1} = (lw_i, mw_i, uw_i) \tag{5}$$

- Step 5: Defuzzify ($\tilde{w}_i$) by performing the Centre of Area method [42] via using Eq. 6. M_i is a non-fuzzy number. Then, normalize M_i via applying Eq. 7.

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \tag{6}$$

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \tag{7}$$

3.2 Decision Making Trial and Evaluation Laboratory (DEMATEL)

DEMATEL is an MCDM technique applied to identify the complex causal relationships between criteria and sub-criteria involved in a multicriteria decision model [43]. DEMATEL it´s based on the graph theory, and the outcome is a visual representation called impact-digraph map that categorizes the criteria into two groups: dispatchers and receivers [44]. Dispatchers are the criteria or sub-criteria that highly influence other criteria or sub-criteria, while the receivers are the affected criteria or sub-criteria [38]. Additionally, the DEMATEL method indicates the influence degree of each element so that significant interdependencies can be identified [46].

The procedure of DEMATEL method is given as follows [38]:

- Step 1: Make the matrix of direct influence: The decision-makers are asked to make comparisons between criteria/sub-criteria to measure their causal relationship. For this, the experts, based on their personal experience, point out the direct impact that each element i exerts on each of the other elements j using this four-level comparison scale: nonexistent impact (0), low impact (1), medium impact (2), high impact (3) and very high impact (4). With these comparisons, an average n x n matrix called the direct relationship matrix is generated. In this matrix, each element *bij* represents the average degree to which the criterion/sub-criterion *i* affect the criterion/sub-criterion *j*.
- Step 2: Normalize the direct influence matrix: The normalized direct relation matrix N is calculated using Eq. 8–9:

$$N = k \cdot B \tag{8}$$

$$k = min\left(\frac{1}{\max_{1\leq \mathrm{i}<\mathrm{n}} \sum_{j=1}^{n} |b_{ij}|}, \frac{1}{\max_{1\leq \mathrm{j}<\mathrm{n}} \sum_{i=1}^{n} |b_{ij}|}\right) i, j \in \{1, 2, 3, \ldots, n\} \tag{9}$$

- Step 3: Obtain the total relation matrix: After normalizing the direct relation matrix N, the total relation matrix S is obtained by implementing Eq. 10, where I is the identity matrix:

$$S = N + N^2 + N^3 + \ldots = \sum_{i=1}^{\infty} N^i = N(I - N)^{-1} \tag{10}$$

- Step 4: Develop a causal diagram: Using the $D + R$ and $D - R$ values, where R_i represents the sum of the $j - th$ column of the matrix S (see Eq. 11–12) and D_i represents the sum of the $i - th$ row of the matrix S (see Eq. 11 and Eq. 13), dispatchers and receivers can be identified. Criteria/Sub-criteria with positive values of D-R, have a strong influence on the other criteria/sub-criteria, and are called dispatchers. The negative values of D − R indicate that the criteria/sub-criteria are very influenced by others (receivers). Besides, the D + R values indicate the degree to which the criteria/sub-criteria i affect or are affected by others.

$$S = \left[s_{ij}\right]_{nxn}, i, j \in \{1, 2, 3, \ldots, n\} \tag{11}$$

$$R = \sum_{j=1}^{n} s_{ij} \tag{12}$$

$$D = \sum_{i=1}^{n} s_{ij} \tag{13}$$

– Step 5: Establish the threshold value and obtain impact-digraph map: The threshold value is calculated to identify the significant interrelationships between criteria or sub-criteria (see Eq. 14). If the influence degree of a criterion/sub-criterion in the matrix S is bigger than the threshold value (p), then this criterion/sub-criterion is included in the map of impact digraphs. This graph is done by assigning the data set ($D + R$, $D - R$).

$$p = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} s_{ij}}{n^2} \tag{14}$$

3.3 The FAHP-DEMATEL Method

A combined FAHP-DEMATEL method is suggested to offer more robust results [45]. The mixed technique tackles the drawbacks of FAHP, which is not capable of assessing the feedback and interdependence among decision elements. It is, therefore, necessary to complement it with DEMATEL, which can help occupational health and safety professionals to design short, medium- and long-term plans that improve the performance evaluation in OHS management. The relative weights of factors and sub-factors (w_j) based on interdependence are obtained by multiplying the weights derived from FAHP and the normalized direct relation matrix N (refer to Eq. 15).

$$wi_j = \begin{matrix} SC_1 \\ SC_2 \\ SC_3 \\ . \\ . \\ SC_z \end{matrix} \begin{bmatrix} SC_1 & SC_2 & \ldots. & SC_z \\ n_{11} & n_{12} & \ldots. & n_{1z} \\ n_{21} & n_{22} & \ldots. & n_{2z} \\ n_{31} & n_{32} & \ldots. & n_{3z} \\ . & . & \ldots.. & . \\ . & . & \ldots.. & . \\ n_{z1} & n_{z2} & \ldots. & n_{zz} \end{bmatrix} * \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ . \\ . \\ w_z \end{bmatrix} \tag{15}$$

4 Application of the Integrating Proposed Methodology

4.1 Design of the Model for Performance Evaluation FAHP/DEMATEL

In this section, an empirical example is presented to validate the proposed methodology. The case study is illustrated in a medium-sized electric company located in Colombia.

One of the objectives of the company is the improve in the levels of customer satisfaction considering their requirements and needs (e.g., quality, delivery times, price, service), through the active development of services and products, the competence and commitment of its human talent, also fulfilling with the legal regulation in occupational safety and health. The company under study supplies electrical products and performs outsourcing services to improve electrical and telecommunications infrastructure. To support the quality and safety in its operations, the company must adequately identify the regulatory requirements in occupational safety and health, through the design of a decision model that involves different criteria and sub-criteria to evaluate and improve their performance in OHS.

Subsequently, a decision-making team was selected to validate the criteria and sub-criteria through the application of FAHP and DEMATEL techniques for the performance evaluation in occupational health and safety management, given their expertise in these topics and the electric sector. In this regard, four types of experts were found to be meaningful for the decision-making process: three leaders of the company under study, two experts consultors in health and safety management with expertise in the electric sector, and two representatives of academic sector linked to the occupational health and safety in companies. The team of experts for develop of integrated methodology is described below:

- Expert 1 is the General Manager of the company, with more than 10 years of experience in the electric sector.
- Expert 2 is the Leader in OHS department of the company, with more than 5 years of the experience.
- Expert 3 is the Head of the legal department of the company, with more than 5 years of experience in government regulations in OHS.
- Expert 4 is a professional in occupational health and safety with a master's degree in Management Systems and 10 years of experience as a consultant in both private and public organizations in the diagnostic, design implementation and improve health and safety programs in different companies.
- Expert 5 is an Electrical Engineer with a specialization in Automatic Control Systems and more than five years of experience and safety standards in the electric sector.
- Expert 6 is industrial engineering, specialist in occupational health with knowledge and 10 years of experience in health and safety in work, regulations and standards in occupational health and safety management (OHS), risk assessment, and industrial hygiene.
- Expert 7 is an Industrial Engineer and specialist in the application of multivariate methods and multi-criteria models for performance evaluation. The industrial engineer acted as a facilitator to take over the judgment process.

Concerning to hierarchy of the decision-making model is composed of four criteria (C1, C2, C3, and C4) and 23 sub-criteria (S1, S2,…, S23) according to the model developed by Jimenez et al. [19]. These criteria and sub-criteria were determined based on the regulations applicable to the electric sector such as the Decree No 1072 of 2015 (establish the rules in occupational health and safety management for companies) [47], Resolution No 0302 of 2019 (minimum standards in occupational health and safety in organizations) [48], and requirements of the international standard in OHS ISO 45001 [22]. Then, the experts validate these criteria and sub-criteria according to the health and safety regulations, and the literature review presented in order to provide an MCDM model responding to the current needs of the electric sector. Subsequently, the multi-criteria hierarchy was then verified and discussed through different sessions with the expert decision-making team to establish the comprehension of the model and the hierarchy. Finally, the decision model is shown in Fig. 2.

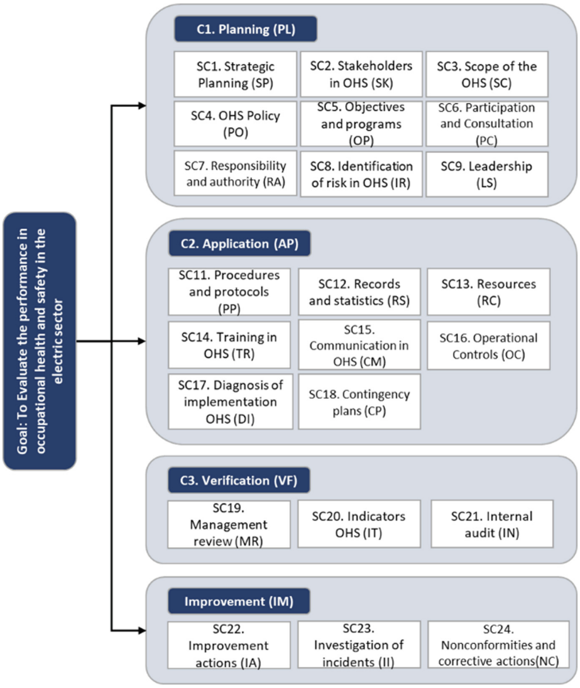


Fig. 2. Multi-criteria decision-making model to evaluate the overall performance in occupational health and safety management in the electric sector

Particularly, the criteria and sub-criteria were labeled and described in Table 3 [19].

4.2 Design of Data Collection Tools for FAHP and DEMATEL

In this step, a data collection instrument was designed for the paired comparisons process performed by the experts (refer to Fig. 3). In this regard, for each pairwise evaluation, the participants answered the following question: According to the goal/criteria, ¿how important is each element on the leftover the item on the right? The experts used Table 1 to represent their responses until finalizing all the factors and sub-factors. Then, via Eqs. 1–7, the weights of criteria and sub-criteria were determined.

On the other hand, we design a survey for the application of the DEMATEL technique (refer to Fig. 4) with the purpose of analyzing the interdependence between factors and sub-factors. Subsequently, it's applying the Eqs. 8–14, to identify the dispatchers and receivers. For each comparison, it was asked: With respect to goal/factor, ¿how much influence each element on the left has over the element on the right? The experts responded by using the 5-point scale shown in Sect. 3.2. The decision process was also repeated to finally calculate D + R and D − R values.

Table 3. Description of criteria

Criterion (C)	Sub-criteria (SC)	Criterion description
C1. Planning (PL)	SC1. Strategic planning (SP) SC2. Stakeholders in OHS (SK) SC3. Scope of the OHS system (SC) SC4. OHS Policy (PO) SC5. Objectives and OHS programs (OP) SC6. Participation and consultation (PC) SC7. Responsibility and authority in OHS (RA) SC8. Identification of risks in OHS (IR) SC9. Leadership (LS)	Planning is defined as the ability of the company to set OHS priorities, objectives, work plans, performance indicators, and resources for the implementation of OHS management, according to stakeholders, risks, current regulations and the context of the organization [19, 22, 47, 48]
C2. Application (AP)	SC10. Procedures and protocols (PP) SC11. Records and statistics (RS) SC12. Resources (RC) SC13. Training in OHS (TR) SC14. Communication in OHS (CM) SC15. Operational Controls (OC) SC16. Diagnosis of implementation OHS (DI) SC17. Contingency plans (CP)	This criterion refers to the aspects that the organization must guarantee to make the management of Occupational Safety and Health operational, such as documentation, procedures, and records, management of accident statistics, resources, training, active communication on OHS issues, initial assessment of OHS compliance, operational controls, and emergency preparedness and response [19, 22, 47, 48]
C3. Verification (VF)	SC18. Management review (MR) SC19. Indicators OHS (IT) SC.20 Internal audits (IN)	Verification in the Health and Safety Management System allows companies to evaluate their performance concerning the OHS, considering their context, processes, and stakeholders. This criterion includes indicators, compliance assessment, internal audits, and management review [19, 22, 47, 48]
C4. Improvement (IM)	SC21. Improvement actions (IA) SC22. Investigation of incidents (II) SC23. Nonconformities and corrective actions (NC)	This criterion assesses the company's ability to improve its performance at OHS taking into account its policy and objectives. [19, 22, 47, 48]

According to your experience with respect to "Improvement" sub-criterion, ¿how important is each sub-criterion on the left concerning the sub-criterion on the right when evaluating the performance in occupational health and safety management in the companies of electric sector?								
		1	2	3	4	5		
Improvement actions	is	○	○	○	○	○	Important than	Investigation of incidents
Improvement actions	is	○	○	○	○	○	Important than	Nonconformities and corrective actions
Investigation of incidents	is	○	○	○	○	○	Important than	Nonconformities and corrective actions

① Much less ③ Equally ⑤ Much more
② Less ④ More

Fig. 3. Data-collection instrument implemented for FAHP judgments

According to your experience with respect to "Improvement" sub-criterion, ¿how much influence each sub-criterion on the left has over the sub-criterion on the right when evaluating the performance in occupational health and safety management in the companies of electric sector?								
		0	1	2	3	4		
Improvement actions	has	○	○	○	○	○	Influence over	Investigation of incidents
Improvement actions	has	○	○	○	○	○	Influence over	Nonconformities and corrective actions
Investigation of incidents	has	○	○	○	○	○	Influence over	Nonconformities and corrective actions

(0) Nonexistent impact (1) Low impact (2) Medium impact (3) high impact (4) Very high impact

Fig. 4. Data-collection instrument implemented for DEMATEL comparisons

4.3 Calculating the Relative Weights of Criteria and Sub-criteria Using FAHP

In this phase, by the application of the FAHP method, the local and global weights of criteria and sub-criteria were determined considering the uncertainty and vagueness in the judgments of experts. In this sense, first, the fuzzy matrixes were calculated, taking into account the paired comparisons made by the selected experts. In Tables 4, 5 and 6, the results of the FAHP process for the criteria comparison matrix can be seen as an example, applying Eqs. 1–7 of the methodology detailed in Sect. 3.1. Finally, Table 7 presents the local and global weights of all the criteria and sub-criteria that make up the multi-criteria decision model.

Table 4. Fuzzy reciprocal comparison matrix for criteria

	C1 (PL)	C2 (AP)	C3 (VF)	C4 (IM)
C1 (PL)	[1, 1, 1]	[2.44,3.47,4.49]	[2.69,3.73,4.76]	[2.21,3.23,4.24]
C2 (AP)	[0.22,0.29,0.41]	[1, 1, 1]	[1.22,1.37,1.49]	[1.10,1.17,1.22]
C3 (VF)	[0.21,0.27,0.37]	[0.67,0.73,0.82]	[1, 1, 1]	[0.35,0.42,0.55]
C4 (IM)	[0.24,0.31,0.45]	[0.82,0.85,0.91]	[1.81,2.36,2.85]	[1, 1, 1]

Table 5. Geometric means of fuzzy comparisons for criteria

Criterion	C1 (PL)	C2 (AP)	C3 (VF)	C4 (IM)
Geometric mean of fuzzy comparisons	[2.44,3.47,4.49]	[0.70,0.81,0.97]	[0.55,0.67,0.83]	[0.71,0.85,1.05]

Table 6. Normalized fuzzy priorities for criteria

Fuzzy weight				Non-fuzzy weight	Normalized weight
C1	17.91	20.14	19.70	19.25	0.589
C2	5.11	4.71	4.24	4.69	0.143
C3	4.02	3.86	3.65	3.84	0.118
C4	5.18	4.96	4.62	4.92	0.150
Total				32.70	

The Fig. 5 shows the results of the FAHP technique show. Firstly, the weights of the criteria associated with the evaluation of performance in OHS applied to the electricity sector. Ac-cording these outcomes, "Planning" (GW = 58.9%) is the most relevant factor in this evaluation is "Planning" (GW = 58.9%). This factor presents a difference greater than 40% with respect to the other criteria of the model. On the other hand, the sub-criteria "Application" (GW = 14.3%), "Verification" (GW = 11.8%), and "Improvement" (15.0%), present minor differences in their weights or importance, to evaluate the performance in OHS. These results demonstrate the importance of planning to obtain a satisfactory performance in the assessment of OHS by the design of strategies and plans focused on generating a culture of prevention and safety in work environments. On the other hand, evaluation can allow decision-makers to establish the most appropriate strategies to improve OHS performance, considering the elements of the P-D-C-A (Plan-Do-Check-Act) cycle.

Regarding the sub-criteria, Figs. 6a, 6b, 7a, and 7b show the distribution by the level of importance of the sub-factors for each cluster in the evaluation of performance in OHS. Regarding these results, in the "Planning" cluster, an essential sub-criterion is "Leadership" (23%) and "Strategic Planning" (19.36%). In the "Application" cluster, the sub-criteria "Diagnosis in OHS" and "Operational Control" were identified as the most relevant (20%). For the "Verification" cluster, "Management review" (59.30%) was identified as the most critical sub-criterion, followed by the "Internal Audits" sub-factor (23.06%). In the "Improvement" cluster, the sub-criterion with the highest weight corresponds to "Improvement Actions" (71.68%). All these factors and sub-factors are part of the legal requirements in OHS in correspondence with the ISO 45001 standard, intending to identify opportunities for improvement in OHS performance, define action plans, resources for its execution, and evaluating their impact on the organization in the prevention of accidents and occupational diseases.

Table 7. Local and global weights of criteria and sub-criteria

Cluster	GW	LW
C1. Planning (PL)	**0.589**	
SC1. Strategic management (SP)	0.114	0.194
SC2. Stakeholders (SK)	0.024	0.041
SC3. Scope of OHS (SC)	0.022	0.037
SC4. Policy of OHS (PO)	0.069	0.117
SC5. Objective of OHS (OP)	0.090	0.153
SC6. Participation of workers (PC)	0.036	0.061
SC7. Responsibilities and authority (RA)	0.038	0.065
SC8. Risk management (IR)	0.062	0.106
SC9. Leadership (LS)	0.134	0.227
C2. Application (C2)	**0.143**	
SC10. Procedures and protocols (PP)	0.112	0.083
SC11. Records and statistics in OHS (RS)	0.012	0.084
SC12. Resources for OHS (RC)	0.027	0.187
SC13. Education and Training (TR)	0.015	0.103
SC14. Communication in OHS (CM)	0.007	0.052
SC15. Operational Controls (OC)	0.028	0.198
SC16. Diagnosis in OHS (DI)	0.028	0.198
SC17. Contingency plans (CP)	0.014	0.095
C3. Verification (C3)	**0.118**	
SC18. Management review (MR)	0.070	0.593
SC19. Evaluation of OHS (IT)	0.021	0.176
SC20. Audit od OHS (IN)	0.027	0.231
C4. Improvement (C4)	**0.150**	
SC21. Improvement plans (IA)	0.108	0.717
SC22. Incident investigation (II)	0.030	0.197
SC23. Nonconformities and corrective plans (NC)	0.013	0.086

Finally, we calculated the consistency (refer to Table 8) to guarantee the reliability of the judgments contributed by the expert team. The outcomes evidence that all criteria present adequate consistency values ($CR \leq 0.1$). Therefore, the factors and sub-factors can be then applied consistently to evaluate the performance in occupational health and safety management.

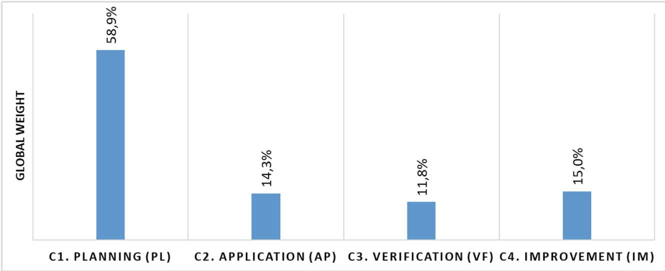


Fig. 5. Global weights of criteria in the performance evaluation in occupational health and safety in companies of electric sector

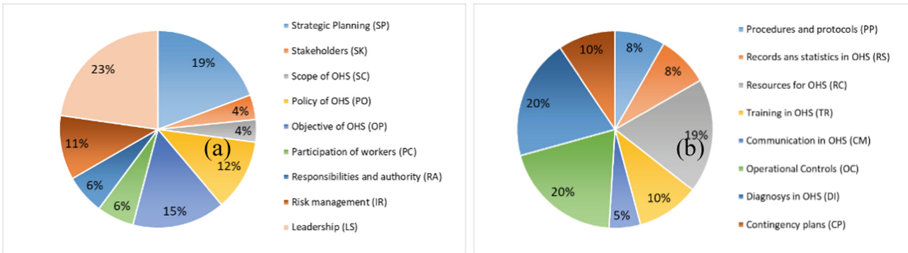
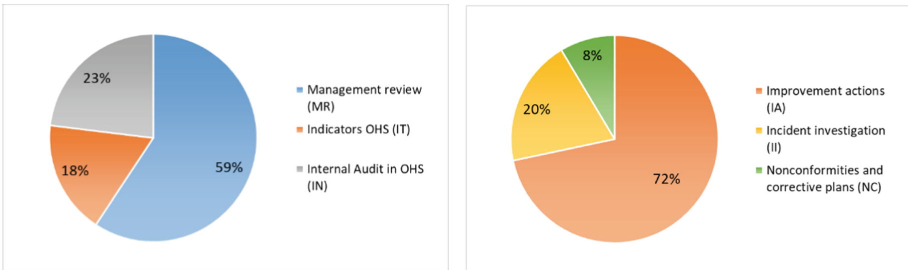


Fig. 6. Local contributions for factors a) Planning b) Application



(a) (b)

Fig. 7. Local contributions for factors a) Verification b) Improvement

Table 8. Consistency values for FAHP matrices

Cluster	Consistency ratio (CR)
Criteria	0.028
Planning	0.065
Application	0.064
Verification	0.025
Improvement	0.034

4.4 Evaluating the Interdependence Between Criteria and Sub-criteria via DEMATEL

In this step, we applied a survey to collect the paired evaluation of the experts for the DEMATEL technique. To do this, the experts answered the following question: "how much influence has each criterion/sub-criterion over the criterion/sub-criterion on the left?" In this regard, the experts responded, taking into account the following scale: Nonexistent impact (0), Low impact (1), Medium impact (2), High impact (3), and Very high impact (4). The experts repeat this procedure until finishing all the evaluations.

Then, applying the Eq. 8–13 of the DEMATEL technique, the prominence (D + R) and relation (D-R) values are calculated (refer to Table 9). As a result of this process, the dispatchers and receivers were identified, as shown in Table 9. According to these results, "Planning" (C1) and "Improvement" (C4) were classified as dispatchers, while "Application" (C2) and "Verification" was identified as receivers. Besides, the outcomes show that "Planning" (C4) has the highest D + R value (3.686), establishing that this criterion is the principal generator of impacts and the most determining factor when evaluating the performance in occupational health and safety management.

Besides, impact-digraph maps were diagrammed for analyzing the interdependencies between each cluster, both criteria, and sub-criteria. "Criteria" (refer to Fig. 8a) and "Verification" (see to Fig. 8b) groups are presented as examples. Concerning the outcomes of the impact digraph, in Fig. 8a shows the unidirectional interrelations (red arrows) between dispatchers and receivers. In particular, the "Planning" and "Improvement" are the criteria that most influence the other factors. Therefore it´s evidenced that the performance in the OHS is controlled by the capability of the companies of the electric sector for planning and establishing improvement actions with impact in the application and verification of the OHS management.

On the other hand, in Fig. 8b, it is observed the presence of one unidirectional interrelation between dispatchers and receivers "Management review" and "Indicators in OHS" (red arrow) and two feedback interdependencies (green arrows) between "Management review" and "Internal Audits," and between "Internal Audits" and "Evaluation of OHS." For example, the "Management review" influences the "Internal audits" through the guidelines and necessary resources for the development of these audits. Moreover, "Internal audits" provide valuable outcomes for "Management review" as an input element for this process.

4.5 Integration of FAHP and DEMATEL Methods

In this section, FAHP and DEMATEL methods are integrated using Eq. 15 to calculate the global and local weights of criteria and sub-criteria in the performance evaluation of occupational health and safety management taking into account factors such as the uncertainty in the pair comparisons of the judgments and the interdependence between criteria and sub-criteria. The final global and local contributions of criteria and sub-criteria were presented in Table 10. Figure 9 shows the ranking of criteria according to their global contributions.

Concerning the results, "Improvement" (0.292) and "Verification" (0.270) were identified as the most relevant criteria in the performance evaluation of OHS management. However, there is not a big difference (9.7%) between the essential criterion "Improvement" and the last in the ranking "Planning." These outcomes can be explained by the

Table 9. Dispatchers and receivers in the decision-making model

Cluster (Criteria/Sub-criteria)	Prominence (D + R)	Relation (D − R)	Dispatcher	Receiver
C1. Planning (PL)	**3.686**	**1.115**	**X**	
SC1. Strategic management (SP)	0.269	0.048	X	
SC2. Stakeholders (SK)	0.235	−0.020		X
SC3. Scope of OHS (SC)	0.245	−0.008		X
SC4. Policy of OHS (PO)	0.240	−0–002		X
SC5. Objective of OHS (OP)	0.251	−0.017		X
SC6. Participation of workers (PC)	0.255	−0.018		X
SC7. Responsibilities and authority (RA)	0.236	−0.023		X
SC8. Risk management (IR)	0.253	−0.016		X
SC9. Leadership (LS)	0.262	0.056	X	
C2. Application (C2)	**3.065**	**−0.768**		**X**
SC10. Procedures and protocols (PP)	0.247	−0.022		X
SC11. Records and statistics in OHS (RS)	0.252	−0.030		X
SC12. Resources for OHS (RC)	0.073	0.174	X	
SC13. Education and Training (TR)	0.256	−0.036		X
SC14. Communication in OHS (CM)	0.250	−0.050		X
SC15. Operational Controls (OC)	0.281	−0.033		X
SC16. Diagnosis in OHS (DI)	0.274	0.002	X	
SC17. Contingency plans (CP)	0.301	−0.005		X
C3. Verification (C3)	**3.205**	**−0.378**		**X**
SC18. Management review (MR)	0.959	0.174	X	

(*continued*)

Table 9. (*continued*)

Cluster (Criteria/Sub-criteria)	Prominence (D + R)	Relation (D − R)	Dispatcher	Receiver
SC19. Evaluation of OHS (IT)	1.008	−0.125		X
SC20. Audit od OHS (IN)	1.006	−0–049		X
C4. Improvement (C4)	**3.308**	**0.030**	**X**	
SC21. Improvement plans (IA)	0.973	0.045	X	
SC22. Incident investigation (II)	0.991	−0–027		X
SC23. Nonconformities and corrective plans (NC)	1.035	−0.018		X

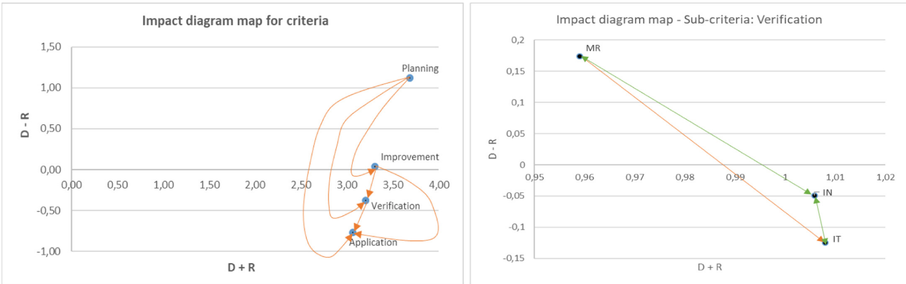


Fig. 8. Impact digraph maps for a) Criteria and b) Improvement (Color figure online)

fact that occupational health and safety management standards regulate all these criteria to guarantee the culture of prevention in the electric sector through adequate performance evaluation in OHS. In this regard, it is crucial to design multi-criteria plans that consider the principles, requirements, and criteria involved in the evaluation process. Thereby, the companies of the electric sector can improve their performance continuously with an impact on the wellness of their workers and stakeholders.

On the other hand, the sub-criteria "Strategic management" (0.025), "Contingency plans" (0.035), "Evaluation of OHS" (0.109) and "Nonconformities and corrective plans" (0.144) were identified as the sub-criteria with the highest global priorities taking into account the integration of FAHP and DEMATEL techniques.

4.6 Validate the Proposed Methodology in a Company of Electric Sector

In this phase, the multi-criteria decision model was applied for the evaluation of the performance in OHS in the electrical sector company described in Sect. 4.1. Table 11 shows the performance obtained by the company, in the first diagnostic evaluation, as in

Table 10. Local and global contributions of criteria and sub-criteria resulting from FAHP-DEMATEL integration

Cluster	GW	LW
C1. Planning (PL)	**0.195**	
SC1. Strategic management (SP)	0.025	0.130
SC2. Stakeholders (SK)	0.020	0.104
SC3. Scope of OHS (SC)	0.022	0.111
SC4. Policy of OHS (PO)	0.020	0.103
SC5. Objective of OHS (OP)	0.020	0.101
SC6. Participation of workers (PC)	0.022	0.115
SC7. Responsibilities and authority (RA)	0.021	0.106
SC8. Risk management (IR)	0.021	0.108
SC9. Leadership (LS)	0.024	0.123
C2. Application (C2)	**0.242**	
SC10. Procedures and protocols (PP)	0.027	0.113
SC11. Records and statistics in OHS (RS)	0.032	0.134
SC12. Resources for OHS (RC)	0.029	0.120
SC13. Education and Training (TR)	0.028	0.114
SC14. Communication in OHS (CM)	0.028	0.115
SC15. Operational Controls (OC)	0.030	0.122
SC16. Diagnosis in OHS (DI)	0.033	0.137
SC17. Contingency plans (CP)	0.035	0.144
C3. Verification (C3)	**0.270**	
SC18. Management review (MR)	0.058	0.213
SC19. Evaluation of OHS (IT)	0.109	0.402
SC20. Audit od OHS (IN)	0.104	0.385
C4. Improvement (C4)	**0.292**	
SC21. Improvement plans (IA)	0.041	0.139
SC22. Incident investigation (II)	0.108	0.370
SC23. Nonconformities and corrective plans (NC)	0.144	0.492

the second evaluation, after implementing the improvement plans. For this, the GAPS or deviations from the maximum value were calculated using the Eq. 16 [39].

$$GAP(\%) = \frac{Score\ obtanied - Score\ max}{Score\ max} \times 100 \quad (16)$$

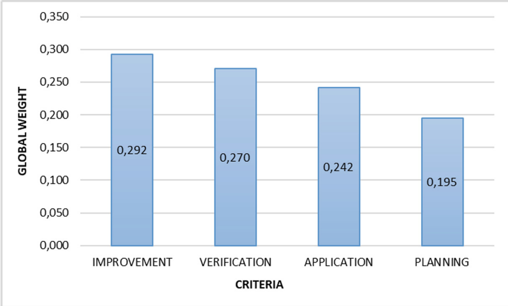


Fig. 9. Ranking of criteria (GW) of FAHP/DEMATEL integration

Table 11. Identification of GAPS and critical variables for improvement of MCDM FAHP-DEMATEL in OHS performance evaluation

Criterion	GW (FAHP/ DEMATEL)	Max Score	Obtained Score (First Evaluation)	Obtained Score (Second Evaluation)	GAP (First Evaluation)	GAP (Second Evaluation)
Planning (C1)	**19.6%**	4.9	0.1	4.0	98.00%	18.00%
Application (C2)	**24.2%**	14.5	3.3	12.7	77.50%	12.50%
Verification (C3)	**27.0%**	1.4	0.0	1.4	100.00%	0.00%
Improvement (C4)	**29.2%**	2.9	0.0	2.9	100.00%	0.00%
Score	**100.0%**	**23.7**	**3.4**	**21.0**	85.80%	11.38%
	% of Compliance		**14.20%**	**88.62%**		

In the first evaluation, it's evidenced that the company has a compliance index of 14% concerning the minimum compliance required by national regulations that are of 86%. According to this evaluation, all evaluation criteria were identified as critical, with GAPS or deviations more significant than 70%.

The results were shared with the company's manager, with whom improvement plans were established according to the company's context and resources. Table 12 shows examples of the improvement plans adopted, and Fig. 10 presents the PERT diagram drawn up with the critical path for the project, which was estimated with an execution time of 42 weeks and an investment of USD 18,000.

On the other hand, we evaluate the effect of the improvement plans both in the evaluation of performance in OHS and in critical indicators for the company. Figure 11 shows the positive evolution in the company's OHS performance, growing from 14.2% to 88.62%, meeting the minimum percentage required established by national regulations in Colombia. The growth mentioned above can be seen in Table 11, where the company meets 100% of the "Verification" and "Improvement" criteria and only presents GAPS of 18% in the "Planning" criterion and 12.5% in the "Application" criterion, which demonstrates the effectiveness of the plans adopted in the performance in OHS.

Table 12. Improvement plans in OHS performance evaluation

No	Improvement plans
1	Define the person responsible for leading OHS management
2	Design of Matrix of Roles and Responsibilities in OHS
3	Design of the policy in OHS
4	Grouping of the emergency brigade
5	Design and implementation of epidemiological surveillance programs to prevent priority risks
6	Design and implementation of safety inspection program
7	Design and implementation of training plans in OHS

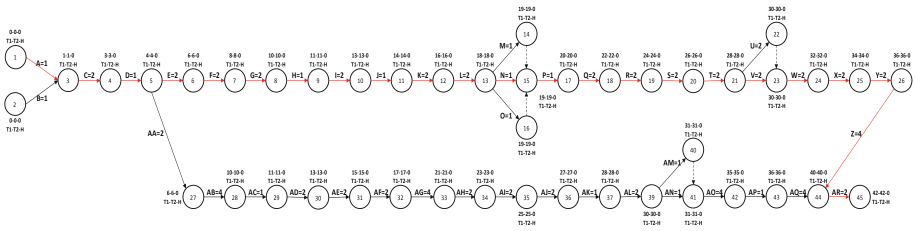


Fig. 10. Scheduling and Critical Route PERT-CPM

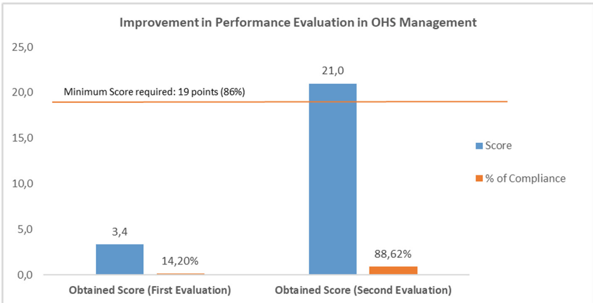
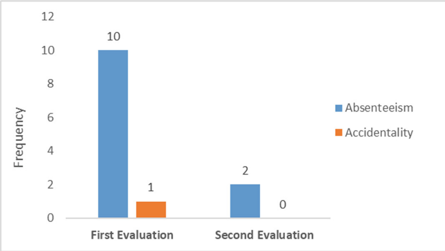
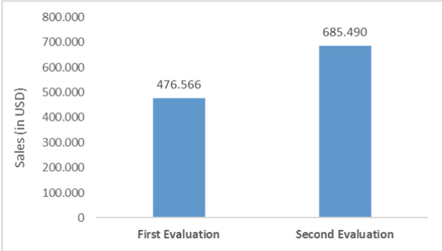


Fig. 11. Improvement in Performance Evaluation in OHS Management

Finally, in Figs. 12a and 12b, the influence of the improvement plans implemented in OHS on critical indicators for the company is observed. In this sense, in Fig. 12a, the 80% reduction in absenteeism from work is evident, as well as the decrease in accidents by 100%, taking into account the data collected between the first and second performance evaluations at OHS. Figure 12b shows the increase in sales derived from improvement in the performance of OHS management, with growth between the first and the second evaluation of 43.83%. The aforementioned outcomes illustrate the positive impact of the assessment of performance in OHS on the well-being of workers, on the productivity of companies, and the competitiveness of the electricity sector.



(a)



(b)

Fig. 12. Improvements in indicators a) Absenteeism and accidentality in OHS b) Sales (in USD) derived from OHS management

5 Conclusions and Future Work

This research presents an integrated fuzzy multicriteria approach using FAHP and DEMATEL to evaluate and improve the performance in occupational health and safety management with application in the electric sector. The proposed methodology includes four phases since the design of the MCDM model, the application of FAHP technique to calculate the importance of the criteria and sub-criteria in OHS performance evaluation, the use of DEMATEL method to identify the interrelations between criteria, the integration of FAHP/DEMATEL to establish the final weights of the criteria, and the validation of the proposed approach in a real context in the electric sector.

Concerning the results of this study, it was obtained two critical conclusions. The first conclusion was the identification of the criteria and sub-criteria with most importance and impact in the performance evaluation in OHS for the companies of the electric sector and the second issue is the evaluation of the effects of the proposed methodology considering the importance and interrelations of different criteria involved in performance in OHS that include the elements of P-D-C-A cycle: planning, application, verification, and improvement.

In this sense, the FAHP-DEMATEL outcomes evidence “Improvement” and “Verification” were identified as the most important criteria with global contributions of 0.292 and 0.270, respectively. However, it is necessary to consider the other criteria that composed the performance evaluation due to the little differences in their contributions. Besides, the criteria “Planning” and “Improvement” were identified as the essential criteria in the performance evaluation of OHS management with $D + R$ of 3.686 and 3.308. The managers and leaders should consider these criteria in OHS to design and implement adequate strategies for improving the performance in OHS with impacts in the companies and their stakeholders. Concerning the effects and benefits of the proposed methodology, its evidence that the company obtained an improvement in their OHS performance of 14.2% until 88.62% exceeds the minimum percentage of compliance requirements by national regulations.

In addition, the company decreased critical indicators in OHS, such as absenteeism and the accidents with reductions of 80% and 100%, respectively. On the other hand, the organization under study obtained an increase of 43.83% in their sales that consequence of their improvement in the performance of OHS management. For the considerations mentioned above, the integrated methodology can be helping the companies to generate a culture of prevention in occupational health and safety, taking into account the complexity of the sector, the multiple criteria involved in the evaluation, and the interdependencies between these criteria.

Finally, as future work, the integrated methodology proposed will be extended in other industries. In addition, we propose continue the develop of the approach proposed using different hybrid methods as Fuzzy DEMATEL, TOPSIS, and VIKOR in order to validate and improve the performance of the method.

Acknowledgments. The authors would like to thank the support of the SEINER S.A.S. Company and the Institucion Universitaria ITSA.

References

1. The World Bank, "Understanding Poverty: Energy Overview". https://www.worldbank.org/en/topic/energy/overview
2. El País, "El mundo consumirá un 30% más de energía en 2040 y se aleja de cumplir el Acuerdo de París. https://elpais.com/economia/2017/11/14/actualidad/1510661591_352717.html
3. Castillo, J., Suárez, M., Rubio, J., Aguado, J.: Personal factors and consequences of electrical occupational accidents in the primary, secondary and tertiary sectors. Saf. Sci. **91**, 286–297 (2017)
4. Cawley, J.C., Homce, G.T.: Occupational electrical injuries in the United States, 1992–1998, and recommendations for safety research. J. Saf. Res. **34**, 241–248 (2003)
5. McCann, M., Hunting, L.K., Murawski, J., Chowdhury, R., Welch, L.: Causes of electrical deaths and injuries among construction workers. Am. J. Ind. Med. **43**, 398–406 (2003)
6. Janicak, C.A.: Occupational fatalities due to electrocutions in the construction industry. J. Saf. Res. **39**, 617–621 (2008)
7. Chi, C.F., Lin, Y.Y., Ikhwan, M.: Flow diagram analysis of electrical fatalities in construction industry. Saf. Sci. **50**(5), 1205–1214 (2012)
8. Kotzé, M., Steyn, L.: The role of psychological factors in workplace safety. Ergonomics **56**(12), 1928–1939 (2013)
9. Organización Internacional del Trabajo OIT. La seguridad en cifras: Sugerencias para una cultura general en materia de seguridad en el trabajo. Ginebra (2003). ISBN 92-2-313741-1. http://www.ilo.org/public/english/standards/relm/ilc/ilc90/pdf/rep-vi.pdf
10. Jimenez, G., Novoa, L., Ramos, L., Martinez, J., Alvarino, C.: Diagnosis of initial conditions for the implementation of the integrated management system in the companies of the land cargo transportation in the City of Barranquilla (Colombia). In: Stephanidis, C. (ed.) HCI 2018. CCIS, vol. 852, pp. 282–289. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-92285-0_39
11. Jimenez, G., Zapata, E.: Metodología integrada para el control estratégico y la mejora continua, basada en el Balanced Scorecard y el Sistema de Gestión de Calidad: aplicación en una organización de servicios en Colombia. In: 51a Asamblea Anual del Consejo Latinoamericano de Escuelas de Administración CLADEA 2016, Medellín, Colombia, pp. 1–20 (2016)

12. Jimenez, G., Hernandez, L., Hernandez, H., Cabas, L., Ferreira, J.: Evaluation of quality management for strategic decision making in companies in the plastic sector of the Colombian Caribbean Region using the TQM diagnostic report and data analysis. In: Stephanidis, C. (ed.) HCI 2018. CCIS, vol. 852, pp. 273–281. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-92285-0_38
13. Jimenez, G.: Procedimientos para el mejoramiento de la calidad y la implantación de la Norma ISO 9001 aplicado al proceso de asesoramiento del Centro de Investigaciones y Desarrollo Empresarial y Regional en una Institucion de Educación Superior basados en la gestión por procesos. In: Congreso de Gestión de la Calidad y Protección Ambiental, GECPA 2014, Habana, Cuba, pp. 1–22 (2014)
14. Marhavilas, P.K., Koulouriotis, D.E., Spartalis, S.H.: Harmonic analysis of occupational-accident time-series as a part of the quantified risk evaluation in worksites: application on electric power industry and construction sector. Reliab. Eng. Syst. Saf. **112**, 8–25 (2013)
15. Rahmani, A., Khadem, M., Madreseh, E., Aghaei, H., Raei, M., Karchani, M.: Descriptive study of occupational accidents and their causes among electricity distribution company workers at an eight-year period in Iran. Saf. Health Work **4**(3), 160–165 (2013)
16. Acakpovi, A., Dzamikumah, L.: An investigation of health and safety measures in a hydroelectric power plant. Saf. Health Work **7**(4), 331–339 (2016)
17. Bakhiyi, B., Labrèche, F., Zayed, J.: The photovoltaic industry on the path to a sustainable future — environmental and occupational health issues. Environ. Int. **73**, 224–234 (2014)
18. Marhavilas, P.K., Koulouriotis, D.E., Mitrakas, C.: On the development of a new hybrid risk assessment process using occupational accidents' data: application on the Greek Public Electric Power Provider. J. Loss Prevent. Process Ind. **24**(5), 671–687 (2011)
19. Jimenez-Delgado, G., Balmaceda-Castro, N., Hernández-Palma, H., de la Hoz-Franco, E., García-Guiliany, J., Martinez-Ventura, J.: An integrated approach of multiple correspondences analysis (MCA) and fuzzy AHP method for occupational health and safety performance evaluation in the land cargo transportation. In: Duffy, V. (ed.) Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management. Human Body and Motion. HCII 2019. LNCS, vol. 11581, pp. 433–457. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-22216-1_32
20. Gul, M.: A review of occupational health and safety risk assessment approaches based on multi-criteria decision-making methods and their fuzzy versions. Hum. Ecol. Risk Assess.: Int. J. (2018). https://doi.org/10.1080/10807039.2018.1424531
21. Inan, U., Gül, S., Yılmaz, H.: A multiple attribute decision model to compare the firms' occupational health and safety management perspectives. Saf. Sci. **91**(106), 221–231 (2017). https://doi.org/10.1016/j.ssci.2016.08.018
22. ISO 45001. Occupational Health and Safety Management Systems (2018)
23. Adema, A., Çolak, A., Dağdeviren, M.: An integrated model using SWOT analysis and Hesitant fuzzy linguistic term set for evaluation occupational safety risks in life cycle of wind turbine. Saf. Sci. **106**, 184–190 (2018)
24. Efe, B., Kurt, M., Efe, F.: An integrated intuitionistic fuzzy set and mathematical programming approach for an occupational health and safety policy. J. Sci. **30**(2), 73–95 (2017)
25. Badria, A., Nadeaua, S., Gbodossoub, A.: Proposal of a risk-factor-based analytical approach for integrating occupational health and safety into project risk evaluation. Accid. Anal. Prevent. **48**, 223–234 (2012)
26. Jiangdong, B., Johansson, J., Zhang, J.: Comprehensive evaluation on employee satisfaction of mine occupational health and safety management system based on improved AHP and 2-tuple linguistic information. Sustainability **2**(133), 1–14 (2017)
27. Sadoughi, S., Yarahmadi, R., Taghdisi, M., Mehrabi, Y.: Evaluating and prioritizing of performance indicators of health, safety, and environment using fuzzy TOPSIS. Afr. J. Bus. Manag. **6**(5), 2026–2033 (2012)

28. Gul, M., Ak, M.: A comparative outline for quantifying risk ratings in occupational health and safety risk assessment. J. Clean. Prod. **196**(20), 653–664 (2018)
29. Hatami-Marbini, A., Tavana, M., Moradi, M., Kangi, F.: A fuzzy group Electre method for safety and health assessment in hazardous waste recycling facilities. Saf. Sci. **51**, 414–426 (2013)
30. Ilbahara, E., Ali Karaşanb, A., Selcuk Cebia, S., Kahraman, C.: A novel approach to risk assessment for occupational health and safety using Pythagorean fuzzy AHP & fuzzy inference system. Saf. Sci. **103**, 124–136 (2018)
31. Koulinas, G., Marhavilas, P., Demesouka, O., Vavatsikos, A., Koulouriotis, D.: Risk analysis and assessment in the work sites using the fuzzy-analytical hierarchy process and a quantitative technique–a case study for the Greek construction sector. Saf. Sci. **112**, 96–104 (2019)
32. Sukran Seker, S., Zavadskas, E.: Application of fuzzy DEMATEL method for analyzing occupational risks on construction sites. Sustainability **9**(11), 2083, 1–19 (2017)
33. Basahel, A., Taylan, O.: Using fuzzy AHP and fuzzy TOPSIS approaches for assessing safety conditions at worksites in construction industry. Int. J. Saf. Secur. Eng. **6**(4), 728–745 (2016)
34. Zheng, G., Zhu, N., Tian, Z., Chen, Y., Sun, B.: Application of a trapezoidal fuzzy AHP method for work safety evaluation and early warning rating of hot and humid environments. Saf. Sci. **50**, 228–239 (2012)
35. Ortiz-Barrios, M., Herrera-Fontalvo, Z., Rúa-Muñoz, J., Ojeda-Gutiérrez, S., De Felice, F., Petrillo, A.: An integrated approach to evaluate the risk of adverse events in hospital sector: from theory to practice. Manag. Decis. (2018). https://doi.org/10.1108/MD-09-2017-0917
36. Maleki, H., Zahir, S.: A comprehensive literature review of the rank reversal phenomenon in the analytic hierarchy process. J. Multi-Criteria Decis. Anal. **20**(3/4), 141–155 (2013)
37. Velasquez, M., Hester, P.T.: An analysis of multi-criteria decision-making methods. Int. J. Oper. Res. **10**(2), 56–66 (2013)
38. Ortiz-Barrios, M.A., Kucukaltan, B., Carvajal-Tinoco, D., Neira-Rodado, D., Jiménez, G.: Strategic hybrid approach for selecting suppliers of high-density polyethylene. J. Multi-Crit. Decis. Anal. **24**, 1–21 (2017). https://doi.org/10.1002/mcda.1617
39. Hernandez, L., Jimenez, G.: Characterization of the current conditions of the ITSA data centers according to standards of the green data centers friendly to the environment. In: Silhavy, R., Senkerik, R., Kominkova Oplatkova, Z., Prokopova, Z., Silhavy, P. (eds.) CSOC 2017. AISC, vol. 574, pp. 329–340. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-57264-2_34
40. Demirel, T., Demirel, N., Kahraman, C.: Fuzzy analytic hierarchy process and its application. In: Kahraman, C. (ed.) Fuzzy Multi-Criteria Decision Making: Theory and Applications with Recent Developments. Springer Optimization and its Applications, vol. 16, pp. 53–83. Springer, Boston (2008). https://doi.org/10.1007/978-0-387-76813-7_3
41. Kusumawardani, R., Agintiara, M.: Application of fuzzy AHP-TOPSIS method for decision making in human resource manager selection process. Procedia Comput. Sci. **72**, 638–646 (2015)
42. Vahidnia, M.H., Alesheikh, A.A., Alimohammadi, A.: Hospital site selection using fuzzy AHP and its derivatives. J. Environ. Manag. **90**(10), 3048–3056 (2009)
43. Shieh, J.I., Wu, H.H., Huang, K.K.: A DEMATEL method in identifying key success factors of hospital service quality. Knowl.-Based Syst. **23**(3), 277–282 (2010)
44. Su, C.M., Horng, D.J., Tseng, M.L., Chiu, A.S., Wu, K.J., Chen, H.P.: Improving sustainable supply chain management using a novel hierarchical grey-DEMATEL approach. J. Cleaner Prod. **134**, 469–481 (2016)
45. Barrios, M.A.O., De Felice, F., Negrete, K.P., Romero, B.A., Arenas, A.Y., Petrillo, A.: An AHP-TOPSIS integrated model for selecting the most appropriate tomography equipment. Int. J. Inf. Technol. Decis. Making **15**(4), 861–885 (2016)

46. Wei, P.L., Huang, J.H., Tzeng, G.H., Wu, S.I.: Causal modeling of web-advertising effects by improving SEM based on DEMATEL technique. Int. J. Inf. Technol. Decis. Making **9**(05), 799–829 (2010)
47. Ministerio del Trabajo: Decreto 1072 de 2015. Por medio del cual se expide el expide el Decreto único reglamentario del sector trabajo, 26 May 2015. http://www.mintrabajo.gov.co/documents/20147/0/DUR+Sector+Trabajo+Actualizado+a+15+de+abril++de+2016.pdf/a32b1dcf-7a4e-8a37-ac16-c121928719c8
48. Ministerio del Trabajo. Resolución 0312 de 2019. Por la cual se definen los estándares mínimos del Sistema de Gestión de la Seguridad y Salud en el Trabajo SG-SST, 13 February 2019. http://www.mintrabajo.gov.co/documents/20147/0/DUR+Sector+Trabajo+Actualizado+a+15+de+abril++de+2016.pdf/a32b1dcf-7a4e-8a37-ac16-c121928719c8