An integrated approach to evaluate the risk of adverse events in hospital sector

From theory to practice

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Abstract

Purpose – The risk of adverse events in a hospital evaluation is an important process in healthcare management. It involves several technical, social, and economical aspects. The purpose of this paper is to propose an integrated approach to evaluate the risk of adverse events in the hospital sector.

Design/methodology/approach – This paper aims to provide a decision-making framework to evaluate hospital service. Three well-known methods are applied. More specifically are proposed the following methods: analytic hierarchy process (AHP), a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology developed by Thomas L. Saaty in the 1970s; decision-making trial and evaluation laboratory (DEMATEL) to construct interrelations between criteria/factors and VIKOR method, a commonly used multiple-criteria decision analysis technique for determining a compromise solution and improving the quality of decision making.

Findings – The example provided has demonstrated that the proposed approach is an effective and useful tool to assess the risk of adverse events in the hospital sector. The results could help the hospital identify its high performance level and take appropriate measures in advance to prevent adverse events. The authors can conclude that the promising results obtained in applying the AHP–DEMATEL–VIKOR method suggest that the hybrid method can be used to create decision aids that it simplifies the shared decision-making process.

Originality/value – This paper presents a novel approach based on the integration of AHP, DEMATEL and VIKOR methods. The final aim is to propose a robust methodology to overcome disadvantages associated with each method.

Keywords AHP, DEMATEL, VIKOR, Public health, Evidence-based medicine

Paper type Research paper

1. Introduction

Nowadays, citizens pay a lot of attention to high-quality medical care and overall service quality performed by the hospital (Lee *et al.*, 2008).

To manage a hospital successfully, the important goals are to attract and then retain as many patients as possible by meeting potential demands of various kinds of the patients (Yoo, 2005). Patient safety is considered as a fundamental critical to satisfaction in healthcare. Nevertheless, there could have errors that can cause injury or death. These errors can be detected before occurring in healthcare services but some of them are not detected and might cause damage to a patient's health. If this error brings about damage, it is called an adverse event. Adverse events or in other words "any unintended or unexpected incident which could have or did lead to harm for one or more patients" in hospitals

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constitute a serious problem with grave consequences. Many studies have been conducted to gain an insight into this problem. An interesting study carried out by Rafter *et al.* (2015) highlights that between 4 and 17 percent of hospital admissions are associated with an adverse event and a significant proportion of these (one- to two-thirds) are preventable. Unfortunately, also in Colombia, adverse events are frequent and cause death in some cases. The above considerations demonstrate "how important is assessing the risk of adverse events in hospitals" in order to manage the causes of adverse events. A variety of methods exist to gather an adverse event but these do not necessarily capture the same events and there is variability in the definition of an adverse event.

In our opinion, in order to solve this "problem" it is necessary to promote a standardization of knowledge and practice in healthcare organizations. However, the complexity of healthcare decision-making and evidence selection make this process problematic.

Developing a decision-making framework for hospital adverse events, considering that the quality of care delivered within a health system depends on how well the causes of adverse events in hospital practice critical factors are managed, could be an useful tool for shared decision making and to benchmark hospital performance. Traditionally, performance in hospitals has been measured using routinely reported health data. Nevertheless, these data failed to identify patient safety.

Thus, a systematic and multi-criteria approach helps to evaluate different factors simultaneously and to weigh the importance and correlation among the factors.

In fact, using multiple-criteria decision-making (MCDM) methods, a compromise solution for a problem with conflicting criteria can be determined and can help the decision-makers to improve the problems for achieving the final decision (Wang and Pang, 2011). Numerous MCDM methods have been developed and there is no best method for the MCDM problem. Each method has its strengths and weaknesses. Therefore, in recent years, researchers have attempted to combine different methods to select the best alternative. The main advantage of MCDM methods is that they can help to manage many dimensions to consider related elements, and evaluate all possible options under variable degrees (Wang and Pang, 2011).

In this respect, this study addresses the two main limitations of evidence-based management (EBMgt). First, past contributions only provided a complete view of EBMgt, identifying potential shortcomings and limitations of data-driven methods (Holmes *et al.*, 2006; Morrell and Learmonth, 2015) "whilst the second limitation refers to the fact that EBMgt contributions focus more on the techniques to evidence generation rather than to the application of this kind of evidence by decision-makers and hospital managers to improve operational performances".

In response to both statements, our paper presents a case study where it is evidenced that the policy-makers used an MCDM model to first define the patient safety performance of hospitals from the public sector in order to then design particular and focused improvement strategies addressing their particular weaknesses.

In particular, this paper aims to provide a decision-making framework to evaluate the risk of adverse events in the hospital sector of Colombia. Three well-known methods are applied. More specifically the following methods are proposed: analytic hierarchy process (AHP), a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology developed by Thomas L. Saaty (1982) in the 1970s; decision-making trial and evaluation laboratory (DEMATEL) to construct interrelations between criteria/factors (Fontela and Gabus, 1974) and VIKOR method a commonly used multiple-criteria decision analysis (MCDA) technique for determining a compromise solution and improving the quality of decision making (Opricovic and Tzeng, 2002).

In the remainder of this work, the characterization of the decision-making scenario is provided in Section 2; then, a literature review on the reported studies in the field is analyzed in Section 3; a description of method is provided in Section 4. In Section 5, the scenario under study is analyzed. Section 6 describes the model verification. In this section, a discussion of results is presented. Finally, Section 7 presents a summary of research contribution and findings.

2. Characterization of the decision-making context from a multiple-criteria decision aid approach

Multiple-criteria decision aid is a research field within the Decision Analysis which assists decision-makers to achieve a suitable compromise solution considering the presence of several and conflicting criteria (Dulmin and Mininno, 2003; Sadok *et al.*, 2009). To this regard, four families have been created to categorize the MCDA methods (Guitoni and Martel, 1998): single methods; the single synthetizing criterion approach; outranking methods; and the mixed methods.

According to our aim or rather to assess the risk of adverse events by identifying and ranking the causes of adverse events, the next step was to select the most appropriate MCDA approach in accordance with the decision-making scenario. The general approach to identifying the decision elements involved in this project is detailed below:

- Trade-off management: in this case, a mixed method has been adopted since its capability of dealing with both qualitative and quantitative variables which are usually found in the healthcare domain. Moreover, it has been proved to be appropriate for providing more robust, realistic and reliable results which is particularly useful for hospital managers to make effective decisions (Zavadskas *et al.*, 2016). In addition, hybrid methods may be used where a compensatory first phase limits the choice followed by a non-compensatory second stage to finally make the decision (Linkov *et al.*, 2011).
- Incomparability of the options: considering that health insurance companies need to choose the hospitals with the lowest risk of adverse events, incomparability is not admitted. In this regard, indifference and preference relations have been linked to the deviations observed between the values of predefined performance criteria and sub-criteria in order to rank the hospitals by taking into account their distance to the ideal solution (e.g. VIKOR does).
- Scaling effects: in order to avoid the introduction of bias and inconsistency in the conclusions of the decision-making process, the scaling effects has been eliminated as suggested by several authors such as Pecchia *et al.* (2013) and Martins *et al.* (2016). This is particularly relevant for hospital and healthcare managers when designing focused strategies reducing the risk of adverse events.
- Rank reversal: it is hard to tell if a particular decision-making method has derived the correct answer or not (García-Cascales and Lamata, 2012). Thus, regarding the stability of results, in our project a compensatory approach based on the use of AHP, DEMATEL, and VIKOR is proposed. In addition, a real case study is analyzed in order to validate the general results.
- Uncertainty in input data: in order to avoid uncertainty in input data, an integrative approach has been adopted. Data have been derived from three types of sources: first-hand data, expert knowledge, or pre-existing (probabilistic or deterministic) models. Of these approaches, using field observation data is in many cases straightforward, and expert elicitation has been covered by excellent reviews (Saaty and Tran, 2007; Zhü, 2014; Pecchia *et al.*, 2013).
- Weights assessment: one of the main activities in several performance evaluation techniques is the assignment of relative contribution to the criteria and sub-criteria

(Izquierdo *et al.*, 2016). In this respect, the consistency index of each judgment has been calculated. Additionally, healthcare managers (in this case, the respondents) are usually unskilled in decision-making and it is therefore necessary to find a method easily guiding them to define the relative priorities of the criteria and sub-criteria when assessing the risk of adverse events in hospitals (e.g. AHP–DEMATEL does).

Considering the aforementioned aspects, a mixed method well matches with the decision-making context regarding the assessment of the patient safety level in hospitals.

3. Literature review

From the late 1990s onwards, analysts began to consider applying an evidence-based approach to the management of healthcare organizations. In particular, evidence-based medicine rose to prominence in the 1990s and can be understood as a movement that sought to improve clinical outcomes across healthcare organizations by standardizing professional decision-making (Timmermans and Berg, 2003; Diaby *et al.*, 2013). The use of MCDA has become the domain of medical assessment in order to help medical staff to make better decisions in critical circumstances (Dolan, 2008). In detail, some authors proposed the use of DEMATEL method within healthcare fields. For example, Li *et al.* (2014) adopt DEMATEL method to find out the total relation of the factors in emergency management and to figure out critical success factors. Supeekit *et al.* (2016) propose a DEMATEL-modified analytic network process (ANP) to evaluate internal hospital supply chain performance. Recently, Si *et al.* (2017) identify key performance indicators for holistic hospital management with a modified DEMATEL approach. Some other authors such as Chang (2014) proposed the use of VIKOR method that evaluates hospital service by employ fuzzy VIKOR. Büyüközkan *et al.* (2016) provide a new perspective for web service performance of healthcare institutions with different quality evaluation criteria for ranking their web services based on fuzzy analytic hierarchy process (IF AHP) and intuitionistic fuzzy Višekriterijumsko kompromisno rangiranje Resenje (IF VIKOR).

The bibliographic research has shown interesting articles written about applying decision support systems to medical and healthcare decision making but little has been published about the complex problem of patient safety and hospital services (Liberatore and Nydick, 2008; De Felice and Petrillo, 2015). There are even few scientific papers that propose an integrated approach to identifying critical success factors in a hospital's management service. Given the relevance of this theme and the lack of studies, this research aims to evaluate the risk of adverse events in hospitalized patients in from Colombia through an MCDM method.

However, selecting an appropriate MCDM approach is a critical step for evaluating the risk of adverse events. In this regard, it is suggested to apply a hybrid approach comprising of more than one MCDM method since the single techniques may provide different results (Royendegh and Erol, 2009; Zavadskas *et al.*, 2016). Besides, Zavadskas *et al.* (2016) concluded that integrating both objective and subjective measures into the utility function is an advantage for an integrated approach over the single method. Several authors have employed the hybrid approaches (two or more techniques) instead of the single methods (e.g. Tzeng and Huang, 2012; Labib and Read, 2015; Hosseini and Al Khaled, 2016).

The combination of different methods allows overcoming the limitations of several techniques. Particularly, "Preference Ranking Organization Method" and "technique for order preference by similarity to ideal solution" (TOPSIS) do not provide an explicit procedure to allocate the relative importance of criteria and sub-criteria (Anand and Kodali, 2008; Behzadian *et al.*, 2010; Behzadian *et al.*, 2012; Velasquez and Hester, 2013). 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 (Wijnmalen and Wedley, 2008; Wang and Luo, 2009; García-Cascales and Lamata, 2012; Maleki and Zahir, 2013). The same drawback was observed in TOPSIS (Shih *et al.*, 2007; Wang and Luo, 2009; Huszak and Imre, 2010; García-Cascales and Lamata, 2012), data envelopment analysis (DEA) (Wu *et al.*, 2010; Guo and Wu, 2013; Soltanifar and Shahghobadi, 2014) and the "simple additive weighting" (Huszak and Imre, 2010; Shin *et al.*, 2013; Shin, 2017) techniques. Another limitation of DEA method is that all outputs and inputs are assumed to be known (Velasquez and Hester, 2013). Regarding ANP, it has been concluded as a highly complex and time-consuming methodology requiring rigorous calculations when assessing composite priorities, it then increases the effort (Percin, 2008; Kumar and Haleem, 2015).

The novelty of the present study is based on the integration of the AHP, perhaps the most well-known and widely used multi-criteria method with DEMATEL and VIKOR methods to identify key success factors of hospital service in order to avoid adverse events for patients. In particular, AHP was chosen due to its capability of calculating the relative importance of decision elements (Saaty and Vargas, 2012; Vargas, 2012). In this case, equal weights of both criteria and sub-criteria cannot be assumed due to some bias may be introduced in the MCDM model and they must be then properly calculated (e.g. as AHP does). In detail, in the present research, AHP method is used to define the global and the local weights of criteria and sub-criteria. It is true that AHP method presents some disadvantages since it is not possible to analyze interactions between elements. But at the same time, a decision-making approach should have some characteristics, satisfied by the AHP, among which is being simple in construct and does not require any inordinate specialization. In other words, the main advantage of AHP compared to its generalization or ANP is its simplicity that allows it to be used also by not experts in mathematical applications that could be involved in the in the governance of their organizations, as outlined and validated by Professor Saaty (2013). Thus to cover the gap to define interrelations between criteria and sub-criteria, the DEMATEL method is integrated to AHP. Our choice to use DEMATEL method and not ANP is motivated also by the consideration that ANP is unable to single out an element and identify its strengths and weaknesses. On the other hand, DEMATEL was selected since it helps healthcare managers to discriminate the interdependencies between the decision elements by deploying an impact-digraph map where the dispatchers and receivers can be clearly identified (Tseng, 2011; Govindan *et al.*, 2015). Ultimately, VIKOR was considered in this study since it provides very precise ranking results (Anojkumar *et al.*, 2014). This method focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria; it can help the decision-makers to reach a final decision as stated by Sayadi *et al.* (2009). Ranking hospitals in accordance with their risk of adverse events (e.g. VIKOR does) is very informative and useful for patients searching for safe care and healthcare authorities who need to prioritize interventions and allocate resources effectively. Even though rank reversal problem may exist in VIKOR, only a low impact can be expected in the top alternative of the ranking (Ceballos *et al.*, 2017). Nevertheless, both criteria and sub-criteria preferences are not explicitly elicited in VIKOR method (Zhang and Wei, 2013). In addition, correlations between decision elements are not considered (Chauhan and Vaish, 2014). In this regard, some studies underpin the fact that there may exist a correlation between factors predicting adverse events (Passarelli *et al.*, 2005; Pocar *et al.*, 2010) and it should be then incorporated into the model (e.g. as DEMATEL does).

4. Description of the proposed framework

The proposed framework aims to evaluate the risk of adverse events in public hospitals. The methodology is comprised of four phases (refer to Figure 1). First, a decision-making

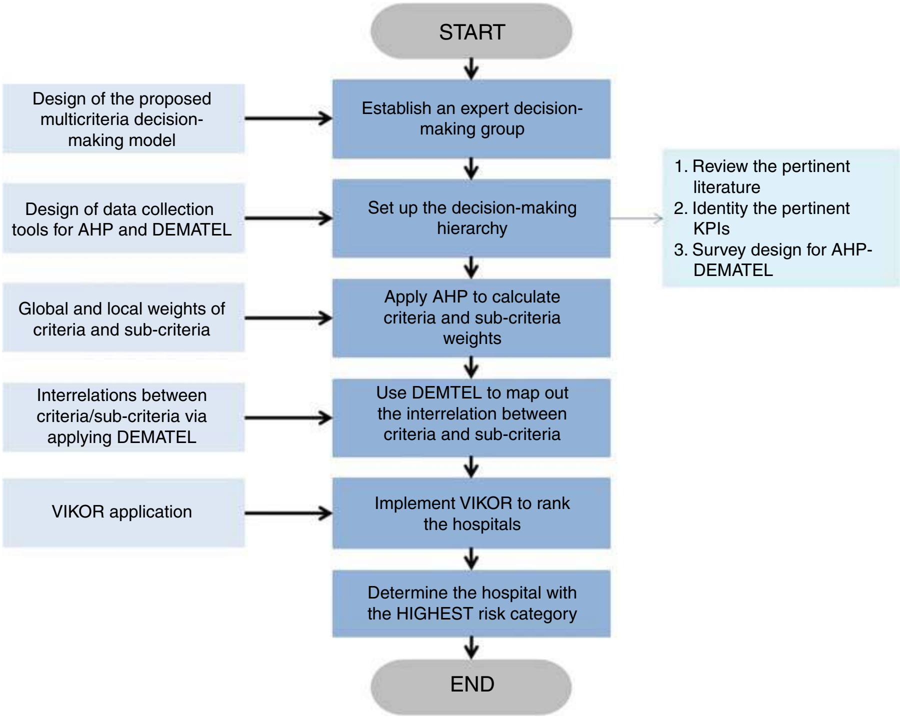


Figure 1.
Proposed framework for evaluating the risk of adverse events in public hospitals

group is established to set up a decision hierarchy considering the personal opinion of the expert decision-makers and the key indicators established by the Ministry of Health and Social Protection. Then, AHP is applied to calculate the criteria and sub-criteria weights. After this, DEMATEL is implemented to map out the interrelations between criteria and sub-criteria as well as identify the receivers and dispatchers. Additionally, it is used to assess the strength of each influence relation. In both AHP and DEMATEL methods, the decision-makers are asked to perform pairwise comparisons between the decision elements of the hierarchy. To this end, VIKOR is developed to rank the hospitals from highest to lowest measure of closeness coefficient. The results from ideal and worst solution are also incorporated into this study. Finally, the hospital with the lowest risk category is identified and improvement opportunities are provided.

Figure 1 summarizes the proposed framework.

5. MCDM methods

In this section AHP, DEMATEL and VIKOR procedures are described in detail. Each method and their applications reveal pros and cons as analyzed by Mandic *et al.* (2015) in their research. This is the main reason for which an integration of the three methods is proposed in the present research, as explained in Section 3.

5.1 Analytic hierarchy process

Criteria and sub-criteria weights are obtained by applying AHP. This method enables experts to calculate these measures by constructing a hierarchy structure decomposing a complex decision-making problem into different levels where the highest represents the goal, the middle contains the assessment criteria and the lowest includes the alternatives (Cannavacciuolo *et al.*, 2012; Lee and Kozar, 2006). A detailed description of this method can be found below:

- Collect the pairwise comparisons for both the criteria and the sub-criteria by using a survey. In this case, in spite of the widely used fundamental scale (Joshi *et al.*, 2011; Shaik and Abdul-Kader, 2013), a three-point scale has been adopted to reduce inconsistencies and facilitate a better comprehension of the decision-making process for the experts who are not qualified in complex mathematics or with the AHP technique (e.g. Wang *et al.*, 2009; Pecchia *et al.*, 2013; Barrios *et al.*, 2016; Meesariganda and Ishizaka, 2017). In this regard, the scale has been defined as follows: 1 as "equal importance," 3 as "moderate importance" and 5 "strong importance." The reciprocal values were assigned to the remaining judgments: 1/3 if "less importance" and 1/5 if "much less importance".
- Aggregate the comparisons by applying the geometric mean formula (Srdjevic, 2007; Saaty, 2008; Jaskowski *et al.*, 2010; Ishizaka *et al.*, 2011) as described in Equation (1). Here, n' represents the number of experts and a_{ij} is represents the relative importance of the ith criterion/sub-criterion compared to the jth criterion/sub-criterion:

$$\left(\prod_{k=1}^{n'} a_{ij}^{k}\right)^{1/n}. \tag{1}$$

- Organize the judgments into an $n \times n$ pairwise comparison matrix A for criteria (Equation (2)) and matrix B for sub-criteria (Equation (3)):

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix}, \tag{2}$$

$$B = \begin{bmatrix} 1 & b_{12} & \ldots & b_{1n} \\ b_{21} & 1 & \ldots & b_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ b_{n1} & b_{n2} & \ldots & 1 \end{bmatrix}. \tag{3}$$

In Equations (2) and (3), it can be appreciated that the diagonal values in the matrices A and B are equal to 1 since $i=j$. In case of a decision-making group, a_{ij} and b_{ij} are obtained by using the geometric mean of all the judgments associated with the comparison:

- Obtain the criteria (Equation (5)) and sub-criteria (Equation (4)) weights. In this respect, the relative importance degree of each sub-criterion i compared to each of the other sub-criteria in the same criterion c is called local weight (LW_i^c). In addition, determine the relative weight of each criteria c in relation to the hierarchy goal (FW^c):

$$LW_i^c = \frac{\left(\prod_{j=1}^{n} b_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} b_{ij}\right)^{1/n}}, \quad i, j = 1, 2, \ldots, n, \tag{4}$$

$$FW_i^c = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}}, \quad i, j = 1, 2, \ldots, n. \tag{5}$$

- To evaluate the suitability of the paired comparisons, it is necessary to calculate the consistency ratio (CR) by performing Equation (7). Here, CI is defined as the consistency index (refer to Equation (6)). In Equation (4), $\lambda_{\max}$ represents the eigenvalue and n is the matrix size. In order to evaluate how much the inconsistency is acceptable, AHP calculates a CR comparing the CI vs the consistency index of a random-like matrix (RI). A random matrix is one where the judgments have been entered randomly and, therefore, it is expected to be highly inconsistent. More specifically, RI is the average CI of 500 randomly filled in matrices which provide the calculated RI value for matrices of different sizes, as explained by Saaty (2012). If CR⩽10 percent is deemed as reasonable. Otherwise, the matrix is categorized as inconsistent and the comparisons should be then reviewed by the decision-makers:

$$CI = \frac{\lambda_{\max} - n}{n-1}, \tag{6}$$

$$CR = \frac{CI}{RI}. \tag{7}$$

- Calculate the relative importance degree of each sub-criteria i in relation to the hierarchy goal, which is called global weight (GW_i), in accordance with the following equation):

$$GW^i = LW_i^c \times FW^c. \tag{8}$$

5.2 Decision-making trial and evaluation laboratory

DEMATEL is a MCDM technique used to visualize the structure of complex causal relationships through matrices and impact digraphs (Li and Tzeng, 2009; Shieh *et al.*, 2010; Chang and Cheng, 2011; Ortiz-Barrios *et al.*, 2017). A typical digraph represents a communication network where influencing and affected criteria/sub-criteria can be clearly appreciated (Yang and Tzeng, 2011). In this respect, the interdependence among decision elements and influence levels can be determined (Amiri *et al.*, 2011). The DEMATEL procedure can be described as follows:

- Collect the pairwise comparisons and generate the group-direct influence matrix Z: the expert decision-makers are asked to make paired comparisons (z_{ij}) between the criteria or sub-criteria aiming at evaluating their interdependence. To perform these judgments, a five-point scale is used: no influence (0), low influence (1), medium influence (2), high influence (3) and very high influence (4). The scores are collected by a data-gathering tool and introduced in matrix Z In this case, if there is a decision-making group.
- Generate the group-direct influence matrix: the experts are asked to evaluate the dependence and feedback between criteria/sub-criteria aiming to identify meaningful interrelationships. For this purpose, the participants, based on their personal opinion, indicate the direct influence that each criterion/sub-criterion i has on each other criterion/sub-criterion j via applying an integer four-point scale where 0

(no influence), 1 (low influence), 2 (medium influence), 3 (high influence) and 4 (very high influence). After this, z_{ij} values are grouped into the $Z_k = [z^k_{ij}]_{n\times n}$ called "individual direct influence" matrix. In this arrangement, the diagonal elements are equal to 0 and the paired comparisons are aggregated by using the following equation:

$$z_{ij} = \frac{1}{l}\sum_{k=1}^{l} z^k_{ij}, \quad i, j = 1, 2, \ldots, n. \tag{9}$$

- Normalize the direct influenced matrix Z: the normalized direct-relation matrix $X=[x_{ij}]_{n\times n}$ can be achieved via applying the following equations:

$$X = \frac{Z}{s}, \tag{10}$$

$$s = \max\left\{\max_{1-\leqslant i\leqslant n}\sum_{j=1}^{n} z_{ij}, \max_{1\leqslant i\leqslant n}\sum_{i=1}^{n} z_{ij}\right\}. \tag{11}$$

- Obtain the total influence matrix T: based on the normalized direct-relation matrix X, the total relation matrix $T=[t_{ij}]_{n\times n}$ can be achieved by using Equation (12) where I represents the identity matrix:

$$T = X+X^2+X^3+\ldots = \sum_{i=1}^{\infty} X^i = X(I-X)^{-1}, \tag{12}$$

- Develop the influential relation map (IRM): By calculating $D+R$ (prominence) and $D-R$ (relation) values, where R_j is the sum of the jth column in total influence matrix T (refer to Equation (13)) and D_i represents the sum of the ith row of matrix T (refer to Equation (14)), dispatcher and receiver criteria/sub-criteria can be determined. If $(D-R) > 0$, the criterion/sub-criterion has a net influence on the other criteria/sub-criteria and can be grouped into the cause set (dispatchers). In turn, if $(D-R) < 0$, then the element is being influenced by the other elements on the whole and can be categorized into the effect group (receivers). On the other hand, $D+R$ values indicate the strength of influences that are given or received by a specific criterion/sub-criterion i. In this regard, both $D+R$ and $D-R$ values provide meaningful outputs for any decision-making process:

$$R = \sum_{j=1}^{n} t_{ij}, \tag{13}$$

$$D = \sum_{i=1}^{n} t_{ij}. \tag{14}$$

- Calculate the threshold value and obtain impact-digraph map (IRM): the threshold value (θ) is used to identify the significant interrelations between criteria or sub-criteria (refer to equation (15)) and filter out negligible effects. In this respect, if the influence level of a criteria/sub-criteria in matrix T is higher than θ, then this criterion/sub-criterion is selected and included in the IRM. Otherwise, the interrelation will be excluded. The IRM graph can be achieved by mapping the data set ($D+R$, $D-R$):

$$\theta = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij}}{n^2}. \tag{15}$$

5.3 Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR)

VIKOR is an outranking method that is implemented to solve a discrete decision-making problem with non-commensurable and decision criteria (Opricovic and Tzeng, 2007; Sayadi *et al.*, 2009; San Cristóbal, 2011). In this regard, this technique ranks a set of alternatives based on the closeness to the ideal scenario (compromise solution) which is represented by predefined decision criteria (Tong *et al.*, 2007; Shemshadi *et al.*, 2011). To do this, VIKOR introduces a multi-criteria ranking index describing the closeness of each alternative to the aspired solution (Ou Yang *et al.*, 2009). In this sense, VIKOR is useful to select the most profitable alternatives for decision-makers (Bazzazi *et al.*, 2011). The procedure of VIKOR is comprised of the following steps:

(1) A set of m alternatives denoted as $P_1, P_2, \ldots, P_m$ is defined for the MCDM problem. Here, each alternative P_i is described by a number of decision criteria (n). The value of each sub-criterion SC_j is represented by f_{ij} and is computed in matrix A according to the following equation:

$$A = \begin{matrix} \\ P_1 \\ P_2 \\ P_3 \\ . \\ . \\ P_m \end{matrix} \begin{bmatrix} SC_1 & SC_2 & \ldots. & SC_n \\ f_{11} & f_{12} & \ldots. & f_{1n} \\ f_{21} & f_{22} & \ldots. & f_{2n} \\ f_{31} & f_{32} & \ldots. & f_{3n} \\ . & . & \ldots. & . \\ . & . & \ldots. & . \\ f_{m1} & f_{m2} & \ldots. & f_{mn} \end{bmatrix}, \tag{16}$$

(2) Identify the best $\left(f_j^*\right)$ and the worst $\left(f_j^-\right)$ values in each sub-criterion by using the following equations correspondingly:

$$f_j^* = \left\{ \begin{matrix} \max_i f_{ij}, & \text{for benefit criteria} \\ \min_i f_{ij}, & \text{for cost criteria} \end{matrix} \right\}, \quad i = 1, 2, \ldots, m, \tag{17}$$

$$f_j^- = \left\{ \begin{matrix} \min_i f_{ij}, & \text{for benefit criteria} \\ \max_i f_{ij}, & \text{for cost criteria} \end{matrix} \right\}, \quad i = 1, 2, \ldots, m. \tag{18}$$

(3) Calculate the S_i and R_i values via applying Equation (19) and (20), respectively. Here, w_j denotes the weight of the sub-criteria SC_j. This measure is provided by the combined technique: AHP–DEMATEL:

$$S_i = \sum_{j=1}^{n} \frac{w_j\left(f_j^* - f_{ij}\right)}{f_j^* - f_j^-}, \tag{19}$$

$$R_i = \max_j \left(\frac{w_j\left(f_j^* - f_{ij}\right)}{f_j^* - f_j^-} \right). \tag{20}$$

(4) Determine the Q_i values by using Equations (21), (22) and (23). Here, v (usually 0.5) represents the weight for the strategy of the maximum group utility; whereas $1-v$

denotes the contribution of the individual regret:

$$Q_i = v\frac{S_i - S^*}{S^- - S^*} + (1-v)\frac{R_i - R^*}{R^- - R^*}, \tag{21}$$

$$S^* = \min_i S_i, \quad S^- = \max_j S_j, \tag{22}$$

$$R^* = \min_i R_i, \quad R^- = \max_j R_j. \tag{23}$$

(5) Rank the alternatives (i.e. hospitals) based on S_i, Q_i and R_i values (set an increasing order for each value).

(6) Provide a compromise solution ($P^{(1)}$) by selecting the best-ranked alternative according to Q_i ranking list and fulfilling the conditions below:

- Acceptable advantage (Equations (24) and (25)):

$$Q\left(P^{(2)}\right) - Q\left(P^{(1)}\right) \geqslant DQ, \tag{24}$$

$$DQ = 1/(m-1). \tag{25}$$

Here, $Q(P^{(2)})$ is the hospital with the second position in the Q_i ranking list:

- Acceptable stability in decision making: the alternative ($P^{(1)}$) must be also the best in S_i and R_i ranking lists.

In case of one the conditions is not satisfied, select one of these solutions:

- $(P^{(1)})y(P^{(2)})$ if there is no acceptable stability in decision making.
- $(P^{(1)}), (P^{(2)}), \ldots, (P^{m})$ if there is no acceptable advantage. Here, $(P^{(m)})$ is subject to the following equation with the purpose of establishing the maximum m:

$$Q\left(P^{(m)}\right) - Q\left(P^{(1)}\right) < DQ. \tag{26}$$

6. Application of the proposed approach

6.1 Evaluating the risk of adverse events in Colombian hospitals

Step 1: design of the multi-criteria decision-making model. Considering that approximately 84 percent of all the medication-related adverse events resulted in severe reactions; in 80 percent of all the hospitals, an adverse event occurs every three to four weeks approximately; the most frequent adverse events are: inpatient fall (45.45 percent), and intravenous fluid infiltration (36.36 percent); all the hospitals are focused on implementing only corrective actions which implies that few efforts have been made to deploy prevention programs diminishing the occurrence and impact of adverse events; it is necessary to satisfy the Colombian regulations on patient safety, e.g. Decree No. 1011 of 2016 (this legislation establishes the mandatory quality-assurance system for general healthcare system in Colombia), Resolution No. 2003 of 2014 (it defines the registration procedures and conditions of healthcare providers in addition to the condition for the approval of healthcare services), Decree No. 903 of 2014 (this normativity reads the provisions and make adjustments to the single system of accreditation in healthcare as a component of the mandatory quality-assurance system for healthcare services and defines rules for its operation in general systems of social security in healthcare and occupations hazards), Resolution No. 256 of 2016 (it reads the provisions related to the quality information system which is a component of the mandatory quality-assurance system for healthcare services. Additionally, it sets performance indicators to monitor healthcare quality), Decree No. 3518 of 2006 (this normativity creates and regulates the Public Health Monitoring System to provide information on the dynamic of the facts that may affect the population health), Resolution No. 1445 of 1996 (this legislation lays down the rules for the compliance of sanitary conditions at hospitals), Administrative Manual for Emergency services (it contains the guidelines for the effective management of healthcare services) and London Protocol (a document covering the research, analysis and recommendation process aiming to minuciously study any adverse event) a multi-criteria decision model was developed to address the problem of assessing the risk of adverse events in hospitals and subsequently help healthcare managers to design and promote prevention programs for patient safety.

This project was presented to the ethics committee of each participant hospital. The chief executive of each entity gave informed consent for participation. Nonetheless, as this study was performed through interviews and patient participation was not queried, no formal approval from the committees was necessary. Then, the expert team was selected. The selection process of these participants began with the identification of decision-maker profiles. In this respect, four types of experts were found to be meaningful for the decision-making process: physicians, healthcare managers, head nurses and representatives of academic sector linked to the healthcare industry.

The team of experts was comprised of:

- One head nurse with a master's degree on healthcare quality and wide experience (11 years in the management of patient safety programs and committees in both private and public hospital sectors) in the management and implementation of patient safety programs.
- One healthcare manager with a specialization in healthcare services and more than eight years of experience in hospital managerial positions related to both public and private healthcare industry.
- One general physician with a master's degree in healthcare management and 13 years of experience in public hospital management.
- One industrial engineer from the academic sector with extensive experience and knowledge in healthcare logistics and multi-criteria models for performance evaluation. The industrial engineer acted as a facilitator to take over the judgment process.

A head nurse was considered to be a part of the expert decision-making team since she has designed, implemented and managed patient safety programs in different hospitals of the public sector; hence, she has significant experience to judge about the relevance and interrelations of different criteria and sub-criteria that converge in adverse events. On the other hand, a healthcare manager was invited to participate in this group due to his wide knowledge and expertise regarding the metrics established by the Ministry of Health and Social Protection to monitor and control patient safety activities. Additionally, a general physician was asked to participate as an expert due to his wide experience when addressing adverse events during the healthcare activities. This is relevant to accurately identify the most influential factors in the decision-making hierarchy while setting improvement strategies to reduce adverse events.

Finally, industrial engineer established the hierarchy with the support of the expert group and gathered the paired judgments for both AHP and DEMATEL methods. Each participant had to demonstrate a wide experience on addressing adverse events in hospitals (> 15 years). Furthermore, the potential decision-maker had to be involved in the public healthcare sector. To finally select the participants, an analysis on "curriculum vitae" data was carried out with the aid of the healthcare cluster representatives and the predefined profiles.

The decision-making group identified a total of six criteria (C1, C2, C3, C4, C5, C6) and 27 sub-criteria (S1, S2, …, S27) to evaluate the risk of adverse events in a hospital from the public sector. The criteria and sub-criteria were established based on the personal experience of experts, the aforementioned regulations and considerations of the London Protocol (Cronin, 2006). The experts took into account all the aforementioned patient safety regulations in order to provide a MCDM model responding to the current needs of Colombian healthcare system.

The multi-criteria hierarchy was then verified and discussed during multiple sessions with the expert decision-making team to establish if it was accurate and comprehensible. The final decision model is presented in Figure 2.

Particularly, the aforementioned criteria were labeled and described as stated in Table I:

Afterwards, a detailed description of the sub-criteria is provided for each criterion. In "patient" dimension (C1), "age" (S1) represents the length of patient's life. In this regard, elderly, neonate and children are the patients with the highest risk of adverse events. On the other hand, "background" (S2) sub-criterion refers to the set of patients' clinical histories that may predispose hospitals to incidents. "Disease complexity" (S3) is also deemed in "patient" criterion. This sub-criterion considers the number of underlying diseases of patients treated in a particular hospital. Additionally, "patient clinical condition" (S4) takes into account the severity of patients' clinical conditions as a potential contributor of clinical errors. Another matter of concern is "social and cultural aspects" (S5) where both limiting social and cultural beliefs can be identified and their affectations measured in order to develop more precise improvement strategies. Finally, "patient personality" (S6) is included to represent the effects of emotional and mental patients' status on activating latent failures.

In "technology" criterion (C2), "state of medical equipment" (S7) is defined as the percentage of medical equipment that is operating at good condition. "Availability of medical equipment" (S8) refers to the percentage of medical equipment that are available for immediate use. Finally, "use of medical equipment" (S9) is described as the percentage of failures produced by an incorrect manipulation of medical devices. A high contribution of these sub-criteria to the risk of adverse events may generate the need of implementing training programs supported by the providers and continuous monitoring in charge of maintenance departments.

Another criterion of importance is "environment" (C3). Herein, "state of the infrastructure" (S10) refers to the physical conditions of the furniture, utensils and accessories used by the hospital during the healthcare services. On the other hand, "work overload" (S11) represents the times of peak demand which may increase the rates of adverse events. "Space conditions" (S12) is also deemed in this dimension. In this respect, S12 encompasses the lighting, ventilation and noise conditions of hospitals to be evaluated as potential root causes of patient safety incidents. Another aspect of concern is "shift pattern" (S13). This criterion determines how the distribution of work shifts may affect the staff performance and consequently generate incidents. Lastly, "labor atmosphere" (S14) describes the employees' perceptions regarding the work environment strongly activating their errors and violations producing conditions in the workplace.

Regarding "work force" (C4) criterion, "fatigue" (S15) may represent a significant source of stress among doctors, nurses and support staff. In this respect, both mental and physical exhaustion may affect them to perform normally and consequently generate errors during healthcare services. On the other side, drowsiness (S16) determines whether the hospital demands are excessive and make employees experience reduced quality and

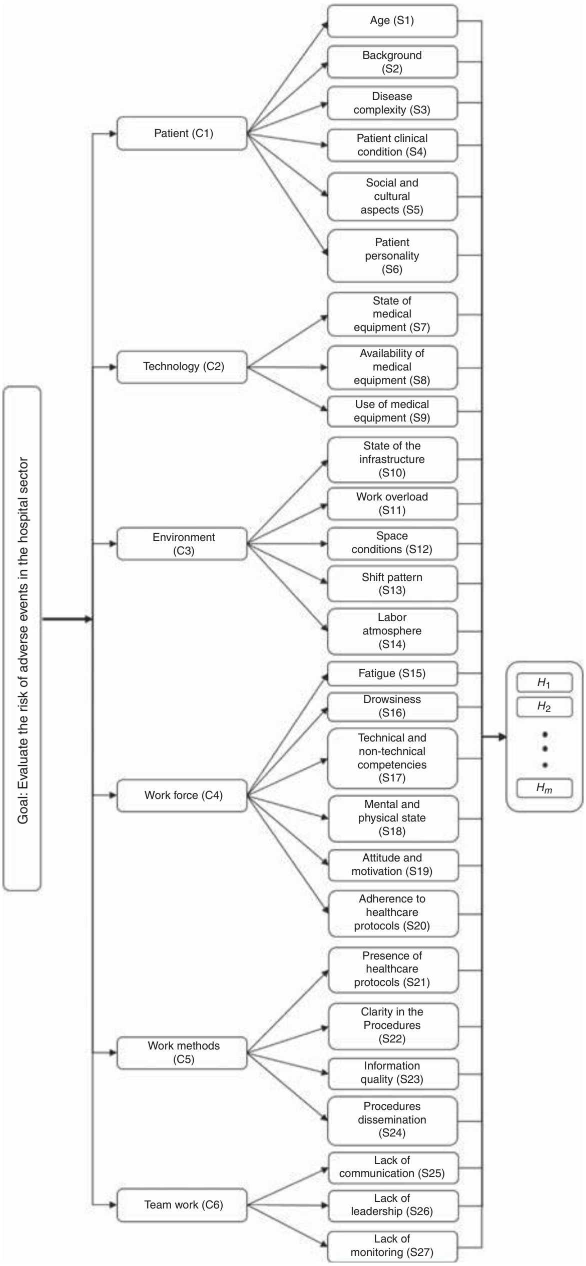


Figure 2.
Multi-criteria decision-making model to evaluate the risk of adverse events in the hospital sector

quantity of sleep. Technical and non-technical competences (S17) is another aspect of interest in this dimension. S17 encompasses a set of generic skills – non-technical – that are outside the formal education syllabus (Sahandri and Abdullah, 2009) and those specific – technical – for a particular hospital job position and workplace environment

Criterion	Sub-criteria	General description of the criterion
Patient (C1)	Age (S1) Background (S2) Disease complexity (S3) Patient clinical condition (S4) Social and cultural aspects (S5) Patient personality (S6)	This criterion considers the physical, social, emotional and mental conditions of patients that may predispose hospitals to generate adverse events during healthcare services
Technology (C2)	State of medical equipment (S7) Availability of medical equipment (S8) Use of medical equipment (S9)	It represents the status and availability of medical equipment and information management systems supporting the healthcare services in a public hospital
Environment (C3)	State of the infrastructure (S10) Work overload (S11) Space conditions (S12) Shift pattern (S13) Labor atmosphere (S14)	This factor involves a set of infrastructure, space and working conditions under which the operations of the hospital take place. It is also deemed a potential cause of adverse events and must be then minuciously analyzed to avoid future difficulties
Work force (C4)	Fatigue (S15) Drowsiness (S16) Technical and non-technical competencies (S17) Mental and physical state (S18) Attitude and motivation (S19) Adherence to healthcare protocols (S20)	This criterion represents the professional, emotional, physical and mental state of doctors, nurses and support staff that may increase the severity and frequency of adverse events
Work methods (C5)	Presence of healthcare protocols (S21) Clarity in the procedures (S22) Information quality (S23) Procedures dissemination (S24)	It evaluates how the healthcare procedures are created, disseminated and deployed to diminish and/or eliminate the risk of adverse events
Team work (C6)	Lack of communication (S25) Lack of leadership (S26) Lack of monitoring (S27)	This dimension assesses how the interdependence and feedback flows between departments may affect the rates of adverse events. In this regard, conflicts of interests may appear and team works should be able to overcome obstacles

Table I.
Description of criteria

(Awang *et al.*, 2006). In this respect, outdated staff with little work experience might cause active failures during the healthcare operations. On the other hand, “mental and physical state” (S18) measures how the contributory factors (e.g. stressors) may lead to a range of physical diseases (e.g. hypertension, diabetes and cardiovascular conditions) and poor mental health. This is increasingly determinant since it negatively influences on absenteeism and profits in addition to leading to human errors, loss of concentration and poor decision-making (World Health Organization and Funk, 2005; Rajgopal, 2010). Furthermore, “attitude and motivation” (S19) represents the motivation level and commitment of healthcare staff when treating patients. In this regard, significant positive associations have been found between staff satisfaction levels and measures of quality improvement and patient safety (Agyepong *et al.*, 2004; Alhassan *et al.*, 2013). Hence, it could be considered as a contributing factor to poor service quality, increased labor strike actions and patient dissatisfaction. Finally, “adherence to service protocols” (S20) was included to identify the gap between patient safety guidelines and clinical practice. In this respect, a significant difference may result in patients not receiving appropriate care and high risk of adverse events.

The “working methods” criteria (C5) is underpinned by four sub-criteria: “presence of healthcare protocols” (S21), “clarity in the procedures” (S22), “information quality” (S23) and “procedure communication” (S24). “Presence of healthcare protocols” indicates whether the hospital adopts healthcare guidelines for specific patient safety circumstances. This is relevant to assist healthcare professionals how to act and which steps to follow for effective patient care (Ebben *et al.*, 2013). Another criterion of particular interest is "clarity in the procedures" which involves measuring the level of understanding and comprehension expressed by the physicians regarding the correct implementation of medical procedures. On the other hand, "information quality" is described as the quality of the content provided by healthcare information systems in terms of timeliness, appropriateness, reliability, accuracy and completeness. Finally, procedure communication is defined as the percentage of processes that are explained to the stakeholders aiming at achieving their commitment during the implementation period.

The "work team" criteria (C6) is evaluated by three sub-criteria: "miscommunication" (S25), "lack of leadership" (S26) and "lack of supervision" (S27). The first sub-criterion measures the effectiveness of communication flows into the work teams of hospitals. This is relevant when considering that miscommunication may lead to employee conflict, a drop in morale and turnover. "Lack of leadership" considers the strength and capability of the supervisors and directors to make hospitals operate effectively in relation to the organizational goals. In this regard, the healthcare leaders should be encouraged to guide the workers to perform satisfactorily in order to avoid adverse events and detect potential risk sources. Finally, "lack of supervision" represents the ability of healthcare leaders to identify potential adverse events aiming at diminishing the occurrence probability.

Step 2: design of data collection tools for AHP and DEMATEL. To efficiently make the pairwise judgments, this section illustrates the data-gathering tools used for both AHP and DEMATEL techniques. The main goal is to expose a simple and understandable way to present the above-mentioned MCDM methods to the participants who are not expert in mathematical applications (e.g. doctors and nurses). In this regard, a survey (Figure 3) was initially created to collect the AHP judgments between criteria/sub-criteria. For each comparison it was asked: "According to your experience, how important is each criterion/sub-criterion on the left with respect to the criterion/sub-criterion on the right when evaluating the risk of adverse events in hospitals?" The respondents answered by using the aforementioned three-level AHP scale (as described in Sub-section 3.1) during a half-hour meeting organized by the industrial engineer. The scale is defined as follows: 1 is assumed as "equally important," 3 as "moderately important," 5 "strongly important," 1/3 "less important" and 1/5 "much less important." The survey scheme diminishes the inconsistency level and eliminates intransitive comparisons. After this, the resulting priorities were aggregated by using the geometric mean (Equation (1)).

Another data collection instrument was designed for DEMATEL comparisons (Figure 4). With this information, both criteria and sub-criteria can be categorized as dispatchers or receivers. In this regard, for each pairwise judgment, it was asked: "According to your experience, how much each criterion/sub-criterion on the left affects the criterion/

According to your experience, how important is each criterion/sub-criterion on the left with respect to the criterion/sub-criterion on the right when evaluating the risk of adverse events in hospitals?

Age	Is	~~Much less~~	Less	Equally	Moderately	Strongly	Important than	Background
Age	Is	Much less	Less	~~Equally~~	Moderately	Strongly	Important than	Disease Complexity
Age	Is	Much less	Less	~~Equally~~	Moderately	Strongly	Important than	Patient clinical condition
Age	Is	Much less	Less	Equally	Moderately	~~Strongly~~	Important than	Social and cultural aspects
Age	Is	Much less	~~Less~~	Equally	Moderately	Strongly	Important than	Patient personality

Figure 3.
Survey layout for AHP (patient cluster)

According to your experience, how much each criterion/sub-criterion on the left affects the criterion/sub-criterion on the right?								
State of medical equipment	Has	No influence	~~Low influence~~	Medium influence	High influence	Very high influence	on	Availability of medical equipment
State of medical equipment	Has	~~No influence~~	Low influence	Medium influence	High influence	Very high influence	on	Use of medical equipment
Availability of medical equipment	Has	No influence	Low influence	~~Medium influence~~	High influence	Very high influence	on	Use of medical equipment
Availability of medical equipment	Has	~~No influence~~	Low influence	Medium influence	High influence	Very high influence	on	State of medical equipment
Use of medical equipment	Has	~~No influence~~	Low influence	Medium influence	High influence	Very high influence	on	State of medical equipment
Use of medical equipment	Has	~~No influence~~	Low influence	Medium influence	High influence	Very high influence	on	Availability of medical equipment

Figure 4. Survey layout for DEMATEL (work force cluster)

sub-criterion on the right?" The participants from the decision-making team used the five-level scale established in Sub-section 3.2 to evaluate interdependence and feedback. This process was then repeated until finalizing all the comparisons.

Step 3: global and local weights of criteria and sub-criteria. The next phase of the proposed approach is the application of the combined AHP–DEMATEL hybrid method. As a consequence, the global (GW) and local weights (LW) of criteria and sub-criteria can be determined. Herein, the GW represents the contribution of a criterion/sub-criterion to the decision-making aim (assess the risk of adverse events in a hospital). On the other side, the LW is the relative relevance of each decision element within each cluster. Both weights will underpin the definition of general policies that should be deemed by the policy-makers and hospital managers in order to improve the performance regarding patient safety. Also, this information will be later used as input of VIKOR method where the three hospitals under analysis, as a supplement of this study, will be finally ranked in accordance with their risk of adverse events. Additionally, the consistency values of AHP matrices are presented to determine whether the judgments are completely trustworthy for the decision-making process.

Initially, the collected pairwise comparisons in AHP technique (refer to Step 1) were aggregated and organized into A (criteria) and B (sub-criteria) matrices correspondingly. An illustration of AHP comparison matrix is presented in Table II.

The judgments were introduced in Superdecisions ® software and the limit matrix was achieved to obtain the GW and LW values (without interdependence) as shown in Table III for both criteria and sub-criteria.

The consistency values were then obtained (Table IV) to validate the reliability of the comparisons. The results demonstrated that all matrices achieved acceptable consistency values ($CR \leqslant 10$ percent). In this respect, the data-gathering process can be considered as satisfactory and survey layout is, therefore, useful to reduce misunderstandings and

	SI	S2	S3	S4	S5	S6
SI	1	2.14	2.14	5	3	5
S2	0.47	1	1	2.28	5	3.41
S3	0.47	1	1	1	3.87	4.51
S4	0.20	0.44	1	1	4.51	3.68
S5	0.33	0.2	0.26	0.22	1	1.32
56	0.20	0.29	0.22	0.27	0.76	1

Table II. AHP comparison matrix for "patient" cluster

Cluster	GW	LW
Patient (C1)	0.368	
Age (S1)	0.130	0.353
Background (S2)	0.076	0.207
Disease complexity (S3)	0.068	0.184
Patient clinical condition (S4)	0.054	0.147
Social and cultural aspects (S5)	0.022	0.060
Patient personality (S6)	0.018	0.049
Technology (C2)	0.071	
State of medical equipment (S7)	0.025	0.357
Availability of medical equipment (S8)	0.029	0.405
Use of medical equipment (S9)	0.017	0.239
Environment (C3)	0.12	
State of the infrastructure (S10)	0.029	0.239
Work overload (S11)	0.028	0.231
Space conditions (S12)	0.023	0.192
Shift pattern (S13)	0.026	0.219
Labor atmosphere (S14)	0.014	0.118
Work force (C4)	0.176	
Fatigue (S15)	0.043	0.246
Drowsiness (S16)	0.025	0.144
Technical and non-technical competences (S17)	0.033	0.188
Mental and physical state (S18)	0.020	0.116
Attitude and motivation (S19)	0.026	0.149
Adherence of healthcare protocols (S20)	0.028	0.157
Work methods (C5)	0.116	
Presence of healthcare protocols (S21)	0.022	0.190
Clarity in the procedures (S22)	0.038	0.333
Information quality (S23)	0.035	0.309
Procedures dissemination (S24)	0.019	0.167
Team work (C6)	0.149	
Lack of communication (S25)	0.049	0.332
Lack of leadership (S26)	0.055	0.374
Lack of monitoring (S27)	0.043	0.294

Table III.
LW and GW values for criteria and sub-criteria (AHP method)

Cluster	CR
Criteria	0.035
Patient	0.059
Work methods	0.067
Work force	0.066
Work team	0.014
Environment	0.014
Technology	0.015

Table IV.
Consistency values for AHP matrices

judgment errors. On the other hand, it is fully appreciated that some complex matrices (e.g. environment, criteria and patient) presented very low CRs so that the above-mentioned declaration can be strongly confirmed.

Even though AHP can calculate both criteria and sub-criteria weights (Saaty and Shang, 2011), it does not consider dependence and feedback. Therefore, a hybrid AHP–DEMATEL technique is proposed to additionally analyze influences among different factors and understand complex cause-and-effect relationships in the decision-making problem (Wu and Tsai, 2012).

This approach provides a more robust framework to create long-term improvement strategies for both healthcare professionals and decision-makers. The ANP can simultaneously deal with linear dependence and feedback; however, the assumption of equal weight for each cluster, when obtaining the weighted supermatrix, is not acceptable in practical applications (Liu *et al.*, 2014; Kou *et al.*, 2014).

To implement AHP–DEMATEL, the relative weights of criteria and sub-criteria on the basis of interdependence (WF_c and WG_c, respectively) are calculated by using Equation (27) (criteria) and Equation (28) (sub-criteria). Herein, the weights derived from AHP application are multiplied by the normalized matrix of DEMATEL X:

$$WG_c = \begin{matrix} \\ P_1 \\ P_2 \\ P_3 \\ . \\ . \\ P_y \end{matrix} \begin{bmatrix} SC_1 & SC_2 & \cdots & SC_z \\ r_{11} & r_{12} & \cdots & r_{1z} \\ r_{21} & r_{22} & \cdots & r_{2z} \\ r_{31} & r_{32} & \cdots & r_{3z} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ r_{y1} & r_{y2} & \cdots & r_{yz} \end{bmatrix} \times \begin{bmatrix} GW^1 \\ GW^2 \\ GW^3 \\ . \\ . \\ GW^m \end{bmatrix}, \tag{27}$$

$$WF_c = \begin{matrix} \\ P_1 \\ P_2 \\ P_3 \\ . \\ . \\ P_y \end{matrix} \begin{bmatrix} SC_1 & SC_2 & \cdots & SC_z & \\ r_{11} & r_{12} & \cdots & r_{1z} & \\ r_{21} & r_{22} & \cdots & r_{2z} & \\ r_{31} & r_{32} & \cdots & r_{3z} & \cdots \\ . & . & \cdots & . & \\ . & . & \cdots & . & \\ r_{y1} & r_{y2} & \cdots. & r_{yz} & \end{bmatrix} \times \begin{bmatrix} FW^1 \\ FW^2 \\ FW^3 \\ . \\ . \\ FW^m \end{bmatrix}. \tag{28}$$

The normalized DEMATEL matrices are derived from the direct influenced matrix Z as stated in Equations (10) and (11). An illustration of a matrix Z is shown (refer to Table V) and its normalized version is presented in Table VI. After this, WF_c and WG_c values were obtained by applying Equation (27) and (28), respectively. Table VII condenses the relative contributions of criteria and sub-criteria considering linear dependence and feedback relationships.

To provide a deeper understanding of the decision-making hierarchy, the global contributions of criteria have been illustrated in Figure 5.

	Age	Background	Disease complexity	Patient clinical condition	Social and cultural aspects	Patient personality
Age	0	3.8	4.6	3.4	1.6	2.4
Background	3.4	0	3.4	3.6	1.4	1.6
Disease complexity	3	4.2	0	4.2	1.4	1.8
Patient clinical condition	4.2	4.6	4.2	0	2.6	2
Social and cultural aspects	1	2	1.8	2	0	1.4
Patient personality	1.4	2.2	1.6	2.6	1.4	0

Table V. Direct influenced matrix (Patient cluster)

In accordance with AHP–DEMATEL results, "work methods" was the criterion with the highest relative contribution (FW = 19.8 percent). However, the difference between "work methods" (first place) and patient (seventh place) is not significant (7.8 percent) which evidences that all the factors should be simultaneously considered to develop clinical improvement strategies preventing injuries or reducing their severity. It will be therefore necessary to create an integrated clinical risk management program involving the aforementioned factors. In this regard, the system surrounding patients should provide a

Table VI. Normalized direct influenced matrix (patient cluster)

	Age	Background	Disease complexity	Patient clinical condition	Social and cultural aspects	Patient personality
Age	0.000	0.226	0.295	0.215	0.190	0.261
Background	0.262	0.000	0.218	0.228	0.167	0.174
Disease complexity	0.231	0.250	0.000	0.266	0.167	0.196
Patient clinical condition	0.323	0.274	0.269	0.000	0.310	0.217
Social and cultural aspects	0.077	0.119	0.115	0.127	0.000	0.152
Patient personality	0.108	0.131	0.103	0.165	0.167	0.000

Table VII. LW and GW values of criteria and sub-criteria (AHP–DEMATEL method)

Cluster	GW	LW
Patient (C1)	0.120	
Age (S1)	0.019	0.157
Background (S2)	0.022	0.184
Disease complexity (S3)	0.023	0.192
Patient clinical condition (S4)	0.030	0.249
Social and cultural aspects (S5)	0.012	0.099
Patient personality (S6)	0.014	0.118
Technology (C2)	0.179	
State of medical equipment (S7)	0.057	0.317
Availability of medical equipment (S8)	0.048	0.270
Use of medical equipment (S9)	0.074	0.414
Environment (C3)	0.167	
State of the infrastructure (S10)	0.041	0.248
Work overload (S11)	0.028	0.165
Space conditions (S12)	0.037	0.219
Shift pattern (S13)	0.027	0.163
Labor atmosphere (S14)	0.034	0.205
Work force (C4)	0.165	
Fatigue (S15)	0.025	0.150
Drowsiness (S16)	0.029	0.177
Technical and non-technical competences (S17)	0.023	0.139
Mental and physical state (S18)	0.033	0.200
Attitude and motivation (S19)	0.033	0.202
Adherence of healthcare protocols (S20)	0.022	0.132
Work methods (C5)	0.198	
Presence of healthcare protocols (S21)	0.053	0.268
Clarity in the procedures (S22)	0.042	0.214
Information quality (S23)	0.050	0.255
Procedures dissemination (S24)	0.052	0.263
Team work (C6)	0.171	
Lack of communication (S25)	0.053	0.312
Lack of leadership (S26)	0.056	0.329
Lack of monitoring (S27)	0.061	0.359

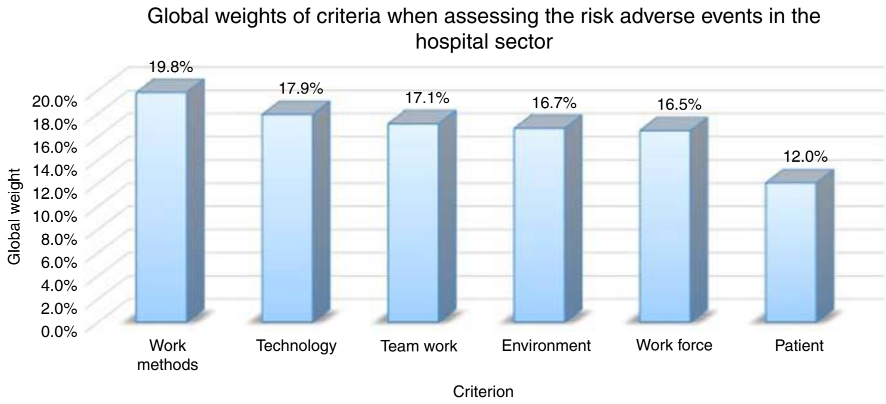


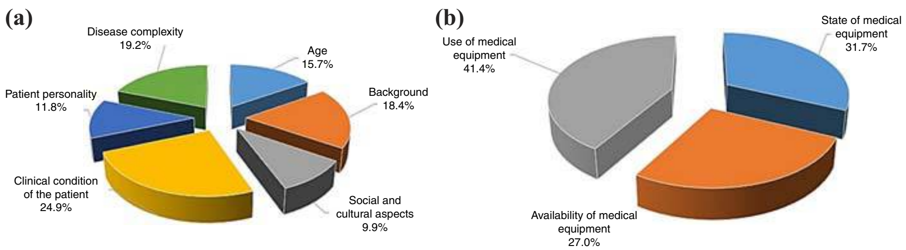
Figure 5.
GW values of criteria to evaluate the risk of adverse events in the hospital sector

safety net for potential complications resulting in prolonged hospital stay, disability at the time of discharge or death.

Regarding "patient" cluster (Figure 6(a)), the most relevant sub-criteria was "patient clinical condition" (24.9 percent). Hence, risk managers have to properly explore the patient status when accessing healthcare services. This knowledge may lead to determining whether an adverse event may occur due to patient incidence. Based on this statement, patients with very complex clinical condition have substantial risks of both poor outcomes and adverse events (Hayward and Hofer, 2001; Forster *et al.*, 2008). In this regard, patients play an increasingly important role in the prevention of clinical incidents and the reduction of non-quality costs.

In "technology" cluster (Figure 6(b)), the most significant element was "use of medical equipment" (41.4 percent). From this result, it can be said that the contributions of inappropriate use of technology to increasing error rates are high. Particularly, this is even sharper in surgical specialties of vascular surgery, cardiac surgery and neurosurgery (Donaldson *et al.*, 2000). This evidences that while technology has the potential to improve medical care, it is not without risks. Furthermore, some experts warned of the introduction of yet-to-be errors after the adoption of new medical equipment (Hughes, 2008). In this respect, difficulties may emerge considering the poor attention paid by nurses to the implementation of new technology settings and its role in healthcare services.

Considering "environment" dimension (Figure 7(a)), "state of infrastructure" represented 24.8 percent of this criterion. Nevertheless, the gap between this sub-criterion and "shift pattern" (16.3 percent) is just 8.5 percent which demonstrates that all the environment-related elements should be concurrently taken into consideration to avoid the fact that a substantial number of patients experience adverse events in hospitals. In this respect, the



Notes: (a) Patient; (b) technology

Figure 6.
LW values

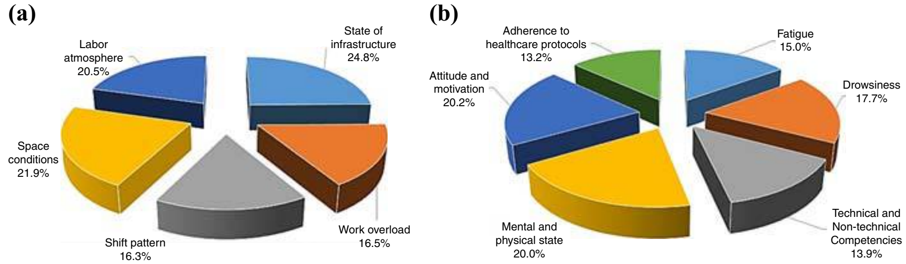


Figure 7.
LW values

Notes: (a) Environment; (b) work force

work environment has been recognized as a contributor to the occurrence of adverse events and medical errors (Rasmussen *et al.*, 2014) and work-related stress has been found as highly associated with this problem (Wrenn *et al.*, 2010). Hence, work environmental conditions must be monitored by risk managers who should verify the unpredictable and shifting working conditions in healthcare departments. Furthermore, special attention must be paid to specialists who have been reported as the cause with the highest risk of adverse events. Summing up, a transformation of the medical environment is highly required with basis on an organizational wide-approach where all healthcare professionals are committed to achieving the desired results of maximum safety.

Regarding "work force" criterion (Figure 7(b)), "attitude and motivation" (20.2 percent) and "mental and physical state" (20.0 percent) were the most crucial sub-criteria. Herein, non-significant differences were also found and therefore, it is suggested considering all the decision elements to create multi-criteria improvement strategies for better performance related to both physicians and medical staff. In this regard, special focus must be given to distractions and interruptions which may precede skill-based errors, especially diverting attention and forgetfulness (Barton, 2009). Additionally, it should be noted that the decisions made by both doctors and nurses are associated with the availability of essential information, workload and barriers to information. Hence, these aspects have to be rigorously reviewed to avoid adverse events. On the other hand, mistakes, violations and incompetence may evidence insufficient training and inadequate experience; therefore, human resources departments must design appropriate competence schemes to reduce the effects of whatever human error occurs. This is even more relevant when considering this factor as the most representative for this particular study.

In "work methods" cluster (Figure 8(a)), procedures dissemination (26.9 percent) was the most representative element. However, no significant difference was found between this sub-criterion and "clarity in the procedures" (21.4 percent) which was considered as the least

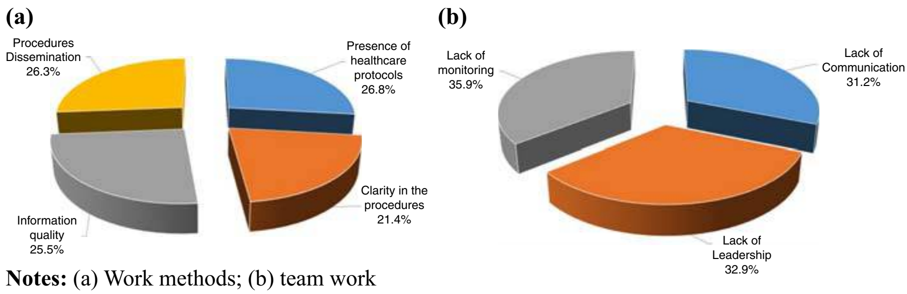


Figure 8.
LW values

Notes: (a) Work methods; (b) team work significant aspect. From these results, it is evident the need of providing a complete multi-criteria framework to ameliorate the gap between healthcare protocols and clinical practice which might result in patients not receiving safe care. In this respect, it is useful to offer concise and clear instructions on how to provide consistent medical services effectively. Additionally, in an effort to take a lead in promoting patient safety, it will be essential to enable clinicians to be aware of protocols and checklists through improved standardization and communication. In this respect, healthcare managers will also have to designate a safety champion in every department/care unit so that organization's commitment can be further evidenced and patient safety policies deployed and efficiently disseminated in clinical practice. Thereby, conditions for safe medical care can be greatly enhanced.

On the other hand, in "team work" criterion (Figure 8(b)), a similar behavior can be observed with little differences between "lack of monitoring" (35.9 percent) and "lack of communication" (31.2 percent). Therefore, the risk managers will have to focus on improving both team collaboration and professional communication channels to diminish potential medical errors and the subsequent implications on patients' safety (e.g. severe injury and unexpected death). Particularly, when clinicians are not communicating effectively, medical errors may occur due to the lack of critical information and unclear orders (O'Daniel and Rosenstein, 2008). Thus, healthcare leaders play a key role to promote a common aim (e.g. reduce adverse events) and carry out plans for patient safety. With this in mind, the decision-makers will have to monitor the progress of these strategies in order to ensure their correct deployment in healthcare services. To do this, process-of-care measures should be incorporated and process-improvement techniques adapted aiming to identify inefficiencies and preventable errors, so that team work can effectively act in accordance with the organization goals and international standards of patient safety.

As next step, a comparative analysis between AHP and AHP–DEMATEL was carried out to identify changes in the GW values of criteria (Figure 9) and sub-criteria (Figure 10).

Regarding the overall importance of the criteria, the most significant change was observed in C1 (patient) with a difference value of −0.2468. The result is largely explained by the *D*−*R* (−0.3350) and *D*+*R* measures (6.6763) through which this factor was strongly categorized as a receiver. Other meaningful differences can be appreciated in C2

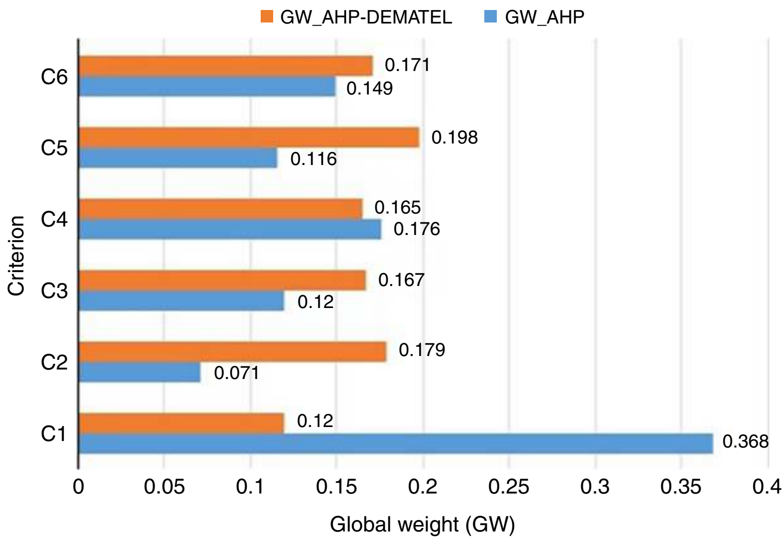


Figure 9.
Comparison between AHP and AHP–DEMATEL (GW values of criteria)

(technology) and C5 (work methods) criteria with 0.108 and 0.082, respectively. Both criteria were qualified as dispatchers with $D–R = 0.3675$, $D+R = 6.4093$ in C2 and $D–R = 0.0831$; $D + R = 7.2216$ for C5 criterion. From these results, a substantial impact on other decision elements could be further evidenced which underpins the increase in the relative contribution of these criteria with respect to the goal.

In accordance with the results provided in Figure 10, all the GW scores were concluded to be different when incorporating DEMATEL method. Particularly, a substantial decrease was found in the sub-criteria weights: S1 (age), S2 (background), S3 (disease complexity) and S4 (patient clinical condition). Herein, it is important to consider the fact that the GW of "patient" criterion changed dramatically (as indicated above) which ended up affecting the overall importance of these elements in the decision-making model. On the contrary, a meaningful increase was observed in: S7 (state of medical equipment), S8 (availability of medical equipment), S9 (use of medical equipment), S10 (state of the infrastructure), S12 (space conditions), S14 (labor atmosphere), S18 (mental and physical state), S19 (attitude and motivation), S21 (presence of healthcare protocols), S23 (information quality), S24 (procedures dissemination) and S27 (lack of monitoring). These results confirm the presence of interrelations in the decision-making model and therefore, the application of AHP–DEMATEL method can be considered as useful to also identify dependence and feedback. Another aspect of interest is the fact that risk managers can properly design and implement long-term strategies to eliminate or diminish the risk of adverse events in hospitals. This is a meaningful advantage of the AHP–DEMATEL hybrid technique over the AHP method and then is recommended for similar applications. For this particular case, the safety patient managers should primarily focus on improving work methods, technology, team work, environment and work force which evidences what the regulations sets (refer to Section 4): the safety patient systems must be ready to address potential adverse events and diminish avoidable latent failures and affectations in patients.

Step 4. Interrelations between criteria/sub-criteria via applying DEMATEL. The third step of the proposed approach evaluates the interrelations between criteria or sub-criteria by implementing DEMATEL technique. For this purpose, IRMs and influence strength calculations are provided to show which factors and sub-factors can be categorized into the cause (dispatcher) and effect (receiver) groups when assessing the risk of adverse events in hospitals. This information offers valuable insights for healthcare decision-making and guides risk managers to the development of strategic frameworks emphasizing on reducing avoidable failures in the long term. Aside from this, it is fully appreciated by the healthcare cluster managers in order to define future prospects and intersectoral projects addressing patient safety difficulties. That is where external healthcare institutions may provide an opportunity to alleviate the burden faced as a result of this problem.

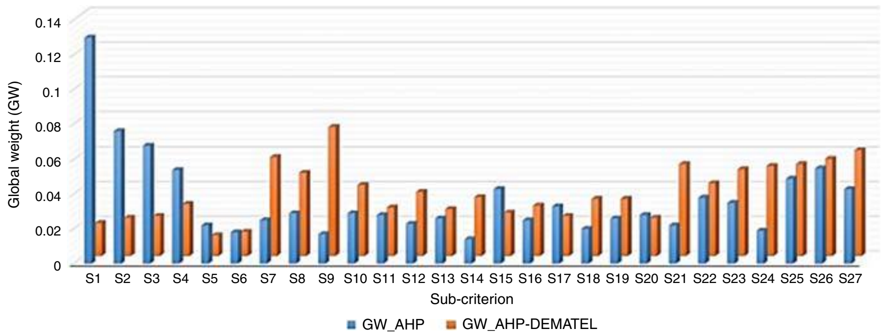
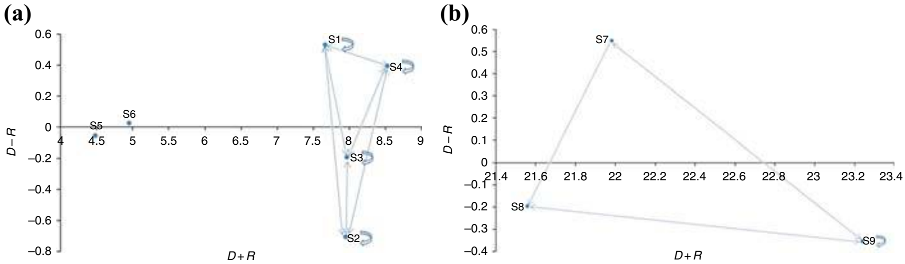


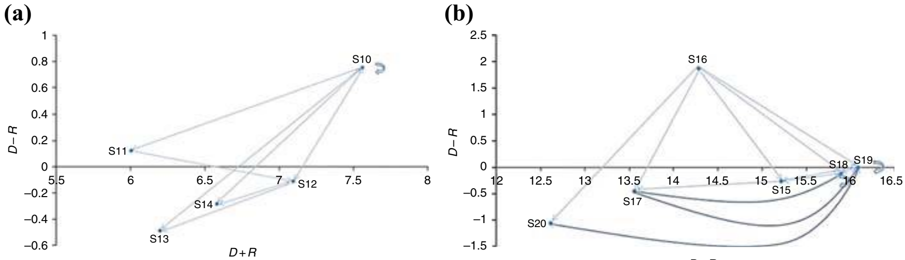
Figure 10.
Comparative analysis between AHP and AHP–DEMATEL (GW values of sub-criteria)

In order to analyze the interrelations, IRMs were developed (Figures 11–13). First, the IRM for "patient" is illustrated (refer to Figure 11(a)). The threshold value for this cluster was defined as $\theta = (20.7625/6^2) = 0.5767$. Based on this reference number, age (S1), patient clinical condition (S4) and patient personality (S6) are the dispatchers; on the other hand, background (S2), disease complexity (S3) and social and cultural aspects (S5) are the receivers. Based on the graph, particular attention must be given to patient clinical condition (S4) since it has a strong influence (D+R = 8.5260) must be therefore highly considered as the focus of improvement strategies regarding patient criterion. In this regard, effective prevention and promotion plans should be created to ensure better health status of the population and consequently reduce the failures caused by patients.



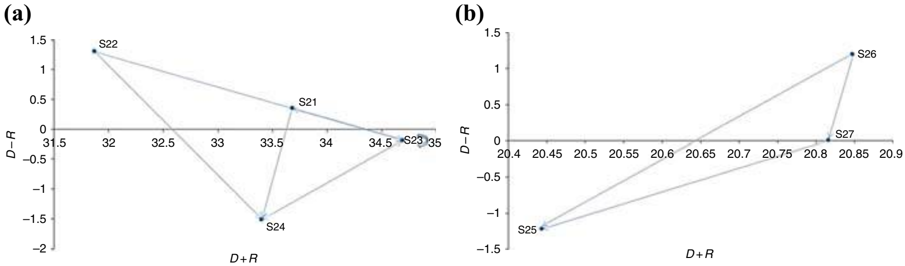
Notes: (a) Patient; (b) technology

Figure 11. Influential-relation map for criteria



Notes: (a) Environment; (b) work force

Figure 12. Influential-relation map for criteria



Notes: (a) Work methods; (b) team work

Figure 13. Influential relation map for criteria

The IRM for technology is presented (Figure 11(b)). The threshold was calculated as $\theta = (33.3894/3^2) = 3.7099$ by the industrial engineer with expertise on decision-making techniques. Herein, state of medical equipment (S7) is the dispatcher whilst, availability of medical equipment (S8) and Use of medical equipment are the receivers. The graph specifies that S7 exerts a meaningful influence on both receivers (D+R = 11.4019); thus, maintenance departments must implement predictive and preventive models to ensure medical equipment functioning according to the standards and greatly diminish the risk of adverse events considering that technology is the factor with the highest contribution.

An impact diagram was also defined for environment criterion (Figure 12(a)). The estimated reference value was $\theta = (16.7171/5^2) = 0.6687$. Thus, state of the infrastructure (S10) and work overload (S11) were concluded as dispatchers; meanwhile, space conditions (S12), shift pattern (S13) and labor atmosphere (S14) were categorized as receivers. Based on these insights, it was found that state of the infrastructure (S10) has a strong effect on most of the sub-criteria in this cluster. Hence, the tasks associated with this sub-factor should be effectively deployed through continuous investment flows and optimized maintenance plans. Additionally, risk managers should incorporate knowledge from reported literature to produce solutions which will provide a safer environment for patients.

An impact map was also drawn for work force criterion (Figure 12(b)). The established threshold value for this cluster was computed to be $\theta = (43.8195/6^2) = 1.2172$. From this graph, it can be assumed that drowsiness (S16) is the only dispatcher and the rest was qualified as receivers. This can be further explained with the map where S16 influences the rest of sub-criteria. In this respect, the cornerstone of this finding lies on the fact that drowsiness has been recognized as a relevant contributing factor to the active failures of patient safety systems. In this context, it is important to continuously evaluate the working load and health status of physicians, nurses and support staff so that skills can be implemented properly.

Another criterion of concern (work methods) described in Figure 13(a) was also mapped searching for prolific areas of intervention. For this purpose, the threshold value was calculated as $\theta = (66.8160/4^2) = 4.1760$. The main outcomes of this analysis refer to the fact that Presence of healthcare protocols (S21) and clarity in the procedures (S22) were categorized as dispatchers. On the other side, procedures dissemination (S24) and information quality (S23) were classified as *receivers*. However, the most relevant finding was on S21 sub-criterion since it affects all the decision elements in "work methods" cluster. Consequently, the healthcare managers should be able to exploit the international standards and regulations on patient safety through better clinical management. In addition, it is necessary to look for scenarios facilitating the correct deployment of these protocols so that implementation errors and the learning curve can be meaningfully slackened.

An IRM was also constructed for "team work" factor (Figure 13(b)). The adopted reference number for this cluster was determined as $\theta = (31.0525/3^2) = 3.4503$. Consequently, lack of leadership (S26) and lack of monitoring (S27) were classified into the cause group and lack of communication (S25) was categorized as part of the effect group. In accordance with the diagram, a special attention must be paid to S26 since it affects the others significantly. This is mainly related to the effort required from healthcare supervisors to support the technical deployments derived from patient safety management. In this regard, effective solutions will be founded on efficient team work where the leaders should guide people to gain a better understanding of the system. Once this happens, it is possible to monitor the sources of potential failures and subsequently reduce the occurrence and severity of adverse events.

As the primary focus of this study is to provide meaningful insights in the decision-making framework, Table VIII specifies the total influence matrix T for criteria. The cells highlighted in gray indicate the significant correlations. The adopted threshold value for this matrix was $\theta = (44.8118/6^2) = 1.2448$. From these results, it can be noted that meaningful correlations are concentrated in technology (C2), Work force (C4), work methods (C5) and team work (C6). Herein, C2, C5 and C6 are of particular interest since they were classified into the cause group and should be therefore considered to reduce the risk of adverse events in hospitals. On the other hand, no affectation was detected on C6 and only one can be seen over C2 reason why these criteria obtained the highest relation values. Finally, prominence and relation values of the criteria and sub-criteria have been enlisted in Table IX where a summary of dispatchers and receivers are also provided.

	C1	C2	C3	C4	C5	C6	*D*	*R*	*D*+*R*	*D*–*R*
C1	1.0880	1.0456	1.1905	1.2555	1.2610	1.0878	6.9285	7.7369	14.6653	−0.8084
C2	1.3097	1.0217	1.2538	1.3662	1.3883	1.1595	7.4991	6.6889	14.1880	0.8102
C3	1.2509	1.0745	1.0916	1.3299	1.3192	1.1154	7.1815	7.4801	14.6616	−0.2985
C4	1.3376	1.1758	1.2737	1.2503	1.3863	1.1857	7.6094	8.0484	15.6579	−0.4390
C5	1.4411	1.2611	1.3826	1.4791	1.3325	1.2408	8.1372	8.0360	16.1732	0.1012
C6	1.3096	1.1103	1.2878	1.3675	1.3486	1.0324	7.4561	6.8216	14.2777	0.6345
R	7.7369	6.6889	7.4801	8.0484	8.0360	6.8216				

Table VIII. Total influence matrix *T* for criteria

Criterion/sub-criterion	Prominence (*D*+*R*)	Relation (*D*–*R*)	Dispatcher	Receiver
Patient (C1)	14.6653	−0.8084		X
Age (S1)	7.6611	0.5324	X	
Background (S2)	7.9435	−0.7073		X
Disease complexity (S3)	7.9655	−0.1931		X
Patient clinical condition (S4)	8.5260	0.3946	X	
Social and cultural aspects (S5)	4.4784	−0.0542		X
Patient personality (S6)	4.9505	0.0276	X	
Technology (C2)	14.1880	0.8102	X	
State of medical equipment (S7)	11,4019	0.5487	X	
Availability of medical equipment (S8)	10.7951	−0.1947		X
Use of medical equipment (S9)	11,4425	−0.3540		X
Environment (C3)	14.6616	−0.2985		X
State of the infrastructure (S10)	7.5604	0.7567	X	
Work overload (S11)	6.0027	0.1234	X	
Space conditions (S12)	7.0939	−0.1102		X
Shift pattern (S13)	6.1967	−0.4867		X
Labor atmosphere (S14)	6.5806	−0.2833		X
Work force (C4)	15,6579	−0.4390		X
Fatigue (S15)	15.2161	−0.2577		X
Drowsiness (S16)	14,2838	1.8735	X	
Technical and non-technical competences (S17)	13,5566	−0.4473	X	
Mental and physical state (S18)	15.8878	−0.1126		X
Attitude and motivation (S19)	16,0831	−0.0024		X
Adherence of healthcare protocols (S20)	12.6116	−1.0534		X
Work methods (C5)	16.1732	0.1012	X	
Presence of healthcare protocols (S21)	33.6785	0.3633	X	
Clarity in the procedures (S22)	31.8680	1.3152	X	
Information quality (S23)	34.6884	−0.1765		X
Procedures dissemination (S24)	33,3971	−1.5020		X
Team work (C6)	14.2777	0.6345	X	
Lack of communication (S25)	20.4428	−1.2123		X
Lack of leadership (S26)	20.8469	1.2017	X	
Lack of monitoring (S27)	20.8153	0.0105	X	

Note: "X" indicates whether or not Dispatcher and Receiver have those parameters

Table IX. Relation (*D*–*R*) and prominence (*D*+*R*) values of criteria and sub-criteria

6.2 Ranking three Colombian hospitals according to the risk of adverse events

Step 5. VIKOR application. Complementary to this analysis, VIKOR method is applied to rank the three hospitals under analysis according to the risk of adverse events in order to inform patients searching for safe care (best-ranked hospitals) and healthcare authorities who need to prioritize interventions and allocate resources effectively. The adoption of VIKOR method extends the usability of the results (practical implications) emanating from AHP and DEMATEL techniques and it hence contributes to the still scant evidence base on EBMgt. VIKOR ranks a set of alternatives based on the proximity to the ideal scenario (compromise solution), taking into account the formulas and conditions described in the Sub-section 3.3. For the project development, three hospitals (P1, P2 and P3) from Colombian healthcare system were selected. These institutions are administrative entities with financial sustainability whose primary aim is to provide a defined set of medical services seeking for preventing diseases and promoting healthcare. Particularly, P1 is a first-level hospital with second-level specialized healthcare with a focus on patient needs and family expectations. Furthermore, it has remodeled facilities with a satisfactory layout and high-tech medical equipment. On the other hand, P2 is also a first-level medical institution comprised of qualified and service-minded human resource with a sense of belonging. However, it has a limited space and old-fashioned medical technology. In turn, P3 can be defined as a hospital with basic medical services provided with quality, efficiency and a patient safety policy. Nonetheless, its facilities are very old and its layout is inefficient. The medical equipment is also antiquated and failures on adverse events monitoring system can be appreciated.

For the VIKOR implementation, a group of indicators or key performance indexes (KPI) was defined, one for each sub-criterion (refer to Table X) based on the regulations established by the Ministry of Health and Social Protection. The mathematical formulation for the calculation of each KPI is also provided in Table X.

After organizing the KPIs in the A matrix of VIKOR method (refer to Table XI), the best (f_j^*) and worst (f_j^-) values for each sub-criterion were determined. The sub-criteria weights were provided by the combined AHP–DEMATEL method.

Then, S_{i} and R_{i} values were calculated by using Equation (19) and (20) respectively (refer to Table XII). After this, by applying Equations (21), (22) and (23), Q_i measures were determined. Herein, $S^* = 0.148$, $S^- = 0.581$, $R^* = 0.033$, $R^- = 0.074$ and $v = 0.5$. Thereby, the hospitals were ranked in accordance with S_i, R_i and Q_i values (refer to Table XIII).

Each ranking of hospitals (alternatives) is made in increasing order and the best-ranked alternative (compromise solution) is determined by corroborating two conditions (Sub-section 3.3): acceptable advantage and acceptable stability in decision-making. A summary of this validation is provided in Table XIV. Both conditions are satisfied and therefore P1 is the hospital with the least risk of adverse events.

In order to facilitate continuous improvement on patient safety management of the hospitals under assessment, the separations from the ideal scenario were illustrated in Figure 14. This is to easily identify how close each alternative is to this performance and which sub-criteria must be improved to reduce the overall gap (S_i). In this sense, it is evident that P1 is the closest to the ideal solution; even though it is recommendable to improve in S19 (attitude and motivation) and S5 (social and cultural aspects). On the other hand, particular attention must be paid to P2 since the major deviations are given in sub-criterion S7 (state of medical equipment), S8 (availability of medical equipment), S10 (state of the infrastructure) and S12 (space conditions) where contributions to adverse events are significant. In this regard, a diagnosis should be firstly performed to determine the causes of these poor measures and then establish effective solutions to the problem with basis on the dispatchers. Finally, the worst-ranked hospital (P3) presents serious difficulties in S9 (use of medical equipment), S16 (drowsiness), S18 (mental and physical state), S22 (clarity

Sub-criteria	KPI	Formula
Age (S1)	Average age of patients	Sum of the ages of the patients/Total of attended patients
Background (S2)	% of patients with one or more of the following clinical conditions: Diabetes Hypertension	(Number of patients with diabetes and/or hypertension/Total number of attended patients)×100
Disease complexity (S3)	% of patients with complex diseases	(Number of patients with complex diseases/Total number of attended patients)×100
Patient clinical condition (S4)	Average stay in ICU (days)	Sum of the individual stay periods in ICU/Total number of attended patients
Social and cultural aspects (S5)	Weighted average of the social strata	A value is assigned to each social strata: Low (1) Medium (2) High (3) n1: Proportion of population in low social strata n2: Proportion of population in medium social strata n3: Proportion of population in high social strata N: Total population. $\sum\left((n1 \times 1)+(n2 \times 2)+(n3 \times 3)/N\right)$
Patient personality (S6)	% of patients with psychological intervention	(Number of patients with psychological intervention/Total of attended patients)×100
State of medical equipment (S7)	% of medical equipment in good condition	(Number of medical equipment in good condition/Number of medical equipment)×100
Availability of medical equipment (S8)	% of medical equipment available	(Number of medical equipment in operation/Number of medical equipment)×100
Use of medical equipment (S9)	Average month number of medical equipment failures due to misuse	(Number of annual medical equipment failures due to misuse/12)
State of the infrastructure (S10)	% of adequate rooms	(Number of adequate rooms/Total number of rooms)×100
Work overload (S11)	% of workers who exceed their working time when performing hospital activities	(Number of workers who exceed their working time when performing hospital activities/Total number of workers)×100
Space conditions (S12)	% of failures due to lack of lighting, ventilation, reduced space or excessive noise	(Number of failures due to lack of lighting, ventilation, reduced space or excessive noise/Total number of failures)×100
Shift pattern (S13)	Risk level of hospital workers	A 5-point scale was defined as follows: Class 1: Minimum risk Class 2: Low risk Class 3: Medium risk Class 4: High risk Class 5: Maximum risk
Labor atmosphere (S14)	% of satisfied workers	(Number of satisfied workers/Total number of workers)×100
Fatigue (S15)	Average overtime worked by employees in a week	(Sum of overtime worked in a hospital per week/Total number of workers)
Drowsiness (S16)	Average number of employees working at night shift	(Sum of employees working at night time/Total number of night shifts)
Technical and non-technical competencies (S17)	% of qualified personnel	(Number of professionals workers/Total number of workers)×100

(continued)

Table X. Key performance indexes for sub-criteria

Sub-criteria	KPI	Formula
Mental and physical state (S18)	% of workers with good physical and mental state	(Number of workers with good physical and mental state/Total number of workers)×100
Attitude and motivation (S19)	% of workers with good attitude and motivation level	(Number of workers with good attitude and motivation level/Total number of workers)×100
Adherence to healthcare protocols (S20)	Proportion of monitored adverse events	(Number of adverse events under supervision/Total number of adverse events)×100
Presence of healthcare protocols (S21)	Presence of healthcare protocols	Yes (1) No (0)
Clarity in the procedures (S22)	Average medical errors per month	(Sum of annual medical errors/12)
Information quality (S23)	% of information requests met	(Number of information requests met/Total number of received requests)×100
Procedures dissemination (S24)	% of disseminated procedures	(Number of disseminated procedures/Total number of procedures)×100
Lack of communication (S25)	Average monthly number of errors due to lack of communication	(Sum of annual number of errors due to lack of communication/12)
Lack of leadership (S26)	% of supervisors with leadership training	(Number of supervisors with leadership training/Total number of supervisors)×100
Lack of monitoring (S27)	Existence of security rounds	Yes (1) No (0)

Table X.

Sub-criterion	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
GW	0.019	0.022	0.023	0.03	0.012	0.014	0.057	0.048	0.074	0.041	0.028	0.037	0.027	0.034
P1	38.6	44%	60%	0	1.5	36%	95%	93%	1	90%	17%	3%	3	96%
P2	41.4	56%	80%	0	1.54	43%	80%	85%	1	60%	14%	5%	3	97%
P3	44.8	52%	70%	0	1.54	19%	91%	89%	2	80%	10%	5%	3	93%
Best value	38.6	44%	60%	0	1.54	19%	95%	93%	1	90%	10%	3%	3	97%
Worst value	44.8	56%	80%	0	1.5	43%	80%	85%	2	60%	17%	5%	3	93%
Sub-criterion	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	
GW	0.025	0.029	0.023	0.033	0.033	0.022	0.053	0.042	0.05	0.052	0.053	0.056	0.061	
P1	9	7	90%	85%	89%	100%	1	3	100%	70%	2	92%	1	
P2	6	9	88%	90%	92%	100%	1	2	100%	62%	2	90%	1	
P3	5	11	86%	75%	95%	100%	1	4	91%	54%	3	88%	1	
Best value	5	7	90%	90%	95%	100%	1	2	100%	70%	2	92%	1	
Worst value	9	11	86%	75%	89%	100%	1	4	91%	54%	3	88%	1	

Table XI.
Initial matrix *A* for hospital alternatives

Sub-criterion	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
GW	0.019	0.022	0.023	0.03	0.012	0.014	0.057	0.048	0.074	0.041	0.028	0.037	0.027	0.034
P1	0	0	0	0	0.012	0.01	0	0	0	0	0.028	0	0	0.009
P2	0.009	0.022	0.023	0	0	0.014	0.057	0.048	0	0.041	0.016	0.037	0	0
P3	0.019	0.015	0.012	0	0	0	0.015	0.024	0.074	0.014	0	0.037	0	0.034
Sub-criterion	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	*Sj*
GW	0.025	0.029	0.023	0.033	0.033	0.022	0.053	0.042	0.05	0.052	0.053	0.056	0.061	
P1	0.025	0	0	0.011	0.033	0	0	0.021	0	0	0	0	0	0.058
P2	0.006	0.015	0.012	0	0.017	0	0	0	0	0.026	0	0.028	0	0.267
P3	0	0.029	0.023	0.033	0	0	0	0.042	0.05	0.052	0.053	0.056	0	0.243

Table XII.
S_i and R_i values

in the procedures), S23 (information quality), S24 (procedures dissemination), S25 (lack of communication) and S26 (lack of leadership) which evidences a fairly catastrophic performance regarding the elements from the cause group (technology, team work, work force and work methods). To address this problem, P3 should create training programs for both nurses and physicians in collaboration with the providers. Additionally, it is recommended to monitor the effectiveness of these programs aiming to evidence the achieved results in terms of reduced number of adverse events and potential failures. On the

Table XIII. S_i, R_i and Q_i ranking for hospitals in accordance with their risk of adverse events

Alternatives	S_i	S_i rank	R_i	R_i rank	Q_i ($v = 0.5$)	Q_i rank
P1	0.148	1	0.033	1	0.000	1
P2	0.369	2	0.057	2	0.548	2
P3	0.581	3	0.074	3	1.000	3

Table XIV. Evaluation of conditions for compromise solution

Condition	Conclusion
C1: Acceptable advantage (0.548≥ 0.5)	Satisfied
C2: Acceptable stability in decision making (1st place in ranking for both S_i and R_i)	Satisfied

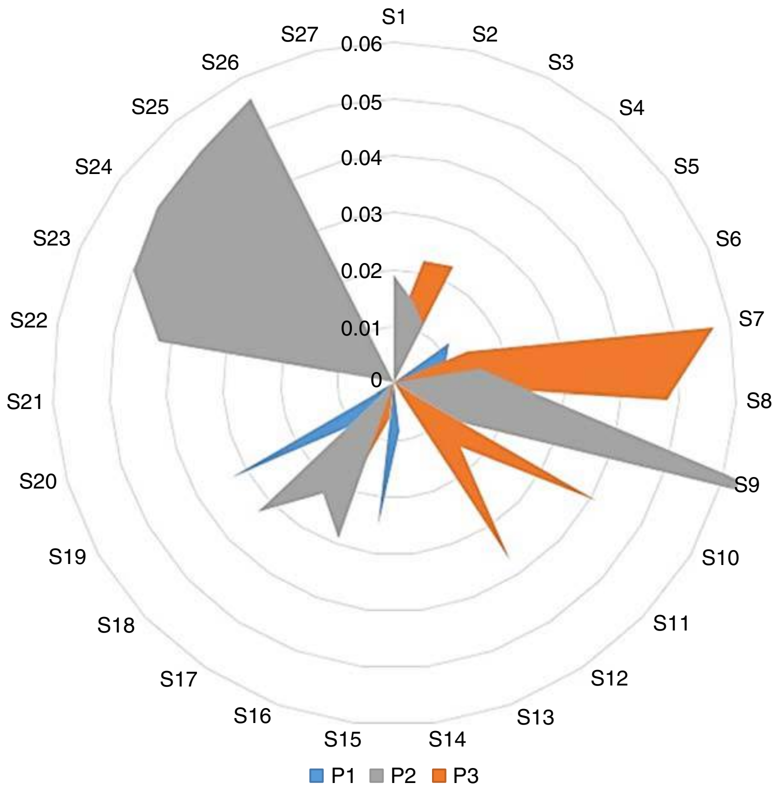


Figure 14. Spider diagram for separations from the ideal scenario

other side, the human resources department of this P3 should evaluate the physical status of employees and determine whether the work load is adequate for the purpose of designing focused improvement plans. Regarding the difficulties with work methods, its patient safety department ought to carefully revise how the protocols are being documented, deployed and disseminated since the system evidences symptoms of poor understanding and comprehension reason which dramatically increases the risk of adverse events and affectations on patients. Finally, it is proposed to verify the accurateness of information flows in work teams and the roles played by its supervisors. In this case, the human resources department should work on designing coaching programs where these details can be analyzed and improved. Furthermore, it is relevant to determine whether the information system is pertinent and useful for P3 hospital. With these strategies, communication and leadership problems can be effectively addressed. The above-mentioned recommendations can be further replicated by other hospitals with similar performance on patient safety.

7. Conclusions

In the context of healthcare, the evaluation of any outcome measure involves several technical, social, and economic aspects. Thus, it is necessary to take into account the relationships between them. At this aim, the multi-criteria decision methods concur. MCDM clearly may help in the matter, although the large literature on the topic does not allow determining easily which procedure is the more appropriate. Each method contains strengths and weaknesses. For example, AHP hierarchy can have as many levels as needed to fully characterize a particular decision situation. Furthermore, AHP can efficiently deal with tangible as well as non-tangible attributes. But, at the same time, perfect consistency is very difficult to obtain with AHP or it does not allow to evaluating interrelations and influences between the elements that compose the decision-making process. Hence, to overcome disadvantages associated with AHP, an integration using DEMATEL method is proposed. DEMATEL is used for researching and solving complicated and intertwined problem groups. In particular, it is useful to investigate interrelationships between the criteria for evaluating effects. Finally, VIKOR method is proposed to calculate the ratio of positive and negative ideal solution. It proposes a compromise solution with an advantage rate. Therefore, the hybrid and integrated approach AHP–DEMATEL–VIKOR was found to provide robust, realistic and reliable results when assessing hospital patient safety level. This increases the likelihood of a favorable outcome derived from the decision-making process. Additionally, it responds to the following facts: equal weights of decision element cannot be assumed since some bias may be incorporated into the MCDM model and they must be then properly estimated; some studies support the fact that there may exist correlation between criteria predicting adverse events; it is relevant to inform patients searching for safe healthcare and authorities who need to prioritize sectorial interventions and properly allocate resources and to overcome the limitations of single MCDM methods.

The example provided has demonstrated that the proposed approach is an effective and useful tool to assess the risk of adverse events in the hospital sector. The results could help the hospital identify its performance level and respond appropriately in advance to prevent adverse events. We can conclude, that the promising results obtained in applying the AHP–DEMATEL–VIKOR method suggest that the hybrid method can be used to create decision aids that it simplifies the shared decision-making process. Furthermore, the decision here formulated (assessing the risk of adverse events in hospitals) has been made conscientiously, explicitly and judiciously (even searching for the best MCM methods) used with basis on the best available evidence (findings from literature review, pairwise judgments from experts and key performance indicators) as stated by Morrell and Learmonth (2015).

It is important to acknowledge that the findings may be related to the characteristics of the study design. Importantly, the study was limited to three hospitals in Colombia, which could partially explain the VIKOR results. Future research will take into account two new aspects: a greater number of hospitals and different countries. On the other hand, a sensitivity analysis based on Monte Carlo approach and three simulation models (random weights, rank-order weights and response distribution weights) will be developed in order to test the influence of both criteria and sub-criteria weights on the final ranking (Butler *et al.*, 1997).

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