A HYBRID FUZZY MULTI-CRITERIA DECISION MAKING MODEL TO EVALUATE THE OVERALL PERFORMANCE OF PUBLIC EMERGENCY DEPARTMENTS: A CASE STUDY

Performance evaluation is relevant for supporting managerial decisions related to the improvement of public emergency departments (EDs). As different criteria from ED context and several alternatives need to be considered, selecting a suitable Multicriteria Decision-Making (MCDM) approach has become a crucial step for ED performance evaluation. Although some methodologies have been proposed to address this challenge, a more complete approach is still lacking. This paper bridges this gap by integrating three potent MCDM methods. First, the Fuzzy Analytic Hierarchy Process (FAHP) is used to determine the criteria and sub-criteria weights under uncertainty, followed by the interdependence evaluation via fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL). The fuzzy logic is merged with AHP and DEMATEL to illustrate vague judgments. Finally, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is used for ranking EDs. This approach is validated in a real 3-ED cluster. The results revealed the critical role of *Infrastructure* (21.5%) in ED performance and the interactive nature of *Patient safety* ($C+R$ =12.771). Furthermore, this paper evidences the weaknesses to be tackled for upgrading the performance of each ED.

Keywords: Emergency departments (EDs), Fuzzy AHP (FAHP), Fuzzy DEMATEL (FDEMATEL), TOPSIS, Performance evaluation.

1. Introduction

Emergency departments (EDs) play an important role in the delivery of acute diagnostic and treatment 24 hours a day and 365 days per year for patients of all age groups who need immediate care for major injuries and life-threatening medical conditions. Much attention should be paid to EDs since their use has been significantly growing and has, therefore, become one of the major contributors to the aggregate healthcare spending.[1] Moreover, EDs are at the interface between the healthcare system and the community and should be then prepared for providing high-standard medical care avoiding readmissions, increasing the patient satisfaction, reducing mortality and decreasing healthcare costs.[2]

Considering the aforementioned framework, it is necessary to properly and continuously evaluate the effectiveness of EDs in the context of the entire delivery system by using high-reliable methods. In this regard, performance evaluation, as a constructive process, can offer managers an opportunity for ensuring constant improvement and accountability.[3] In ED context, it aims to provide a foundation for understanding the response of this healthcare service while improving the quality of decisions made by all the participants within this department. Therefore, it is important to define a clear, consistent and pertinent approach so that implementation can be facilitated with a high level of effectiveness. In this regard, although considerable effort has been made in measuring different types of healthcare (e.g. acute hospital care, primary care), little progress has been evidenced regarding the design of methodologies evaluating the overall performance of EDs.[4]

The reasoning for continuously evaluating the overall performance of EDs is first and foremost to address the increased demand for emergency services while ensuring efficiency, high quality and safety. It is then necessary to select a set of metrics representing the domains of interest in emergency care management. Such metrics enable healthcare managers to have a broad and comprehensive view of the core operations and the effectiveness of improvement actions.[5,6] Although there are widely acknowledged performance evaluation approaches (e.g. Business Excellence[7] and Balance Scorecard[8] that have been used to face this challenge, some studies have reported serious difficulties during their implementation due to unsuitable design, low pertinence and high complexity.[4,9] Additionally, much attention has been only paid to single time-related measures which, although they contribute to the timeliness, efficiency and effectiveness domains, do not evidence high levels of performance. It is hence relevant to consider hybrid frameworks additionally taking into account other domains that may affect the response of EDs. If this is not considered, areas of interest in emergency care can be unmonitored and not targeted for continuous improvement.

The development of performance evaluation frameworks requires concerted expert and political participation in order to better define the healthcare domains (criteria) [95] and sub-criteria that are directly attributable to the EDs. Yet, as in different fields, since there are several decision elements (criteria and sub-criteria) to be deemed in the healthcare sector, selecting a suitable decision-making approach has become a critical step for assessing the performance of EDs. Several frameworks have been developed for this purpose. Such frameworks involved combining quantitative and qualitative criteria considering government regulations and ED goals. In this respect, multicriteria decision-making methods (MCDM) seem to be the appropriate tool for prioritizing these quantitative and qualitative factors based on experts' opinion.[10,11,96] However, it is also relevant to consider the vagueness and vagueness of human judgments.[12] To do this, it is necessary to incorporate the fuzzy concept into the MCDM structure.[13] The advantage of using the fuzzy approach is its capability of representing the uncertain nature of real decision-making problems through triangular numbers.[14] On the other hand, according to the review reported by Sørup, Jacobsen, and Forberg,[4] it is imperative to define the interconnectivity between the criteria for a better understanding of the ED performance which can be properly addressed by an MCDM hybrid approach. The hybrid methods address the limitations of single methods and provide more robust solutions in accordance with the decision-making context. Nevertheless, the studies directly concentrating on evaluating the ED performance with the use of MCDM hybrid methods are largely limited which evidences that this research area is at a much earlier stage. Additionally, a more complete decision-making model for ED performance assessment is lacking since several domains (e.g. medical equipment, procedures and protocols, infrastructure and medical supplies) have not been considered in previous studies. This paper then bridges this gap through the integration of potent MCDM methods: Fuzzy Analytic Hierarchy Process (FAHP), Fuzzy Decision Making Trial and Evaluation Laboratory (FDEMATEL) and Technique for Order Preference and Similarity to Ideal Solution (TOPSIS).

In summary, the motivation of this research lies in several facts: i) the lack of an ED performance assessment model covering the multifactorial context of emergency care, ii) the need for analyzing the interrelations between the criteria/sub-criteria affecting the performance of EDs, iii) the demand for realistic performance assessment approaches considering the human thought nature and the practical implications of real-world applications in EDs, iv) the absence of a unified MCDM approach for appropriately ranking EDs based on their performance and v) the urgency of assisting cluster managers and decision-makers in identifying the weaknesses of each ED and designing focused improvement strategies. The model usefulness will be tested through a real case study consisting of 3 EDs from the public healthcare sector of a Colombian region. Practical insights will be provided throughout the paper to easily guide ED decision-makers and cluster managers towards the effective implementation of the proposed approach in the wild.

The remainder of this paper is organized as follows. In Section 2, a literature review on related studies is provided whereas Section 3 describes the proposed approach. In Section 4, the results from a real case study are detailed and discussed. Section 5 presents a sensitivity analysis while Section 6 exposes the practical and managerial implications. Finally, the conclusions are shown in Section 7.

2. Literature review

For a complete literature review on methods assessing the overall performance of emergency departments, an investigation of different library databases was conducted. Scholarly journals are a relevant source of high-quality research information and were therefore selected for this review. Meanwhile, textbooks, doctoral dissertations and master's theses were therefore excluded from this review. The primary aim of this initial search was to define the level of attention paid to this research area when considering the annual number of publications. The analysis on the above-mentioned databases indicated that from 2005 (the time in which the first paper appears) to June 2018 (research date), only 30 documents have been published: 23 articles and 7 conference papers. Considering our field of interest, we refined our search by using the next string: "emergency department and performance evaluation" The extensive search was performed in the (a) ARTICLE TITLE, (b) ABSTRACT and (c) KEYWORDS of journal papers. Out of 30 documents, 7 papers from 2012 to 2018 (research date). Most of them were published in the last three years.

Among the selected papers, Mohammadi *et al.*[15] used single measures (e.g. percent of failed CPR, waiting time duration, percent of released emergency departments with personal responsibility, percent of released emergency patients in specific times) and paired independent t-tests to evaluate the emergency department's performance. In this study, percent of failed CPR, waiting time duration in level 4 triage, the emergency patients who were settled in 6 hours and patients who moved out of the department in 12 hours; were found as significant (p-value < 0.05). Another application of single indicators was exposed by Yamani *et al.*[16] where a 360-degree evaluation was performed to assess the emergency medicine departments in the areas of education, service provision and interaction with other departments. The above-mentioned metrics were compiled in a review study carried out by Sørup, Jacobsen and Forberg[4] who identified a total of 55 ED performance measures. The study recommended using indicators related to patient-centeredness and safety performance. Also, it established that employee-related performance measures are rarely considered in the reported literature. Interesting frameworks were proposed by Zhao and Paul[17] and Pan and Chang.[18] Specifically, Zhao and Paul[17] proposed a modification of the American Productivity and Quality Center (QAPC) method for assessing the performance of hospital emergency departments. This approach is based on efficiency and price recovery ratio to better connect quality and financial domains. Pan *et al.*[18] applied the kinetics analysis for ED performance considering the relationship between the ED retained patients and the ED departure velocity. Other authors proposed MCDM methods to address the performance evaluation problem. For instance, Ketabi, Teymouri and Ketabi[19] applied Data Envelopment Analysis (DEA) to evaluate the efficiency of ED's. In their work, 24 ED's of hospitals in Iran were assessed by considering input (4 criteria) and output (4 criteria) factors. A similar DEA application was undertaken by Yeh and Cheng[91] who assessed the performance of 28 hospitals in Taiwan. In both cases, the approach was also found to be useful for designing focused improvement strategies in the performance of each hospital. Likewise, Gul *et al.*[20] combined Interval Type-2 Fuzzy Analytic Hierarchy Process (IT2-FAHP) and ELECTRE (Elimination and Choice Expressing the Reality) for performance evaluation of an ED system in a university hospital. Particularly, this method enables decision-makers to select the best scenarios based on the number of shifts, nurses and physicians.

Table 1. Summary of studies exposing ED performance evaluation approaches

Authors	Aim	Method	Criteria	Results	Limitations
Mohammadi *et al.*[15]	The study aims to measure and compare emergency departments' performance before and after the health reform.	Descriptive statistics and paired independent t-test	% of patients settled in < 6 h, % of temporary hospitalized patients in the ED in < 12 h, Failed CPR, % of release with personal responsibility, and triage time in each triage level.	Failed CPR, waiting time in triage level 4, % of patients settled in < 6h, and % of temporary hospitalized patients in the ED < 12h were found to be significantly lower compared to the initial status ($p < 0.05$).	- The criteria here considered do not entirely represent the multifactorial context of ED performance. - The criteria were not weighted. -No potential interrelations between criteria were taken into account.

Table 1 (Continued)

					-Vagueness and imprecision of data were not incorporated. - No ranking of EDs was provided. -No improvement strategies were proposed based on detected weaknesses.
Yamani *et al.*[16]	The primary aim is to evaluate the performance of EDs in Alzahra Hospital	360-degree evaluation	Therapeutic, interactional, and educational.	The results revealed that the hospital has a good overall performance in educational, therapeutic, and interactional domains.	- The criteria here considered do not entirely represent the multifactorial context of ED performance. - The criteria were not weighted -No potential interrelations between criteria were taken into account. -Vagueness and imprecision of data were not incorporated. - Only one hospital was assessed. -No improvement strategies were proposed based on detected weaknesses.

Table 1 (Continued)

Zhao and Paul[17]	The objective is to evaluate the profitability and productivity performance of hospital emergency departments.	Modified American Productivity and Quality Center (MAPQC)	Financial and operational	The results evidenced that the inclusion of the price change ratio removes the confounding effect of changes in sales which distort the performance measures.	- The criteria here considered do not entirely represent the multifactorial context of ED performance. -Vagueness and imprecision of data were not incorporated. -No improvement strategies were proposed based on detected weaknesses.
Pan *et al*.[18]	The aim is to develop an improved and robust global standard model for ED performance.	Kinetic analysis	ED departure, ED length of stay, ED medical personal unit, ED working bed, and retained patients.	The outcomes of this research proved that there is a significant relationship between ED retained patients and ED departure velocity. However, it concludes that the proposed measure (EDMPU TON) cannot completely solve every issue of ED performance.	- The criteria here considered do not entirely represent the multifactorial context of ED performance. -Vagueness and imprecision of data were not incorporated. -Not all the interrelations are evaluated. -No improvement strategies were proposed based on detected weaknesses.
Yeh and Cheng[91]	This study aimed to conduct operation performance evaluations of Taiwan's national hospitals during the period 2005–2008 and propose appropriate suggestions for performance improvements	DEA and Malmquist productivity index	Number of doctors, medical personnel, nurses, administration personnel, patient beds, operation and management costs, number of outpatients and emergency patients, hospital man-time and medical care revenues.	The study concluded that nearly 60% of national hospitals ran inefficiently. In addition, a significant gap was observed between urban and non-urban hospitals.	- The criteria here considered do not entirely represent the multifactorial context of ED performance. -Vagueness and imprecision of data were not incorporated.

Table 1 (Continued)

Gul *et al.*[20]	The research aims to evaluate the performance of an ED in a university hospital and select the best scenario considering different number of doctors and nurses.	Computer simulation, IT2-FAHP and ELECTRE	Number of patients discharged, length of stay in the ED, utilization of human resources (doctors, nurses, etc.), and multiple capacity locations (monitors bed area, emergency-1 area, etc.)	The study concluded that the hospital can upgrade his performance by adding one nurse and decreasing number of doctors by one at the least busy shift. The integrated approach was found to be useful for assessing the ED performance and selecting the best improvement scenario considering capacity changes.	- The criteria here considered do not entirely represent the multifactorial context of ED performance. - No potential interrelations between criteria were taken into account. - Only one hospital was assessed.
Ortíz-Barrios and Alfaro-Saíz (The current research)	This paper aims to evaluate the overall performance of Colombian EDs. The study also reveals the weaknesses to be tackled for upgrading the performance of each ED. In the meantime, it considers the multifactorial context of ED performance, the presence of interrelations among criteria, the vagueness/imprecision of data, and ED ranking.	FAHP, FDEMATEL, and TOPSIS	8 criteria (Infrastructure, Medical equipment, Procedures and protocols, Supporting processes, Human resources, Supplies, medicines, and accessories, Quality, and Patient safety) and 35 sub-criteria.	See Section 4-6	- It does not consider interval valued indicators.

Table 1 summarizes the research on ED performance evaluation. Despite the efforts made through these studies, a more complete decision-making model for ED performance assessment is lacking since several domains (e.g. medical equipment, procedures and protocols, infrastructure and medical supplies) have been not taken into account. It can be also observed that none of the approaches simultaneously consider: i) the interdependence among criteria, ii) the high uncertainty inherent in ED operations, iii) a performance-based ranking of EDs, and iv) suggestions for performance improvements. Additionally, considering the literature, it became apparent that the studies concentrating on the use of MCDM techniques to evaluate the overall performance of emergency departments are largely limited; such methods can provide a wide understanding of the ED performance context given the multidimensional nature of emergency services and the presence of causal effects. In this regard, several MCDM methods (e.g. Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), TOPSIS, Data Envelopment Analysis (DEA), VIKOR, Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), Simple Additive Weighting (SAW)[92] and their fuzzy versions can be applied by researchers[96]. In this respect, researchers employ either a single MCDM method,[21-23] or a combination of two or more techniques called hybrid as shown in Lee et al.[24], Labib and Read[25] and Hosseini and Al Khaled.[26] However, the use of hybrid methods has been found to provide more robust results.[27] The combination of different methods also allows overcoming the limitations of several techniques[94,97]. Particularly, PROMETHEE (Preference Ranking Organization Method) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) do not provide an explicit procedure to allocate the relative importance of criteria and sub-criteria.[28-31,90] Therefore, there may be some imprecision, arbitrariness and lack of consensus regarding the weights used in the decision-making model. Concerning AHP method, several authors have highly concerned on the rank reversal phenomenon relating to the preference order changes after an alternative is added or deleted.[32-35,110] The same drawback was observed in Data Envelopment Analysis – DEA,[36,37,95] and the Simple Additive Weighting – SAW techniques.[38-40] Another limitation of the DEA method is that all outputs and inputs are assumed to be known.[31] Regarding ANP, it has been concluded as a highly complex and time-consuming methodology when performing sensitivity analysis.[41,42] Hence, by taking into account the aforementioned facts and aiming at delivering more robust, realistic and reliable results, a hybrid approach is decided to be implemented in this study.

In addition, to overcome the vagueness derived from human judgments, which are the cornerstone of several MCDM methods (e.g. AHP, ANP and DEMATEL), fuzzy sets are introduced in the present research. The reasoning of employing a fuzzy framework is based on the fact that the preference relationships provided by decision-makers are vague, uncompleted and imprecise.[43,44,93] Furthermore, high uncertainty in ED operations has been reported in Gul *et al*.[20] In this sense, several fuzzy approaches can be proposed for dealing with the human thought nature. For example, the fuzzy set theory is able to represent vague data by introducing interval judgments (triangular numbers) while enabling us to generate scales between different criteria and subsequently allocate a specific weight to each one.[43] On a different tack, the Intuitionistic fuzzy set theory (IFS) is applied when the decision-makers do not possess a precise or sufficient knowledge of the decision-making scenario. Such condition may be exhibited during the judgment process through the characteristics of "affirmation" (agreement/truthiness degree) and "negation" (disagreement/falsity degree).[105] In addition to these characteristics, Neutrosophic set theory (NFS) incorporates the "hesitation" (abstention) or indeterminacy that could also occur due to the lack of information and knowledge relating, in this case, to the performance evaluation context[106].

However, if there are experts with extensive experience in the decision-making context, it is not then necessary to incorporate falsity degrees and indeterminacy. Thereby, unnecessary complexity and long processing time associated with IFS and NFS could be avoided. Grey numbers can be also used for this particular aim; however, fuzzy sets are easier to implement and better adapt to the MCDM techniques proposed in this study (ANP and DEMATEL).

In light of the above-mentioned aspects and findings from the reported literature, the research question is: How to evaluate the performance of EDs considering the different components of emergency care? To answer this question, this study proposes a novel hybrid method based on FAHP, FDEMATEL and TOPSIS methods which addresses the limitations of previous studies and is useful to provide a decision support system for assisting emergency department managers and practitioners. The hybrid approach is a combination of the three methods that allows benefiting from the advantages of fuzzy AHP in establishing the weights of criteria and sub-criteria under vagueness, the application of fuzzy DEMATEL to evaluate complex interrelations (under uncertainty) among criteria; followed by the use of TOPSIS for ranking the EDs and detecting primary areas of intervention. The novelty of this study is then six-fold: i) an ED performance evaluation model representing the multifactorial context of emergency care (8 criteria and 35 sub-criteria), ii) the assessment of interdependence among performance criteria/sub-criteria, iii) the inclusion of fuzzy logic for representing the uncertainty of ED operations, iv) the performance-based ranking of EDs, v) the provision of potential improvement strategies considering the weaknesses of each ED, and vi) the integration of FAHP, FDEMATEL, and TOPSIS methods whose application has not been reported in the context of ED performance evaluation.

3. Proposed Methodology: FAHP, FDEMATEL and TOPSIS

An approach comprised of four phases has been proposed to evaluate the overall performance of EDs considering the different components of emergency service. This methodology, described step by step in Fig. 1, has been developed with the foresight to be replicated in a wide range of healthcare clusters and can be applied without any restriction. In Phase 1, a group of experts is formed to perform the paired judgments required in both FAHP and FDEMATEL techniques. A performance evaluation model is then set up by considering the expertise of decision-makers and the performance metrics regulated by the Columbian Ministry of Health and Social Protection. Afterwards, in Phase 2, FAHP is applied to calculate the weights of decision elements under uncertainty and define improvement interventions in the short run. In particular, Fuzzy AHP considers linear dependency and vagueness associated with the uncertainty of decision-makers' judgments. However, FAHP does not take into account the feedback and interdependence between the decision elements as often found in the ED context.[50,51,32] To tackle this disadvantage and offer more solid outcomes, in Phase 3, FDEMATEL is used separately to support the interdependence evaluation among criteria, identify the receivers and dispatchers, and develop long-term improvement strategies[107]. Short term and long term interventions are consistent with the time horizons specified in the development plans of goverments, healthcare clusters, and EDs. In Phase 4, the final criteria and sub-criteria weights are used by TOPSIS as an input to rank the emergency departments in accordance with their overall performance. In addition, improvement opportunities for each ED are proposed by considering their closeness to both ideal and anti-ideal scenarios. The methods here used respond to the emergency care context: i) the presence of complex interrelations among criteria (FDEMATEL), ii) the need for developing short-term (FAHP) and long-term (FDEMATEL) interventions in line with the time horizons of improvement plans, iii) proper assessment of criteria and sub-criteria weights under uncertainty (FAHP), iv) the need for ranking hospitals and detecting improvement areas in each institution (TOPSIS). The MDCM techniques considered in this approach are further explained in the next sub-sections.

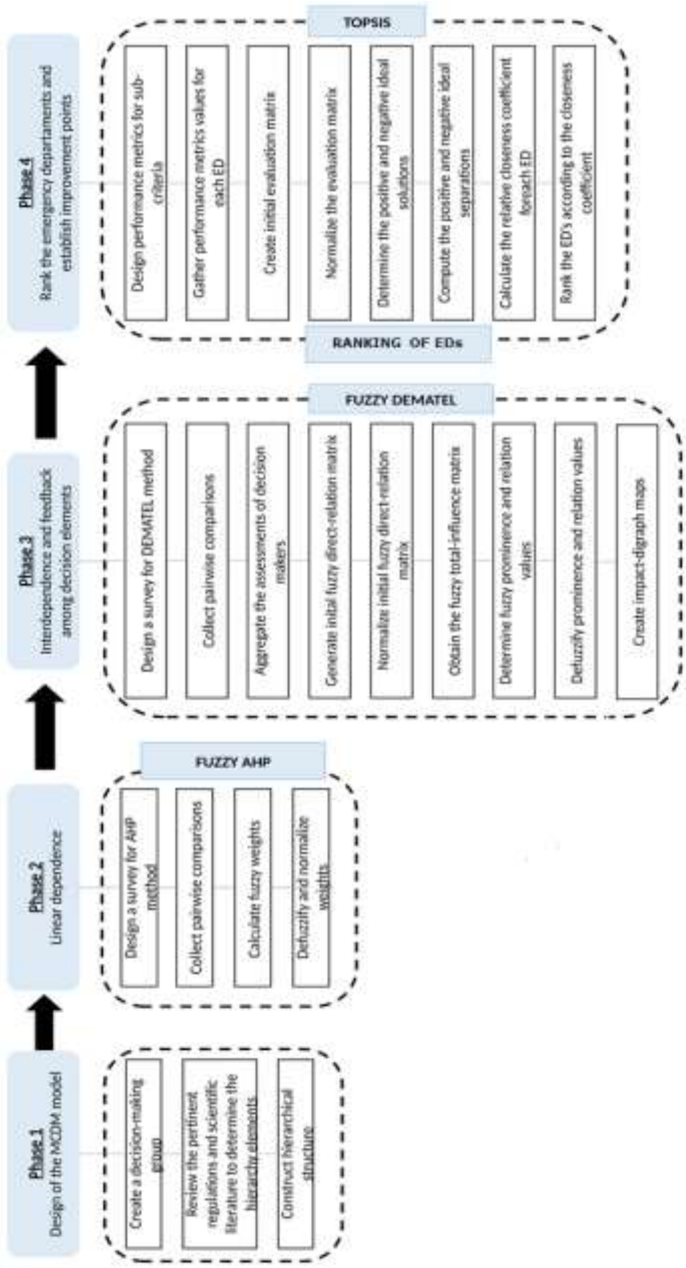


Fig. 1. Proposed methodology for ranking the ED’s in accordance with their overall performance

3.1 Fuzzy Analytic Hierarchy Process (FAHP)

In accordance with the reported literature, AHP does not take into account the vagueness derived from human judgments.[12] Hence, fuzzy sets were introduced to deal with this problem[93] (as presented in pairwise comparisons). In this respect, AHP can be "fuzzified" by generalizing the concept of crisp data to a fuzzy set with blurred boundaries.[45] With this modification, AHP, now FAHP, can be more realistic and is, therefore, more precise to solve real-world MCDM problems which inexorably entails some degree of noise in their variables.[46] The comparisons are described by triangular numbers M which are represented by (a,b,c) and the membership function is defined as follows:

$$\mu_{\tilde{M}}(x) = \begin{cases} \dfrac{x-a}{b-a}, & a \le x \le b \\ \dfrac{c-x}{c-b}, & b \le x \le c \\ 0, & otherwise \end{cases}$$

Here, $-\infty < a \le b \le c < \infty$ additionally, the strongest grade is represented by parameter b whilst, a and c are the lower and upper bounds. The fuzzy triangular numbers to be used in FAHP are enlisted in Table 2 where can be easily matched with the AHP scale. Also, a reduced version of the Saaty natural scale with only three points is adopted to facilitate the engagement of unskilled respondents and then reduce inconsistencies in the decision-making process.

Table 2. Fuzzy triangular numbers used in FAHP (taken from ref. 98)

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

The FAHP algorithm can be summarized as follows[98]:

- **Step 1:** Perform paired judgments between decision elements by using the fuzzy triangular numbers described in Table 2. With this information, a fuzzy judgment matrix $\tilde{A}^k\left(a_{ij}\right)$ can be obtained as defined below in Eq. 1:

$$A^k = \begin{bmatrix} d_{11}^k & d_{12}^k & \dots & d_{1n}^k \\ d_{21}^k & d_{22}^k & \dots & d_{2n}^k \\ \dots & \dots & \dots & \dots \\ d_{n1}^k & d_{n2}^k & \dots & d_{nn}^k \end{bmatrix} \tag{1}$$

  $\tilde{d}_{ij}^k$ Denotes the kth decision-maker's preference of ith element over jth element via fuzzy triangular numbers.
- **Step 2:** In the case of an expert group, the comparisons are averaged in accordance with Eq. 2, where K represents the number of decision-makers involved in the process[109]. Afterwards, the fuzzy judgment matrix is updated as presented in Eq. 3.

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

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

- **Step 3:** Determine the geometric mean of fuzzy judgments $(\tilde{r}_i)$ for each decision element via applying Eq. 4.

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

- **Step 4:** Calculate the fuzzy weights of each decision element $(\tilde{w}_i)$ by using Eq.5.

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

- **Step 5:** Defuzzify $(\tilde{w}_i)$ by implementing the Centre of Area method[47] by applying Eq. 6. M_i is a non-fuzzy number. Finally, normalize M_i by using 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 Fuzzy Decision Making Trial and Evaluation Laboratory (FDEMATEL)

DEMATEL is a potent method that has been widely used to evaluate the interdependence between decision elements (i.e. criteria and sub-criteria) and identify causal relationships in a complex MCDM model.[48] This method uses digraphs to categorize criteria and sub-criteria into cause group and effect group effectively. Whereas the pairwise judgments provided by experts are crisp values, it is necessary to incorporate fuzzy logic to represent the vagueness contained in real-world problems and deal with the imprecision of human comparisons.[49] Although Fuzzy ANP (FANP) can also assess dependency and feedback, the disadvantages mentioned in Section 2 and the assumption of equal weight for each cluster to achieve a weighted supermatrix in this method does not make its application reasonable for practical situations.[87,88].

Table 3. Fuzzy triangular numbers used in FDEMATEL (taken from Ref. 99).

DEMATEL scale	Definition	Fuzzy triangular number
0	No influence	[0,0,0.25]
1	Low influence	[0,0.25,0.5]
2	Medium influence	[0.25,0.5,0.75]
3	High influence	[0.5,0.75,1]
4	Very high influence	[0.75,1,1]

To effectively apply the conventional DEMATEL technique for group decision-making in a fuzzy environment the following steps must be considered.[100]

- **Step 1:** Create the Fuzzy linguistic scale: To cope with the ambiguities of human judgments (expert opinion) five linguistic qualifications are used to represent the "influence" variable. This is expressed as a fuzzy triangular number $(l_{ij}^k, m_{ij}^k, r_{ij}^k)$ which denotes the kth decision-maker's preference of ith element over jth, as shown in Table 3.
  When there is an expert group, the preferences are averaged based on Eq. 8-10, where K indicates the number of specialists.

$$l_{ij} = \frac{\sum_{k=1}^{K} l_{ij}^k}{K} \qquad (8)$$

$$m_{ij} = \frac{\sum_{k=1}^{K} m_{ij}^k}{K} \qquad (9)$$

$$r_{ij} = \frac{\sum_{k=1}^{K} r_{ij}^k}{K} \qquad (10)$$

- **Step 2:** Determine the fuzzy direct-influence matrix: Considering the experts' opinion expressed through the linguistic scale the fuzzy direct-influence matrix $\tilde{\boldsymbol{D}}$ can be calculated by using Eq. 11.

$$\tilde{\boldsymbol{D}} = \left[\tilde{d}_{ij}\right]_{n\,x\,m}, \quad \text{where } \tilde{d}_{ij} = \left(d_{ij}^l, d_{ij}^m, d_{ij}^r\right) \qquad (11)$$

- **Step 3:** Normalize the fuzzy direct-influence matrix: the normalized fuzzy direct-relation matrix $\tilde{\boldsymbol{N}}$ is obtained through the fuzzy direct-influence matrix $\tilde{\boldsymbol{D}}$ by applying Eq. 12.

$$\tilde{\boldsymbol{N}} = \tilde{\boldsymbol{D}}/u, \text{ where } u = \max_{ij}\left\{\max_i \sum_{j=1}^{n} d_{ij},\ \max_j \sum_{i=1}^{n} d_{ij}\right\},\ i, j \in \{1,2,\ldots,n\} \qquad (12)$$

$$\tilde{\boldsymbol{N}} = \left[\tilde{e}_{ij}\right]_{n\,x\,n}, \tilde{e}_{ij} = \left(e_{ij}^l, e_{ij}^m, e_{ij}^r\right).$$

- **Step 4:** Reach the fuzzy total-influence matrix: After calculating the normalized fuzzy direct-influence matrix. $\tilde{\boldsymbol{N}} = \left(N^l, N^m, N^r\right)$ where $\boldsymbol{N}^l = \left[e_{ij}^l\right]_{n\,x\,n}$, $\boldsymbol{N}^m = \left[e_{ij}^m\right]_{n\,x\,n}$, *and* $\boldsymbol{N}^r = \left[e_{ij}^r\right]_{n\,x\,n}$, the fuzzy total-influence matrix $\tilde{\boldsymbol{T}}$ can be obtained by Eq. 13. Here, the $\boldsymbol{I}$ indicates the identity matrix.

$$\tilde{\boldsymbol{T}} = \left[\tilde{t}_{ij}\right]_{n\,x\,n},\ where\ \tilde{t}_{ij} = \left(t_{ij}^l, t_{ij}^m, t_{ij}^r\right) \tag{13}$$

Where $\boldsymbol{T}^l = \left[t_{ij}^l\right]_{n\,x\,n} = \boldsymbol{N}^l\left(\boldsymbol{I} - \boldsymbol{N}^l\right)^{-1}$, $\boldsymbol{T}^m = \left[t_{ij}^m\right]_{n\,x\,n} = \boldsymbol{N}^m\left(\boldsymbol{I} - \boldsymbol{N}^m\right)^{-1}$.

$$and\ \ \boldsymbol{T}^r = \left[t_{ij}^r\right]_{n\,x\,n} = \boldsymbol{N}^r\left(\boldsymbol{I} - \boldsymbol{N}^r\right)^{-1}$$

The triangular fuzzy numbers in fuzzy total-influence matrix $\tilde{\boldsymbol{T}}$ are divided into $\boldsymbol{T}^l = \left[t_{ij}^l\right]_{n\,x\,n}$, $\boldsymbol{T}^m = \left[t_{ij}^m\right]_{n\,x\,n}$, $\boldsymbol{T}^m = \left[t_{ij}^m\right]_{n\,x\,n}$, when $e_{ij}^l < e_{ij}^m < e_{ij}^r$ for any $i, j \in \{1, 2, \ldots, n\}$.

- **Step 5:** Compute the threshold value *p* to then determine the structural model through the causal diagram (refer to Eq. 14).

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

The sum of rows and columns are indicated as separate vectors $\tilde{C}_i$ and $\tilde{R}_i$ respectively, where *i* = *j*. The horizontal axis vector called "Prominence" is achieved by adding this vectors $\left(\tilde{C}_i + \tilde{R}_i\right)$.This relationship represents the influence of each sub-criterion *i* (*i* = 1, 2,…, *s*) whereas the prominence of criterion *k* (*k* = 1, 2, …, *m*) is denoted by $\left(\tilde{C}_k + \tilde{R}_k\right)$. Here, *m* represents the total number of criteria while *s* denotes the total number of sub-criteria considered in the performance assessment model.
Similarly, the vertical axis $\left(\tilde{C}_i - \tilde{R}_i\right)$ called "Relation" separates the sub-criteria into a cause group and effect group. When $\left(\tilde{C}_i - \tilde{R}_j\right)$ is negative, the criterion belongs to the receiver group; otherwise, it is categorized as a dispatcher. This is also applicable for criteria where relation parameter is symbolized by $\left(\tilde{C}_k - \tilde{R}_k\right)$.
Applying the CFCS method indicated in Eq. 15-23, the fuzzy vectors $\left(\tilde{C}_i + \tilde{R}_j\right)$ and $\left(\tilde{C}_i - \tilde{R}_j\right)$ are defuzzified into crisp values. Then, the causal diagram can be obtained by mapping the dataset$\left(\left(\tilde{C}_i + \tilde{R}_j\right)^{def}, \left(\tilde{C}_i - \tilde{R}_j\right)^{def}\right)$.
(1) Normalization

$$xl_{ij}^k = \left(l_{ij}^k - min\, l_{ij}^k\right) / \Delta_{min}^{max} \tag{15}$$

$$xm_{ij}^k = \left(m_{ij}^k - min\, l_{ij}^k\right) / \Delta_{min}^{max} \tag{16}$$

$$xr_{ij}^k = \left(r_{ij}^k - min\, l_{ij}^k\right) / \Delta_{min}^{max} \tag{17}$$

Where $\Delta_{min}^{max} = max\, r_{ij}^{k} - min\, l_{ij}^{k}$ (18)

(2) Compute left (ls) and right (rs) normalized value:

$$xls_{ij}^{k} = xm_{ij}^{k} \;/\left(1 + xm_{ij}^{k} - xl_{ij}^{k}\right) \tag{19}$$

$$xrs_{ij}^{k} = xr_{ij}^{k} \;/\left(1 + xr_{ij}^{k} - xm_{ij}^{k}\right) \tag{20}$$

(3) Compute total normalized crisp value:

$$x_{ij}^{k} = \left[xls_{ij}^{k}\left(1 - xls_{ij}^{k}\right) + xrs_{ij}^{k} xrs_{ij}^{k}\right] / \left[1 - xls_{ij}^{k} + xrs_{ij}^{k}\right] \tag{21}$$

(4) Compute crisp value:

$$z_{ij}^{k} = \min l_{ij}^{k} + x_{ij}^{k} \Delta_{min}^{max} \tag{22}$$

(5) Integrate crisp values:

$$z_{ij} = \frac{1}{K}\left(z_{ij}^{1} + z_{ij}^{2} + \ldots + z_{ij}^{K}\right) \tag{23}$$

3.3 Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is a ranking technique aiming at selecting alternatives with the shortest distance from the positive ideal solution (PIS) and the farthest distance from negative ideal solution – NIS simultaneously.[30] In this respect, PIS considers the best value $\left(A^{+}\right)$ of each criterion/sub-criterion whilst NIS represents the worst scenario $\left(A^{-}\right)$. TOPSIS then uses an aggregating function denoting the closeness (Euclidean distance) to the reference points as stated by Zyoud and Fuchs-Hanusch.[52] The result is an index called as *closeness coefficient* which helps to identify the best alternative quickly. Although fuzzy TOPSIS, gray TOPSIS, and interval-valued intuitionistic fuzzy TOPSIS can be also proposed for this particular aim, its use is discarded due to the presence of indicators defined by crisp values (as those often stated by health institutions), in addition to the complex computational processing and data collection.[89] On a different tack, the Weighted Aggregated Sum Product Assessment (WASPAS)[101] is not preferred over TOPSIS because it does not provide a contribution measure of each criterion/sub-criterion to the overall performance, which does not facilitate the identification of weaknesses and the subsequent design of focused improvement strategies. On the other hand, the Complex Proportional Assessment (COPRAS)[102] is not considered in this context since it may be less stable compared to TOPSIS in case of data variation, a situation often expected in the ED framework. Other methods that could be proposed for this particular aim are: Evaluation Based on Distance from Average Solution (EDAS)[103] and the Combinative distance-based assessment (CODAS).[104] However, they do not allow identifying how far each alternative is from the desired performance in each criterion/sub-criterion, an aspect that is widely addressed by TOPSIS. This is of extreme importance considering that managers and decision-makers need to determine which criteria/sub-criteria should be prioritized for ED performance improvement. Crisp TOPSIS then responds to the current healthcare monitoring system of Colombia and facilitates the implementation of the evaluation model in EDs where the performance measurement culture is at the earlier stages. The TOPSIS method is easy to understand and implement for unskilled decision-makers. A simplified version of the TOPSIS procedure is presented below[90]:

- **Step 1:** Set a decision matrix X with "e" emergency departments and "n" sub-criteria. Xij represents the value of the sub-criterion (i = 1, 2,…, n) in each emergency department ED_r (r = 1, 2,…, s).

$$X = \begin{array}{c} ED_1 \\ ED_2 \\ ED_3 \\ . \\ . \\ ED_s \end{array} \begin{bmatrix} SC_1 & SC_2 & \dots & SC_n \\ x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ x_{31} & x_{32} & \dots & x_{3n} \\ \vdots & \vdots & \dots & \vdots \\ x_{y1} & x_{y2} & \dots & x_{ys} \end{bmatrix} \quad (24)$$

- **Step 2:** Compute the normalized decision matrix R via applying Eq. 25. Let n_{ij} be the norm used by TOPSIS method (Refer to Eq. 26). Furthermore, r_{ij} denotes an element of this matrix.

$$R = X \cdot n_{ij} \quad (25)$$

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{y} x_{ij}^2}} \quad (26)$$

- **Step 3:** Obtain the weighted normalized decision matrix V (Refer to Eq. 27). The set of global sub-criteria contributions GW_i (i = 1, 2,…, s) arises from the FAHP method.

$$V = \left[GW_i r_{ij} \right] = \left[v_{ij} \right] \quad (27)$$

- **Step 4:** Determine the PIS A^+ and NIS A^- in accordance with Eq. 28-29 respectively:

$$A^+ = \left\{ \left({}^{max}_{i} a_{ij} \mid j \in J \right), \left({}^{min}_{i} a \mid j \in J' \right) \; for\, i = 1, 2, \dots, m \right\} = \left\{ a_1^+, a, \dots, a, \dots, a \right\}$$
(28)

$$A^- = \left\{ \left({}^{min}_{i} a_{ij} \mid j \in J \right), \left({}^{max}_{i} a_{ij} \mid j \in J' \right) \; for\, i = 1, 2, \dots, m \right\} = \left\{ a_1^-, a, \dots, a_j^-, \dots, a_n^- \right\} \quad (29)$$

Here:

$$J = \{ j = 1, 2, ..., n | j \text{ associated with the benefit sub} - \text{criterion / criterion} \} \cdot$$

$$J' = \{ j = 1, 2, ..., n | j \text{ associated with the cost sub} - \text{criterion / criterion} \} \cdot$$

- **Step 5:** Estimate the separation values of each emergency department to the PIS and NIS via applying Euclidean distance as detailed in Eq. 30-31.
  Separation from PIS.

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(a_{ij} - a_j^+ \right)^2} \qquad i = 1, 2, \ldots, m \tag{30}$$

  Separation from NIS

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(a_{ij} - a_j^- \right)^2} \qquad i = 1, 2, \ldots, m \tag{31}$$

- **Step 6:** Calculate the closeness coefficient R_i by using Eq. 32. If $R_i = 1$, the emergency department operates in accordance with d_i^+ .Hence, high *Ri* measures denote satisfactory overall performances.

$$R_i = \frac{d_i^+}{\left(d_i^+ + d_i^- \right)}, \quad 0 < R_i < 1, \quad i = 1, 2, \ldots, m \tag{32}$$

- **Step 7:** Rank the emergency departments in accordance with the preference order of *Ri*.

4. Model verification and phases

4.1. *Phase 1: design of the MCDM model*

The main motivation of this research lies on the need of providing safety, satisfaction and high quality of care to the patients asking for ED services in a region of Colombia. Particularly, its patient satisfaction level continues to decrease and the likelihood of waiting for more than the upper specification limit (30 minutes/patient) is about 93.13%. Therefore, it is necessary to perform high-effective interventions on ED's to avoid increased mortality rates, augmented readmission rates and patient dissatisfaction. In an effort to address this problem, three decrees were created by the government: Decree N°1761 of 1990 and Decree N°4747 of 2007. The first regulation establishes specific guidelines and protocols governing the emergency services in Colombia; on the other side, the Decree N°4747 of 2007 regulates the financial relations between healthcare insurance companies and hospitals/clinics. However, in spite of this legal framework, there is still a gap between theory and practice which can be further evidenced by the fact that ED's continue to be full of inefficiencies and medical errors.

Looking into the root causes of the problem, it was concluded that there was not a complete and understandable approach to effectively measure the overall performance of these departments. Without this model, analysis and decision-making processes performed by the healthcare cluster managers could not be fully supported and the resulting action plans were then poorly focused and less effective. Therefore, an MCDM framework was proposed to be designed and implemented in the healthcare public sector of this region as a response to the aforementioned need. In this respect, three ED's (ED1, ED2, and ED3) were invited to participate in this study. These departments are part of the regional network of emergency services whose primary targets are patients coming from small towns located in the surroundings.

Considering the above mentioned panorama, this proposal was presented to the ethics committee of each ED. However, no formal approval was required since it did not involve patient participation. In addition, this project was discussed with the ED managers who gave informed consent and legal permission to contribute to this research. After this, the decision-making group was formed based on a selection scheme carefully considering particular expert profiles aiming to diminish inconsistencies of the FAHP and FDEMATEL matrixes. In this respect, three types of professionals were concluded to be appropriate for the decision-making process: healthcare inspectors, ED managers and researchers (academic sector).

Particularly, the *Healthcare inspectors* were invited to be part of the expert group since they have extensive knowledge and experience on the patient flow, system failures and criteria to be considered when assessing the effectiveness of EDs from the public sector; hence, their judgments on the importance and influence of different criteria and sub-criteria can be deemed as highly relevant for the hierarchical model proposed in this study. On the other hand, the *ED managers* were asked to participate in this process due to their wide comprehension and experience concerning the metrics, aims and requirements established by both health insurance companies and the Ministry of Health and Social Protection. This is important to design a Multicriteria decision-making model responding to the current regulations and needs of EDs from the public sector. Additionally, it contributes to reducing the current gap between theory and practice resulting in poor analysis and decision-making. Finally, the *researchers* designed the hierarchical structure with the aid of the expert committee and gathered the paired judgments for both FAHP and FDEMATEL techniques. Each participant had to demonstrate a wide experience in analysing and evaluating emergency departments from the public healthcare industry (>12 years). In addition, the expert had to be directly or indirectly associated with the ED's from this sector. Based on these conditions, an exploratory assessment of up-to-date curriculum vitae was carried out to finally select the experts participating in the decision-making process.

The chosen expert team is presented below:

- *Three ED managers*: All of them associated with hospitals from the public sector. Furthermore, they have an extensive experience (more than 15 years) and knowledge concerning the administration, planning and supervision of emergency room operations.

- *Two healthcare inspectors*: Both have performed audits in different EDs linked to the municipal healthcare network. During their careers, they have aggressively propelled sweeping changes in order to provide better emergency care. With their experience (12 and 20 years respectively) and understanding of the government policies, can also help non-profit and inefficient EDs develop improvement programs.
- *Two researchers*: Both currently working on the academic sector and taking part in projects related to the healthcare industry. They are experts on the implementation of MCDM techniques for the performance evaluation and identification of potential improvement points. Additionally, they have been working with the healthcare cluster and therefore fully know the strategic plans derived from the current needs of emergency services.

The group of experts incorporated a total of **8 criteria** and **35 sub-criteria** to assess the overall performance of emergency departments from the public sector. The decision elements were defined with basis on the personal experience of each decision maker and the performance metrics defined by the Ministry of Health and Social Protection of Colombia through Resolution No. 0256 of 2016 (Quality Information System and Indicators for Healthcare Quality Monitoring), Resolution No. 5596 of 2015 (Technical Criteria for the System of Selection and Classification of Patients in Emergency Departments – Triage) and Decree No. 903 of 2014 (Single Accreditation System on Healthcare) which provide a solid and realistic foundation for the creation and implementation of performance evaluation models in emergency departments. The resulting multicriteria model was then reviewed during several sessions with the experts' group to verify if it was useful and easy-to-understand. The final version of the hierarchy is presented in Figure 2. Each criterion and sub-criterion is labelled and described in Table 4. Finally, the experts involved in the decision-making team judged on the importance and influence of criteria and sub-criteria after a careful explanation of FAHP and FDEMATEL methods.

Table 4. Description of criteria and sub-criteria

Criterion	**Sub-criteria**	**Criterion description**
Infrastructure (C1)	Physical condition (SC1) Ventilation and lighting (SC2) Toilet facilities (SC3) Delimitation of ED areas (SC4) Physical capacity (SC5)	Represents the set of space, design, power, water, hygiene, sanitation and equipment requirements that are necessary to deliver high-quality emergency care.[53]
Medical equipment (C2)	Availability of medical equipment (SC6) Suitability of medical equipment (SC7) State of medical equipment (SC8)	Refers to the availability, suitability and state conditions of the devices that are used in the prevention, diagnosis or treatment of diseases in EDs aiming to detect, measure, restore, correct or modify the structure or function of the body for some health purpose.[54,90]

Table 4 (Continued)

Procedures and protocols (C3)	Presence of healthcare procedures (SC9) Dissemination of procedures and protocols (SC10) Adherence of healthcare protocols and procedures (SC11)	Encompasses the activities performed for the implementation of the statements developed to assist practitioners, doctors and patient decisions about suitable ED care for particular circumstances.[55]
Supporting processes (C4)	Effectiveness of radiology process (SC12) Effectiveness of clinical lab (SC13) Effectiveness of hospitalization process (SC14) Effectiveness of pharmaceutical service (SC15) Transportation effectiveness (SC16) Effectiveness of sterilization process (SC17) Effectiveness of non-core activities (SC18)	Denotes a group of processes co-ordinately assisting emergency care. These processes contribute to the effective communication for both fast and appropriate decision-making.[56]
Human resources (C5)	Availability of specialists (SC19) Availability of general practitioners (SC20) ALS certification (SC21) Availability of nurses (SC22)	Symbolizes the availability and skills of the medical staff for Advanced Life Support in emergency departments.[57]
Supplies, medicines and accessories (C6)	Availability of accessories and instrumentation (SC23) Availability of supplies (SC24) Availability of medicines (SC25) Availability of beds (SC26)	Represents the availability of the supplies, accessories, instrumentation, medicines and beds that are used for the prevention, diagnosis or treatment of patients' illnesses during ED healthcare.[58]
Quality (C7)	Average physician waiting time (SC27) Patient satisfaction level (SC28) Average length of stay (SC29) Readmission rate (SC30) Waiting time for triage classification (SC31)	Defines the degree to which the healthcare provided by the EDs increase the likelihood of desired health outcomes and is consistent with current professional knowledge in terms of effectiveness, efficiency, equity, patient-centeredness and timeliness.[59]
Patient safety (C8)	Hospital-acquired infections (SC32) Medication errors (SC33) Errors of clinical diagnosis (SC34) Patient misidentification (SC35)	Patient safety is the cornerstone of high-quality ED care.[60] In this regard, this criterion denotes how well these departments prevent errors and adverse effects to patients associated with health care.[61,62]

Below is an explanation of each sub-element of the model. First, “INFRASTRUCTURE” criterion is comprised of five sub-criteria: PHYSICAL CONDITION (SC1), VENTILATION AND LIGHTING (SC2), TOILET FACILITIES (SC3), DELIMITATION OF ED AREAS (SC4) and PHYSICAL CAPACITY (SC5).

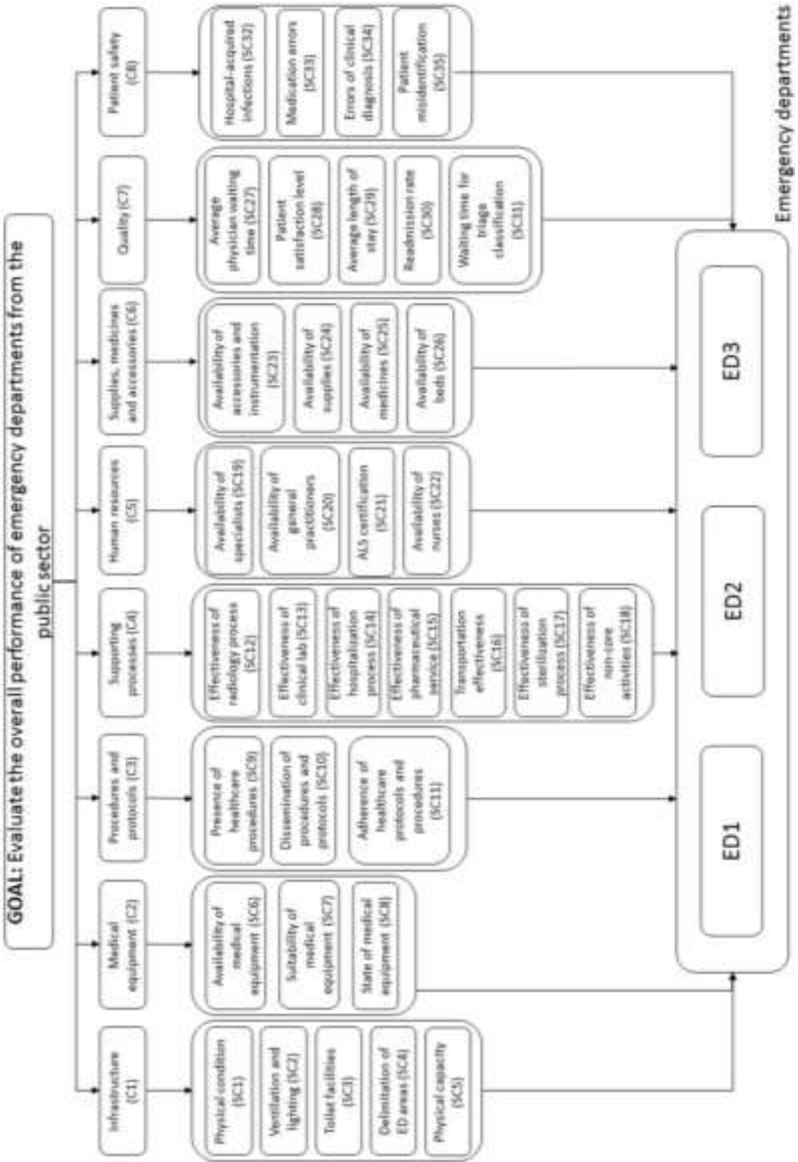


Fig.2. Decision-making model to evaluate the overall performance of emergency departments from the public sector.

Particularly, PHYSICAL CONDITION represents the current status of the ED facilities in terms of functionality, safety and comfort. On the other hand, VENTILATION AND LIGHTING considers how well the emergency department meets the air supply and illumination standards. Another aspect of interest is TOILET FACILITIES which denotes the availability of cleaning areas in the emergency department. The next in order is DELIMITATION OF ED AREAS which assesses whether the major (i.e. triage, resuscitation room, immediate care unit, space for minor emergencies, room for minor surgeries, paediatric emergencies, computed tomography and critical observer) and minor areas of the emergency departments are fully identified and marked with proper signs. Another decision element considered in this cluster is PHYSICAL CAPACITY which establishes the number of available beds in a particular ED.

The second criterion considered in the hierarchical model is “MEDICAL EQUIPMENT”. Medical devices used in EDs are included in the information technology area given their ability to store, retrieve, transmit, and manipulate data (through computer hardware and software) derived from patients and emergency care processes. Herein, three decision elements can be found: AVAILABILITY OF MEDICAL EQUIPMENT (SC6), SUITABILITY OF MEDICAL EQUIPMENT (SC7) and STATE OF MEDICAL EQUIPMENT (SC8). Specifically, AVAILABILITY OF MEDICAL EQUIPMENT represents the percentage of medical devices that is fully or partially functional to be used by the medical staff during ED care. The second criterion is SUITABILITY OF MEDICAL EQUIPMENT which determines whether the medical devices are pertinent to both ED needs and patient expectations. The third decision element within “Medical equipment” cluster is STATE OF MEDICAL EQUIPMENT which evaluates the current technical conditions of the medical devices that are used during prevention, treatment, rehabilitation and diagnosis activities performed by EDs. The proposed hybrid model can then provide meaningful insights on these information technology sub-criteria for further monitoring and improvement. For example, poor performance in “Suitability of medical equipment” may lead to a better selection of health information technology (HIT).

Concerning “PROCEDURES AND PROTOCOLS” criterion, three sub-elements are also deemed: PRESENCE OF HEALTHCARE PROCEDURES (SC9), DISSEMINATION OF PROCEDURES AND PROTOCOLS (SC10) and ADHERENCE OF HEALTHCARE PROTOCOLS (SC11). The first sub-criterion assesses if the standard operation procedures (SOP) have been documented and included in the quality management system (QMS) of the emergency departments.[63] On the other hand, DISSEMINATION OF PROCEDURES AND PROTOCOLS determines whether the SOPs have been fully known and understood by the medical and administrative staff involved. Apart from these sub-criteria, we also considered the ADHERENCE OF HEALTHCARE PROTOCOLS. Particularly, this sub-element establishes how well the EDs comply with the protocols, regulations and international standards documented in the QMS.

In “SUPPORTING PROCESSES” factor, seven decision elements have been taken into account: EFFECTIVENESS OF RADIOLOGY PROCESS (SC12), EFFECTIVENESS OF CLINICAL LAB (SC13), EFFECTIVENESS OF HOSPITALIZATION PROCESS

(SC14), EFFECTIVENESS OF PHARMACEUTICAL SERVICE (SC15), TRANSPORTATION EFFECTIVENESS (SC16), EFFECTIVENESS OF STERILIZATION PROCESS (SC17) and EFFECTIVENESS OF NON-CORE SERVICES (SC18). The first sub-element evaluates the rapidness of radiology units to provide diagnostic imaging to EDs. Likewise, EFFECTIVENESS OF CLINICAL LAB examines the turnaround time (TAT) for laboratory results. On the other hand, EFFECTIVENESS OF HOSPITALIZATION PROCESS measures the average waiting time between the request for a bed and the time in which the ED patient is transferred to it. Another aspect considered in the regulations was the EFFECTIVENESS OF PHARMACEUTICAL SERVICE. This sub-factor represents the time in which the medication orders are dispensed in accordance with the need established by the ED physicians. In addition to the aforementioned decision sub-elements, the group of experts recommended assessing the TRANSPORTATION EFFECTIVENESS. Specifically, this aspect determines whether the ED has ambulances satisfying the government standards and regulations. Another sub-criterion of interest in this cluster is EFFECTIVENESS OF STERILIZATION PROCESS. Particularly, this sub-factor seeks to define if the EDs apply disinfection and sterilization protocols in healthcare settings. Government laws also evaluate the EFFECTIVENESS OF NON-CORE SERVICES to support ED operations. This domain encompasses the Maintenance, cooking, laundry and surveillance activities performed in ED settings. Their contribution is relevant to assist a service subject to patient turnover and even overcrowding.[64]

Up to this point, we have explained the aspects related to the infrastructure, medical equipment, supporting processes and protocols assisting ED operations. Yet, other elements cannot be discarded from this study. In this regard, “HUMAN RESOURCES” has been also included in the decision hierarchy containing four sub-criteria: AVAILABILITY OF SPECIALISTS (SC19), AVAILABILITY OF GENERAL PRACTITIONERS (SC20), ALS CERTIFICATION (SC21) and AVAILABILITY OF NURSES (SC22). Frequently, the AVAILABILITY OF SPECIALISTS has been associated with ED overcrowding.[65-67] This sub-factor represents the number of full-time and part-time specialists that is intended to respond to the risen demand for advanced emergency care. It is also necessary to verify the availability of both general practitioners (GPs) and nurses. The AVAILABILITY OF GENERAL PRACTITIONERS focuses on how many GPs have been employed by the ED in order to provide care for patients with less urgent clinical problems.[68] On the other hand, the AVAILABILITY OF NURSES refers to the number of nursing professionals directly associated with attending patients during the ED service. In addition to the above-mentioned sub-elements, it was considered essential to evaluate ALS CERTIFICATION in EDs. This sub-criterion establishes the percentage of nursing and medical staff certified in Advanced Life Support (ALS).

We also assessed the SUPPLIES, MEDICINES AND ACCESSORIES criterion which is defined by four decision elements: AVAILABILITY OF ACCESSORIES AND INSTRUMENTATION (SC23), AVAILABILITY OF SUPPLIES (SC24), AVAILABILITY OF MEDICINES (SC25) and AVAILABILITY OF BEDS (SC26). The presence of “AVAILABILITY OF ACCESSORIES AND INSTRUMENTATION” sub-criterion allows decision-makers to determine if the EDs pose the medical instruments necessary to stabilize patients who are found to have an emergency medical condition.[69] Regarding AVAILABILITY OF SUPPLIES, the reported literature has evidenced its influence on ED efficiency.[70,71] In this respect, the scarcity of medical supplies may contribute to poor quality emergency service and increased mortality rate. Thus, policymakers should evaluate the governance of the delivery system and focus on stakeholders’ performance. On the other hand, AVAILABILITY OF MEDICINES sets whether the service level provided by the inventory of drugs is enough to satisfactorily respond to the emergency services demand. Another aspect of concern in EDs is the AVAILABILITY OF BEDS. Deficiencies in bed capacity generate the boarding of admitted patients in EDs.[72] In this sense, the patients are placed in hallways and storage rooms resulting in ED congestion and poor healthcare outcomes.

The performance of EDs is also influenced by QUALITY. To well define this domain, five sub-elements were considered: AVERAGE PHYSICIAN WAITING TIME (SC27), PATIENT SATISFACTION LEVEL (SC28), AVERAGE LENGTH OF STAY (SC29), READMISSION RATE (SC30) and WAITING TIME FOR TRIAGE CLASSIFICATION (SC31). Special attention has been paid to timely clinical care in EDs. Prolonged PHYSICIAN WAITING TIME augments patient dissatisfaction, causes delayed admissions of new patients and interferes with providing effective medical care.[73] In this sense, it is therefore important to continuously measure and control this performance metric in order to improve the efficacy of emergency departments. The second aspect is a significant mediator for a range of outcomes in EDs (i.e. quality of care and service delivery). Satisfied patients have a meaningful impact on the public view of emergency care in general. To a great extent, ED managers must use satisfaction data to analyse overtime, study improvement strategies, evaluate physician’s performance and design incentive programs.[74] Another element of importance in this cluster is AVERAGE LENGTH OF STAY (ALOS) which refers to the time elapsed between patient registration and departure. In the decision-making model, READMISSION RATE was also considered as a potential determinant of ED overall performance. Readmissions are costly and interventions are then necessary to alleviate the subsequent burden faced by EDs.[75] Thus, it should be continuously monitored as a purported measure of quality.[76] Another measure under consideration is WAITING TIME FOR TRIAGE CLASSIFICATION. Triage systems have been designed to rapidly discriminate critical ill patients in EDs and have contributed to improved patient satisfaction and diminished waiting times;[73] although, if it is not well implemented and administrated, it may increase the waiting time interval and subsequently influences patient morbidity and nurses dissatisfaction indirectly.

Considering the goal of assessing the overall performance of EDs, PATIENT SAFETY criterion was also taken into account in this study. With regard to this area, four decision elements were identified: HOSPITAL-ACQUIRED INFECTIONS (SC32), MEDICATION ERRORS (SC33), ERRORS OF CLINICAL DIAGNOSIS (SC34) and PATIENT MISIDENTIFICATION (SC35). First, SC32 denote the infections acquired in healthcare facilities and may result in increased morbidity, mortality and costs. In turn, MEDICATION ERRORS have been defined as "*any preventable event that may cause or lead to inappropriate medication use or patient harm while medication is in the control of the healthcare professional, patient or consumer"*.[77,78] Another aspect of interest is ERRORS OF CLINICAL DIAGNOSIS. These are described as the inaccurate and delayed diagnosis which may lead to serious harm or treatment changes.[79] Whilst, PATIENT MISIDENTIFICATION is the failure to correctly identify patients which results in medication errors, testing errors and disruptive care.

4.2. *Phase 2: final criteria and sub-criteria weights*

This phase initially presents the data-collection instrument implemented for gathering all the pairwise comparisons in the FAHP method. The main objective is to propose an easy-to-understand and effective way to introduce FAHP to the decision makers who are untrained in complex mathematics (e.g. medical and administrative staff). Thereby, inconsistency can be meaningfully diminished so that reliability of the decision-making process can be significantly augmented. In this regard, a survey (refer to Fig. 3) was created and used during a 20-minute session led by the researchers. For each pairwise comparison, it was asked: *Considering your experience in ED management how relevant is each criterion/sub-criterion on the left compared to the criterion/sub-criterion on the right?* The experts considered in Sub-section 4.1 filled out the survey by using the aforementioned three-level scale stated in Section 3.1. This procedure was then repeated until completing all the judgments. Particularly, the survey layout and the shorter version of Saaty's scale greatly helps to diminish intransitive comparisons during the process.

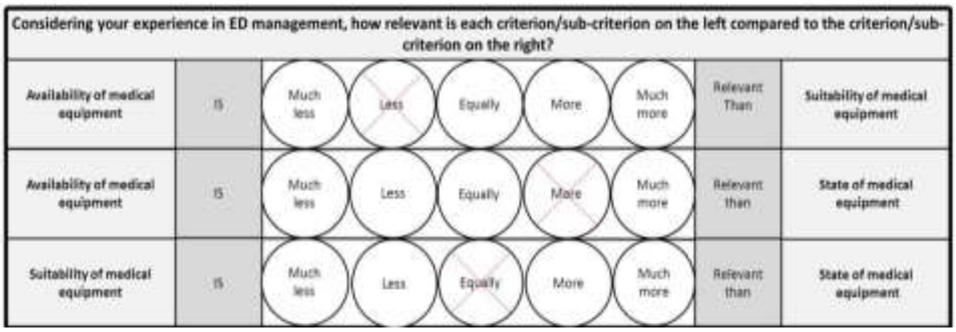


Fig. 3. Data-collection instrument for FAHP comparisons

The collected data were then aggregated and arranged using Eq. 1-3. An example of a fuzzy judgment matrix is presented in Table 5. After this, by using Eq. 4, the geometric means of fuzzy judgments were estimated for each decision element. An illustration of these results is described in Table 6. Furthermore, by applying Eq. 5-7, the normalized weight values of criteria and sub-criteria were achieved (refer to Table 7). The fuzzy and non-fuzzy global criterion (k = 1, 2, …, m) weight GW_k , local sub-criterion (i = 1, 2, …, s)

weight LW_i^k , and global sub-criterion (i = 1, 2, …, s) priorities GW_i^k were enlisted in Table 8 to present the outcomes of the FAHP method.

Table 5. Fuzzy judgment matrix for “criteria”

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
C1	[1.000,1.000,1.000]	[2.167,2.667,3.167]	[1.708,2.222,2.750]	[2.167,2.667,3.167]	[1.542,1.888,2.250]	[1.125,1.332,1.583]	[1.833,2.333,2.833]	[2.500,3.333,4.167]
C2	[0.595,0.622,0.667]	[1.000,1.000,1.000]	[1.500,2.000,2.500]	[1.375,1.888,2.417]	[1.083,1.443,1.833]	[0.875,0.888,0.917]	[1.333,1.667,2.000]	[0.875,0.888,0.917]
C3	[0.777,0.977,1.208]	[0.625,0.665,0.750]	[1.000,1.000,1.000]	[1.333,1.667,2.000]	[1.542,2.222,2.917]	[1.208,1.555,1.917]	[1.500,2.000.2.500]	[1.000,1.000,1.000]
C4	[0.595,0.622,0.667]	[0.792,0.998,1.250]	[0.750,0.777,0.833]	[1.000,1.000,1.000]	[1.667,2.333,3.000]	[0.750,0.777,0.833]	[1.333,1.667,2.000]	[0.917,1.110,1.333]
C5	[0.902,1.088,1.292]	[1.083,1.443,1.833]	[0.667,0.887,1.167]	[0.500,0.553,0.667]	[1.000,1.000,1.000]	[1.333,1.667,2.000]	[1.375,1.555,1.750]	[1.833,2.333,2.833]
C6	[1.360,1.867,2.375]	[1.167,1.333,1.500]	[0.917,1.110,1.333]	[1.333,1.667,2.000]	[0.750,0.777,0.833]	[1.000,1.000,1.000]	[1.333,1.667,2.000]	[0.875,0.888,0.917]
C7	[0.610,0.643,0.708]	[0.750,0.777,0.833]	[0.625,0.665,0.750]	[0.750,0.777,0.833]	[1.027,1.200,1.375]	[0.750,0.777,0.833]	[1.000,1.000,1.000]	[1.333,1.667,2.000]
C8	[0.345,0.398,0.500]	[1.167,1.333,1.500]	[1.000,1.000,1.000]	[1.208,1.555,1.917]	[0.610,0.643,0.708]	[1.167,1.333,1.500]	[0.750,0.777,0.833]	[1.000,1.000,1.000]

Table 6. Geometric means of fuzzy comparisons for "factors" cluster

Criterion	**Geometric mean of fuzzy comparisons**
C1	[1.810, 2.268, 2.740]
C2	[1.045, 1.238, 1.433]
C3	[1.088, 1.333, 1.587]
C4	[0.916, 1.071, 1.245]
C5	[1.013, 1.246, 1.514]
C6	[1.246, 1.448, 1.620]
C7	[1.042, 1.076, 1.104]
C8	[0.850, 0.930, 1.000]

Table 7. Normalized fuzzy global weights for "criteria"

Fuzzy weight				**Non-fuzzy weight**	**Normalized weight**
C1	0.148	0.214	0.304	0.222	0.215
C2	0.085	0.117	0.159	0.120	0.117
C3	0.089	0.126	0.176	0.130	0.126
C4	0.075	0.101	0.138	0.105	0.101
C5	0.083	0.117	0.168	0.123	0.119
C6	0.102	0.103	0.180	0.139	0.135
C7	0.085	0.101	0.123	0.103	0.100
C8	0.069	0.088	0.111	0.089	0.087
Total				1.032	1

Table 8. Local and global weights of criteria and sub-criteria by using FAHP

Criterion-sub criterion	**Local weight**	**Global weight**
Infrastructure (C1)		0.215
Physical condition (SC1)	0.256	0.055
Ventilation and lighting (SC2)	0.126	0.027
Toilet facilities (SC3)	0.160	0.034
Delimitation of ED areas (SC4)	0.290	0.062
Physical capacity (SC5)	0.168	0.036
Medical equipment (C2)		0.117
Availability of medical equipment (SC6)	0.423	0.049
Suitability of medical equipment (SC7)	0.365	0.043
State of medical equipment(SC8)	0.212	0.025
Procedures and protocols (C3)		0.126
Presence of healthcare procedures (SC9)	0.333	0.042
Dissemination of procedures and protocols (SC10)	0.333	0.042
Adherence of healthcare protocols and procedures (SC11)	0.333	0.042
Supporting processes (C4)		0.101
Effectiveness of radiology process (SC12)	0.198	0.020
Effectiveness of clinical lab (SC13)	0.209	0.021
Effectiveness of hospitalization process (SC14)	0.130	0.013
Effectiveness of pharmaceutical service (SC15)	0.167	0.017
Transportation effectiveness (SC16)	0.124	0.013
Effectiveness of sterilization process (SC17)	0.115	0.012
Effectiveness of non-core activities (SC18)	0.058	0.006

Table 8 (Continued)

Human resources (C5)		0.119
Availability of specialists (SC19)	0.345	0.041
Availability of general practitioners (SC20)	0.364	0.043
ALC certification (SC21)	0.224	0.027
Availability of nurses (SC22)	0.067	0.008
Supplies, medicines and accessories (C6)		0.135
Availability of accessories and instrumentation (SC23)	0.307	0.041
Availability of supplies (SC24)	0.276	0.037
Availability of medicines (SC25)	0.270	0.036
Availability of beds (SC26)	0.148	0.020
Quality (C7)		0.100
Average physician waiting time (SC27)	0.149	0.015
Patient satisfaction level (SC28)	0.280	0.028
Average length of stay (SC29)	0.145	0.015
Readmission rate (SC30)	0.332	0.033
Waiting time for triage classification (SC31)	0.092	0.009
Patient safety (C8)		0.087
Hospital-acquired infections (SC32)	0.280	0.024
Medication errors (SC33)	0.262	0.023
Errors of clinical diagnosis (SC34)	0.203	0.018
Patient misidentification (SC35)	0.255	0.022

Infrastructure was the criterion with the highest priority level (GW = 21.5%) while *Supplies, medicines and accessories* was ranked in the second place (GW = 13.50%) (Fig. 4). However, the difference between *C6* (2nd place) and *C8* (8th place) is not significant (4.8%). This evidences that multidimensional improvement strategies should be designed with a huge focus on *Infrastructure* so that the overall ED performance can be continuously and significantly augmented. ED managers should then convert these outcomes into new management policies coping with the rapid changes addressed by emergency services in terms of increasing patient numbers and limited resources. On the other hand, given the multifactorial nature of the strategies, it is important to ensure the participation and commitment of all the departments involved in the ED core operations both directly and indirectly. This is to avoid quality-related problems such as overcrowding, patients leaving without their care being finished, adverse events, high mortality rate, and increased readmission. Indeed, similar studies as those presented by Mohammadi *et al.*[15], Zhao and Paul[17], and Pan *et al*.[18] have highlighted the need for continuously monitoring these measures in EDs in order to provide satisfactory emergency care to patients.

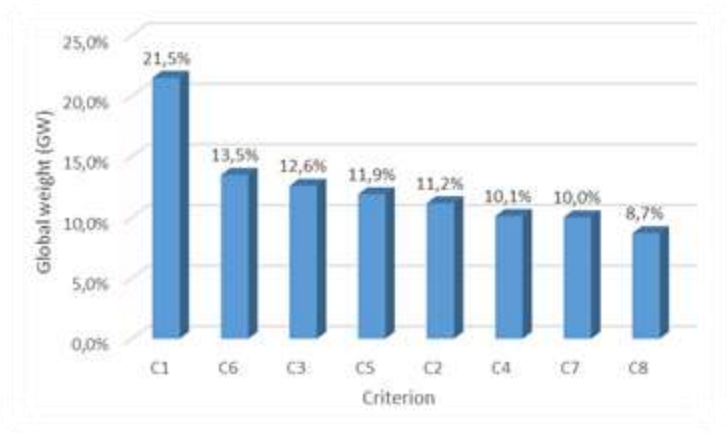


Fig. 4. Global criteria weights derived from the FAHP method

Local weights were also analysed after performing FAHP calculations (Eq. 1-7). Particularly, in *Infrastructure* cluster (Figure 5a), the most important sub-criterion was *Delimitation of areas – SC1* (29.0%). In this regard, several studies have concluded that proper demarcation facilitates patient flow within EDs. If this is not well implemented, negative effects can be expected regarding the length of stay and patient safety. In fact, this has to be considered as a major requirement for future ED architectural designs in order to avoid patients' stress and ensure timely physician assessment. Moreover, this aspect is also regulated by control agencies during accreditation visits and should be therefore further prioritized by the ED managers for continuous monitoring and intervention.

In *Medical equipment* cluster (Figure 5b), the most relevant decision element was *Availability of medical equipment – SC6* (42.3%). Constant management efforts should be then directed towards the monitoring and evaluation of stock-outs and equipment breakdowns as well as service contracts and local repair capabilities. This facilitates the effective procurement and stock management, activities of great importance for defining rapid interventions and underpinning ED core operations. These considerations have to be also inserted into the planning processes of EDs to ensure budget availability and timely maintenance interventions. Similarly to *Physical condition*, deficiencies in equipment availability may result in poor patient outcomes and reduced quality of care. Furthermore, as slight difference was detected between this sub-criterion and *Suitability of medical equipment - SC7* (5.8%), *SC7* is also called to be considered within the improvement strategies created in this domain.

(a) (b)

Fig. 5. Local contributions in a) Infrastructure cluster b) Medical equipment cluster

In *Procedures and protocols* cluster (Figure 6a), the sub-criteria were found equally important (33.3%). This result bears out the importance of correctly translating the ED guidelines to the stakeholders in order to ensure that they are recognized and well understood prior to implementation. Such intervention helps to reduce the gap between the protocols and clinical practice which results in a lessened number of patients not receiving appropriate care. In addition, the correct dissemination of protocols enables nurses to initiate diagnostic tests on-time so that length of patient stay can be diminished while improving the bedtime availability. This finding confirms the urgent need for appropriately creating, disseminating and adhering to ED protocols and procedures as a path towards the decline of adverse events and patient dissatisfaction within ED settings. As explained by Yamani et al.[16], this is propelled by the effective interaction between ED physicians and nurses, a space where their communicational skills should be often converge for providing well and efficient care.

In *Supporting processes* criterion (Figure 6b), the most important sub-criterion was *Effectiveness of clinical lab - SC13* (20.9%). Laboratory testing has been found to have a significant influence on patients' length of stay in emergency departments.[81] In this regard, clinical laboratories have to be effectively managed in order to reduce ED overcrowding. Interventions may include controlling the laboratory service performance through increasing lab resources and staffing after-hours. Aside from clinical lab, 5 more supporting processes (*SC12, SC14, SC15, SC16,* and *SC17*) were found to have non-significant gaps with respect to the leading sub-criterion and should be hence considered to be inserted into future improvements programs.

(a) (b)

Fig. 6. Local contributions in a) Procedures and Protocols cluster b) Supporting processes cluster

In *Human resources* cluster (Figure 7a), the most relevant decision element was *Availability of general practitioners - SC20* (36.4%). General practitioners (GPs) play a crucial role in EDs since they provide primary care to patients. In fact, GPs are a response to the increased number of non-urgent patients, one of the main causes of ED overcrowding and extended waiting times. Additionally, it has been proved that GPs tend to make fewer referrals to other specialists, order fewer tests and work under ED standards which is beneficial to reduce the financial burden faced by policymakers.[82] However, the GPs are advised to work together with specialists in order to ensure high quality of care. This could be an explanation of why *Availability of specialists – SC19* (34.5%) was ranked second in *Human resources* criterion. These findings are consistent with Gul *et al.*[20], Yeh and Cheng[91] and Ketabi, Teymouri, and Ketabi[19] whose DEA models qualified "number of staff" as a critical input in EDs. Regarding *Supplies, medicines and accessories* cluster (Figure 7b), *Availability of accessories and instrumentation - SC23* was ranked in the first place. Being aware of its importance, *World Health Organization (WHO)* has established a list of essential supplies for providing a basic emergency care.[83] Policymakers must then ensure high fill rate of these material resources to meet priority health needs while saving in acquisition costs. This is even more important in the developing world where resources are largely limited. It is therefore necessary to properly promote collaborations between suppliers and policymakers for allocating financial resources properly.

(a) (b)

Fig. 7. Local contributions in a) Human resources cluster b) Supplies, medicines and accessories cluster

In *Quality* cluster (Figure 8a), the most relevant sub-criterion was *Readmission rate – SC30* (33.2%). Today's emergency departments have to focus on reducing readmission rates in order to restore patient's confidence, diminish unnecessary overcrowding, and minimize the cost of medical care.[84] It is then relevant to find the factors associated with patients' return by studying the pre-discharge, ED care, and post-discharge processes to subsequently establish targeted interventions addressing this problem. To this particular aim, discharge planning, outpatient monitoring, and education can be implemented. It is also good to highlight the importance of *patient satisfaction level* (28.0%) which was ranked second according to the FAHP results. In this regard, the DEA model developed by Ketabi, Teymouri, and Ketabi[19] found that the number of patients' complaints is an aspect of extreme consideration in emergency care services. In fact, the selection of EDs is strongly influenced by the quality perception of patients as also stated by Yamani *et al.*[16]

through their 360 degree evaluation. Another significant finding is the accumulated sum of relative weights corresponding to the waiting times (24.1%). The increasing attention on this indicator is consistent with the focus of several performance evaluation models as those designed by Mohammadi *et al.*[15], Yamani *et al.*[16], and Ketabi, Teymouri, and Ketabi[19]. On the contrary, despite its inclusion in the performance model proposed by Pan *et al.*[18], length of stay was not considered as highly important in this study (14.5%). Regarding *Patient safety* criterion (Figure 8b), the most significant element was *Hospital-acquired infections – SC32* (28.0%). However, little difference (7.7%) was found between this sub-criterion and *Errors of clinical diagnosis*. This is an evidence of the multidimensional nature of patient safety, which demands multifactorial strategies (including the aspects described in this cluster) to reduce the negative impact on patients' health. In this respect, it is important to better characterize the adverse events occurring in ED settings and their causes (e.g. multiple transitions in care and ED overcrowding). Furthermore, system failure prevention must be a priority for ED directors and quality managers considering that EDs are prone to patient safety incidents and demands for emergency services continue to rise.[85]

(a) (b)

Fig. 8. Local contributions in a) Quality cluster b) Patient safety cluster

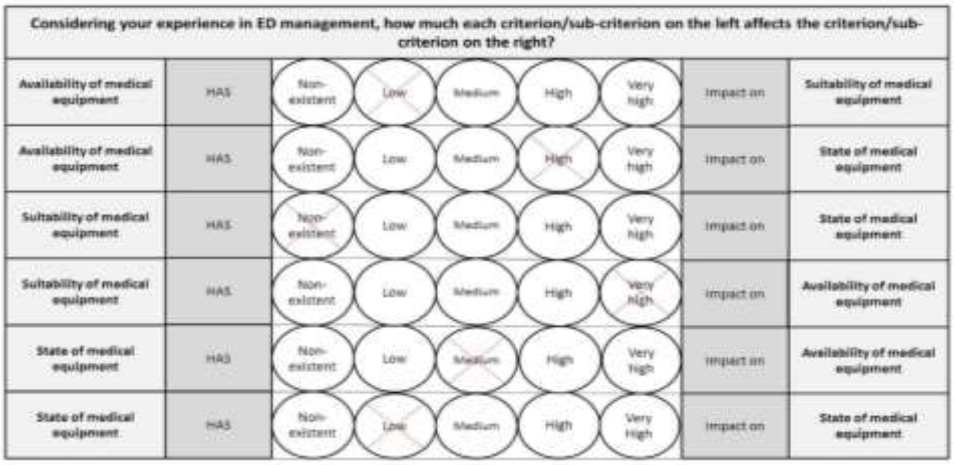
The consistency ratios (CR)[111] were also computed (refer to Table 9). Since CR values are not greater than 10%, the calculated weights can be used to establish the priority ranking of EDs. In this regard, the experts were neither inconsistent nor random when making the comparisons. Therefore, the evaluation process can be considered as satisfactory and both reduced FAHP scale and survey layout can be effectively replicated in real-world scenarios.

Table 9. Consistency ratios for fuzzy judgment matrixes

Matrix	Consistency ratio (CR)
Criteria	0.058
Infrastructure	0.046
Medical equipment	0.024
Procedures and protocols	0.003
Supporting processes	0.046
Human resources	0.062
Supplies, medicines and accessories	0.057
Quality	0.097
Patient safety	0.020

4.3. *Phase 3: Interdependence and feedback among decision elements*

Similar to the FAHP method, a survey was designed for collecting FDEMATEL comparisons (refer to Figure 9) which will evidence the interdependence and feedback among criteria/sub-sub-criteria. For each judgment, it was asked: *Considering your experience in ED management, how much each criterion/sub-criterion on the left affects the criterion/sub-criterion on the right?* The decision-makers considered in Sub-section 4.1 answered in accordance with the five-point scale presented in Table 3. The evaluation process was also repeated until completing all the comparisons.



Considering your experience in ED management, how much each criterion/sub-criterion on the left affects the criterion/sub-criterion on the right?								
Availability of medical equipment	HAS	Non-existent	Low	Medium	High	Very high	Impact on	Suitability of medical equipment
Availability of medical equipment	HAS	Non-existent	Low	Medium	High	Very high	Impact on	State of medical equipment
Suitability of medical equipment	HAS	Non-existent	Low	Medium	High	Very high	Impact on	State of medical equipment
Suitability of medical equipment	HAS	Non-existent	Low	Medium	High	Very high	Impact on	Availability of medical equipment
State of medical equipment	HAS	Non-existent	Low	Medium	High	Very high	Impact on	Availability of medical equipment
State of medical equipment	HAS	Non-existent	Low	Medium	High	Very High	Impact on	State of medical equipment

Fig. 9. Data-collection instrument for FDEMATEL comparisons

The pair-wise fuzzy judgments were then aggregated by applying Eq. 8-11. An example of a fuzzy direct-influence matrix $\tilde{\boldsymbol{D}}$ is presented in Table 10. Then, via using Eq. 12, the normalized fuzzy direct-relation matrix $\tilde{\boldsymbol{N}}$ is obtained (refer to Table 11). After this, the fuzzy total-influence matrix is computed by implementing Eq. 13. An illustration of this matrix is described in Table 12.

Table 10. Fuzzy direct-influence matrix for "Patient safety" cluster

	SC32	**SC33**	**SC34**	**SC35**
SC32	[0.000,0.000,0.000]	[0.542,0.792,0.917]	[0.292,0.500,0.750]	[0.375,0.625,0.792]
SC33	[0.500,0.750,0.958]	[0.000,0.000,0.000]	[0.500,0.750,0.958]	[0.250,0.458,0.708]
SC34	[0.417,0.667,0.875]	[0.542,0.792,0.958]	[0.000,0.000,0.000]	[0.250,0.458,0.708]
SC35	[0.333,0.583,0.792]	[0.542,0.792,0.958]	[0.542,0.792,0.958]	[0.000,0.000,0.000]

Table 11. Fuzzy normalized direct-influence matrix for "Patient safety" cluster

	SC32	**SC33**	**SC34**	**SC35**
SC32	[0.000,0.000,0.000]	[0.200,0.292,0.338]	[0.108,0.185,0.277]	[0.138,0.231,0.292]
SC33	[0.158,0.277,0.354]	[0.000,0.000,0.000]	[0.158,0.277,0.354]	[0.092,0.169,0.262]
SC34	[0.154,0.246,0.323]	[0.200,0.292,0.353]	[0.000,0.000,0.000]	[0.092,0.169,0.262]
SC35	[0.123,0.215,0.292]	[0.200,0.292,0.354]	[0.200,0.292,0.354]	[0.000,0.000,0.000]

Table 12. Fuzzy total-influence matrix for "Patient safety" cluster

	SC32	SC33	SC34	SC35	$\tilde{R}$
SC32	[0.015,0.530,4.750]	[0.307,0.827,5.258]	[0.271,0.690,4.996]	[0.203,0.610,4.363]	[0.842,2.657,19.367]
SC33	[0.274,0.754,5.240]	[0.143,0.608,5.245]	[0.274,0.752,5.268]	[0.169,0.573,4.543]	[0.861,2.687,20.295]
SC34	[0.249,0.726,5.109]	[0.306,0.824,5.387]	[0.116,0.528,4.893]	[0.166,0.565,4.444]	[0.837,2.643,19.832]
SC35	[0.242,0.762,5.343]	[0.328,0.889,5.653]	[0.305,0.815,5.410]	[0.092,0.464,4.455]	[0.966,2.930,20.860]
$\tilde{C}$	[0.088,2.772,20.441]	[1.084,3.148,21.542]	[0.913,2.784,20.568]	[0.629,2.213,17.804]	

$\tilde{C}_i$ and $\tilde{R}_j$ values were calculated to finally obtain prominence $\left(\tilde{C}_i + \tilde{R}_j\right)$ and relation $\left(\tilde{C}_i - \tilde{R}_j\right)$ measures (refer to Table 13). The *dispatchers* and *receivers* were then identified and indicated in Table 13. The results revealed that *Patient safety (C8)* has the highest positive $C + R$ value (12.771) is then considered as the most influencing factor when assessing the overall performance of emergency departments. Hence, *Patient safety (C8)* should be greatly prioritized for continuous improvement in these institutions. It is interesting to note that while *Patient safety* (C8) has been defined as the least important criterion (GW = 8.70%) through the FAHP method, it has been concluded as the most influential factor (C + R = 12.771) in the performance evaluation network. This is explained by the fact that *Patient safety* (C8) implementations are at the earlier stages and has not been highly prioritized by the control institutions; nonetheless, it is widely acknowledged that the application of *Patient safety* programs influence on medical equipment, procedures and protocols, supporting processes, human resources, supplies, medicines, and accessories, and quality. An interesting finding is that while *Infrastructure* (C1) was categorized as the most relevant criterion (GW = 21.5%) in the FAHP technique; it was found as the least influential factor (C + R = 11.470) in the performance evaluation model by FDEMATEL. *Infrastructure* (C1) (in terms of beds, emergency care rooms) has become a need in the short term given the increasing demands on emergency care services especially in disaster situations. Despite the last place in the FDEMATEL ranking, its interrelation strength is over the threshold demonstrating the interactive nature of this factor within the emergency care context.

Additionally, the high prominence values ($C + R > 10$) evidence the existence of strong correlations between criteria which confirms the interactive nature of emergency care processes. There is also a good chance that *Patient safety (C8)* would be influenced by the rest of the criteria. In this regard, Lisbon *et al.* (2016)[80] revealed that failure to engage in teamwork behaviours may cause adverse events. Thus, it is important that EDs endeavour to implement formal teamwork training with the goal of reducing medical errors affecting patients of each complexity level. On a different tack, it is necessary to ensure that online decision support tools and medical equipment (C2) are smoothly integrated into all process management systems so that reliable clinical data can be obtained and efficiently analysed for risk management in EDs.

Also, potential dangers of overcrowding should be carefully deemed and addressed as a future *Infrastructure (C1)* challenge. In this respect, physical capacity and facilities of EDs should be adapted to the expected growing demand and required patient safety conditions as highlighted by Gul *et al.*[20] On the other hand, the DEMATEL outcomes evidence the influence of *Human resources (C5)* and the corresponding shift patterns in the generation of hazardous conditions within EDs. In fact, the probability of making medical errors and the occurrence of accidents may increase three times with longer work hours. Additionally, errors may occur when the ED staff is stressed and overloaded. Thus, staff scheduling and working conditions should be carefully reviewed in order to diminish both the risk of adverse events and absenteeism. Special attention should be also paid on any deviation from *Procedures and protocols (C3)* which could result in patient deterioration. Indeed, standard operating procedures have been concluded to be in their infancy and ED managers must, therefore, propose solutions aiming to reduce such errors and proactively prevent negative impact on patients' health.

Inefficiencies concerning *Supporting processes (C4)* also appear to contribute to patient safety problems. Actually, delay in ED diagnoses, testing or treatment has been identified to be a risk factor for in-hospital infections and other negative patient outcomes. It is hence necessary to alleviate the burden faced by both patients and EDs through the implementation of improvement projects considering interactions between ED and supporting processes while targeting higher efficiency rates. Likewise, *Supplies, medicines and accessories (C6)* are a vital component for ensuring the effective deployment of patient safety programs. Inappropriate resource management may cause adverse events, especially when combined with already existing problems related to the aforementioned criteria. There is then a need to effectively implement inventory management systems providing satisfactory fill rates of supplies, medicines and accessories with a high turnover rate. Furthermore, it is relevant to purchase items fulfilling patient safety standards so that events such as falls and bloodstream infections can be prevented. Another aspect to be considered in this discussion is *Quality (C7)* which was found to be the dispatcher with the highest prominence (C + R = 12.368). This is explained by the presence of multiple agents as well as the interactions amidst complex diagnostic, healthcare, and logistics processes. A multidisciplinary system-wide approach is then required to increase the overall performance of EDs. ED managers should thus consider all the criteria when designing effective improvement strategies addressing the current challenges of emergency services including collaboration practices and increased demand.

Table 13. Dispatchers and receivers in the decision-making model

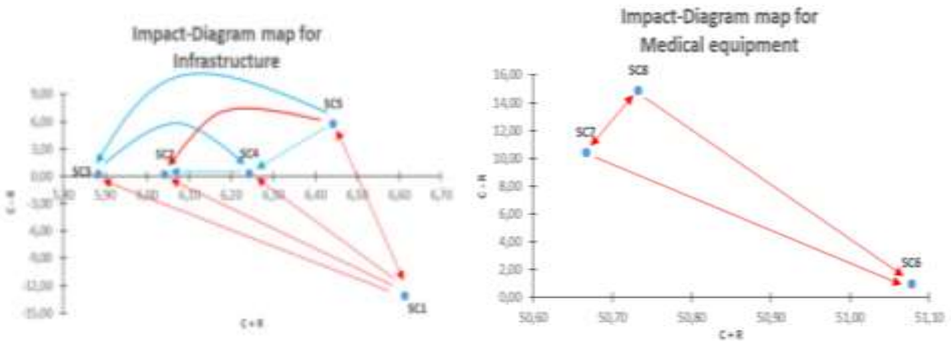
Criterion/Sub-criterion	*Prominence (C + R)*	*Relation (C– R)*	*Dispatcher*	*Receiver*
Infrastructure (C1)	11.470	-0.095		✓
Physical condition (SC1)	6.614	-13.074		✓
Ventilation and lighting (SC2)	6.042	0.244	✓	
Toilet facilities (SC3)	5.883	0.183	✓	
Delimitation of ED areas (SC4)	6.243	0.303	✓	
Physical capacity (SC5)	6.443	5.784	✓	
Medical equipment (C2)	11.778	0.348	✓	
Availability of medical equipment (SC6)	51.078	0.997	✓	
Suitability of medical equipment (SC7)	50.667	10.406	✓	
State of medical equipment (SC8)	50.733	14.854	✓	
Procedures and protocols (C3)	12.146	-0.040		✓
Presence of healthcare procedures (SC9)	16.509	-0.237		✓
Dissemination of procedures and protocols (SC10)	16.386	-12.689		✓
Adherence of healthcare protocols and procedures (SC11)	16.212	0.399	✓	
Supporting processes (C4)	11.711	-4.974		✓
Effectiveness of radiology process (SC12)	7.471	-0.037		✓
Effectiveness of clinical lab (SC13)	7.464	0.104	✓	
Effectiveness of hospitalization process (SC14)	8.371	4.535	✓	
Effectiveness of pharmaceutical service (SC15)	7.342	4.423	✓	
Transportation effectiveness (SC16)	7.125	4.385	✓	
Effectiveness of sterilization process (SC17)	7.000	4.414	✓	
Effectiveness of non-core activities (SC18)	7.203	0.105	✓	
Human resources (C5)	11.704	-0.030		✓
Availability of specialists (SC19)	12.404	-0.041		✓
Availability of general practitioners (SC20)	12.476	2.707	✓	

Table 13 (Continued)

ALS certification (SC21)	12.037	0.050	✓	
Availability of nurses (SC22)	12.042	0.190	✓	
Supplies, medicines and accessories (C6)	11.763	0.016		✓
Availability of accessories and instrumentation (SC23)	13.106	-1.965		✓
Availability of supplies (SC24)	12.846	-1.385		✓
Availability of medicines (SC25)	12.796	- 1.781		✓
Availability of beds (SC26)	12.633	-2.146		✓
Quality (C7)	12.368	0.382		✓
Average physician waiting time (SC27)	18.225	0.360	✓	
Patient satisfaction level (SC28)	17.820	0.226	✓	
Average length of stay (SC29)	18.216	1.153	✓	
Readmission rate (SC30)	18.052	0.624	✓	
Waiting time for triage classification (SC31)	17.707	0.327	✓	
Patient safety (C8)	12.771	0.120	✓	
Hospital-acquired infections (SC32)	11.250	0.288	✓	
Medication errors (SC33)	11.866	0.555	✓	
Errors of clinical diagnosis (SC34)	11.336	0.253	✓	
Patient misidentification (SC35)	10.852	3.706	✓	

Correlations among sub-criteria of each cluster were later analysed by adopting impact-relation maps - IRM (Figure 10a, 10b). IRMs for *Infrastructure* and *Medical equipment* are provided to give an overview of the DEMATEL application. First, the influence diagram for *Infrastructure* is presented (Figure 10a). The threshold value was set as $p = 15,646 / 5^2 = 0,626$ after defuzzifying the corresponding fuzzy total-influence matrix. It can be mentioned that *Ventilation and lighting (SC2), Toilet facilities (SC3), Delimitation of ED areas (SC4),* and *Physical capacity (SC5)* are the *dispatchers* while *Physical condition (SC1)* is the receiver. According to the graph, the dispatchers have similar prominence values and therefore, multifactorial improvement strategies considering these sub-criteria have to be performed in order to satisfy the expected ED requirements and effectively underpin the core operations of emergency care. While FAHP evidenced that *Delimitation of ED areas* – SC4 (LW = 29.0%) is the most important sub-criterion within the *Infrastructure* (C1) cluster, *Physical condition* – SC1 was identified as the most influential element (C + R = 6.614) in the fuzzy DEMATEL method. These results are consistent with the fact that the physical condition of emergency care rooms, waiting spaces, and other units within the ED gets deteriorated in the long term whilst the delimitation of ED areas is an aspect of strict control by healthcare authorities. In spite of *Delimitation of ED areas* – SC4 was not ranked first in the FDEMATEL method, its C + R (6.243) is close to that obtained in SC1; thereby indicating a critical sub-criterion for continuous monitoring in EDs.

An influence diagram was also drawn for *Medical equipment* sub-criteria (Figure 10b). The established threshold value was established as $p = 76,541 / 3^2 = 8,505$. In this case, *Availability of medical equipment (SC6), Suitability of medical equipment (SC7),* and *State of medical equipment (SC8)* were categorized as dispatchers. Additionally, a feedback relationship is observed between *Suitability of medical equipment (SC7)* and *State of medical equipment (SC8)*. Given the fact that all the sub-criteria were qualified as dispatchers, ED managers are advised to design multidimensional strategies to ensure the effective incorporation and functioning of the medical equipment during the ED care. In this case, *Availability of medical equipment (SC6)* was found as both the most important sub-criterion in the FAHP method (LW = 42.3%) and the most influential element (C + R = 51.078) in the medical equipment domain by the fuzzy DEMATEL technique. Such a finding is supported by the fact that the number of available medical equipment should be congruous with the current (short-term period) and projected increased demand (long-term period), especially in disaster situations such as the Covid-19[114].



(a) (b)

Fig. 10. Impact-relation map for a) Infrastructure b) Medical equipment

4.4. Phase 5: TOPSIS method

To complete implementation of the proposed approach, the EDs were ranked according to their overall performance by using the TOPSIS method. Initially, a set of metrics was defined for each sub-criterion (refer to Table 14) considering the current regulations set by the Ministry of Health and Social Protection. The mathematical formulas of these indicators were also enlisted in Table 14.

Table 14. Key performance metrics for sub-criteria

Sub-criterion	Metric	Formula
Physical condition (SC1)	% of ED rooms with adequate infrastructure conditions	$\frac{\text{Number of ED rooms with adequate infrastructure conditions}}{\text{Total of rooms in ED}} * 100$
Ventilation and lighting (SC2)	% of ED rooms without appropriate lighting, cleaning and noise conditions	$\frac{\text{Number of ED rooms without appropriate lighting, cleaning and noise conditions}}{\text{Total of rooms in ED}} * 100$
Toilet facilities (SC3)	Availability of toilet facilities	If available (1), otherwise (0)

Table 14 (Continued)

Delimitation of ED areas (SC4)	Delimitation of ED areas	If delimited (1), otherwise (0)
Physical capacity (SC5)	Floor area	Floor area in m^2
Availability of medical equipment (SC6)	% of available medical equipment	$\frac{Number\ of\ available\ medical\ equipment}{Total\ of\ medical\ equipment} * 100.$
Suitability of medical equipment (SC7)	% of medical equipment with high quality standards	$\frac{Number\ of\ medical\ equipment\ with\ high\ quality\ standards}{Total\ of\ medical\ equipment} * 100.$
State of medical equipment (SC8)	% of damaged medical equipment	$\frac{Number\ of\ damaged\ medical\ equipment}{Total\ of\ medical\ equipment} * 100.$
Presence of healthcare procedures (SC9)	Presence of healthcare procedures	If present (1), otherwise (0)
Dissemination of procedures and protocols (SC10)	% of disseminated procedures and protocols	$\frac{Number\ of\ disseminated\ procedures\ and\ protocols}{Total\ of\ procedures\ and\ protocols} * 100.$
Adherence of healthcare protocols and procedures (SC11)	Proportion of monitored adverse events in ED	$\frac{Number\ of\ monitored\ adverse\ events}{Total\ of\ adverse\ events} * 100.$
Effectiveness of radiology process (SC12)	Average waiting time for radiology results	$\sum_{i=1}^{n} \frac{DD_i - RD_i}{n}.$ Where: $n : number\ of\ radiology\ tests\ in\ a\ year.$ $DD_i : delivery\ date\ of\ radiology\ order\ i.$ $RD_i : request\ date\ of\ radiology\ order\ i.$
Effectiveness of clinical lab (SC13)	Average waiting time for laboratory test results	$\sum_{j=1}^{n} \frac{DD_j - RD_j}{n}.$ Where: $n : number\ of\ laboratory\ tests\ in\ a\ year.$ $DD_j : delivery\ date\ of\ laboratory\ test\ order\ j\ \cdot$ $RD_j : request\ date\ of\ laboratory\ test\ order\ j$

Table 14 (Continued)

Effectiveness of hospitalization process (SC14)	Average transfer time from the ED to inpatient bed	$\sum_{k=1}^{n} \frac{RTD_k - STD_k}{n}$. Where: n : *number of transferred patients in a year* . RTD_k : *real transfer date for patient k* . STD_k : *scheduled transfer date for patient k* .
Effectiveness of pharmaceutical service (SC15)	Average waiting time for drug delivery	$\sum_{l=1}^{n} \frac{DD_l - RD_l}{n}$. Where: n : *number of drug orders in a year* . DD_l : *delivery date of drug order l* . RD_l : *request date of drug order l* .
Transportation effectiveness (SC16)	Availability of ambulances according to the standards	If available (1), otherwise (0)
Effectiveness of sterilization process (SC17)	Application of sterilization protocols in ED	If available (1), otherwise (0)
Effectiveness of non-core activities (SC18)	Number of non-core activities	Number of non-core activities supporting ED operations
Availability of specialists (SC19)	Number of vacant positions for ED specialists	Number of specialists needed in ED for covering the current demand
Availability of general practitioners (SC20)	Number of vacant positions for ED general practitioners	Number of general practitioners needed in ED for covering the current demand
ALS certification (SC21)	Percentage of physicians and nurses with ALS certification	$\frac{\text{Number of physicians and nurses with ALS certification}}{\text{Total of adverse events}} *100$.
Availability of nurses (SC22)	Number of vacant positions for ED nurses	Number of nurses needed in ED for covering the current demand
Availability of accessories and instrumentation (SC23)	Availability of accessories and instrumentation	Number of medical devices and instruments needed for covering the current demand
Availability of supplies (SC24)	Fill rate (medical supplies)	$\frac{\text{Number of satisfied orders}}{\text{Total of required orders}} *100$.
Availability of medicines (SC25)	Fill rate (Medicines)	$\frac{\text{Number of satisfied orders}}{\text{Total of required orders}} *100$.
Availability of beds (SC26)	Bed-occupancy rate	$\frac{\text{Number of occupied beds in ED}}{\text{Total of beds in ED}} *100$.

Table 14 (Continued)

Average physician waiting time (SC27)	Average physician waiting time	$\sum_{k=1}^{n} \frac{AT_k - CT_k}{n}$ Where: n : *number of patients in a year* . AT_k : *arrival time for patient k* . CT_k : *consultation time for patient k* .
Patient satisfaction level (SC28)	Patient satisfaction level	$\frac{Number\ of\ satisfied\ patients}{Number\ of\ patients\ received\ in\ ED} * 100$.
Average length of stay (SC29)	Average length of stay	$\frac{Total\ length\ of\ stay\ in\ ED}{Number\ of\ patients\ received\ in\ ED}$.
Readmission rate (SC30)	Readmission rate	$\frac{Number\ of\ readmitted\ patients\ within\ a\ 72\text{-}hour\ period\ due\ to\ the\ same\ cause}{Number\ of\ patients\ received\ in\ ED} * 100$
Waiting time for triage classification (SC31)	Average waiting time for triage classification	$\sum_{k=1}^{n} \frac{AT_k - TCT_k}{n}$. Where: AT_k : *arrival time for patient k* TCT_k : *triage classification time for patient k* n : *number of patients in a year* .
Hospital-acquired infections (SC32)	Average number of hospital-acquired infections per month	$\frac{Total\ of\ hospital-acquired\ infections\ in\ a\ year}{12}$.
Medication errors (SC33)	Average number of medication errors per month	$\frac{Total\ of\ medication\ errors\ in\ a\ year}{12}$
Errors of clinical diagnosis (SC34)	Average number of clinical diagnosis errors per month	$\frac{Total\ of\ clinical\ diagnosis\ errors\ in\ a\ year}{12}$.
Patient misidentification (SC35)	Average number of patient misidentification errors per month	$\frac{Total\ of\ patient\ misidentification\ errors\ in\ a\ year}{12}$.

Tables 15a-15b depicted the TOPSIS decision matrix X (Eq. 24) where emergency departments (ED1, ED2, and ED3) were matched to the above-mentioned sub-criteria. KPIs values were then introduced in this table considering the description presented in Table 14. The positive A^+ and negative A^- ideal scenarios were also established in this table. Additionally, the sub-criterion global weights were derived from the FAHP method using Eq. 1-7. On the other hand, Tables 16a-16b show the normalized decision matrix *R* in accordance with Eq. 25 and Eq. 26. Tables 17a-17b present the weighted normalized decision matrix *V* (Eq.27) while Table 18 evidences the distance of each ED from the positive ideal solution d_i^+. Table 18 also provide~~s~~ the contribution of each sub-criterion to the total PIS separation. Lately, Table 19 describes the distance of each ED from the negative ideal scenario d_i^- and the influence of each decision element on this distance.

Table 15a. TOPSIS decision matrix *X* (SC1 – SC18)

	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12	SC13	SC14	SC15	SC16	SC17	SC18
ED1	1.000	0.900	1.000	1.000	690.000	0.950	0.850	0.930	1.000	1.000	1.000	1.500	1.000	25.000	1.500	1.000	1.000	4.000
ED2	0.950	0.800	1.000	1.000	580.000	0.880	0.780	0.850	1.000	1.000	1.000	1.000	1.000	25.000	3.500	1.000	1.000	3.000
ED3	1.000	0.930	1.000	1.000	420.000	0.900	0.750	0.880	1.000	0.900	1.000	1.500	1.000	30.000	3.000	1.000	1.000	3.000
A+	1.000	0.930	1.000	1.000	690.000	0.950	0.850	0.930	1.000	1.000	1.000	1.000	1.000	25.000	1.500	1.000	1.000	4.000
A-	0.950	0.800	1.000	1.000	420.000	0.880	0.750	0.850	1.000	0.900	1.000	1.500	1.000	30.000	3.500	1.000	1.000	3.000
W	0.055	0.027	0.034	0.062	0.036	0.049	0.043	0.025	0.042	0.042	0.042	0.020	0.021	0.013	0.017	0.013	0.012	0.006
Norm	1.704	1.521	1.732	1.732	994.435	1.577	1.376	1.537	1.732	1.676	1.732	2.345	1.732	46.368	4.848	1.732	1.732	5.831

Table 15b. TOPSIS decision matrix *X* (SC19 – SC35)

	SC19	SC20	SC21	SC22	SC23	SC24	SC25	SC26	SC27	SC28	SC29	SC30	SC31	SC32	SC33	SC34	SC35
ED1	0.000	1.000	0.850	1.000	1.000	0.850	0.900	0.200	35.000	0.950	1.500	0.150	30.000	2.000	2.000	3.000	1.000
ED2	1.000	1.000	0.900	1.000	1.000	0.800	0.850	0.200	45.000	0.900	2.000	0.200	25.000	1.000	1.000	2.000	0.000
ED3	2.000	1.000	0.850	1.000	1.000	0.830	0.900	0.150	40.000	0.900	1.500	0.350	25.000	0.000	3.000	3.000	2.000
A+	0.000	1.000	0.900	1.000	1.000	0.850	0.900	0.200	35.000	0.950	1.500	0.150	25.000	0.000	1.000	2.000	0.000
A-	2.000	1.000	0.850	1.000	1.000	0.800	0.850	0.150	45.000	0.900	2.000	0.350	30.000	2.000	3.000	3.000	2.000
W	0.041	0.043	0.027	0.008	0.041	0.037	0.036	0.020	0.015	0.028	0.015	0.033	0.009	0.024	0.023	0.018	0.022
Norm	2.236	1.732	1.502	1.732	1.732	1.432	1.531	0.320	69.642	1.588	2.915	0.430	46.368	2.236	3.742	4.690	2.236

Table 16a. Normalized decision matrix *R* for emergency departments (SC1 – SC18)

	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12	SC13	SC14	SC15	SC16	SC17	SC18
ED1	0.587	0.592	0.577	0.577	0.694	0.602	0.618	0.605	0.577	0.597	0.577	0.640	0.577	0.539	0.309	0.577	0.577	0.686
ED2	0.558	0.526	0.577	0.577	0.583	0.558	0.567	0.553	0.577	0.597	0.577	0.426	0.577	0.539	0.722	0.577	0.577	0.514
ED3	0.587	0.611	0.577	0.577	0.422	0.571	0.545	0.573	0.577	0.537	0.577	0.640	0.577	0.647	0.619	0.577	0.577	0.514
A+	0.587	0.611	0.577	0.577	0.694	0.602	0.618	0.605	0.577	0.597	0.577	0.426	0.577	0.539	0.309	0.577	0.577	0.686
A-	0.558	0.526	0.577	0.577	0.422	0.558	0.545	0.553	0.577	0.537	0.577	0.640	0.577	0.647	0.722	0.577	0.577	0.514
W	0.055	0.027	0.034	0.062	0.036	0.049	0.043	0.025	0.042	0.042	0.042	0.020	0.021	0.013	0.017	0.013	0.012	0.006

Table 16b. Normalized decision matrix *R* for emergency departments (SC19 – SC35)

	SC19	SC20	SC21	SC22	SC23	SC24	SC25	SC26	SC27	SC28	SC29	SC30	SC31	SC32	SC33	SC34	SC35
ED1	0.000	0.577	0.566	0.577	0.577	0.593	0.588	0.625	0.503	0.598	0.514	0.349	0.647	0.894	0.535	0.640	0.447
ED2	0.447	0.577	0.599	0.577	0.577	0.559	0.555	0.625	0.646	0.567	0.686	0.465	0.539	0.447	0.267	0.426	0.000
ED3	0.894	0.577	0.566	0.577	0.577	0.579	0.588	0.469	0.574	0.567	0.514	0.814	0.539	0.000	0.802	0.640	0.894
A+	0.000	0.577	0.599	0.577	0.577	0.593	0.588	0.625	0.503	0.598	0.514	0.349	0.539	0.000	0.267	0.426	0.000
A-	0.894	0.577	0.566	0.577	0.577	0.559	0.555	0.469	0.646	0.567	0.686	0.814	0.647	0.894	0.802	0.640	0.894
W	0.041	0.043	0.027	0.008	0.041	0.037	0.036	0.020	0.015	0.028	0.015	0.033	0.009	0.024	0.023	0.018	0.022

Table 17a. Weighted normalized decision matrix *V* for emergency departments (SC1 – SC18)

	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12	SC13	SC14	SC15	SC16	SC17	SC18
ED1	0.032	0.016	0.019	0.035	0.025	0.029	0.026	0.015	0.024	0.025	0.024	0.013	0.012	0.007	0.005	0.008	0.007	0.004
ED2	0.030	0.014	0.019	0.035	0.021	0.027	0.024	0.014	0.024	0.025	0.024	0.008	0.012	0.007	0.012	0.008	0.007	0.003
ED3	0.032	0.016	0.019	0.035	0.015	0.028	0.023	0.014	0.024	0.022	0.024	0.013	0.012	0.008	0.010	0.008	0.007	0.003
A+	0.032	0.016	0.019	0.035	0.025	0.029	0.026	0.015	0.024	0.025	0.024	0.008	0.012	0.007	0.005	0.008	0.007	0.004
A-	0.030	0.014	0.019	0.035	0.015	0.027	0.023	0.014	0.024	0.022	0.024	0.013	0.012	0.008	0.012	0.008	0.007	0.003

Table 17b. Weighted normalized decision matrix *V* for emergency departments (SC19 – SC35)

	SC19	SC20	SC21	SC22	SC23	SC24	SC25	SC26	SC27	SC28	SC29	SC30	SC31	SC32	SC33	SC34	SC35
ED1	0.000	0.025	0.015	0.004	0.024	0.022	0.021	0.012	0.007	0.017	0.007	0.011	0.006	0.021	0.013	0.012	0.010
ED2	0.018	0.025	0.016	0.004	0.024	0.020	0.020	0.012	0.009	0.016	0.010	0.015	0.005	0.011	0.006	0.008	0.000
ED3	0.036	0.025	0.015	0.004	0.024	0.021	0.021	0.009	0.008	0.016	0.007	0.027	0.005	0.000	0.018	0.012	0.019
A+	0.000	0.025	0.016	0.004	0.024	0.022	0.021	0.012	0.007	0.017	0.007	0.011	0.005	0.000	0.006	0.008	0.000
A-	0.036	0.025	0.015	0.004	0.024	0.020	0.020	0.009	0.009	0.016	0.010	0.027	0.006	0.022	0.018	0.012	0.019

Table 18. Separation measures from PIS

Sub-criterion	ED1	ED2	ED3
SC1	0.0000000	0.0000026	0.0000000
SC2	0.0000003	0.0000053	0.0000000
SC3	0.0000000	0.0000000	0.0000000
SC4	0.0000000	0.0000000	0.0000000
SC5	0.0000000	0.0000159	0.0000955
SC6	0.0000000	0.0000047	0.0000024
SC7	0.0000000	0.0000048	0.0000098
SC8	0.0000000	0.0000017	0.0000007
SC9	0.0000000	0.0000000	0.0000000
SC10	0.0000000	0.0000000	0.0000063
SC11	0.0000000	0.0000000	0.0000000
SC12	0.0000175	0.0000000	0.0000175
SC13	0.0000000	0.0000000	0.0000000
SC14	0.0000000	0.0000000	0.0000020
SC15	0.0000000	0.0000492	0.0000277
SC16	0.0000000	0.0000000	0.0000000
SC17	0.0000000	0.0000000	0.0000000
SC18	0.0000000	0.0000009	0.0000009
SC19	0.0000000	0.0003362	0.0013448
SC20	0.0000000	0.0000000	0.0000000
SC21	0.0000008	0.0000000	0.0000008
SC22	0.0000000	0.0000000	0.0000000
SC23	0.0000000	0.0000000	0.0000000
SC24	0.0000000	0.0000017	0.0000003
SC25	0.0000000	0.0000014	0.0000000
SC26	0.0000000	0.0000000	0.0000098
SC27	0.0000000	0.0000045	0.0000011
SC28	0.0000000	0.0000008	0.0000008
SC29	0.0000000	0.0000066	0.0000000
SC30	0.0000000	0.0000147	0.0002355
SC31	0.0000009	0.0000000	0.0000000
SC32	0.0004608	0.0001152	0.0000000
SC33	0.0000378	0.0000000	0.0001511
SC34	0.0000147	0.0000000	0.0000147
SC35	0.0000968	0.0000000	0.0003872
S_i^+	0.0250930	0.0237937	0.0480495

Table 19. Separation measures from NIS

Sub-criterion	ED1	ED2	ED3
SC1	0.0000026	0.0000000	0.0000026
SC2	0.0000031	0.0000000	0.0000053
SC3	0.0000000	0.0000000	0.0000000
SC4	0.0000000	0.0000000	0.0000000
SC5	0.0000955	0.0000336	0.0000000
SC6	0.0000047	0.0000000	0.0000004
SC7	0.0000098	0.0000009	0.0000000
SC8	0.0000017	0.0000000	0.0000002
SC9	0.0000000	0.0000000	0.0000000
SC10	0.0000063	0.0000063	0.0000000
SC11	0.0000000	0.0000000	0.0000000
SC12	0.0000000	0.0000175	0.0000000
SC13	0.0000000	0.0000000	0.0000000
SC14	0.0000020	0.0000020	0.0000000
SC15	0.0000492	0.0000000	0.0000031
SC16	0.0000000	0.0000000	0.0000000
SC17	0.0000000	0.0000000	0.0000000
SC18	0.0000009	0.0000000	0.0000000
SC19	0.0013448	0.0003362	0.0000000
SC20	0.0000000	0.0000000	0.0000000
SC21	0.0000000	0.0000008	0.0000000
SC22	0.0000000	0.0000000	0.0000000
SC23	0.0000000	0.0000000	0.0000000
SC24	0.0000017	0.0000000	0.0000006
SC25	0.0000014	0.0000000	0.0000014
SC26	0.0000098	0.0000098	0.0000000
SC27	0.0000045	0.0000000	0.0000011
SC28	0.0000008	0.0000000	0.0000000
SC29	0.0000066	0.0000000	0.0000066
SC30	0.0002355	0.0001324	0.0000000
SC31	0.0000000	0.0000009	0.0000009
SC32	0.0000000	0.0001152	0.0004608
SC33	0.0000378	0.0001511	0.0000000
SC34	0.0000000	0.0000147	0.0000000
SC35	0.0000968	0.0003872	0.0000000
S_i^-	0.0437648	0.0347650	0.0219795

The closeness coefficients R_i and final ranking of EDs are detailed in Figure 11. These metrics were computed by implementing Eq. 32. In contrast to the measure proposed by Pan *et al.*[18], the closeness coefficient can better represent the entire context of ED performance which is advantageous for supporting government stimulation programs and measuring the effectiveness of interventions. The outcomes obtained from TOPSIS method reveals that ED1 was ranked first with 0.6356 whilst ED3 achieved the lowest score (0.3139). Additionally, a little difference was found between the performance measures of the first-ranked and second-ranked departments (0.0419). Such outcomes are an evidence of the regular and poor performance of these EDs in the wild. A similar finding was presented by Yeh and Cheng[91] who detected that 60% of national Taiwanese hospitals ran an inefficient performance. It is then important to further seek the reasons explaining the aforementioned results. To this aim, Fig. 12 and Fig. 13 were derived. In particular, ***Hospital-acquired infections "SC32"*** (2 cases/month - Separation = 0.0004608), ***Patient misidentification "SC35"*** (1 case/month - Separation = 0.0000968), ***Medication errors "SC33"*** (2 cases/month - Separation = 0.0000378), ***Errors of clinical diagnosis "SC34"*** (3 cases/month - Separation = 0.0000147), and ***Effectiveness of radiology process "SC12"*** (1.5 weeks - Separation = 0.0000175) were found as the most significant contributors to the total separation from positive ideal solution. This demonstrates that ED1 has to mainly focus on *Patient Safety* to augment its overall performance score and then benefit both patient care and ED sustainability. In this sense, ED1 has to emphasize on i) preventing errors ii) identifying lessons learned from errors and iii) providing an overarching umbrella of safety involving healthcare managers, medical staff, patients, and policymakers. Furthermore, ED1 should examine the causes of inefficiencies in radiology process. Specifically, healthcare managers should evaluate whether its radiology department is able to respond to the increased demand for emergency services. A gap between capacity and demand may cause extended waiting times for radiology results, and therefore lead to prolonged ED stay and increased costs. Such capacity could be slackened by delays related to preliminary reporting and transportation as well as ineffective job scheduling.

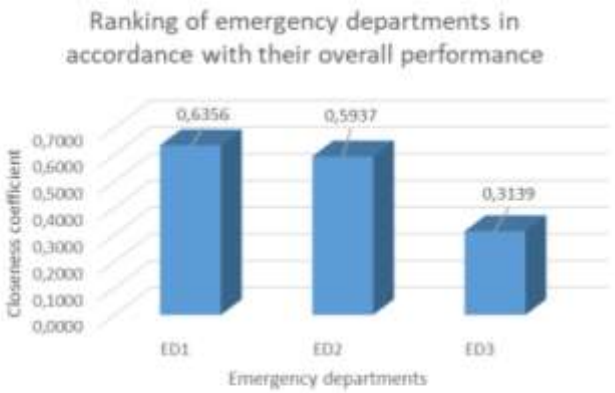


Fig. 11. Final ranking of emergency departments

Likewise, meaningful effects on the separation from ideal solutions in ED2 were also noted (refer to Fig 12, 13). In this department, ***Availability of specialists "SC19"*** (1 vacant position - Separation = 0.0003362), ***Hospital-acquired infections "SC32"*** (1 case/month - Separation = 0.0001152), and ***Effectiveness of pharmaceutical service "SC15"*** (3.5 days/order – Separation = 0.0000492) were concluded to be the main sources of this distance. Hence, improvement strategies must be primarily focused on *supporting processes*, *human resources*, and *patient safety* domains. Regarding the *availability of specialists*, ED2 should secure partnership agreements with international universities to address the lack of these medical personnel in the local market. In addition, incentive programs should be fostered to keep specialists motivated while new specialization programs can be set in local universities. In relation to *Hospital-acquired infections*, ED2 must search for infection prevention practices to avoid meaningful clinical consequences for both patients and medical staff. Furthermore, ED2 should focus on minimizing the infection risk associated with emergency services and the transmission of infectious diseases to both ED staff and patients. On the other hand, the average waiting time for drug delivery has to be significantly diminished in this emergency department. In this regard, it is suggested to implement a decision support system (DSS) for the correct and fast procurement of drugs. The DSS can help managers to monitor and prioritize the prescription orders in accordance with the triage category reported by the ED physicians. It is also recommended to collaborate with physicians to promote safe an effective medication use in ED2, and thereby ensuring the timely provision of drugs and continuity of emergency care.

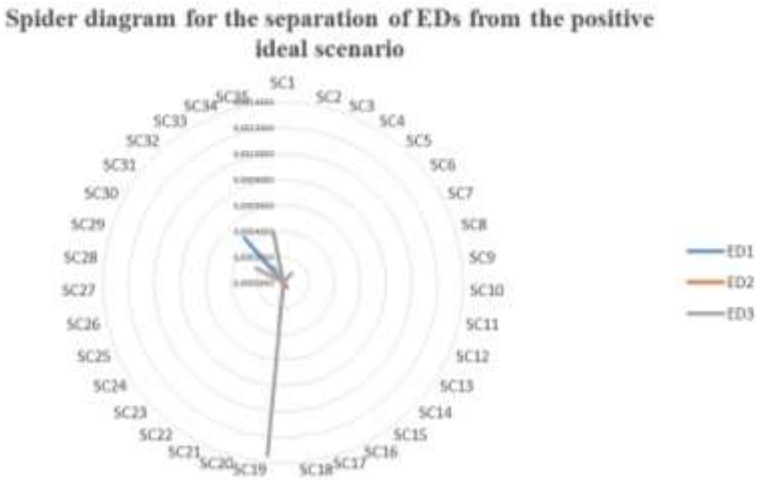


Fig.12. Spider diagram for positive ideal scenario

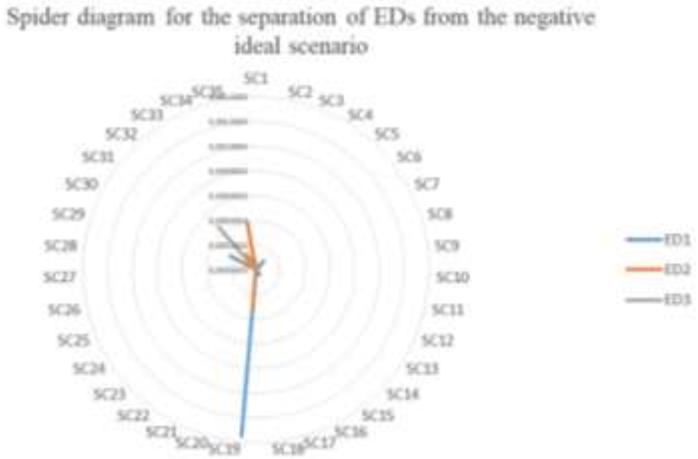


Fig.13. Spider diagram for negative ideal scenario

An analysis was also carried out to determine the root causes of poor performance in ED3. In this sense, the following decision elements were concluded to be the highest contributors: ***Availability of specialists "SC19"*** (two vacant positions - Separation = 0.0013448), ***Patient misidentification "SC35"*** (two cases/month – Separation = 0.0003872), and ***Readmission rate "SC30"*** (35% - Separation = 0.0002355). ED3 should then prioritize interventions related to *Human resources, patient safety, and quality* domains. In relation to the *availability of specialists*, the same strategies recommended for ED2 should be followed by ED3. Another aspect of concern in ED3 was the *patient misidentification*. In this respect, nurses have recognized that the most important factors causing the problem are: desire not to undermine patients' trust, time pressure, and confidence in their ability to informally identify patients.[86] Therefore, it is necessary to adopt technologies (e.g. ID wristband, barcodes) supporting the fast identification and tracking of patients while staying in ED3. Such technologies will help managers to avoid other errors related to clinical diagnosis and treatment.

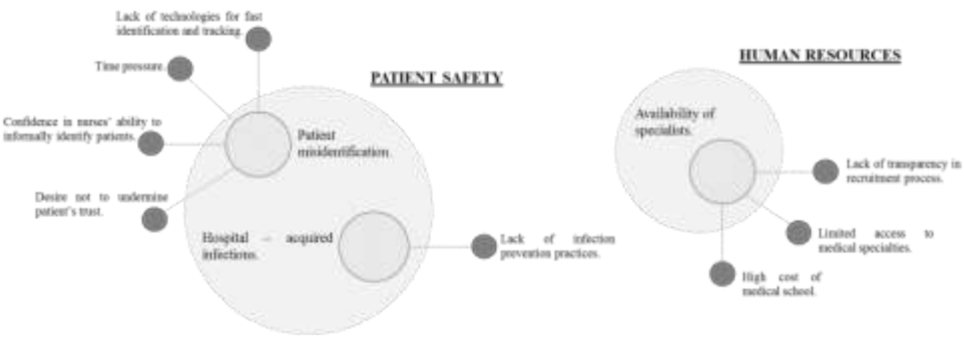


Fig.14. Map of performance improvement interventions to be undertaken within ED cluster

From a general perspective, the commonest and most critical criterion in this group of emergency departments is *Patient safety.* For this purpose, government authorities and managers of healthcare clusters should work together with EDs for supporting the creation of improvement strategies addressing this problem immediately. This motivates the revision of the medical care resources allocation in the public health sector as also proposed by Yeh and Cheng[91] who suggested the Taiwanese government reconsider the budget distribution between urban and non-urban hospitals. Additionally, *patient misidentification* and *hospital-acquired infections* should be measured and monitored progressively since they have been identified as common symptoms in most of the departments. Finally, the Ministry of Education, Ministry of Health and Social Protection and EDs should jointly define actions propelling the constant production of specialist physicians. In this respect, three barriers have to be overcome: i) the high cost of medical school, ii) the limited access to medical specialties, and iii) the lack of transparency in the recruitment process. By addressing these weaknesses (Fig. 14), the overall performance of emergency departments can be meaningfully augmented. Thereby, healthcare costs can be diminished while outcomes for patients requiring emergency care may be improved. This is consistent with Yamani *et al.*[16] who mentioned that the identification of strengths and weaknesses leads to better planning process and subsequent increased performance in EDs. In parallel, as also recommended by Yeh and Cheng,[91] ED performance can be regarded as a prerequisite for government incentives; thereby, performance improvement and self-efficiency operation can be effectively fostered within the public EDs.

5. Sensitivity analysis

A sensitivity analysis was undertaken to show the effects of changing the global sub-criterion weights on the final TOPSIS scores and ranking of EDs. The results of this analysis are depicted in Table 20 and Fig. 15. In this case, we considered the effects of varying the GW_1 ($\Delta_1 = 0.055$) values which represents changes in the global weights of the other sub-criteria $\{GW_1, GW_2, \ldots, GWn\}$ in accordance with the approach depicted in Alinezhad and Amini.[108] For example, if $GW_1 = 0.220$, the set of weights will be {0.220, 0.022, 0.028, 0.051, 0.030, 0.040, 0.035, 0.021, 0.035, 0.035, 0.035, 0.016, 0.017, 0.011, 0.014, 0.011, 0.010, 0.005, 0.034, 0.035, 0.022, 0.007, 0.034, 0.031, 0.030, 0.017, 0.012, 0.023, 0.012, 0.027, 0.007, 0.020, 0.019, 0.015, 0.018}.

Table 20: Sensitivity analysis results

	Closeness coefficient (CC_i)			**Ranking**		
GW_1	**ED1**	**ED2**	**ED3**	**ED1**	**ED2**	**ED3**
0.000	0.6354	0.5942	0.3133	1	2	3
0.055	0.6356	0.5937	0.3139	1	2	3
0.110	0.6361	0.5917	0.3159	1	2	3
0.165	0.6372	0.5880	0.3198	1	2	3
0.220	0.6391	0.5817	0.3263	1	2	3

Table 20 (Continued)

0.275	0.6419	0.5724	0.3360	1	2	3
0.330	0.6461	0.5593	0.3496	1	2	3
0.385	0.6522	0.5417	0.3679	1	2	3
0.440	0.6607	0.5190	0.3915	1	2	3
0.495	0.6724	0.4906	0.4209	1	2	3
0.550	0.6880	0.4565	0.4566	1	3	2
0.605	0.7084	0.4167	0.4987	1	3	2
0.660	0.7343	0.3714	0.5475	1	3	2
0.715	0.7661	0.3211	0.6029	1	3	2
0.770	0.8035	0.2662	0.6650	1	3	2
0.825	0.8460	0.2074	0.7340	1	3	2
0.880	0.8924	0.1451	0.8098	1	3	2
0.935	0.9412	0.0800	0.8926	1	3	2
0.990	0.9909	0.0125	0.9828	1	3	2

In summary, 19 combinations of sub-criteria were analysed. For each set of weights, the closeness coefficients and ranking of EDs were established. According to Table 20, ED_1 will have the best performance (CC_1 = 0.909) when GW_1 = 0.990, while the lowest score (CC_1 = 0.6354) will be reached in GW_1 = 0. Regarding ED_2, the highest closeness coefficient (CC_2 = 0.5942) will be obtained when GW_1 = 0 whilst the worst score (CC_2 = 0.0125) can be expected if GW_1 = 0.990. Concerning ED_3, the major performance (CC_3 = 0.9828) will be achieved when GW_1 = 0.990 whereas the poorest qualification (CC_3 = 03133) can be foreseen when $0 \leq GW_1 \leq 0.055$. Based on Fig. 15, ED_2 (the second ranked alternative), under the current conditions (expressed through the KPIs), will maintain this place if $0 \leq GW_1 < 0.550$. Then, as GW_1 increases, its overall performance continues falling. Specifically, when $0.550 \leq GW_1 < 0.990$, ED_2 is expected to be placed "third". The opposite behaviour is observed in ED_1 and ED_3 whose closeness coefficient rises as the GW_1 increases.

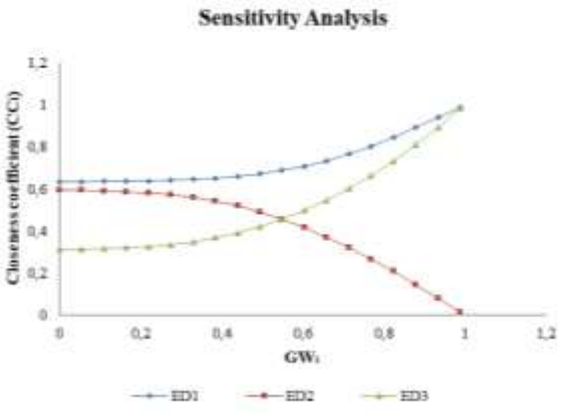


Fig.15. Sensitivity analysis of ED TOPSIS scores

6. Managerial and practical implications

The aforedescribed model provides meaningful insights to decision-makers, practitioners, cluster managers, and researchers involved in ED-related interventions. One of the major contributions is the identification of weaknesses and strengths in ED performance. In particular, the detection of shortcomings facilitates the design of focused interventions and the correct resource allocation during improvement process. Thereby, investments can be made on projects targeting an increased performance of EDs, an aspect of extreme importance in the public sector where the budget is highly constrained. In the cited example, *patient misidentification* and *hospital-acquired infections* were found to be the weakest points of ED cluster and special attention should be therefore paid to these sub-criteria for further improvement. On the other hand, as strengths are pointed out, cluster managers can replicate the good practices in EDs with similar deficiencies. For instance, a deepest exploration on maintenance plans can be undertaken on ED1 in order to understand the causes behind the high *availability of medical equipment* and widespread their adoption in the other EDs. As demands on emergency services continue to widen in the future, such strategies become the foundation that will propel the development of cost-effective collaborative structures providing highly satisfactory care.

From a cluster perspective, the approach here described can support the implementation of before-and-after analysis that enables decision-makers to assess the effectiveness of the applied strategies. Furthermore, such framework serves as a solid foundation for deploying incentive programs rewarding high-performance EDs. In this respect, it is also necessary to count on a mature performance measurement system continuously supplying high-quality data to the model. As such system is at the earlier stages and faces increasing criticism, it is advisable that cluster managers offer the appropriate endorsement through the path from data collection to reporting. In addition, adaptive measurement systems can be adopted for tackling the administrative and financial burden often addressed by EDs when administering their data.

On a different tack, the FAHP and FDEMATEL results underpin the effective creation and deployment of long-term plans through the identification of *dispatcher* criteria and sub-criteria. Development plans can be then centred on these elements for propelling multi-factorial interventions that respond to the multi-causality and interactive nature of ED context. For example, in the afore-detailed application, *suitability of medical equipment* and *state of medical equipment* can be prioritized in long-range planning for increasing the *availability of medical equipment* within EDs.

The above-mentioned implications end up affecting the patients’ perceptions regarding the care received at ED settings. Patients are increasingly becoming aware of EDs’ performance and their expectations are constantly evolving towards more challenging and complex scenarios. In fact, the selection of emergency care providers has been greatly influenced by the experience of others. Such considerations then confirm the relevant role that our proposed approach can play in a decision-making context where both patient care and financial sustainability often converge.

7. Conclusion

EDs are an important component of healthcare systems since they are responsible for providing timely and high-quality emergency care to patients with major injuries and life-threatening medical conditions. In this regard, multiple agents, factors, and processes should effectively interact to face the increased demand for emergency services while reducing operational costs. It is then essential to establish appropriate methods for progressively monitoring and assessing the overall performance of EDs.

Although performance evaluation has become a critical task for supporting the continuous development and improvement of EDs, the studies concentrating on deploying methodological frameworks addressing this problem are largely limited. In addition, the approaches presented in these studies do not represent the entire ED performance context since several important domains (e.g. medical equipment, human resources and infrastructure) have not been included in the assessment models. On the other hand, interrelations among criteria have not been studied which is a relevant aspect when considering the presence of interactions in emergency services and the need for creating long-term development plans. Another aspect of concern lies in the fact that poor effort has been made to represent the vagueness in performance evaluation models which limits their effectiveness in practical scenarios. The present paper bridged the aforementioned gaps through a novel MCDM hybrid model based on FAHP, FDEMATEL, and TOPSIS techniques. This approach provides more robust results, overcomes the limitations of single methods, and deals with the vagueness derived from human judgments. Hence, our proposed method is useful to provide decision support to policymakers, healthcare managers, government authorities, cluster directors, and practitioners when making managerial decisions targeting improved patient safety, satisfaction level, and quality of care.

The proposed approach is also a guide to evaluate the response of EDs when facing a rising number of patients, which facilitates the development of more efficient planning processes. This specific aspect is even more critical in the public sector where the financial resources are greatly limited and should be hence assigned properly. In the present study, 8 domains, 35 sub-criteria, and 3 public emergency departments were considered with the basis on the current healthcare regulations, reported literature, and experts' opinion. The outcome is a multi-criteria model evaluating the overall performance of emergency departments which is relevant when targeting i) decreased readmission rate, ii) increased patient satisfaction, iii) reduced mortality rate, and iv) decreased healthcare costs.

From the managerial perspective, the aforesaid model provides significant support to decision-makers, practitioners, cluster managers, and researchers involved in emergency care services. The contributions are summarized as follows: i) Identification of weaknesses and strengths in ED performance ii) Implementation of before-and-after analysis that enables decision-makers to assess the effectiveness of the applied strategies, and iii) Identification of *dispatcher* criteria and sub-criteria for supporting the creation of short-term and long-term development plans.

In relation to the scenario under study, the results show that ED1 ($R_1 = 0.6356$) is the emergency department with the highest overall performance. In addition, considering the FAHP results, *Infrastructure* was the parameter with the highest importance (GW = 21.50%). However, given the little difference found between the second and last criterion, it is recommended to deploy multifactorial improvement strategies with a primary focus on *Infrastructure*. On a different tack, *Patient safety* obtained the highest positive *C + R* value (12.771) and it is therefore considered as the main generator of effects in emergency departments. Hence, it should be highly prioritized for continuous monitoring and intervention. *Patient safety* was also concluded to be the weakest aspect in the cited set of emergency departments. Such finding calls for the rapid intervention of the local government and healthcare cluster in order to avoid poor clinical outcomes in admitted ED patients and the associated cost overruns as established by Zhao and Paul[17] through their MAPQC approach. The *availability of specialists* was also found to be a primary intervention point in the ED cluster. The cluster manager should thus secure partnership agreements with international universities to address the lack of these medical personnel in the local market. Moreover, barriers such as: high cost of medical school, limited access to medical specialties, and lack of transparency in the recruitment process have to be tackled to ensure the constant provision of specialists that face the projected increased demand on emergency care services. Lately, the sensitivity analysis revealed that, under current conditions, ED_2 will be ranked second if $0 \leq GW_1 < 0.550$. In addition, its overall performance will fall as GW_1 increases, which is opposite to the behaviour observed in ED_1 and ED_3.

The robustness of the results presented in this paper is limited to the consulted experts and may thus vary in other contexts. Therefore, complementary to this approach, future studies may consider financial[112] and environmental domains to better assist ED managers and policymakers in decision-making processes. Thereby, the tactical-operational processes and the most strategic level of the EDs can be further integrated for better resource allocation and emergency care. The proposed approach can be also adapted for measuring the performance of EDs when addressing pandemics outbreaks such as the current Covid-19[113, 114]. Furthermore, it is envisioned to incorporate interval data in TOPSIS method in order to represent the variation of KPIs, upgrade the maturity of the ED performance measurement system, and subsequently provide deepest insights for future interventions. This is, of course, subject to the adoption of interval-valued indicators supporting the effective application of interval TOPSIS in the wild. Finally, it is intended to contrast our hybrid approach with other vagueness-based methods (i.e. Intuitionistic fuzzy set theory and Neutrosophic set theory) so that similarities and differences regarding the criteria/sub-criteria weights, robustness, and final rankings can be identified.

Acknowledgments

We would like to express our very great appreciation to Gloria Osorio, Janeth Rebolledo, Aurora Piñeres, Giuseppe Polifrony, Zulmeira Herrera, Javier Rúa, and Natalia Jaramillo for their valuable suggestions, recommendations and support during this project.

References

1. K. Lord, V. Parwani, A. Ulrich, A. Finn, E. B. Rothenberg, C. Emerson and A. K. Venkatesh, Emergency department boarding and adverse hospitalization outcomes among patients admitted to a general medical service, *Am. J. Emerg. Med.* **36**(7) (2018) 1246-1248, doi: 10.1016/j.ajem.2018.03.043
2. T. W. Wong, The role of the Emergency Department: beyond gatekeeping, *Hong. Kong. Med. J.* **168**(1) (2010) 4.
3. M. Ortiz, J. E. Caballero, and F. S. Sánchez, A methodology for the creation of integrated service networks in outpatient internal medicine, *Proc. Lect. Notes. Comput. Sc*, Vol. 9456, Puerto Varas, 2015, pp. 247-257, doi: 10.1007/978-3-319-26508-7_24 P
4. C. M. Sørup, P. Jacobsen, and J. L. Forberg, Evaluation of emergency department performance– a systematic review on recommended performance and quality-in-care measures, *Scand. J. Trauma. Resus.* **21**(1) (2013) 62, doi: 10.1186/1757-7241-21-62
5. S. Farokhi, and E. Roghanian, E. Determining quantitative targets for performance measures in the balanced scorecard method using response surface methodology, *Manage. Decis*. **56**(9) (2018) 2006-2037, doi: 10.1108/MD-08-2017-0772
6. M. Ortiz, and H. F. Jiménez, Use of six sigma methodology to reduce appointment lead-time in obstetrics outpatient department, *J. Med. Syst.* **40**(10) (2016) 220, doi: 10.1007/s10916-016-0577-3
7. M.V. Sunder, L. S. Ganesh, and R. R. Marathe, A morphological analysis of research literature on Lean Six Sigma for services, *Int. J. Oper. Prod. Man.* **38**(1) (2018)149-182, doi: 10.1108/IJOPM-05-2016-0273
8. B. P. Bergeron, Performance management in healthcare: from key performance indicators to balanced scorecard (Taylor & Francis, New York, 2017).
9. S. P. Santos, V. Belton, S. Howick, and M. Pilkington, Measuring organisational performance using a mix of OR methods, *Technol. Forecast. Soc.* **131** (2018) 18-30, doi: 10.1016/j.techfore.2017.07.028
10. W. Ho, and X. Ma, The state-of-the-art integrations and applications of the analytic hierarchy process, *Eur. J. Oper. Res.* **267**(2) (2018) 399-414, doi: 10.1016/j.ejor.2017.09.007
11. A. Dargi, A. Anjomshoae, M. R. Galankashi, A. Memari, and M. B. M. Tap, Supplier selection: A fuzzy-ANP approach, *Procedia. Comput. Sci*. **31**(2014) 691-700, doi: 10.1016/j.procs.2014.05.317
12. M. Jing, Y. Jie, L. Shou-yi, and W. Lu, Application of fuzzy analytic hierarchy process in the risk assessment of dangerous small-sized reservoirs, *Int. J. Mach. Learn. Cyb*. **9**(1) (2018) 113-123, doi: 10.1007/s13042-015-0363-4
13. F. Samanlioglu, Y. E. Taskaya, U. C. Gulen, and O. Cokcan, A fuzzy AHP–TOPSIS-based group decision-making approach to IT personnel selection, *Int. J. Fuzzy Syst.* **20**(5) (2018) 1576-1591, doi: 10.1007/s40815-018-0474-7
14. M. F. Chen, G. H. Tzeng, and T. I. Tang, Fuzzy MCDM approach for evaluation of expatriate assignments, *Int. J. Inf. Tech. Decis.* **4**(02) (2005) 277-296, doi: 10.1142/S0219622005001520
15. E. Mohammadi, Y. Zaebi, S. H. Mousavi, M. Mahboubi, M. Mohammadi, A. Zangeneh, and F. Soleymani, Emergency department performance evaluation indicators in pre and post-health care reform in kermanshah public hospitals. *Res. J. Med. Sci.* **10**(2) (2016) 54-59, doi: 10.3923/rjmsci.2016.54.59
16. N. Yamani, S. A. Moosavi, M. Alizadeh, F. Khorvash, and M. A. Ghiasi, 360-degree performance evaluation of emergency medicine ward in Alzahra Hospital. *J. Pak. Med. Assoc.* **62**(3, Suppl. 2) (2012) S13-7.

17. R. Zhao, and D. Paul III, Performance Evaluation of Hospitals' Emergency Departments using a Modified American Productivity and Quality Center Approach. *Int. J. Soc. Eco.* **3**(4) (2012), 34-47, doi: 10.4018/jsesd.2012100103
18. C. L. Pan, C. F. Chang, C. W. Chiu, C. H. Chi, Z. Tian, J. H. Wen, and J. C. Wen, What can emergency medicine learn from kinetics: introducing an alternative evaluation and a universal criterion standard for emergency department performance. *Medicine.* **95**(11) (2016), doi: 10.1097/MD.0000000000002972
19. S. Ketabi, E. Teymouri, and M. Ketabi, Efficiency measurement of emergency departments in Isfahan, Iran. *Int. J. Process. Manag.* **8**(2) (2018) 142-155.
20. M. Gul, E. Celik, A. T. Gumus, and A. F. Guneri, Emergency department performance evaluation by an integrated simulation and interval type-2 fuzzy MCDM-based scenario analysis, *Eur. J. Ind. Eng.* **10**(2) (2016) 196-223, doi: 10.1504/EJIE.2016.075846
21. S. Jovčić, P. Průša, M. Dobrodolac, and L. Švadlenka, A Proposal for a Decision-Making Tool in Third-Party Logistics (3PL) Provider Selection Based on Multi-Criteria Analysis and the Fuzzy Approach, *Sustainability-Basel*, **11**(15) (2019) 4236, doi: 10.3390/su11154236
22. T. L. Saaty, and L. G. Vargas, *Models, methods, concepts & applications of the analytic hierarchy process* (Springer Science & Business Media. New York, 2012), doi: 10.1007/978-1-4614-3597-6
23. L.G. Vargas, Voting with Intensity of preferences, *Int. J. Inf. Tech. Decis.* **15**(04) (2016) 839-859, doi: 10.1142/S0219622016400058
24. K. C. Lee, W. H. Tsai, C. H. Yang, and Y. Z. Lin, An MCDM approach for selecting green aviation fleet program management strategies under multi-resource limitations, *J. Air Transp. Manag*. **68** (2018) 76-85, doi: 10.1016/j.jairtraman.2017.06.011
25. A. Labib, and M. Read, A hybrid model for learning from failures: The Hurricane Katrina disaster, *Expert Syst. Appl.* **42**(21) (2015) 7869-7881, doi: 10.1016/j.eswa.2015.06.020
26. S. Hosseini, and A. Al Khaled, A hybrid ensemble and AHP approach for resilient supplier selection, *J. Intell. Manuff.* **30**(1) (2019) 207-228, doi: 10.1007/s10845-016-1241-y
27. E. K. Zavadskas, K. Govindan, J. Antucheviciene, and Z. Turskis, Hybrid multiple criteria decision-making methods: A review of applications for sustainability issues, *Econ. Res-Ekon. istraž.* **29(1)** (2016) 857-887, doi: 10.1080/1331677X.2016.1237302
28. F. Lolli, E. Balugani, A. Ishizaka, R. Gamberini, M. A. Butturi, S. Marinello, and B. Rimini, On the elicitation of criteria weights in PROMETHEE-based ranking methods for a mobile application, *Expert Syst. Appl.* **120** (2019) 217-227, doi: 10.1016/j.eswa.2018.11.030
29. A. T. de Almeida Filho, T. R. Clemente, D. C. Morais, and A. T. de Almeida, Preference modeling experiments with surrogate weighting procedures for the PROMETHEE method, *Eur. J. Oper. Res.* **264**(2) (2018) 453-461, doi: 10.1016/j.ejor.2017.08.006
30. G. Sun, X. Guan, X. Yi, and Z. Zhou, An innovative TOPSIS approach based on hesitant fuzzy correlation coefficient and its applications, *Appl. Soft Comput.* **68** (2018) 249-267, doi: 10.1016/j.asoc.2018.04.004
31. T. D. Frazão, D. G. Camilo, E. L. Cabral, and R. P. Souza, Multicriteria decision analysis (MCDA) in health care: a systematic review of the main characteristics and methodological steps, *BMC Med. Inform. Decis.* **18**(1) (2018) 90, doi: 10.1186/s12911-018-0663-1
32. M. A. Ortiz-Barrios, Z. Herrera-Fontalvo, J. Rúa-Muñoz, S. Ojeda-Gutiérrez, F, De Felice, and A. Petrillo, An integrated approach to evaluate the risk of adverse events in hospital sector: from theory to practice, *Manage. Decis*. **56**(10) (2018) 2187-2224, doi: 10.1108/MD-09-2017-0917
33. A. A Al Salem, and A. Awasthi, Investigating rank reversal in reciprocal fuzzy preference relation based on additive consistency: Causes and solutions, *Comput. Ind. Eng.* **115** (2018) 573-581, doi: 10.1016/j.cie.2017.11.027
34. R. F. de Farias, and L. Ferreira, A new approach to avoid rank reversal cases in the TOPSIS method, *Comput. Ind. Eng.* **132** (2019) 84-97, doi: 10.1016/j.cie.2019.04.023

35. W. Ho, and X. Ma, The state-of-the-art integrations and applications of the analytic hierarchy process, *Eur. J. Oper. Res*. **267**(2) (2018) 399-414, doi: 10.1016/j.ejor.2017.09.007
36. A. Emrouznejad, and G. L. Yang, A survey and analysis of the first 40 years of scholarly literature in DEA: 1978–2016, *Socio-Econ. Plan. Sci.* **61**(2018) 4-8, doi: 10.1016/j.seps.2017.01.008
37. A. Arya, and S. P. Yadav, Development of FDEA models to measure the performance efficiencies of DMUs, *Int. J. Fuzzy Syst.* **20**(1) (2018) 163-173, doi: 10.1007/s40815-017-0325-y
38. S. Mufazzal, and S. M. Muzakkir, A new multi-criterion decision making (MCDM) method based on proximity indexed value for minimizing rank reversals, *Comput. Ind. Eng*. **119** (2018) 427-438, doi: 10.1016/j.cie.2018.03.045
39. I. Kaliszewski, and D. Podkopaev, Simple additive weighting—A metamodel for multiple criteria decision analysis methods, *Expert Syst. Appl.* **54**(2016) 155-161, doi: 10.1016/j.eswa.2016.01.042
40. S. H. Mousavi-Nasab, and A. Sotoudeh-Anvari, A new multi-criteria decision making approach for sustainable material selection problem: A critical study on rank reversal problem, *J. Clean. Prod*. **182**(2018) 466-484, doi: 10.1016/j.jclepro.2018.02.062
41. Z. Chen, X. Ming, X. Zhang, D. Yin, and Z. Sun, A rough-fuzzy DEMATEL-ANP method for evaluating sustainable value requirement of product service system, *J. Clean. Prod*. **228** (2019) 485-508, doi: 10.1016/j.jclepro.2019.04.145
42. F. M. Jumaah, A. A. Zadain, B. B. Zaidan, A. K. Hamzah, and R. Bahbibi, Decision-making solution based multi-measurement design parameter for optimization of GPS receiver tracking channels in static and dynamic real-time positioning multipath environment, *Measurement*. **118**(2018), 83-95, doi: 10.1016/j.measurement.2018.01.011
43. A. Singh, and A. Prasher, Measuring healthcare service quality from patients' perspective: using Fuzzy AHP application, *Total Qual. Manag. Bus.* **30**(3-4)(2019), 284-300, doi: 10.1080/14783363.2017.1302794
44. İ. Otay, B. Oztaysi, S. C. Onar, and C. Kahraman, Multi-expert performance evaluation of healthcare institutions using an integrated intuitionistic fuzzy AHP&DEA methodology, *Knowl-Based Syst.* **133**(2017), 90-106, doi: 10.1016/j.knosys.2017.06.028
45. A. Awasthi, K. Govindan, and S. Gold, Multi-tier sustainable global supplier selection using a fuzzy AHP-VIKOR based approach, *Int. J. Prod. Econ*. **195**(2018), 106-117, doi: 10.1016/j.ijpe.2017.10.013
46. N. V. Izquierdo, O. B. P. Lezama, R. G. Dorta, A. Viloria, I. Deras, and L. Hernández-Fernández, Fuzzy Logic Applied to the Performance Evaluation. Honduran Coffee Sector Case, *Proc. Lect. Notes. Comput. Sc,* Vol. 10942, Chiang Mai, 2018, pp. 164-173, doi: 10.1007/978-3-319-93818-9_16
47. M. Gul, A. F. Guneri, and S. M. Nasirli, A fuzzy-based model for risk assessment of routes in oil transportation, *Int. J. Environ. Sci. Te*. **16**(8) (2019), 4671-4686, doi: 10.1007/s13762-018-2078-z
48. M. O. Barrios, H. F. Jiménez, and S. N Isaza, Comparative analysis between ANP and ANP-DEMATEL for six sigma project selection process in a healthcare provider, *Proc. Lect. Notes. Comput. Sc*, Vol. 8868, Belfast, 2014, pp. 413-416, doi: 10.1007/978-3-319-13105-4_62
49. Y. Kazancoglu, I. Kazancoglu, and M. Sagnak, Fuzzy DEMATEL-based green supply chain management performance: application in cement industry, *Ind. Manage. Data Syst.* **118**(2) (2018), 412-431, doi: 10.1108/IMDS-03-2017-0121
50. L. Abdullah, and N. Zulkifli, Integration of fuzzy AHP and interval type-2 fuzzy DEMATEL: An application to human resource management, *Expert Syst. Appl.* **42**(9) (2015), 4397-4409, doi: 10.1016/j.eswa.2015.01.021

51. M. Ashtiani, and M. A. Azgomi, A hesitant fuzzy model of computational trust considering hesitancy, vagueness and uncertainty, *Appl. Soft Comput.* **42**(2016), 18-37, doi: 10.1016/j.asoc.2016.01.023
52. S. H. Zyoud, and D. Fuchs-Hanusch, A bibliometric-based survey on AHP and TOPSIS techniques, *Expert Syst. Appl*. **78**(2017), 158-181, doi: 10.1016/j.eswa.2017.02.016
53. S. Scholz, B. Ngoli, and S. Flessa, Rapid assessment of infrastructure of primary health care facilities–a relevant instrument for health care systems management, *BMC Health Serv. Res.* **15**(1)(2015), 183, doi: 10.1186/s12913-015-0838-8
54. I. Ivlev, J. Vacek, and P. Kneppo, Multi-criteria decision analysis for supporting the selection of medical devices under uncertainty, *Eur. J. Oper. Res.* **247**(1) (2015), 216-228, doi: 10.1016/j.ejor.2015.05.075
55. E. Kovacs, R. Strobl, A. Phillips, A. J. Stephan, M. Müller, J. Gensichen, and E. Grill, E, Systematic review and meta-analysis of the effectiveness of implementation strategies for non-communicable disease guidelines in primary health care, *J. Gen. Intern. Med.* **33**(7) (2018), 1142-1154, doi: 10.1007/s11606-018-4435-5.
56. C. Morley, M. Unwin, G. M. Peterson, J. Stankovich, and L. Kinsman, Emergency department crowding: A systematic review of causes, consequences and solutions, *Plos One*. **13**(8) (2018), e0203316, doi: 10.1371/journal.pone.0203316
57. R. M. Hermann, E. Long, and R. L. Trotta, Improving Patients' Experiences Communicating With Nurses and Providers in the Emergency Department, *J. Emerg. Nurs*. **45**(5)(2019), 523-530, doi: 10.1016/j.jen.2018.12.001
58. K. L. Hawley, M. Mazer-Amirshahi, M. S. Zocchi, E. R. Fox, and J. M. Pines, Longitudinal trends in US drug shortages for medications used in emergency departments (2001–2014), *Acad. Emerg. Med.* **23**(1), 63-69, doi: 10.1111/acem.12838
59. A. S. Stang, J. Crotts, D. W. Johnson, L. Hartling, and A. Guttmann, Crowding measures associated with the quality of emergency department care: a systematic review, *Acad. Emerg. Med.* **22**(6) (2015), 643-656, doi: 10.1111/acem.12682.
60. N. Chanamool, and T. Naenna, Fuzzy FMEA application to improve decision-making process in an emergency department, *Appl. Soft Comput.* **43**(2016), 441-453, doi: 10.1016/j.asoc.2016.01.007
61. P. Farup, Are measurements of patient safety culture and adverse events valid and reliable? Results from a cross sectional study, *BMC Health Serv. Res.* **15**(1) (2015), 186, doi: 10.1186/s12913-015-0852-x
62. E. J. Carter, S. M. Pouch, and E. L Larson, The relationship between emergency department crowding and patient outcomes: a systematic review, *J. Nurs. Scholarship.* **46**(2) (2014) 106-115, doi: https://doi.org/10.1111/jnu.12055
63. R. H. Ebben, F. Siqeca, U. R. Madsen, L. C. Vloet, and T. Van Achterberg, Effectiveness of implementation strategies for the improvement of guideline and protocol adherence in emergency care: a systematic review, *BMJ Open*. **8**(11) (2018), e017572, doi: 10.1136/bmjopen-2017-017572
64. G. D. Innes, M. L. Sivilotti, H. Ovens, K. McLelland, A. Dukelow, E. Kwok, ... and C. K. Sing, Emergency overcrowding and access block: A smaller problem than we think. *Can. J. Emerg. Med.* **21**(2) (2019), 177-185, doi: 10.1017/cem.2018.446
65. S. S. Chan, N. K. Cheung, C. A. Graham, and T. H. Rainer, Strategies and solutions to alleviate access block and overcrowding in emergency departments, *Hong Kong Med. J*, **21**(4) (2015), 345-52, doi: 10.12809/hkmj144399
66. M. H. Yarmohammadian, F. Rezaei, A. Haghshenas, and N. Tavakoli, Overcrowding in emergency departments: A review of strategies to decrease future challenges. *J. Res. Med. Sci.* **22**(2017), doi: 10.4103/1735-1995.200277

67. S. Di Somma, L. Paladino, L. Vaughan, I. Lalle, L. Magrini, and M. Magnanti, Overcrowding in emergency department: an international issue, *Intern. Emerg. Med*. **10**(2) (2015), 171-175, doi: 10.1007/s11739-014-1154-8
68. O. A. Uthman, C. Walker, S. Lahiri, D. Jenkinson, V. Adekanmbi, W. Robertson, and A. Clarke, General practitioners providing non-urgent care in emergency department: a natural experiment, *BMJ Open*. **8**(5) (2018), e019736, doi: 10.1136/bmjopen-2017-019736
69. J. A. Razzak, S. M. Baqir, U. R. Khan, D. Heller, J. Bhatti, and A. A. Hyder, Emergency and trauma care in Pakistan: a cross-sectional study of healthcare levels, *Emerg. Med. J*, 32(3) (2015), 207-213, doi: 10.1136/emermed-2013-202590
70. R. C. Dart, L. R. Goldfrank, B. L. Erstad, D. T. Huang, K. H. Todd, J. Weitz, ... and W. Banner, Expert consensus guidelines for stocking of antidotes in hospitals that provide emergency care, *Ann. Emerg. Med.* **71**(3) (2018), 314-325, doi: 10.1016/j.annemergmed.2017.05.021
71. D. A. Mkoka I. Goicolea, A. Kiwara, M. Mwangu, and A. K. Hurtig, Availability of drugs and medical supplies for emergency obstetric care: experience of health facility managers in a rural District of Tanzania, *BMC Pregnancy Childb.* **14**(1) (2014) 108, doi: 10.1186/1471-2393-14-108
72. M. J. Beck, D. Okerblom, A. Kumar, S. Bandyopadhyay, and L. V. Scalzi, Lean intervention improves patient discharge times, improves emergency department throughput and reduces congestion, *Hosp. Pract.* **44**(5) (2016), 252-259, doi: 10.1080/21548331.2016.1254559
73. M. M. Oliveira, C. Marti, M. Ramlawi, F. P. Sarasin, O. Grosgurin, P. A. Poletti,... and O. T. Rutschmann, Impact of a patient-flow physician coordinator on waiting times and length of stay in an emergency department: A before-after cohort study, *Plos One*, **13**(12) (2018), e0209035, doi: 10.1371/journal.pone.0209035
74. M. J. Vermeulen, T. A. Stukel, A. S. Boozary, A. Guttmann, and M. J. Schull, The effect of pay for performance in the emergency department on patient waiting times and quality of care in Ontario, Canada: a difference-in-differences analysis, *Ann. Emerg. Med.* **67**(4) (2016), 496-505, doi: 10.1016/j.annemergmed.2015.06.028
75. S. Singh, Y. L. Lin, A. B. Nattinger, Y. F. Kuo, and J. S. Goodwin, Variation in readmission rates by emergency departments and emergency department providers caring for patients after discharge, *J. Hosp. Med.* **10**(11) (2015) 705-710, doi: 10.1002/jhm.2407
76. A. K. Venkatesh, C. Wang, Y. Wang, F. Altaf, S. M. Bernheim, and L. Horwitz, Association Between Postdischarge Emergency Department Visitation and Readmission Rates, *J. Hosp. Med.* **13**(9) (2018), 589-594, doi: 10.12788/jhm.2937
77. A. S. Källberg, K. E. Göransson, J. Florin, J. Östergren, J. J. Brixey, and A. Ehrenberg, Contributing factors to errors in Swedish emergency departments, *Int. Emerg. Nurs.* **23**(2) (2015), 156-161, doi: 10.1016/j.ienj.2014.10.002
78. M. Riga, A. Vozikis, Y. Pollalis, and K. Souliotis, MERIS (Medical Error Reporting Information System) as an innovative patient safety intervention: A health policy perspective, *Health Policy.* **119**(4) (2015), 539-548, doi: 10.1016/j.healthpol.2014.12.006
79. G. R. Norman, S. D. Monteiro, J. Sherbino, J. S. Ilgen, H. G. Schmidt, H. G and S. Mamede, The causes of errors in clinical reasoning: cognitive biases, knowledge deficits, and dual process thinking, *Acad. Med.* **92**(1) (2017) 23-30, doi: 10.1097/ACM.0000000000001421
80. D. Lisbon, D. Allin, C. Cleek, L. Roop, M. Brimacombe, C. Downes, and S. K. Pingleton, Improved knowledge, attitudes, and behaviors after implementation of TeamSTEPPS training in an academic emergency department: a pilot report. *Am. J. Med. Qual*. **31**(1) (2016), 86-90, doi: 10.1177/1062860614545123
81. L. Li, A. Georgiou, E. Vecellio, A. Eigenstetter, G. Toouli, R. Wilson, and J. I. Westbrook, The Effect of Laboratory Testing on Emergency Department Length of Stay: A Multihospital Longitudinal Study Applying a Cross-classified Random-effect Modeling Approach, *Acad. Emerg. Med.* **22**(1) (2015) 38-46, doi: 10.1111/acem.12565

82. O. A. Uthman, C. Walker, S. Lahiri, D. Jenkinson, V. Adekanmbi, W. Robertson, and A. Clarke, General practitioners providing non-urgent care in emergency department: a natural experiment, *BMJ Open.* **8**(5) (2018), e019736, doi: 10.1136/bmjopen-2017-019736
83. World Health Organization WHO, Generic essential emergency equipment list (2004), http://apps.who.int/medicinedocs/es/m/abstract/Js17374e/
84. D. A. Telem, J. Yang, M. Altieri, W. Patterson, B. Peoples, H. Chen, ... and A. D. Pryor, Rates and risk factors for unplanned emergency department utilization and hospital readmission following bariatric surgery, *Ann. Surg.* **263**(5) (2016), 956-960, doi: 10.1097/SLA.0000000000001536
85. M. C. G. Rigobello, R. E. F. L. de Carvalho, J. M. Guerreiro, A. P. G. Motta, E. Atila, and F. R. E. Gimenes, The perception of the patient safety climate by professionals of the emergency department, *Int. Emerg. Nurs.* **33**(2017), 1-6, doi: 10.1016/j.ienj.2017.03.003
86. B. M. Farmer, Patient safety in the emergency department. *Emerg. Med*. **48**(9) (2016), 396-404, doi: 10.12788/emed.2016.0052
87. H. C. Liu, J. X. You, L. Zhen, and X. J. Fan, A novel hybrid multiple criteria decision making model for material selection with target-based criteria, *Mater. Design*. **60**(2014) 380-390, doi: 10.1016/j.matdes.2014.03.071
88. G. Kou, D. Ergu, and J. Shang, Enhancing data consistency in decision matrix: Adapting Hadamard model to mitigate judgment contradiction, *Eur. J. Oper. Res.* **236**(1) (2014) 261-271, doi: 10.1016/j.ejor.2013.11.035
89. M. Keshavarz Ghorabaee, M. Amiri, E. K. Zavadskas, and J. Antucheviciene, Supplier evaluation and selection in fuzzy environments: A review of MADM approaches, *Econ. Res-Ekon. Istraž.* **30**(1) (2017), 1073-1118, doi: 10.1080/1331677X.2017.1314828
90. M. A. O. Barrios, F. De Felice, K. P. Negrete, B. A. Romero, A. Y. Arenas, and A. Petrillo, An AHP-topsis integrated model for selecting the most appropriate tomography equipment, *Int. J. Inf. Tech. Decis.* **15**(04) (2016) 861-885, doi: 10.1142/S021962201640006X
91. D. Y. Yeh, and C. H. Cheng, Performance management of Taiwan's national hospitals, *Int. J. Inf. Tech. Decis.* **15**(01) (2016) 187-213, doi: 10.1142/S0219622014500199
92. T. Y. Chen, An interactive signed distance approach for multiple criteria group decision-making based on simple additive weighting method with incomplete preference information defined by interval type-2 fuzzy sets, *Int. J. Inf. Tech. Decis.* **13**(05) (2014) 979-1012, doi: 10.1142/S0219622014500229
93. X. Gou, Z. Xu, and H. Liao, Hesitant fuzzy linguistic possibility degree-based linear assignment method for multiple criteria decision-making, *Int. J. Inf. Tech. Decis.* **18**(01) (2019) 35-63, doi: 10.1142/S0219622017500377
94. K. Saksrisathaporn, A. Bouras, N. Reeveerakul, and A. Charles, Application of a decision model by using an integration of AHP and TOPSIS approaches within humanitarian operation life cycle, *Int. J. Inf. Tech. Decis.* **15**(04) (2016) 887-918, doi: 10.1142/S0219622015500261
95. B. Hsiao, and L. H. Chen, Performance Evaluation for Taiwanese Hospitals by Multi-Activity Network Data Envelopment Analysis, *Int. J. Inf. Tech. Decis.* **18**(03) (2019) 1009-1043, doi: 10.1142/S0219622018500165
96. T. L. Saaty, and D. Ergu, When is a decision-making method trustworthy? Criteria for evaluating multi-criteria decision-making methods, *Int. J. Inf. Tech. Decis.* **14**(06) (2015) 1171-1187, doi: 10.1142/S021962201550025X
97. K. H. Chang, Y. C. Chang, and Y. T. Lee, Integrating TOPSIS and DEMATEL methods to rank the risk of failure of FMEA, *Int. J. Inf. Tech. Decis.* **13**(06) (2014) 1229-1257, doi. 10.1142/S0219622014500758
98. M. Ortíz-Barrios, D. Neira-Rodado, G. Jiménez-Delgado, and H. Hernández-Palma, Using fahp-vikor for operation selection in the flexible job-shop scheduling problem: A case study in textile

industry, *Proc. Lect. Notes. Comput. Sc*, Vol. 10942, Chiang Mai, 2018, pp. 189-201, doi: 10.1007/978-3-319-93818-9_18

99. T. M. Yeh, and Y. L. Huang, Factors in determining wind farm location: Integrating GQM, fuzzy DEMATEL, and ANP, *Renew. Energ.* **66**(2014) 159-169, doi: 10.1016/j.renene.2013.12.003
100. M. A. Ortíz, H. A. Felizzola, and S. N. Isaza, A contrast between DEMATEL-ANP and ANP methods for six sigma project selection: a case study in healthcare industry, *BMC Med. Inform. Decis. Mak.* **15**(3) (2015) S3, doi: 10.1186/1472-6947-15-S3-S3
101. M. Deveci, F. Canıtez, and I. Gökaşar, WASPAS and TOPSIS based interval type-2 fuzzy MCDM method for a selection of a car sharing station, *Sustain. Cities Soc*. **41**(2018), 777-791, doi: 10.1016/j.scs.2018.05.034
102. J. Roy, H. K. Sharma, S. Kar, E. K. Zavadskas, and J. Saparauskas, An extended COPRAS model for multi-criteria decision-making problems and its application in web-based hotel evaluation and selection, *Econ. Res-Ekon. Istraž.* **32**(1)(2019), 219-253, doi: 10.1080/1331677X.2018.1543054
103. M. K. Ghorabaee, M. Amiri, E. K. Zavadskas, and Z. Turskis, and J. Antucheviciene, A new multi-criteria model based on interval type-2 fuzzy sets and EDAS method for supplier evaluation and order allocation with environmental considerations. *Comput. Ind. Eng.* **112**(2017), 156-174, doi: 10.1016/j.cie.2017.08.017
104. M. Keshavarz Ghorabaee, E. K. Zavadskas, L. Olfat, and Z. Turskis, Multi-criteria inventory classification using a new method of evaluation based on distance from average solution (EDAS). *Informatica*. **26**(3) (2015), 435-451, doi: 10.1108/MD-05-2017-0458
105. C. Kahraman, S. C. Onar, and B. Oztaysi, Fuzzy multicriteria decision-making: a literature review. *Int. j. Comput. Int. Sys.* **8**(4) (2015), 637-666, doi: 10.1080/18756891.2015.1046325
106. M. Abdel-Basset, G. Manogaran, A. Gamal, and F. Smarandache, A hybrid approach of neutrosophic sets and DEMATEL method for developing supplier selection criteria. *Des. Autom. Embed. Syst.* **22**(3) (2018), 257-278, doi: 10.1007/s10617-018-9203-6
107. K. Govindan, R. Khodaverdi, and A. Vafadarnikjoo, Intuitionistic fuzzy based DEMATEL method for developing green practices and performances in a green supply chain. *Expert Syst. Appl*, **42**(20) (2015), 7207-7220, doi: 10.1016/j.eswa.2015.04.030
108. A. Alinezhad and A. Amini, Sensitivity Analysis of TOPSIS Technique: The Results of Change in the Weight of One Attribute on the Final Ranking of Alternatives. *J. Optim. Ind. Eng.* **7**(4) (2011), 23–28.
109. C. Lin, G. Kou, Y. Peng, and F. E. Alsaadi, Aggregation of the nearest consistency matrices with the acceptable consensus in AHP-GDM. *Ann. Oper. Res*. (2020) 1-17, doi: 10.1007/s10479-020-03572-1
110. G. Kou and C. Lin, A cosine maximization method for the priority vector derivation in AHP. *Eur. J. Oper. Res.* **235**(1) (2014), 225-232, doi: 10.1016/j.ejor.2013.10.019
111. G. Kou, D. Ergu, and J. Shang, Enhancing data consistency in decision matrix: Adapting Hadamard model to mitigate judgment contradiction. *Eur. J. Oper. Res*. **236**(1) (2014), 261-271, doi: 10.1016/j.ejor.2013.11.035
112. H. Wang, G. Kou, and Y. Peng, Multi-class misclassification cost matrix for credit ratings in peer-to-peer lending. *J. Oper. Res. Soc*. (2020) 1-12, doi: 10.1080/01605682.2019.1705193
113. M. Ortiz-Barrios, M. Gul, P. López-Meza, M. Yucesan, and E. Navarro-Jiménez, Evaluation of hospital disaster preparedness by a multi-criteria decision making approach: The case of Turkish hospitals. *Int. J. Disast. Risk Re*. **49**(1) (2020) 101748, doi: 10.1016/j.ijdrr.2020.101748
114. World Health Organization Coronavirus disease 2019 (COVID-19) situation report–182. Retrieved from: https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200720-covid-19-sitrep-182.pdf?sfvrsn=60aabc5c_2 (2020)