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A hybrid model to support decision making in emergency department management

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ABSTRACT

The Emergency Department (ED) plays a key role in restoring the health of patients. Ensuring the availability of the ED and achieving rational use of its resources is critical to avoiding ED overcrowding by patients. Given this, the critical question is how ED managers can design and select improvement actions that reduce ED overcrowding. Designing and selecting enhancement actions are viewed as a Multiple Criteria Decision Making (MCDM) problem. Thus, this work provides a hybrid MCDM model combining Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Preference Ranking Organization (PROMETHEE II) methods to help ED managers design improvement actions and make decisions that reduce ED overcrowding. In the model, the role of DEMATEL method is to generate knowledge to support the design of improvement actions from the causal relationships among the criteria governing the management of the patient care and treatment process in ED units. However, as EDs have costly resources, actions need to be prioritized. Therefore, the PROMETHEE II method composes the model to prioritize improvement actions that reduce short-term ED overcrowding. The model was validated by applying it in the ED of one of the largest hospitals in the state of Paraná, Brazil, that exclusively serves patients with the Brazilian federal government's single healthcare system (Sistema Único de Saúde — SUS). The model was easily understood by the ED managers due to its ease of use, and the integration among these managers necessitated by its development and application enriched the discussion of the overcrowding problem faced by the ED.
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1. Introduction

A hospital's Emergency Department (ED), as an important component of a healthcare system, plays a strategic role in restoring patient health, as it is one of a hospital's main entry points and provides nonstop health services for patients with various needs [1]. The managers of an ED have to cope with random demands for patient health complexity, and the lack of a decision support structure can lead to low productivity, delayed patient treatment, longer waiting times for medical care than recommended by Medical Guidelines, long duration of stay in the ED, as well as overloaded staff. Combined with budget constraints, this leads to the problem of overcrowding, which is considered as a major problem that adversely affects patient care and outcomes worldwide [1–3].

The decision-making process to support overcrowding reduction in an ED can become very complex [2]. This complexity arises because decision making is a collective process with numerous alternatives governed by several criteria. Moreover, the process requires a consensus solution by Decision-Makers (DMs) or specialists or managers which in turn is arrived at by resolving conflicting perspectives [4–6]. Including the manager's preferences during the decision-making process may be essential to efficient deployment of hospital resources [2,4].

To structure and support decision making in managing the patient care and treatment process in an ED with a focus on reducing overcrowding, operational research uses Multiple Criteria Decision Making (MCDM) methods [2]. MCDM methods are classified as a toolkit that standardizes the decision-making process through mathematical modeling and supports managers throughout a decision-making process with conflicting criteria [7].

In the healthcare domain, MCDM methods are gaining ground as a way to facilitate and improve the quality of decision making [2]. To this end [8,9], studies have reported an increase in the use of MCDM methods in healthcare. These authors concluded that more than 56% of MCDM methods were applied in health

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investment, 12% supported authorization decisions, 22% were linked to drug-prescribing decision making, and 2% supported research decision making. In [10] articles reporting the application of MCDM in the healthcare domain published from 1960 to 2011 were bibliometrically evaluated, and the conclusion was that the applications showed a significant and constant increase, with resource allocation being the most relevant topic of MCDM applications in healthcare. In a recent study [11], the authors evaluated 36 studies published from 1990 to 2018 that used MCDM knowledge to support Health Technology Assessment (HTA) agencies in setting health priorities. However, its implementation has been criticized for being "fully mechanistic" and not following best practice guidelines. The authors concluded that MCDM has great potential to support HTA agencies in setting health priorities, but their implementation needs to be improved.

As already stated, the managers of an ED may face several conflicting criteria and different priorities and influences that may guide the process of designing improvement actions (i.e., alternatives) for problem solving in the area [12,13]. Moreover, the criteria that guide actions are rarely independent and usually involve levels of causal relationships, sometimes with dependence effects [14–16].

Given the context of the decision-making environment in healthcare, the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method was developed as a way to design more appropriate improvement actions (e.g., [12,13,17–22]. The DEMATEL method not only takes into account the relationships of influence and interdependence between the criteria for selecting the appropriate solutions, but also prioritizes the most important criteria using weighting. This can be useful for designing improvement actions more rationally. That is, improvement actions can be conceived using influential and important criteria within the defined criteria set [12]. The DEMATEL method is based on graph theory, which helps achieve a better understanding of the causal relationships between decision criteria, which are characterized by complexity and, in many cases, imperceptibility [23].

However, EDs may have budgetary constraints due to factors such as the high costs of drugs, equipment, or labor. Therefore, improvement actions need to be implemented in an order of importance/prioritization. When it comes to actions to address a problem in a short period of time, DMs can use this information to decide which improvement actions to implement that will generate the greatest impact in the short term for patient care and treatment, with the aim of reducing overcrowding of the ED.

In this sense, the PROMETHEE II method is one approach for classifying the order of importance for implementing the improvement actions. Its overarching approach is based on the concept of dominance, where the alternatives are compared in pairs by the DMs in terms of each criterion [2]. The PROMETHEE II method allows a deeper analysis, mainly through the criteria that impact the defined improvement actions to a greater or lesser degree, besides being able to balance the actions with n qualitative and quantitative criteria [2].

However, for the PROMETHEE II method, the DMs may be required to assign weights to the different defined criteria that support the choices of the alternatives [2]. The PROMETHEE II method has no formal support for establishing weights for the criteria, so an approach is needed to address this gap [24,25]. In this sense, it is important in the context of the health management domain to highlight the approach used by the DEMATEL method to deal with the complexity of defining the criteria weights, which in turn will enable the PROMETHEE II method to support the decision-making process. The advantage of using DEMATEL as a way of determining weights for the criteria is its consideration of the influences from the analysis of cause and effect relationships between the elements of a system [12].

In this sense, considering the problem of overcrowding in EDs, where alternatives are not yet defined or prioritized for implementation, we realize that if we approach the decision-making process to solve the problem as defined by one MCDM method acting in isolation, the decision-making process may be limited. The fact is that unique methods may have limitations in their structures, thereby not giving the necessary contributions to the decision-making process [14–16]. In this case, seeking to offer more robust responses to the problem of overcrowding faced by the EDs, we present a hybrid MCDM approach.

To guide the design and prioritization of improvement actions to reduce overcrowding in EDs, this study proposes the use of a hybrid model of MCDM that combines the DEMATEL and PROMETHEE II methods. We believe that the proposed hybrid model can help systematize the decision-making process involving the rationale offered by the formal methods MCDM used, to support ED managers in making complex decisions in the face of the problem of ED overcrowding.

This paper is organized as follows: Section 2 presents the proposed hybrid model, highlighting how the DEMATEL and PROMETHEE II methods can jointly support the decision making process to reduce ED overcrowding. The Section 3 briefly reviews the DEMATEL and PROMETHEE II methods and related works on the application of these methods in the healthcare area. Following Section 4, the hybrid model is applied in the ED of Cajuru University Hospital (Hospital Universitário Cajuru — HUC), one of the largest hospitals in the state of Paraná, Brazil, and which exclusively serves patients with the Brazilian federal government's single healthcare system (Sistema Único de Saúde — SUS). In turn, the discussion of results are presented in Section 5. Finally, in Section 6 the conclusion of this paper and future studies are presented.

2. The hybrid model

The hybrid model consists of the three steps shown in Fig. 1. The model embodies the rationale employed to help managers or specialists in the management of the patient care and treatment process in ED units design improvement actions and make decisions to reduce ED overcrowding in the short-term. Therefore, the hybrid model follows the structure defined by [4] for implementing the MCDM methods. Thus, Step 1 has as its starting point the overcrowding of patients in the HUC ED as the identified problem, followed by the derivation of the criteria governing the management of the patient care and treatment process in ED units. Step 2, on the other hand, deals with the application of the DEMATEL method for designing improvement actions to solve the problem. In Step 3, the PROMETHEE II method is utilized to help the HUC ED managers prioritize actions. Actions that have the greatest impact on solving the problem of overcrowding in the HUC ED in the short term will be prioritized.

2.1. Step 1 - define the problem and derive the criteria

Step 1 of the hybrid model, with the problem defined, begins the derivation of the criteria that guide the management of the care and treatment process of patients in ED units. To this end, the medical guidelines that regulate and guide the management process of EDs have been explored, such as the Manchester Triage System (MTS), which is one of the most widely used systems for EDs in Brazil and worldwide for patient health risk classification. This system uses five colors that set the maximum waiting time for the initiation of medical care. This one uses 5 colors that set the maximum waiting time for the start of medical care [26,27].

Similarly, other medical guidelines such as the regulations of the Brazilian Federal Council of Medicine (Conselho Federal de

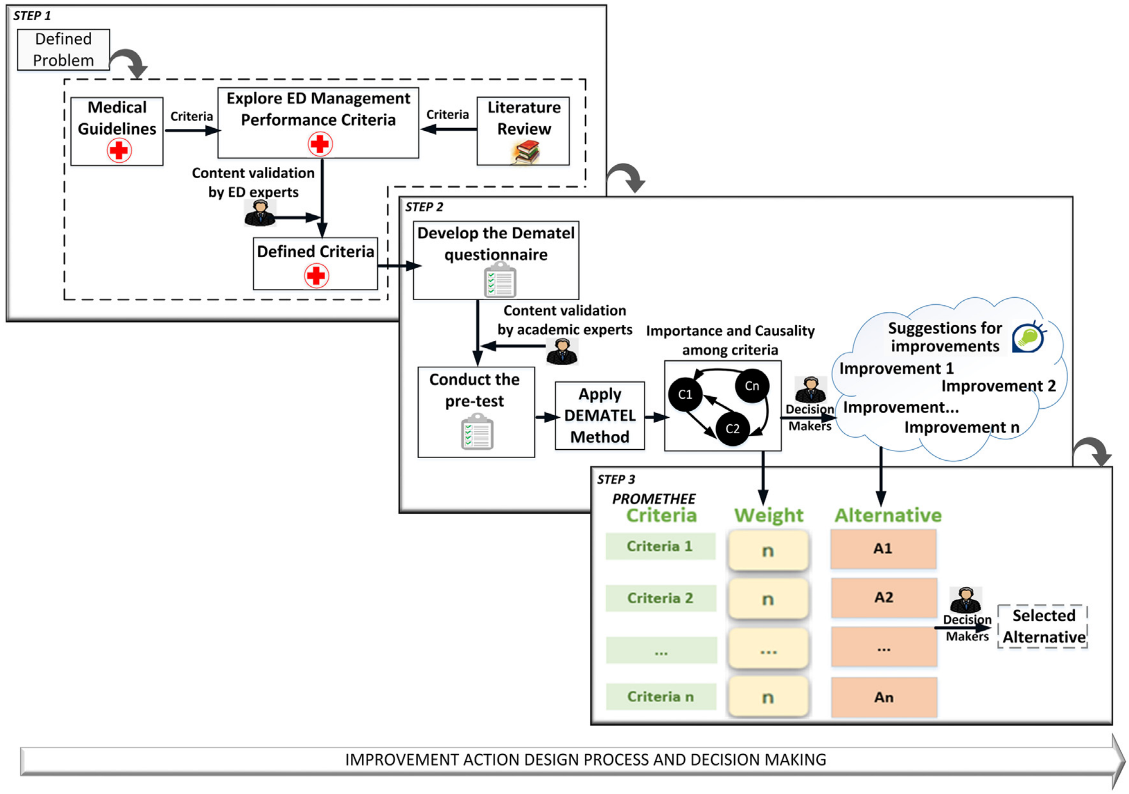

Fig. 1. Proposed hybrid model.

Medicina — CFM) [28] and the Ministry of Health (Ministério da Saúde — MS) of the Brazilian government [29] were explored, and scientific papers were also assessed. To confirm that the criteria derived from the medical guidelines and the literature are suitable for guiding the management of the patient care and treatment process in the ED of the studied hospital, a discussion should be held through a formal meeting with the specialists in the ED management process.

2.2. Step 2 - apply the DEMATEL method

A questionnaire on the DEMATEL method that collates the opinions of process specialists will help identify the causal relationships and the levels of importance of the defined criteria. A formal meeting with academic experts will help design, revise, and validate the questionnaire to meet the requirements of the DEMATEL method. Subsequently, a pretest should be conducted with one of the process specialists to validate the efficiency of the questionnaire application. With the defined criteria and validated questionnaire, the DEMATEL method can be implemented.

The selected process specialists must have adequate knowledge of the problem to be solved. Thus, the set of physicians, nurses, and managers who are directly involved with the management of the patient care and treatment process in the ED will be studied. Based on the opinion of the specialists, the following can be obtained: The level of influence that criterion i exerts on another criterion j and, vice versa, using a scale from 0 to 4, values that correspond in ascending order to "no influence", "low influence", "medium influence", "high influence", and "very high influence", respectively [23,30]. The Fig. 2 presents, from a pair of defined criteria, an example of the questionnaire that will be applied.

Thus, knowledge will be generated by the DEMATEL method about the causal relationships, influences, and levels of importance of the criteria. Using this knowledge, specialists will be able to improve the diagnostic evaluation of the problems faced by the ED and to define more objectively the improvement actions that will reduce overcrowding, focusing on the criteria that generate causality, influences, and those defined as important. When the importance of the criteria is established and its causal relationships are observed, improvement actions may be defined [12].

2.3. Step 3 - prioritize actions defined using the PROMETHEE II method

With the defined improvement actions, the ED specialists of the studied hospital should, in order of prioritization, implement the defined actions. Prioritization of actions may be necessary because EDs often face budgetary constraints owing to the high cost of technological, human, and material resources. Prioritizing actions allows specialists to focus efforts on actions that have the greatest impact on overcrowding reduction in the short-term. To this end, the PROMETHEE II method will be used, which employs pairwise comparisons and prioritization ranking. Comparisons are made from overclassification, with the aim of representing the performance of the alternative for a given criterion, considering the relationships between them.

The PROMETHEE II method is validated in the case of the present work, which, although subject to subjectivity, is more resistant to parameter variations, being able to classify and order alternatives that are complex and difficult to compare [2]. The classifying approach of the PROMETHEE II method can be considered appropriate to solve problems of decision making where they involve characteristics of prioritization/overclassification of alternatives to be implemented in the context of the decision of hospital services [2,31].

PROMETHEE II method assumes that the DMs is able to quantify weights according to the defined criteria [24]. Quantifying weights is considered essential information in the PROMETHEE

According to your knowledge, how much each criterion on the left influences the relation with the criterion on the right?								
Resources Utilization	**has**	Non-existent (0)	Low (1)	Medium (2)	High (3)	Very High (4)	**Influence on**	Layout Efficiency
Layout Efficiency	**has**	Non-existent (0)	Low (1)	Medium (2)	High (3)	Very High (4)	**Influence on**	Resources Utilization

Fig. 2. Dematel questionnaire.
Source: Adapted from [23,30].

II method, the weights representing the preferences of DMs in the decision context [2]. However, a limitation of the PROMETHEE II method is that it does not provide any formal guidelines for weighing the criteria, and [24,25] it is appropriate to bring an approach that bridges this gap. This may be necessary for a hospital management environment, as the relative importance of each criterion may be conflicting, with different weight scales provided by different patient care process management specialists in an ED unit [2]. As the number of specialists increases, the process of weighting decision-making criteria may become complex, as two or more specialists may approach a problem using differently defined criteria [4].

Thus, in this paper, as a methodology for weighting the criteria for the PROMETHEE II method, we use the approach of the DEMATEL method and to deal with the complexity of the definition of the weights of the criteria. According to [12,30] through the DEMATEL approach, the value of the direct and indirect effects caused and received by the criterion can be defined; the higher this value, the greater the weight and degree of importance of the criterion in the set of established criteria. When establishing feedback relationships, a criterion may be considered relevant in the relationship network because of the influences provided and received [12].

3. Literature review

In a typical health decision-making environment, DMs often use a variety of criteria to evaluate different alternatives for making a decision [4]. However, some criteria are difficult to measure for benefits or costs, for example, patient safety, patient satisfaction, hospital image, social impact, quality, comfort, working atmosphere, etc. Although they could be incorporated into a mathematical model of classical optimization through constraints, these criteria would still have the disadvantage of preventing any intervention by the DMs, leading to inflexible decision making. In this case, modeling the problem and arriving at a decision using MCDM methods is more advisable [2,4].

Thus, selection of the best possible option by the DMs is one of the advantages of MCDM methods, in that there are no simultaneously optimal decisions across all points of analysis [32]. Thus, according to [33], the optimal result "does not exist" in a multicriteria structure. Often, none of the decision support alternatives perfectly match the objective to be achieved, in which case the alternative that best fits the objectives can be selected by evaluating the different alternatives against a set of criteria [34]. Given this context, this section aims to theoretically support the proposed model through the theoretical concepts, main ideas, and approaches of the DEMATEL and PROMETHEE II methods in healthcare area.

3.1. The dematel method

The DEMATEL method proposed by the Battelle Memorial Association in Geneva was intended to analyze complex and interconnected problems and to help identify viable solutions through a network structure. This method emphasizes the interdependence among the criteria and restricts the essential relationships to the system and its development [15]. In this way, DEMATEL method improves understanding of a specific problem and evaluates viable solutions using a hierarchical structure. With DEMATEL's structural modeling techniques, the causal relations among criteria in a system can be identified by using a causal diagram [12].

In a complex system, such as healthcare, it is believed that all system criteria are directly or indirectly related to one another. In these intricate systems, it is very difficult for a DM to achieve a specific goal if he or she wants to avoid interference from the rest of the system [15]. Therefore, the DEMATEL method may be assumed to classify the criteria that influence the management of an ED and assist its managers in identifying improvement actions that focus on reducing its overcrowding. The DEMATEL method follows a six-step process.

Step 1: Initial direct relation matrix *Z*.

This is the first step of the method, in which each specialist is questioned about the degree of influence between two criteria based on a pairwise comparison [35]. A rating, with scales ranging from 0 (no influence), 1 (low influence), 2 (medium influence), 3 (high influence) to 4 (very high influence) is used for the comparisons [23,30]. The degree to which criterion i affects the criterion j is denoted by x_{ij}. For $i = j$, the diagonal elements are set to zero. For each specialist, a non-negative matrix $n \times n$ is constructed because $M^k = [x^k_{ij}]$ where k is the number of specialists participating in the comparison between pairs of criteria, with $1 \le k \le S$. Therefore, $M^1, M^2, M^3, \ldots, M^S$ is the number of matrices for S specialists. To incorporate the judgments of all S specialists, the initial direct relation matrix $Z = [a_{ij}]$ is calculated using Eq. (1) [12].

$$a_{ij} = \frac{1}{S}\sum_{k=1}^{S} x^k_{ij} \tag{1}$$

Step 2: Calculate the matrix *D*

Matrix D is the normalized matrix Z and is calculated using Eq. (2) e (3).

$$D = Z \times k \tag{2}$$

Each element in the matrix D varies between [0,1]:

$$k = min\left[\frac{1}{max_{1\le i\le n}\sum_{j=1}^{n}|a_{ij}|}, \frac{1}{max_{1\le j\le n}\sum_{i=1}^{n}|a_{ij}|}\right] \tag{3}$$

Step 3: Obtaining the total relation matrix *T*.

This step obtaining the matrix T, also called the total relationship matrix $n \times n$ which reflects the total relationship between each pair of criteria. The calculation of matrix T is denoted by Eq. (4), where I is an identity matrix $n \times n$ and the elements $[T_{i_j}]$ represent the direct and indirect effects that criterion i has on criterion j.

$$T = D + D^2 + D^3 + \cdots = \sum_{i=1}^{\infty} D^i = D(I - D)^-1 \tag{4}$$

Step 4: Calculate the intensity of the effects caused and received by the criteria

In the total relationship matrix T, the sum of the rows and columns are represented by the values of R_i and C_j according to Eqs. (5) and (6).

$$R_i = \sum_{j=1}^{n} T_{i_j} \; (where\; i = 1, 2, \ldots, n) \tag{5}$$

$$C_j = \sum_{i=1}^{n} T_{i_j} \; (where\; j = 1, 2, \ldots, n) \tag{6}$$

The value R_i indicates the total direct and indirect influences of criterion i in relation to the other defined criteria. The value of C_j indicates the total influence received directly and indirectly, that all other criteria exert on the criterion j. The value $(R_i + C_j)$ and represents the degree of importance that criterion i plays throughout the system. The higher the value of $(R_i + C_j)$, the more important the criterion [12]. If $(R_i - C_j)$ is positive, the criterion i is considered causative in the cause and effect diagram, that is, influencing other criteria in the relationship network. Similarly, if $(R_i - C_j)$ is negative, the criterion i is a receiver in this network, i.e., it is influenced by other criteria [12,36–38].

Step 5: Set a threshold value for analysis (α)

The total ratio matrix T provides information on how one criterion affects another criterion. Thus, a threshold value is calculated to eliminate the matrix T relationships among criteria with negligible values. Therefore, if in matrix T the degree of influence of a given criterion is greater than the limit value (α), the relationship among the criteria analyzed is included in the cause and effect diagram. If it is below this limit, then it is not included in the diagram. One of the ways of identifying the threshold value is to average the matrix elements T[12,30].

$$\alpha = \frac{1}{N} \sum_{i=1}^{n} \sum_{j=1}^{n} [T_{ij}] \tag{7}$$

where N is the total of elements in the matrix T.

Step 6: Build the diagram of influences

The final step of the DEMATEL method produces a cause and effect diagram by mapping all sets of coordinates $(R_i + C_j)$ (values on the horizontal axis) and $(R_i - C_j)$ (values on the vertical axis) of the diagram, respectively. In the diagram, it is possible to view the interrelationship and information about the influencing criteria as well as the criteria being influenced [12,39].

3.2. The PROMETHEE II method

The PROMETHEE II method admits situations of incomparability among alternatives with the "indifference" classification, which were lost with other MCDM methods. In this study, we use PROMETHEE II, which provides a complete ordering of the alternatives or actions analyzed, thus overcoming the limitation of PROMETHEE I, whose ordering is partial [40,41].

The PROMETHEE II method builds an overclassification relationship by aggregating information among alternatives and criteria, taking advantage of this relationship to support decision making [42]. The method was developed to deal specifically with discrete multicriteria problems, where the set of decision-making alternatives is finite. The advantage of the PROMETHEE II method in classifying the improved actions is evidenced in the relative comparisons made. These comparisons assess the preferences of the DMs for each pair of alternatives, as based upon the differences presented by $u_j(x_i)$ - $u_j(x_k)$, where x_i and x_k are potential alternatives and u_j represents an evaluation through a criterion. In addition, PROMETHEE II is excellent for balancing i actions with j qualitative and/or quantitative criteria [40]. For example, the method enables the managers of an ED to compare in a single decision-making process a quantitative criterion such as the "Use of Physician" with qualitative criteria such as "Satisfaction in the Workplace".

In this study, the PROMETHEE II method is used with a five-step approach [43], as follows:

Step 1: Normalize the decision matrix using Eq. (8).

$$\delta_{ij} = \frac{[x_{ij} - min(x_{ij})]}{[max(x_{ij}) - min(x_{ij})]} \; (Where\; i = 1, \ldots, n\; and\; j = 1, \ldots, m) \tag{8}$$

δ_{ij} denotes the DM's preference of alternative ith against criterion jth.

Step 2: Set how two alternatives lie in relation to each criterion. For this, it is necessary to calculate the differences δ_{ik} of DMs preferences for each pair of alternatives considering the defined criteria, according to Eq. (9).

$$\delta_{ik} = |u_j(x_i) - u_j(x_k)| \tag{9}$$

δ_{ik} represents the performance difference of the alternative x_i with alternative x_k for criterion j. The relative preference function of each criterion j is calculated using Eq. (10).

$$P_j(x_i, x_k) = P_j(|u_j(x_i) - u_j(x_k)|) = P_j(\delta_{ik}) \tag{10}$$

In the construction of the preference function, different models could be employed to define the discriminatory power of the criterion. Considering the criteria in which alternative x_i is preferable or indifferent to alternative x_k, six types of preference functions could be used [42]. Each preference function ranges from 0 and 1 and provides the degree of preference for selecting alternative x_i over alternative x_k for each criterion j [24]. The preference function Type I is used in this work because it is not necessary to define preference and indifference parameters. The Type I function is defined by Eqs. (11) and (12).

$$P_j(\delta_{ik}) = 0\; if\; \delta_{ij} \leq \delta_{kj} \tag{11}$$

$$P_j(\delta_{ik}) = 1\; if\; \delta_{ij} > \delta_{kj} \tag{12}$$

Step 3: The calculation of the multicriteria preference index is denoted by $\pi(x_i, x_k) = \pi(\delta_{ik})$ according to Eq. (13). $\pi(\delta_{ik})$ is calculated for each pair and is in the range [0 and 1]. It expresses the preference of alternative x_i over alternative x_k considering all criteria.

$$\pi(\delta_{ik}) = \frac{\sum_{j=1}^{k} W_j P_j(\delta_{ik})}{\sum_j W_j} \tag{13}$$

where W_j is the weight between [0 and 1] associated with each criterion j, where $j = 1, \ldots, m$ [24]. In the PROMETHEE II method, the weights constitute the additional information required to enrich the structure of preference among the criteria.

Step 4: The PROMETHEE II method outputs the preference index, which expresses the degree to which one alternative is chosen/preferred over another alternative. In turn, overclassification flows are established to observe how each alternative outperforms and, at the same time, is surpassed by the $(n-1)$ defined alternatives. For this, the positive and negative flows are calculated.

- The positive flow represents the degree to which alternative x_i is better compared to other alternatives through Eq. (14).

$$\phi^{+}(i) = \frac{1}{n-1} \sum_{k=1}^{n} \pi(\delta_{ik}) \tag{14}$$

- The negative flow represents the degree to which all other alternatives are preferred over alternative i through Eq. (15).

$$\phi^{-}(i) = \frac{1}{n-1}\sum_{k=1}^{n}\pi(\delta_{ki}) \tag{15}$$

Step 5: Establish a net overcoming flow $\phi(i)$.

The PROMETHEE II method introduces a net flow that is governed by Eq. (16) and represents the balance between the strength and weakness of the alternative. Thus, a final ordaining of the alternatives, from the most efficient to the least efficient, could be performed in decreasing order of the values of $\phi(i)$ obtaining a total preorder.

$$\phi(i) = \phi^{+}(i) - \phi^{-}(i) \tag{16}$$

In turn, the PROMETHEE-GAIA extension (Geometrical Analysis for Interactive Aid) describes the results of the PROMETHEE II method in the form of a visual and interactive guided graph procedure, providing graphical information about the conflicting criterion and the impact of weights on the final decision. The GAIA has sensitivity tools, which give DMs additional insight into the defined problem, and it is possible to clearly appreciate the quality of the alternatives against different criteria [7].

3.3. Related works

In this section, we describe the approaches of the DEMATEL and PROMETHEE methods to support the decision-making process, presenting the advantages and disadvantages of each in the context of health. Finally, we present the advantages of a hybrid model designed to make complex decisions in the face of the problem of overcrowding EDs units.

[13] analyzed the Value Perceived by the Patient (VPP) in applying the Lean Manufacturing principles in ED. The DEMATEL method was suggested to specify the degree of influence of these values on ED. Results show that the criterion "availability of equipment" has a strong influence on the other criteria. [18] feature a study using DEMATEL and Delphi by Iranian specialists selected through intentional sampling, with a view to identifying and listing components affecting access to ED services. In turn [19] applied to identify the influent determinants in the performance of pre-hospital emergency system in Iran and analyze the relations among them. The most important determinants include "organization", "transportation", "communications", "accessibility", "model of assistance", "combination of labor", "regulations" and "training". [17] developed of a hybrid MCDM and DEMATEL approach in assessing influent indicators in the area of healthcare. Results show that "accidents/adverse events", "nosocomial infection", "incidents/errors", "number of surgeries/procedures" are significant influent indicators. In addition, indicators "in-hospital time", "occupation of beds" and "financial metrics" come up as important in assessing the performance of healthcare organizations. [20] proposed a hybrid model based on Analytics Hierarchy Process (AHP), DEMATEL and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to evaluate the state of readiness of three public EDs in Colombia in terms of being prepared for a disaster situation. [12] evaluated the relations of influence and importance among the seven main criteria that direct the services delivered by Show Chwan Memorial Hospital in Changhua City, Taiwan. The criterion "reliable, professionally competent medical staff" is the most important. Therefore, the authors suggested training for the clinical team in communication skills and problem solving as strategy to drive up user satisfaction levels. [21] says that in the event of decision-making issues there usually is a limited number of possible alternatives, but a high number of criteria that drive the choice of the solution chosen. Therefore, this study features a hybrid approach based on the DEMATEL and AHP methods in defining the best hospital allied to outpatient services. Finally, [22] proposed a new Fuzzy MCDM model incorporating Fuzzy DEMATEL and Fuzzy Gray Relational Analysis (GRA). The model is used to classify occupational risk levels for activities undertaken by professionals working in DEs of three hospitals in the city of Erzurum, Turkey. This study provides a reliable and effective model to obtain risk levels in EDs and determine the required precautionary strategies.

In turn, the PROMETHEE method has also contributed to helping the decision-making process in the healthcare area. [44] highlighted that the determination of specialization degrees for hospitals was considered by the Coordinating Office of an administrative region in Quebec, Canada. Several points of view needed to be examined and the use of a multi-criteria method to aid decision-making was well suited for this problem. Therefore, the authors used the PROMETHEE method and compared its results with the graphical representation constructed by the GAIA method. [25] showed that to increase the number of patients treated, and thus decrease the patients' cycle time, it is important to add a specialist or a trained general practitioner to the staff. The researchers used the diffuse PROMETHEE method to determine who the managers should add to the ED. Furthermore, the PROMETHEE method the parameterization of the criteria weights is done in a non-systematized manner. Thus, it may be appropriate to introduce an approach that bridges this gap. [45] compared two overclassification methods: PROMETHEE II and Elimination Et Choix Traduisant la Realité (ELECTRE) II, and applied them to an emergency hospital to demonstrate their advantages and disadvantages. Both placed the "Discipline the Medical Team" alternative first. However, the results showed that the PROMETHEE II method algorithm managed to avoid a tie between alternatives. [2] applied the PROMETHEE II method to support decision-making and resource management in an ED. It was chosen for this study because its overcoming approach is considered appropriate for the decision-making context of hospital services. The PROMETHEE II ranking showed the best alternatives in improving patient performance in the "Blue Room". Six months later, the waiting time during overpopulation periods was reduced by about 70%. The PROMETHEE II method has proven to be a rational tool to support the DM in choosing alternatives to solve bottlenecks related to overcrowding in an ED. [31] investigated different multi-criteria methods such as the Analytic Hierarchy Process (AHP), ELECTRE, and PROMETHEE for decision-making support in healthcare. The experimental results proved that the PROMETHEE method is the most appropriate method in solving problems regarding decision-making with various criteria when choosing the desired health services. [46] suggested a new approach to improve the flow of patients using MCDM methods. The objective was to make a rational choice of the appropriate department to which the patient should be assigned to, even if the department related to their pathology is crowded at that moment. Finally, [47] presented a methodology to be used in the evaluation of the quality of health services. In a real-life case study of a public hospital in Istanbul, the Interval Valued Intuitionistic Fuzzy (IVIF)-PROMETHEE method was applied to assess the quality of service based on the patients' opinions. Thereafter, the results were compared with those of the IVIF-TOPSIS method. The proposed methodology can be a useful tool for hospital management.

In reviewing relevant published studies, we have identified that the DEMATEL and PROMETHEE methods assist hospital managers in supporting their decision-making processes. However, the use of methods in isolation may have limitations, weakening the decision-making process in general. In this sense, we believe

Table 1
Most demanded medical specialties.

Medical specialties	Demand
Orthopedics	45.39%
General surgery	25.21%
Internal medicine	12.00%
Ophthalmology	8.76%
Others	8.64%

Table 2
Risk classification of patients treated in the ED and times to start the care recommended by MTS.

Color of classification	Percentage of patients serviced	Waiting times established by MTS
Green	63.87%	120 min
Yellow	20.76%	60 min
Blue	13.67%	240 min
Orange	1.66%	10 min
Red	0.04%	0 min
Total	100%	

that the hybrid model may be necessary to help systematize the decision-making process involving the rationalities on offer by the formal methods MCDM — formal methods used as means to support EDs managers in making complex decisions regarding the problem of patient overcrowding.

Given this context, the union of the methods may be necessary, since, in a decision-making environment concerning the reduction of overcrowding of patients in an ED, managers may face several conflicting criteria with different levels of importance and influences. We believe that these factors can guide the design process of an improved methodology (so as to provide alternatives) aimed at solving problems present in such a context. Thus, the DEMATEL method proved to be useful in the design of improved actions with a higher level of rationality. This rationality is supported by the fact that the improved actions were defined through an understanding of the relationships between influences and levels of relative importance, as they exist among the decision criteria, and as proposed by [12].

In turn, we believe that the improved actions (as designed) needed to be implemented along an order of importance/prioritization due to the high costs of medicines, equipment, labor, etc. This, in turn, can generate more satisfactory impacts to patient care and treatment in the short term, via the aim of reducing ED overcrowding. In this context, PROMETHEE II method was presented as a satisfactory method in classifying the implementation of improvement actions an order of importance (as generated by the knowledge obtained through the DEMATEL method).

For this reason, our study focuses on how managers of an ED can better manage the patient care and treatment process; this would allow for a more appropriate handling of a high flow of patients and management resources. The final result of the hybrid model (DEMATEL-PROMETHEE II) is to assist in systematizing the decision-making process involving the rationalities on offer by the formal methods MCDM, as well as to support ED managers in making complex decisions in the face of patient overcrowding.

4. Applications of the hybrid model

Data collection was performed between January to March 2019 at the HUC ED located in the city of Curitiba, State of Paraná, Brazil. The HUC is a reference center for medical emergencies and serves only SUS patients, which establishes the incentive for hospitals that are nonprofit private legal entities. In orthopedics and general surgery, the HUC services approximately 4,500 monthly ED visits. Through the HUC's Hospital Information Systems (HIS), data from approximately 13,000 patients were evaluated to obtain characteristics — such as the profiles of the most demanded medical specialties (see Table 1), as well as the risk classifications of the patients treated by the HUC's ED, according to Table 2. The knowledge of these characteristics by the HUC's ED managers aided in the decision-making process.

The managers of HUC reported that the ED has faced problems with overcrowding, causing patients to remain in the ED for a prolonged period of time, contributing to long waiting times in commencing medical care. These characteristics of the ED (overcrowding, waiting times, etc.) fall outside of the recommendations made by the Medical Guidelines. These problems may reflect the scarcity of professionals (physicians, nurses, etc.), infrastructure that does not support the levels of patient demand, or the scarcity of adequate management of patient care and treatment processes, thereby compromising the efficiency of ED.

In the HUC ED, there are two distinct modes of patient arrival. One set of patients, who are considered "emergency patients", arrive by land or air ambulance. The other set of patients come to the ED voluntarily, walking alone or accompanied. The specialists believe that this problem is being caused by the large number of patients classified by the MTS as somewhat urgent (green) and non-urgent (blue) who seek care voluntarily in the ED (walking alone or accompanied) in the time period 07:00 am to 11:00 pm. This is a typical situation, as similarly reported on by [48].

Given this situation and the budget constraints, the HUC ED specialists find it difficult to design improvement and decision-making actions that could lead to better performance in managing the patient care and treatment process and, consequently, reduce ED overcrowding in the short-term. Table 2 shows the risk classification for patients who arrive on their own at the ED, as well as the suitable times for onset of medical care starting from the moment of admission of the patient to the ED in accordance with the MTS.

In this context, after the HUC ED team (as formed by the managers and authors of this paper) held formal meetings to discuss the problem faced by the ED, the team decided to integrate the DEMATEL and PROMETHEE II methods. The decision was based on a belief by the participants that the selected methods fit the problem which needed to be addressed.

Fig. 3 represents the flow of activities of the patient care process for those who come walking to the ED. The process is as follows: the patient arrives, goes to the reception and takes a token number, and waits in a waiting room for triage. When the patient's number is called, depending on the availability of the triage team, the patient is then taken to a room where he/she is assessed by the triage nurse. Depending on the patient's health condition as assessed by the triage nurse, each patient receives a priority classification for treatment at the ED based on the MTS. Once the patient priority has been assigned, and if it is a high priority (i.e., red or orange), the patient is admitted to the ED trauma room (CPR), where physicians perform the first procedures. Otherwise (i.e., yellow, green, or blue) the patient is taken to a reception for registration. After being registered, the patient waits in a waiting room until a physician is available in the appropriate treatment area based on his or her care needs; i.e., patients who upon triage receive the color yellow have priority over green, and patients with green have priority over those with blue.

4.1. Step 1 of the hybrid model

A set of specialists is responsible for managing the patient care and treatment process in the ED. The team consists of the

Table 3
ED management performance criteria.

Criteria	Code	Definition	Source
Resources Utilization	C_1	Percentage of usage of human resources physicians; Percentage of usage of human resources nurses; Percentage of usage of space for resuscitation of patient; Percentage of usage of beds available to hold patients; Percentage of usage of area for outpatient reception.	CFM; MTS; MS, and [1,5,49–54] [2,6,55–60] [61–66]
Layout Efficiency	C_2	Average physician displacement distance inside ED to address patients; Average nurse displacement distance inside ED to address patients.	MTS, and [5,51,60,66]
ED Productivity	C_3	Percentage of patients treated by physician; Percentage of patients treated by nurses; Percentage of patients treated in ED.	CFM; MS, and [5,50,51] [52,54–57,60,64]
Working Environment in ED	C_4	Amount of training received by ED teams; Percentage of ED professionals motivated; Care delivered compliant with clinical protocols.	CFM; MTS
Materials	C_5	Medical supplies available to address patients; Medication available to treat patients.	MS; CFM, and [20]
Technology	C_6	State of repair of medical equipment; Quantity of medical equipment available for exams, diagnostic and treatment of patients; Information systems available to support ED management.	CFM; MS, and [12,13,20,60]
Patient Safety	C_7	Mortality rate during stay in ED; Mortality rate during admission; Hospital infection rate.	[2,6,20,62,67–69]
Patient Throughput	C_8	Average waiting time before patient receives first medical attention; Average waiting time before onset of triage; Average time patient remains in ED, from admission until exit from ED.	MTS; CFM; MS, and [2,5,6,18,49–59,61–63,66,70,71]

following: three nurses responsible for the patient triage process, one managing nurse of the ED, three physicians, two who work in the patient treatment process, and one clinical director of the ED, in addition to the administrative manager. They were invited to participate in a formal discussion to validate the criteria explored from the medical guidelines and scientific papers governing the management of the ED. This resulted in the eight defined criteria presented in Table 3.

With the defined criteria, the questionnaire for the DEMATEL method shown in Fig. 2 was given to the set of process specialists described earlier. From the filled-in questionnaire, eight non-negative 8×8 matrices were constructed as shown in Fig. 4.

Continuing as specified in Step 1 of the DEMATEL method, the calculation of the average matrix Z is performed according to Eq. (1). $Z = [a_{ij}]$ is constructed to incorporate all the opinions of the S respondents, and the data obtained are shown in Table 4.

Table 4
Mean relation matrix Z.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0.0000	2.7500	3.2500	2.6250	3.1250	3.1250	3.1250	3.1250
C_2	2.8750	0.0000	3.7500	3.1250	2.5000	2.6250	3.2500	3.3750
C_3	3.3750	2.6250	0.0000	3.3750	3.2500	2.5000	3.3750	3.8750
C_4	2.5000	2.3750	3.2500	0.0000	2.5000	2.2500	3.2500	3.1250
C_5	2.6250	2.1250	2.8750	2.5000	0.0000	2.3750	3.0000	2.7500
C_6	2.7500	3.1250	3.2500	2.5000	2.5000	0.0000	3.0000	3.2500
C_7	2.7500	3.0000	2.8750	2.5000	2.6250	2.5000	0.0000	2.3750
C_8	2.7500	2.3750	3.1250	2.8750	2.7500	2.3750	3.7500	0.0000

In Step 2 of the DEMATEL method, the normalized initial direct-binding matrix D is built applying Eq. (2) and the results are shown in Table 5.

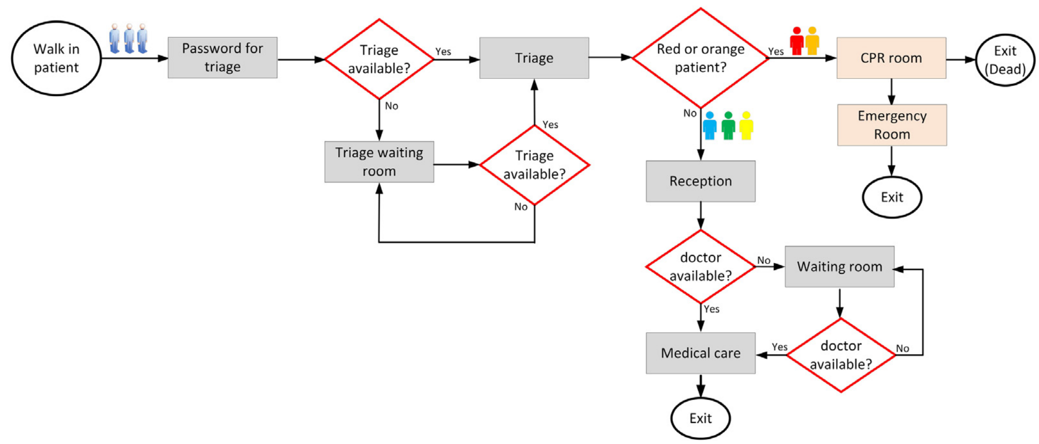

Fig. 3. Activities flow of the patient care process. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

$$X^1=\begin{bmatrix}0&2&3&2&3&2&2&3\\2&0&4&3&2&1&3&3\\4&3&0&3&3&2&1&4\\3&3&4&0&2&2&2&2\\1&1&2&1&0&2&1&0\\2&4&4&2&1&0&2&4\\2&2&1&2&1&1&0&2\\2&2&3&3&2&1&4&0\end{bmatrix}\quad X^2=\begin{bmatrix}0&3&3&2&3&3&3&3\\3&0&3&2&2&3&3&3\\3&3&0&3&3&3&4&4\\2&2&3&0&3&3&4&4\\2&2&3&2&0&3&3&3\\3&3&3&3&3&0&3&3\\2&2&3&2&2&3&0&3\\3&2&3&3&3&3&4&0\end{bmatrix}\quad X^3=\begin{bmatrix}0&2&3&3&4&3&4&2\\3&0&4&4&3&3&3&4\\3&2&0&4&3&1&4&4\\2&2&4&0&2&1&3&4\\3&3&2&3&0&2&3&2\\4&3&3&3&3&0&3&4\\4&3&2&3&2&2&0&1\\2&3&4&3&1&1&4&0\end{bmatrix}$$

$$X^4=\begin{bmatrix}0&4&4&3&3&4&3&4\\2&0&3&4&2&4&3&4\\3&3&0&2&3&3&3&4\\3&3&4&0&2&3&3&3\\2&4&3&3&0&3&3&4\\3&3&4&4&3&0&4&4\\3&4&4&3&4&3&0&3\\3&3&2&2&3&4&4&0\end{bmatrix}\quad X^5=\begin{bmatrix}0&3&3&3&2&3&3&3\\3&0&4&3&2&2&4&4\\3&3&0&4&4&3&4&4\\2&2&2&0&2&2&3&3\\3&2&2&3&0&2&3&3\\2&3&2&2&2&0&2&2\\2&3&3&2&3&3&0&2\\2&3&3&3&3&3&3&0\end{bmatrix}\quad X^6=\begin{bmatrix}0&3&3&3&3&4&4&4\\3&0&4&3&3&4&3&3\\3&3&0&3&3&4&4&4\\3&3&3&0&3&4&4&3\\4&2&4&2&0&4&4&3\\3&3&4&2&3&0&4&3\\3&3&3&3&3&4&0&3\\3&3&2&2&3&4&4&0\end{bmatrix}$$

$$X^7=\begin{bmatrix}0&2&4&4&4&4&4&4\\4&0&4&2&4&2&4&4\\4&3&0&4&4&2&4&4\\4&3&4&0&4&2&4&4\\4&2&4&3&0&2&4&4\\4&4&4&3&4&0&4&4\\4&4&4&3&4&2&0&4\\4&3&4&3&4&2&4&0\end{bmatrix}\quad X^8=\begin{bmatrix}0&3&3&1&3&2&2&2\\3&0&4&4&2&2&3&2\\4&1&0&4&3&2&3&3\\1&1&2&0&2&1&3&2\\2&1&3&3&0&1&3&3\\1&2&2&1&1&0&2&2\\2&3&3&2&2&2&0&1\\3&0&4&4&3&1&3&0\end{bmatrix}$$

Fig. 4. Evaluation matrices.

Table 5
Normalized matrix D.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0.0000	0.1209	0.1429	0.1154	0.1374	0.1374	0.1374	0.1374
C_2	0.1264	0.0000	0.1648	0.1374	0.1099	0.1154	0.1429	0.1484
C_3	0.1484	0.1154	0.0000	0.1484	0.1429	0.1099	0.1484	0.1703
C_4	0.1099	0.1044	0.1429	0.0000	0.1099	0.0989	0.1429	0.1374
C_5	0.1154	0.0934	0.1264	0.1099	0.0000	0.1044	0.1319	0.1209
C_6	0.1209	0.1374	0.1429	0.1099	0.1099	0.0000	0.1319	0.1429
C_7	0.1209	0.1319	0.1264	0.1099	0.1154	0.1099	0.0000	0.1044
C_8	0.1209	0.1044	0.1374	0.1264	0.1209	0.1044	0.1648	0.0000

Table 6
Total relation matrix T.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0.9008	0.9548	1.1306	0.9985	1.0071	0.9412	1.1475	1.1085
C_2	1.0300	0.8626	1.1666	1.0333	1.0020	0.9387	1.1714	1.1359
C_3	1.0740	0.9914	1.0548	1.0683	1.0550	0.9595	1.2071	1.1819
C_4	0.9283	0.8740	1.0503	0.8241	0.9149	0.8448	1.0705	1.0297
C_5	0.8930	0.8282	0.9933	0.8835	0.7770	0.8136	1.0166	0.9732
C_6	0.9831	0.9439	1.1023	0.9691	0.9599	0.7969	1.1142	1.0850
C_7	0.9150	0.8755	1.0136	0.9013	0.8974	0.8342	0.9198	0.9801
C_8	0.9635	0.8995	1.0756	0.9624	0.9498	0.8738	1.1177	0.9375

In Step 3 of the DEMATEL method, the matrix of total relations T is obtained through Eq. (4). The matrix is shown in Table 6.

Step 4 of the DEMATEL method calculates the sum of the rows and columns of the total relation matrix T. R_i is obtained by summing the row of the matrix T according to Eq. (5), while C_j is obtained by summing the column of the matrix T according to Eq. (6), as shown in Table 7.

Table 7
Values of R_i and C_j.

Codes	Criteria	R_i	C_j
C_1	Resources Utilization	8.1890	7.6877
C_2	Layout Efficiency	8.3404	7.2298
C_3	ED Productivity	8.5920	8.5870
C_4	Working Environment at ED	7.5365	7.6406
C_5	Materials	7.1785	7.5631
C_6	Technology	7.9545	7.0027
C_7	Patient Safety	7.3370	8.7649
C_8	Patient Throughput	7.7799	8.4319

Table 8
Influences provided and received among the eight criteria.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1			1.1306	0.9985	1.0071		1.1475	1.1085
C_2	1.0300		1.1666	1.0333	1.0020		1.1714	1.1359
C_3	1.0740	0.9914	1.0548	1.0683	1.0550		1.2071	1.1819
C_4			1.0503				1.0705	1.0297
C_5			0.9933				1.0166	
C_6	0.9831		1.1023				1.1142	1.0850
C_7			1.0136					
C_8			1.0756				1.1177	

Table 9
Values of $(R_i + C_j)$ and $(R_i - C_j)$.

Codes	Criteria	$(R_i + C_j)$	$(R_i - C_j)$
C_1	Resources Utilization	15.8767	0.5013
C_2	Layout Efficiency	15.5702	1.1105
C_3	ED Productivity	17.1790	0.0049
C_4	Working Environment at ED	15.1771	−0.1041
C_5	Materials	14.7415	−0.3846
C_6	Technology	14.9572	0.9518
C_7	Patient Safety	16.1018	−1.4279
C_8	Patient Throughput	16.2117	−0.6520

HUC ED specialists along with the authors of this paper decided to use average as a threshold value (α), as proposed by [12, 30]. Thus, the threshold value obtained in accordance with Eq. (7) by following Step 5 of the DEMATEL method. This value must be set to eliminate minimal effect elements in the total relation matrix T. Therefore, the total relationship matrix values T that are less than α are disregarded in the analysis.

$$\alpha = \frac{62.9077}{64} = 0.9829$$

Next, Table 8 is constructed using the predefined threshold value and shows the influences emitted and received among the criteria. Thus, Table 8 shows only the values of $[T_{ij}]$ greater than 0.9829, where $[T_{ij}]$ represents the interaction between each pair of criteria. For example, the value of $[T_{21}]$ which corresponds to the influence that Layout Efficiency (C_2) has on Resources Utilization (C_1) is shown in Table 8 because its value is 1.0300. Finally, the cause and effect diagram was drawn in Fig. 5, producing graphs originating in criterion C_2 toward criterion C_1, showing that C_2 influences C_1. The cause and effect diagram in Fig. 5 contains the eight criteria applicable to the management of the studied ED and represents the last step of the DEMATEL method.

From Table 9 based on the expression $(R_i + C_j)$ the relative importance of the eight criteria is established such that $C_3 > C_8 > C_7 > C_1 > C_2 > C_4 > C_6 > C_5$. ED Productivity ($C_3$) is the most important criterion with a value of 17.1790, while Materials (C_5) is the least important criterion with value of 14.7415.

From the influence level according to the values of the expression $(R_i - C_j)$, the criteria Deployment of Resources (C_1), Efficiency of Layout (C_2), ED Productivity (C_3) and Technology (C_6) are influencers. On the other hand, the criteria the Working Environment in ED (C_4), Materials (C_5), Patient Safety (C_7), Patient Throughput (C_8) are receivers in the diagram; i.e., they are influenced.

Although ED Productivity (C_3) is the most important criterion, its value according to the expression $(R_i - C_j)$ is very close to zero, which means that it exerts minimal influence on the other criteria. However, it is important that improvement actions focus on this criterion, such as staff training, etc. These actions may significantly reduce Patient Throughput, represented by criterion (C_8), as well as significantly increase the number of patient handled by the ED.

Efficiency of Layout (C_2) is the criterion with the highest positive value for $(R_i - C_j)$. Thus, improvement actions that focus on this criterion will also improve the other criteria. For example, an improved layout may reduce travel by medical staff when treating patients and thus significantly reduce Patient Throughput. Improvement actions that focus on criterion (C_2) could, in addition to improving emergency productivity by increasing the number of patients attended, improve the working environment in the ED for professionals.

Patient Throughput (C_8) and Patient Safety (C_7) are second and third, respectively, in order of importance, as illustrated by Table 9. However, these two criteria are influenced because they have negative $(R_i - C_j)$. Thus, for example, layout improvement actions related to Deployment of Resources in ED, result in positive gains on both of these criteria (C_8) and (C_7). Therefore, as these criteria are important according to $(R_i + C_j)$, to increase ED performance, process specialists should consider actions that address the criteria that influence them. For example, developing professional skills in the team could help the professionals involved increase their performance and shorten patient's treatment time, accompanied by more accurate diagnoses and treatments that are more appropriate to each patient's specific conditions. All of these actions improve Patient Safety (C_7) by reducing erroneous prescriptions and treatments.

According to DEMATEL's assessment, it was observed that Technology (C_6), despite having a value of $(R_i + C_j)$ below the other criteria, displays a positive value for $(R_i - C_j)$, i.e., it is an influencer in the relationships network. An ED equipped with Hospital Information Systems (HIS) technologies and electronic patient data may improve quality and healthcare decisions, and make it easier to access available services. Through the HIS, medical teams can access patient information in real time, making the process of diagnosing and prescribing therapies faster and more efficient.

Given this context, investing in Technology (C_6) may bring positive benefits, impacting criteria such as ED Productivity (C_3) by enabling healthcare professionals to increase the number of patients received and treated, and facilitating rapid and authoritative medical decisions, thus reducing Patient Throughput (C_8) and improving Patient Safety (C_7).

Finally, it is important to highlight that Resources Utilization (C_1), Layout Efficiency (C_2), ED Productivity (C_3), and Technology (C_6) deserve special attention, as they may improve ED management performance. These criteria are net causes and influence the criteria Working Environment in ED (C_4), Materials (C_5), Patient Safety (C_7), Patient Throughput (C_8) in the relationship network, as seen in the graphs of Fig. 5. Therefore, designing improvement actions addressing the respective network influencing criteria may be beneficial when the objective is to obtain rational answers to the HUC ED overcrowding problems.

4.2. Proposed improvement actions for HUC

Based on the results generated by the DEMATEL method, the next step of the hybrid model addressed in this paper is to design improvement actions. Thus, we focus on the top four positive value criteria $(R_i - C_j)$ that are influencers in the relationship network. Table 10 presents improvement actions that help reduce HUC ED overcrowding.

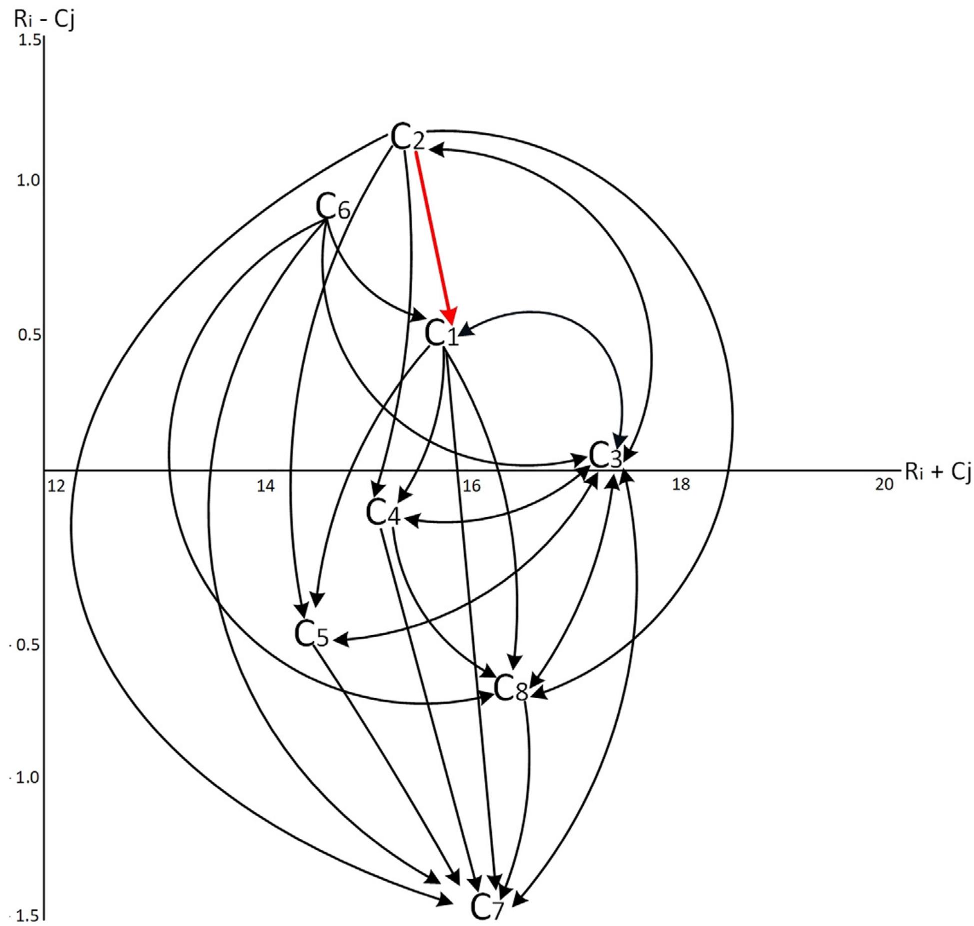

Fig. 5. Map of influences among the 8 ED performance criteria.

Table 10
Improvement actions that help reduce HUC ED overcrowding.

Criteria	Improvement actions
Resources Utilization (C_1)	**Action 1:** Provide one more nurse and one room to perform triage of patients in the period of greatest demands from 07:00 am to 11:00 pm. **Action 2:** Considering that the greatest demand for care is in the area of orthopedics as identified by Table 1, an improvement action would be the insertion of one more orthopedic physician in the process.
Layout Efficiency (C_2)	**Action 3:** Due to a high number of not very urgent (green) and non-urgent (blue) patients highlighted in Table 2, an improvement action may contemplate the availability of one room in the ED for **fast-track** care to treat these patients through orthopedic physician and orthopedic resident physician in the period from 07:00 am to 11:00 pm.
ED Productivity (C_3)	**Action 4:** Training for nurses and physicians for fast-track care.
Technology (C_6)	**Action 5:** Acquire a new HIS that covers all stages of admittance and treatment of patients and of management of ED and that is interoperable with other HIS. **Action 6:** Considering the demand in orthopedics, an improvement action would be the insertion of another X-ray equipment in the ED and the accomplishment of predictive maintenance to avoid the stoppage of the unplanned equipment. **Action 7:** Automate password removal for patient triage.

4.3. Obtaining the weights for the PROMETHEE II method

The weights to feed the PROMETHEE II method, denoted by W_{ij}, are derived from the DEMATEL method through the values of (R_i+C_j), which represent the relative importance of each criterion defined to support management of the patient care and treatment process in the HUC ED, which is described in Table 9. As the PROMETHEE II method does not have methodological support for establishing the criteria weights [24], it was decided to use the mathematical support of the DEMATEL method for this purpose. However, the (R_i+C_j) values of the criteria need to be normalized between [0 and 1] according to Eq. (17) which, in turn, will reflect the criteria weight vector, with $\sum W_{ij} = 1$.

$$W_{ij} = \frac{(R_i + C_j)}{\sum_{i=1}^{n}(R_i + C_j)} \; Where\; j = 1, \ldots, n \tag{17}$$

In Eq. (17), the $(R_i + C_j)$ value of each criterion is divided by the sum of the $(R_i + C_j)$ values of all criteria. Table 11 presents the normalized weights of the criteria.

Table 11
Normalized weights.

Criteria	W_{ij}
C_1	0.1262
C_2	0.1238
C_3	0.1365
C_4	0.1206
C_5	0.1172
C_6	0.1189
C_7	0.1280
C_8	0.1289

Table 12
Decision matrix.

Actions	Criteria							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
A_1	VG	G	VG	G	B	A	G	VG
A_2	VG	G	VG	A	A	A	VG	VG
A_3	VG	VG	VG	VG	G	A	VG	VG
A_4	A	A	G	VG	B	A	G	G
A_5	A	G	G	G	A	VG	G	A
A_6	A	A	VG	A	A	G	VG	VG
A_7	B	VB	A	B	B	VG	A	A

VB	B	A	G	VG
0.1	0.3	0.5	0.7	0.9

Fig. 6. 5-point verbal scale.

4.4. Application of the PROMETHEE II method

The first step in applying the PROMETHEE II method is to identify the degree of preference $P(x_i, x_k)$ in each criterion, using a 5-point verbal scale provided by Visual PROMETHEE software to express the subjectivity of the experts, as shown in Fig. 6. ED managers decided to use the 5-point verbal scale because it is easy to compare the preference of improvement action i against criterion j. The linguistic terms used on the verbal scale were as follows: Very Good—VG (0.9), Good—G (0.7), Average—A (0.5), Bad—B (0.3) e Very Bad—VB (0.1), based on [2].

Defining the verbal scale, specialists compared improvement actions with each criterion, after which a decision matrix was constructed according to Table 12. Table 12 illustrates the evaluation of improvement actions judged by managers. For example, specialists claimed that the improvement action A_1 would have a preference (VG) in the criterion C_1 in the first row. In contrast, the improvement action A_7 would have a preference (B) in criterion C_1.

The information in the decision matrix was converted to clear scores using a verbal scale. The matrix was then normalized using Eq. (8). Table 13 displays the preference matrix using the usual preference function. The preference function was calculated for the 42 improvement actions pairs using Eqs. (11) and (12). The preference function assumes a value of 0 if the performance difference is negative, or value of 1 if the difference is positive. Any difference between the assessment of improvement actions for a given criterion implies a strict preference situation. For example, when managers compare action A_1 with A_2 in the first row of Table 13, the results show that A_1 is not preferred over A_2 considering criterion C_1. When considering criterion C_4, A_1 is preferable over A_2.

Following the application of the PROMETHEE II method, Table 14 shows the aggregate preference function for improvement actions pairs using Eq. (13). In Table 14 $\pi(A_3, A_1)$ denotes that A_3 is preferred over A_1. Eq. (14), (15), and (16) calculate

Table 13
Preference functions for the pairs of alternatives.

Actions	Criteria							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
$P(A_1, A_2)$	0	0	0	1	0	0	0	0
$P(A_1, A_3)$	0	0	0	0	0	0	0	0
$P(A_1, A_4)$	1	1	1	0	0	0	0	1
$P(A_1, A_5)$	1	0	1	0	0	0	0	1
$P(A_1, A_6)$	1	1	0	1	0	0	0	0
$P(A_1, A_7)$	1	1	1	1	0	0	1	1
$P(A_2, A_1)$	0	0	0	0	1	0	1	0
$P(A_2, A_3)$	0	0	0	0	0	0	0	0
$P(A_2, A_4)$	1	1	1	0	1	0	1	1
$P(A_2, A_5)$	1	0	1	0	0	0	1	1
$P(A_2, A_6)$	1	1	0	0	0	0	0	0
$P(A_2, A_7)$	1	1	1	1	1	0	1	1
$P(A_3, A_1)$	0	1	0	1	1	0	1	0
$P(A_3, A_2)$	0	1	0	1	1	0	0	0
$P(A_3, A_4)$	1	1	1	0	1	0	1	1
$P(A_3, A_5)$	1	1	1	1	1	0	1	1
$P(A_3, A_6)$	1	1	0	1	1	0	0	0
$P(A_3, A_7)$	1	1	1	1	1	0	1	1
$P(A_4, A_1)$	0	0	0	1	0	0	0	0
$P(A_4, A_2)$	0	0	0	1	0	0	0	0
$P(A_4, A_3)$	0	0	0	0	0	0	0	0
$P(A_4, A_5)$	0	0	0	1	0	0	0	1
$P(A_4, A_6)$	0	0	0	1	0	0	0	0
$P(A_4, A_7)$	1	1	1	1	0	0	1	1
$P(A_5, A_1)$	0	0	0	0	1	1	0	0
$P(A_5, A_2)$	0	0	0	1	0	1	0	0
$P(A_5, A_3)$	0	0	0	0	0	1	0	0
$P(A_5, A_4)$	0	1	0	0	1	1	0	0
$P(A_5, A_6)$	0	1	0	1	0	1	0	0
$P(A_5, A_7)$	1	1	1	1	1	0	1	0
$P(A_6, A_1)$	0	0	0	0	1	1	1	0
$P(A_6, A_2)$	0	0	0	0	0	1	0	0
$P(A_6, A_3)$	0	0	0	0	0	1	0	0
$P(A_6, A_4)$	0	0	1	0	1	1	1	1
$P(A_6, A_5)$	0	0	1	0	0	0	1	1
$P(A_6, A_7)$	1	1	1	1	1	0	1	1
$P(A_7, A_1)$	0	0	0	0	0	1	0	0
$P(A_7, A_2)$	0	0	0	0	0	1	0	0
$P(A_7, A_3)$	0	0	0	0	0	1	0	0
$P(A_7, A_4)$	0	0	0	0	0	1	0	0
$P(A_7, A_5)$	0	0	0	0	0	0	0	0
$P(A_7, A_6)$	0	0	0	0	0	1	0	0

Table 14
Aggregated preference function.

Actions	A_1	A_2	A_3	A_4	A_5	A_6	A_7
A_1	0.0000	0.1206	0.0000	0.5154	0.3916	0.3706	0.7640
A_2	0.2452	0.0000	0.0000	0.7606	0.5196	0.2500	0.8812
A_3	0.4896	0.3616	0.0000	0.7606	0.8812	0.4878	0.8812
A_4	0.1206	0.1206	0.0000	0.0000	0.2495	0.1206	0.7640
A_5	0.2361	0.2395	0.1189	0.3599	0.0000	0.3633	0.7523
A_6	0.3641	0.1189	0.1189	0.6295	0.3934	0.0000	0.8812
A_7	0.1189	0.1189	0.1189	0.1189	0.0000	0.1189	0.0000

positive, negative, and net flows, respectively. The results are shown in Table 15. The last column displays the ranking of improvement actions. The ranking showed that the improvement action A_3 is the best action to reduce ED overcrowding in the short-term, because has the largest $\phi(i)$ of all the eight criteria considered. However, action A_2 may also have a good impact on the HUC ED overcrowding problem.

The PROMETHEE visual software features GAIA Visual, which is a complementary tool to the PROMETHEE II method. This tool was developed by Marechal and Brans in 1988 and is used to analyze the influence of criteria weights and alternatives [2]. In other words, with the help of GAIA, it is possible to visually check the quality of the actions against the different criteria of the network. The GAIA $k-$*dimensional* space may assist specialists in assessing a decision-making problem that includes k distinct

Table 15
Positive, negative and net flows, and ranking of alternatives.

Actions	Phi+	Phi−	Phi	Rank
A_1	0.3604	0.2624	0.0980	4
A_2	0.4428	0.1800	0.2628	2
A_3	0.6437	0.0595	0.5842	**1**
A_4	0.2292	0.5242	−0.2949	6
A_5	0.3450	0.4059	−0.0609	5
A_6	0.4177	0.2852	0.1325	3
A_7	0.0991	0.8207	−0.7216	7

criteria [7]. In $k - dimensional$ space the criteria weight vector could be considered as a decision axis. In the GAIA, the projection of this axis indicates the direction of the decision considering the criteria weights. In the PROMETHEE method, this direction is characterized as the decision axis π [72]. The GAIA plan generated by the Visual PROMETHEE software is presented in Fig. 7. In the plan, improvement actions are represented by squares and criteria by axes. According to Fig. 7, GAIA analysis shows that the criteria that express different preferences face opposite directions in the plane, for example, the criteria C_4 e C_6.

The GAIA plan allows the use of the weight vector as a "decision stick" to guide decision making through the decision axis [2]. Note that improvement actions A_3 e A_2 are considered to be the best options in the short-term for reducing HUC ED overcrowding. These actions are characterized by being, among the evaluated alternatives, those that have the largest distances from the origin in the direction of the decision axis π because they are the actions with the largest net flows in relation to the specialist's evaluations. Similarly, it is observed that the improvement action C_7 "Automate password removal for patient triage", scored the worst, and therefore the action is located in a direction opposite to the decision axis π.

5. Discussion of results

The services provided by EDs play a strategic role in patient health. However, in many cases, process specialists may not identify the problems that cause EDs overcrowding due to the complexity of the various conflicting and interdependent criteria governing the management of the patient care and treatment process in EDs. Given this context, it is necessary to use formal tools that provide the specialists with a better diagnostic evaluation of the process. This allows alternatives to be designed that may be more effective in solving a problem.

In this way, the DEMATEL method can help specialists in the management of the process of care and treatment of patients in ED units make appropriate improvements to solve a problem. The method is based on the relationships of feedback, interdependence, and influences among the defined criteria that drive the improvements. By applying the DEMATEL method, the importance of the eight criteria governing ED management was determined by weights, and the causal relationships among the criteria could be constructed. The results of applying the DEMATEL method show that Resources Utilization (C_1), Layout Efficiency (C_2), ED Productivity (C_3) and Technology (C_6) are the influential criteria in the relationships network. Through this knowledge, the specialists enriched the discussion of the HUC ED overcrowding problem, and a set of seven improvement actions could be devised.

However, as ED resources are scarce and expensive, specialists need to make assertive decisions to remedy an identified problem. Therefore, the PROMETHEE II method was used to help specialists order the improvement actions identified through the DEMATEL method. Given the ranking provided by the PROMETHEE II method and the GAIA Plan, the specialists identified the best improvement actions to reduce HUC ED overcrowding in the short-term. It could be concluded from the GAIA decision axis that actions A_3 and A_2 have more satisfactory results because they are closer to it. However, the specialists decided to implement improvement action A_3 because it has the largest net flow. This action involves adding a space in the ED for an orthopedic physician and medical residents in orthopedics to attend (fast-track) the high demand of patients with a low-risk classification. Low risk is indicated by the MTS in green and blue colors, as well as, in the HUC ED medical specialty profile as presented in Table 1. With this action, the specialists aim to obtain better answers to the problem faced by ED. After implementing the A_3 improvement action, additional actions, such as A_2 will be implemented, according to the prioritization offered by the PROMETHEE II method.

6. Conclusions and future studies

Our study contributes by presenting a hybrid model of MCDM methods, which combines the DEMATEL and PROMETHEE II methods. We believe that the hybrid model helps systematize the decision-making process involving the rationalities on offer by the formal methods MCDM — formal methods used as means to support EDs managers in making complex decisions regarding the problem of patient overcrowding.

The hybrid model DEMATEL-PROMETHEE II was useful for assisting specialists during the conception and prioritization of improvement actions for addressing the issue of overcrowding in the studied ED. Integrating the two models enhanced the advantages of each method and minimized their inherent weaknesses.

Based on these findings, we conclude that the DEMATEL method can be effectively used for designing improvement actions to reduce overcrowding in the ED, as well as defining criteria for weights using causality and interdependence relationships among the defined criteria. The PROMETHEE II method provided a prioritization order that process experts could use to define which actions could be implemented to address the problem faced by HUC in the short term.

The model was easily understood by HUC's ED specialists due to its simplicity and usability. The way the model was developed and applied encouraged discussion and obtaining necessary information by managers to solve the problem of overcrowding faced by HUC's EDs. In addition, the model was suitable for managing resource allocation through a set of improvement actions that were ordered by considering the relative importance of the different criteria that govern the management of patient care and the treatment process.

We believe that our research can contribute to the application of MCDM methods for the management of patient care and the treatment process in EDs. The paper also offers insights on defining the criteria that govern the management of EDs as well as providing support for health managers to make more informed and rational decisions.

However, in order to successfully implement the decision-making process of the hybrid model, we also considered the shared responsibility and integration of the ED work team. The lack of integration and commitment between the teams can result in poor participation (e.g., low interest in answering the questionnaires). Though, this limitation was overcome through formal meetings between the managers and authors of this study to discuss how the methods (DEMATEL and PROMETHEE II) can be combined to support the decision-making process in addressing the overcrowding problem in the HUC's ED.

We emphasize that there is a need to adapt our approach to different locations, as we know that each ED has its own unique characteristics (e.g., the region that is located, available

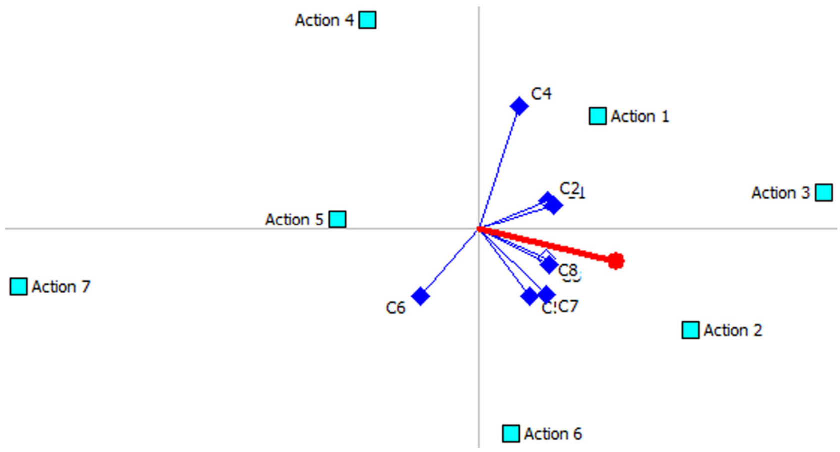

Fig. 7. Gaia visual analysis.

infrastructure, training of human resources, budget restrictions due to the high cost of medicine, equipment, etc.). Therefore, the approach must be adjusted to the specific needs of each location through the use of specific tactics, such as formal meetings with ED managers. This allows for the consideration of different problems, which may require using different criteria and approaches to solve them.

Finally, the specialists in the patient care and treatment process of the HUC ED believe that the hybrid model could also help them design improvements and make decisions for the elective surgery department. This department has been facing the problem of long waiting times for patients who need surgery, and future research is heading in this direction.

CRediT authorship contribution statement

All authors actively participated in all stages of the conception, development, and application of the MCDM Hybrid Model in HUC's ED. Substantial comments were made in all editions until the production of the final edition. All authors read and approved the final manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] L. Vanbrabant, K. Braekers, K. Ramaekers, I. Van Nieuwenhuyse, Simulation of emergency department operations: a comprehensive review of kpis and operational improvements, Comput. Ind. Eng. (2019).

[2] T.M. Amaral, A.P. Costa, Improving decision-making and management of hospital resources: An application of the promethee ii method in an emergency department, Oper. Res. Health Care 3 (1) (2014) 1–6.

[3] L.S.H. Warner, J.M. Pines, J.G. Chambers, J.D. Schuur, The most crowded US hospital emergency departments did not adopt effective interventions to improve flow, 2007–10, Health Aff. 34 (12) (2015) 2151–2159.

[4] P. Thokala, N. Devlin, K. Marsh, R. Baltussen, M. Boysen, Z. Kalo, T. Longrenn, F. Mussen, S. Peacock, J. Watkins, et al., Multiple criteria decision analysis for health care decision making—an introduction: report 1 of the ispor mcda emerging good practices task force, Value Health 19 (1) (2016) 1–13.

[5] W. Abo-Hamad, A. Arisha, Simulation-based framework to improve patient experience in an emergency department, European J. Oper. Res. 224 (1) (2013) 154–166.

[6] O.M. Ashour, G.E. Okudan, C.A. Smith, An improved triage algorithm for emergency departments based on fuzzy ahp and utility theory, in: IIE Annual Conference. Proceedings, Institute of Industrial and Systems Engineers (IISE), 2010, p. 1.

[7] J.-P. Brans, B. Mareschal, Promethee methods, in: Multiple Criteria Decision Analysis: State of the Art Surveys, Springer, 2005, pp. 163–186.

[8] K. Marsh, T. Lanitis, D. Neasham, P. Orfanos, J. Caro, Assessing the value of healthcare interventions using multi-criteria decision analysis: a review of the literature, Pharmacoeconomics 32 (4) (2014) 345–365.

[9] G. Adunlin, V. Diaby, H. Xiao, Application of multicriteria decision analysis in health care: a systematic review and bibliometric analysis, Health Expect. 18 (6) (2015) 1894–1905.

[10] V. Diaby, K. Campbell, R. Goeree, Multi-criteria decision analysis (mcda) in health care: a bibliometric analysis, Oper. Res. Health Care 2 (1–2) (2013) 20–24.

[11] R. Baltussen, K. Marsh, P. Thokala, V. Diaby, H. Castro, I. Cleemput, M. Garau, G. Iskrov, A. Olyaeemanesh, A. Mirelman, et al., Multicriteria decision analysis to support hta agencies: Benefits, limitations, and the way forward, Value Health (2019).

[12] J.-I. Shieh, H.-H. Wu, K.-K. Huang, A dematel method in identifying key success factors of hospital service quality, Knowl.-Based Syst. 23 (3) (2010) 277–282.

[13] B. Efe, Ö.F. Efe, An application of value analysis for lean healthcare management in an emergency department, Int. J. Comput. Intell. Syst. 9 (4) (2016) 689–697.

[14] G.-H. Tzeng, C.-H. Chiang, C.-W. Li, Evaluating intertwined effects in e-learning programs: A novel hybrid mcdm model based on factor analysis and dematel, Expert Syst. Appl. 32 (4) (2007) 1028–1044.

[15] J.J. Liou, H. Wang, C. Hsu, S. Yin, A hybrid model for selection of an outsourcing provider, Appl. Math. Model. 35 (10) (2011) 5121–5133.

[16] J. Liou, M.-T. Lu, S.-K. Hu, C.-H. Cheng, Y.-C. Chuang, A hybrid mcdm model for improving the electronic health record to better serve client needs, Sustainability 9 (10) (2017) 1819.

[17] S.-L. Si, X.-Y. You, H.-C. Liu, J. Huang, Identifying key performance indicators for holistic hospital management with a modified dematel approach, Int. J. Environ. Res. Public Health 14 (8) (2017) 934.

[18] M. Bahadori, R. Ravangard, E. Teymourzadeh, Development of emergency medical services (ems) in Iran: Components of access, Int. J. Collaborat. Res. Intern. Med. Public Health 4 (4) (2012) 387.

[19] A.A. Nasiripour, M. Bahadori, S. Tofighi, M. Gohari, Analysis of the relationships between the determinants influential in performance of pre-hospital emergency system of Iran using the dematel approach, HealthMED 4 (3) (2010) 567–572.

[20] M.A. Ortiz-Barrios, B.A. Aleman-Romero, J. Rebolledo-Rudas, H. Maldonado-Mestre, L. Montes-Villa, F. De Felice, A. Petrillo, The analytic decision-making preference model to evaluate the disaster readiness in emergency departments: The adt model, J. Multi-Criteria Decis. Anal. 24 (5–6) (2017) 204–226.

[21] M.A. Ortiz Barrios, C. Nino, J. Patricia, A.A. La De Hoz, F. De Felice, A. Petrillo, An integrated approach of AHP-DEMATEL methods applied for the selection of allied hospitals in outpatient service, Int. J. Med. Eng. Inf. (2016).
[22] E.K. Delice, S. Zegerek, Ranking occupational risk levels of emergency departments using a new fuzzy mcdm model: A case study in Turkey, Appl. Math. Inf. Sci. 10 (6) (2016) 2345–2356.
[23] M.A. Ortíz, H.A. Felizzola, S.N. Isaza, A contrast between DEMATEL-ANP and ANP methods for six sigma project selection: a case study in healthcare industry, BMC Med. Inf. Decis. Mak. 15 (3) (2015) S3.
[24] A.-U.-R. Lateef-Ur-Rehman, Manufacturing configuration selection using multicriteria decision tool, Int. J. Adv. Manuf. Technol. 65 (2013) 625–639.
[25] J. Jlassi, A. El Mhamedi, H. Chabchoub, The improvement of the performance of the emergency department: application of simulation model and multiple criteria decision method, J. Ind. Eng. Int. (2011).
[26] T.R.M. Azeredo, H.M. Guedes, R.A.R. de Almeida, T.C.M. Chianca, J.C.A. Martins, Efficacy of the manchester triage system: a systematic review, Int. Emerg. Nurs. 23 (2) (2015) 47–52.
[27] N. Parenti, M.L.B. Reggiani, P. Iannone, D. Percudani, D. Dowding, A systematic review on the validity and reliability of an emergency department triage scale, the manchester triage system, Int. J. Nurs. Stud. 51 (7) (2014) 1062–1069.
[28] F.C. of Medicine, Provides for the standardization of the operation of urgency and emergency hospital services, as well as the dimensioning of the medical staff and the work system. Resolution n 2077 of July 24, 2014, in: Portuguese: Conselho Federal de Medicina - CFM. Dispõe Sobre a Normatização do Funcionamento Dos Serviços Hospitalares De Urgência E Emergência, Bem Como Do Dimensionamento Da Equipe Médica E Do Sistema De Trabalho. Resolução n 2077 De 24 De Julho De 2014, 2014, https://portal.cfm.org.br/images/PDF/resolucao2077.pdf/, [Online; accessed 24-February-2019].
[29] M.o.H. Brazil, Establishes the technical regulation of the state urgency and emergency systems. ordinance n 2048, of november 05, 2002, in: Portuguese: Brasil, Ministério da Saúde - MS, Institui O Regulamento Técnico Dos Sistemas Estaduais De Urgência E Emergência. Portaria N 2048, De 05 De Novembro De 2002, 2002, https://bvsms.saude.gov.br/bvs/saudelegis/gm/2002/prt2048_05_11_2002.html/, [Online; accessed 10-February-2019].
[30] L.E. Quezada, H.A. López-Ospina, P.I. Palominos, A.M. Oddershede, Identifying causal relationships in strategy maps using anp and dematel, Comput. Ind. Eng. 118 (2018) 170–179.
[31] S. Silas, E.B. Rajsingh, Performance analysis on algorithms for selection of desired healthcare services, Perspect. Sci. 8 (2016) 107–109.
[32] P. Vincke, Multicriteria Decision-Aid, John Wiley & Sons, 1992.
[33] V. Belton, T. Stewart, Multiple Criteria Decision Analysis: an Integrated Approach, Springer Science & Business Media, 2002.
[34] J.R.S.C. Mateo, Multi-criteria analysis, in: Multi Criteria Analysis in the Renewable Energy Industry, Springer, 2012, pp. 7–10.
[35] U.A. Kahraman, Analysis of interactions between performance indicators with fuzzy decision making approach in healthcare management, J. Intell. Manuf. (2015) 1–16.
[36] W.-W. Wu, Choosing knowledge management strategies by using a combined anp and dematel approach, Expert Syst. Appl. 35 (3) (2008) 828–835.
[37] J.J. Liou, Developing an integrated model for the selection of strategic alliance partners in the airline industry, Knowl.-Based Syst. 28 (2012) 59–67.
[38] S.A.M. Ali, S. Sorooshian, C.J. Kie, Modelling for causal interrelationships by dematel, Contemp. Eng. Sci. 9 (9) (2016) 403–412.
[39] Y.-P.O. Yang, H.-M. Shieh, J.-D. Leu, G.-H. Tzeng, A novel hybrid mcdm model combined with dematel and anp with applications, Int. J. Oper. Res. 5 (3) (2008) 160–168.
[40] M.M.L. Canedo, A.T. de Almeida, Electronic government: a multi-criterion approach to prioritizing projects by integrating balanced scorecard methodology indicators, Braz. J. Oper. Prod. Manage. 5 (2) (2008) 49–72.
[41] R. Dulmin, V. Mininno, Supplier selection using a multi-criteria decision aid method, J. Purch. Supply Manag. 9 (4) (2003) 177–187.
[42] J.-P. Brans, P. Vincke, Note—A preference ranking organisation method: (the promethee method for multiple criteria decision-making), Manage. Sci. 31 (6) (1985) 647–656.
[43] V.M. Athawale, S. Chakraborty, Facility location selection using promethee ii method, in: Proceedings of the 2010 International Conference on Industrial Engineering and Operations Management, Bangladesh Dhaka, 2010, pp. 9–10.
[44] G. D'Avignon, B. Mareschal, Specialization of hospital services in Québec: an application of the promethee and gaia methods, in: Mathematical and Computer Modelling, Elsevier, 1989, pp. 1393–1400.
[45] C.F.D. Arcanjo, T.M. Amaral, G.L.P. de Sá, Aplicação e comparação dos métodos Electre II e Promethee II como ferramentas de auxílio à tomada de decisões hospitalares, Exacta 13 (2) (2015) 177–186.
[46] M. Chalgham, I. Khatrouch, M. Masmoudi, O.C. Walha, A. Dammak, Inpatient admission management using multiple criteria decision-making methods, Oper. Res. Health Care 23 (2019) 100173.
[47] G. Tuzkaya, B. Sennaroglu, Z.T. Kalender, M. Mutlu, Hospital service quality evaluation with ivif-promethee and a case study, Soc.-Econ. Plann. Sci. 68 (2019) 100705.
[48] J. Bergs, D. Vandijck, O. Hoogmartens, P. Heerinckx, D. Van Sassenbroeck, B. Depaire, W. Marneffe, S. Verelst, Emergency department crowding: time to shift the paradigm from predicting and controlling to analysing and managing, 2016.
[49] H. Eskandari, M. Riyahifard, S. Khosravi, C.D. Geiger, Improving the emergency department performance using simulation and mcdm methods, in: Proceedings of the Winter Simulation Conference, Winter Simulation Conference, 2011, pp. 1211–1222.
[50] M. Gul, A.F. Guneri, A computer simulation model to reduce patient length of stay and to improve resource utilization rate in an emergency department service system, Int. J. Ind. Eng. 19 (5) (2012) 221–231.
[51] W. Abo-Hamad, A. Arisha, Multi-criteria framework for emergency department in irish hospital, in: Proceedings of the Winter Simulation Conference, Winter Simulation Conference, 2012, p. 88.
[52] W. Abohamad, A. Ramy, A. Arisha, A hybrid process-mining approach for simulation modeling, in: Proceedings of the 2017 Winter Simulation Conference, IEEE Press, 2017, p. 117.
[53] S. Groothuis, G. Van Merode, A. Hasman, et al., Simulation as decision tool for capacity planning, Comput. Methods Programs Biomed. 66 (2–3) (2001) 139–151.
[54] M.A. Ahmed, T.M. Alkhamis, Simulation optimization for an emergency department healthcare unit in kuwait, European J. Oper. Res. 198 (3) (2009) 936–942.
[55] D. Sinreich, O. Jabali, Staggered work shifts: a way to downsize and restructure an emergency department workforce yet maintain current operational performance, Health Care Manage. Sci. 10 (3) (2007) 293–308.
[56] M. Gul, E. Celik, A.T. Gumus, A.F. Guneri, Emergency department performance evaluation by an integrated simulation and interval type-2 fuzzy mcdm-based scenario analysis, Eur. J. Ind. Eng. 10 (2) (2016) 196–223.
[57] A.G. Uriarte, E.R. Zúñiga, M.U. Moris, A.H. Ng, How can decision makers be supported in the improvement of an emergency department? a simulation, optimization and data mining approach, Oper. Res. Health Care 15 (2017) 102–122.
[58] F. McGuire, Using simulation to reduce length of stay in emergency departments, in: Proceedings of Winter Simulation Conference, IEEE, 1994, pp. 861–867.
[59] A. Aroua, G. Abdulnour, Optimization of the emergency department in hospitals using simulation and experimental design: Case study, Procedia Manuf. 17 (2018) 878–885.
[60] I.W. Gibson, An approach to hospital planning and design using discrete event simulation, in: Proceedings of the 39th Conference on Winter Simulation: 40 Years! the Best Is Yet to Come, IEEE Press, 2007, pp. 1501–1509.
[61] D. Sundaramoorthi, V.C. Chen, J.M. Rosenberger, S.B. Kim, D.F. Buckley-Behan, A data-integrated simulation model to evaluate nurse–patient assignments, Health Care Manage. Sci. 12 (3) (2009) 252.
[62] M.H. Rahman, T.J. Tumpa, S.M. Ali, S.K. Paul, A grey approach to predicting healthcare performance, Measurement 134 (2019) 307–325.
[63] F. Zeinali, M. Mahootchi, M.M. Sepehri, Resource planning in the emergency departments: A simulation-based metamodeling approach, Simul. Model. Pract. Theory 53 (2015) 123–138.
[64] Y. Sun, B.H. Heng, S.Y. Tay, K.B. Tan, Unplanned 3-day re-attendance rate at emergency department (ed) and hospital's bed occupancy rate (bor), Int. J. Emerg. Med. 8 (1) (2015) 32.
[65] R. Davies, See and treat or see and treat in an emergency department, in: Proceedings of the 39th Conference on Winter Simulation: 40 Years! the Best Is Yet to Come, IEEE Press, 2007, pp. 1519–1522.
[66] M. Khadem, H.A. Bashir, Y. Al-Lawati, F. Al-Azri, Evaluating the layout of the emergency department of a public hospital using computer simulation modeling: A case study, in: 2008 IEEE International Conference on Industrial Engineering and Engineering Management, IEEE, 2008, pp. 1709–1713.
[67] R.M. Bilow, K. Shanmuganathan, J.H. Harris Jr, Toward reduction of post–hospital admission death rate caused by acute traumatic aortic tear, J. Emerg. Med. 51 (2) (2016) 114–119.
[68] A.A. Elsamadicy, T.Y. Wang, A.G. Back, A. Sergesketter, H. Warwick, I.O. Karikari, O.N. Gottfried, Impact of intraoperative steroids on postoperative infection rates and length of hospital stay: a study of 1200 spine surgery patients, World Neurosurg. 96 (2016) 429–433.
[69] E.K. Lee, H.Y. Atallah, M.D. Wright, E.T. Post, C. Thomas IV, D.T. Wu, L.L. Haley Jr, Transforming hospital emergency department workflow and patient care, Interfaces 45 (1) (2015) 58–82.

[70] S. Horng, L. Pezzella, C.D. Tibbles, R.E. Wolfe, J.M. Hurst, L.A. Nathanson, Prospective evaluation of daily performance metrics to reduce emergency department length of stay for surgical consults, J. Emerg. Med. 44 (2) (2013) 519–525.
[71] A. Wijewickrama, S. Takakuwa, Simulation analysis of an outpatient department of internal medicine in a university hospital, in: Proceedings of the 38th Conference on Winter Simulation, Winter Simulation Conference, 2006, pp. 425–432.
[72] J. Brans, B. Mareschal, PROMETHEE: Une Méthodologie D'aide À La Décision En Présence De Critères Multiples, Collection ''Statistique et Mathématiques Appliquées''. Editions de l'Université de Bruxelles, Paris, 2002.

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