Health Policy and Technology 8 (2019) 365–376

Contents lists available at ScienceDirect

Health Policy and Technology

journal homepage: www.elsevier.com/locate/hlpt

Emergency department ergonomic design evaluation: A case study using fuzzy DEMATEL-focused two-stage methodology

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ARTICLE INFO

Article history:
Available online 9 October 2019

Keywords:
Emergency department
Ergonomic design
Check-list
FDEMATEL

ABSTRACT

Objectives: An emergency department (ED) is a unit of a hospital that is designed, staffed, and equipped to treat injured people and those afflicted with sudden and severe illness. Evaluation of ergonomic design of these departments with respect to specific criteria/standards is expected to contribute to the improvement of productivity and service quality since EDs have too much complexity and volume in the patient flow. Therefore, this paper proposes a two-stage methodology for evaluation of ED ergonomic design.
Methods: The first stage provides a check-list with 137 items on six main headings to evaluate the ergonomics of ED physical design with the opinions of medical staff. The second stage offers a fuzzy-based cause and effect decision-making model for the decreased items assessed in the first stage. In this stage, a fuzzy decision-making trial and evaluation laboratory (FDEMATEL) is used since the decision-making process involves the vagueness of human judgments.
Results: Considering the interdependence among items, proposed FDEMATEL reflects the causal relationships among criteria through a cause-effect relationship diagram. A case study was carried out at a training and research hospital ED in Istanbul, Turkey.
Conclusion: In conclusion, several suggestions are offered that the ED needs interventions on accessibility, patient and personnel accommodations, and personnel privacy.

Introduction

Ergonomics is defined as the study of designing or arranging workplaces, products and systems for useful purposes [18,20]. Although ergonomic attempts have been widely carried out in the industry, studies are very few in health care [8,15,16,19]. Emergency departments, which are the most essential units of the hospitals, are designed, staffed, and equipped to treat injured people and those afflicted with sudden and severe illness. To evaluate ergonomic patient care system at the EDs improves the quality of life for the patients and health professionals, compatible with the physical, social and psychological characteristics of human beings [3]. Personnel in the ED environments are always in interaction with technology, especially fixed and portable instruments. This interaction causes an important influence on human performance. Inadequacy in workload and stress, decision making, human-machine interaction, system design, appropriate human settlement, employer and employee education, employee supervision, rotation, heat, noise, radiation, confusion / regulation of work, work and rest periods, behaviour modification, use of personal protective equipment are factors affecting system performance directly in the ED environments [3]. In Xie and Carayon [22], three crucial ED ergonomic redesign issues were pointed out as follows: (1) physical, (2) cognitive, and (3) organizational. When compared to other institutions, hospitals are more complex in terms of layout, and technology of device and medical equipment. The complexity is more noticeable than outpatient clinics in terms of medical processes and layout design. Working in an unplanned and uncontrolled environment in EDs causes material waste, accidents and various financial losses. Therefore, evaluating ergonomic design of these departments with respect to specific criteria/standards is important to facilitate redesign efforts.

This study includes a two-stage methodology for evaluation of ED ergonomic design. The first stage is a check-list study with 138 items on six main headings to evaluate the ergonomics of ED physical design with the opinions of medical staff. The second stage proposes an FDEMATEL model for the decreased items assessed in the first stage. A case study is carried out in a training and research hospital ED in Istanbul, Turkey.

The rest of the paper comprises four sections. In Section "*Ergonomics in healthcare management and emergency departments*", a review of ergonomics related studies in healthcare management and emergency departments is provided. Next, we provide the

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https://doi.org/10.1016/j.hlpt.2019.09.005
2211-8837/

methodology developed for this study. The fourth section provides an application of the methodology for a case study and the results of the study. Finally, concluding remarks and further research are presented.

Ergonomics in healthcare management and emergency departments

Business executives generally ignore the effect of the workplace environment on employees and their reflection on their performance. However, the employee-oriented improvements made for the workplaces significantly affect the performance of the enterprises. According to a study conducted at a children's hospital in Cincinnati, the throughput time in the working has been reduced by more than 50% with the efforts regarding work, patient, the flow of documents and communication with doctors, nurses and other personnel. These have resulted in significant cost reductions. Beyond that, the run-up has been diminished. The moral level of patients and staff have been increased [14]. In a study by Tarcan et al. [17], specific criteria were set up to measure the performance of health care facilities and to obtain information about the general adequacy of buildings. The study emphasizes the effects of the adequacy of the working environment on the performances of the enterprises. Wears and Perry [20] examined patient reception, stages of emergency response, ergonomic deficiencies and correct practices in a case study carried out Florida university hospital ED. The study reveals some principles by analyzing an all too routine clinical event from an ergonomic point of view. In another study, Çelik and Oğulata [4] investigated the structure of the functional areas of service units and their interrelationships in Balçalı Hospital of Çukurova University and pointed out the problems in these units. An optimal workflow from an ergonomic point of view was proposed. Majidi et al. [12] aimed at establishing ergonomic criteria to guide ED service design. A check-list was created for the ergonomic evaluation of the EDs in 138 subjects with six main headings. Hsieh et al. [9] investigated the most important human error factors in the emergency departments. They carried out a case study in Taiwan and used the methods of human factors analysis and classification system (HFACS), analytic hierarchy process (AHP) and fuzzy technique for order preference by similarity to ideal solution (FTOPSIS) to evaluate the importance of error factors.

Research gap and contributions

The above-mentioned studies show how important hospitals and EDs are in terms of human life. Unfortunately, studies on how well a hospital organization structure is designed in terms of ergonomics are limited. With regret, there is not a framework or a methodology in which EDs can be evaluated in terms of ergonomic point of view in specific criteria/standards. Although there are a few studies in the field of hospital ergonomics in general, ergonomics studies for EDs, which are an area of expertise in itself, are too few. The primary purpose of this study is, in particular for EDs, to develop a methodology that can make it easier to demonstrate the necessity and importance of implementing ergonomic principles.

Methodology

Adapted check-list

A check-list was adapted from the study of Majidi et al. [12] to evaluate the ergonomics of ED physical design with the opinions of medical staff. 137 items were gathered from this referenced study. The Items were categorized under six areas as follows: (1) accessibility, (2) physical spaces, structures and equipment, (3) patient accommodation, (4) personnel accommodation, (5) patient privacy, and (6) personnel privacy. Each item was expressed as a Yes/No question for ease of analysis, meaning that the criterion is either met or not. The items considered for the check-list study are provided in Tables 1–6.

FDEMATEL method

The DEMATEL method was first conducted by Gabus and Fontela [6]. It converts the relationship between cause and effect factors into an intelligent structural model of the system [1,7]. The main advantage of FDEMATEL is to consider the fuzziness and to provide flexibility in a fuzzy environment [1,21]. Therefore, prior to giving the details of FDEMATEL method, it requires to mention some preliminaries of fuzzy set theory and important notations.

Fuzzy set theory reflects the uncertainties that result from vague and imprecise linguistic expressions [11]. It can demonstrate the ambiguity of the human judgments required in the proposed FDEMATEL model. Some definitions for fuzzy set theory are provided as follows [11,21]:

Firstly, a fuzzy set $\tilde{A}$ is a subset of the universe of discourse X, which is characterized by a membership function $\mu_{\tilde{A}}(x)$. This function takes values between zero and one as here $\mu_{\tilde{A}}(x) \in [0, 1]$. $\mu_{\tilde{A}}(x) = 1$ indicates that x ultimately belongs to the fuzzy set $\tilde{A}$ and $\mu_{\tilde{A}}(x) = 0$ shows that x does not belong to $\tilde{A}$.

Secondly, a triangular fuzzy number $\tilde{T}$ is a triplet (l, m, r), where the membership function $\mu_{\tilde{T}}(x)$ is defined as in Eq. (1):

$$\mu_{\tilde{T}}(x) = \begin{cases} (x-l)/(m-l) & l \le x \le m \\ (r-x)/(r-m) & m < x \le r \\ 0 & otherwise \end{cases} \tag{1}$$

where l, m, and r are real numbers and $l \le m \le r$.

The implementation steps of FDEMATEL method are explained briefly in the following [1,7]:

Step 1: In this step, the expert team who has experience about the problem is set up.

Step 2: Evaluation criteria are determined. A five-point linguistic scale is used (no influence, very low influence, low influence, high influence, and very high influence) considering linguistic terms and corresponding triangular fuzzy.

Step 3: The pairwise comparisons of experts are performed considering linguistics variables, as stated in Step 2. As a result, initial direct-relation fuzzy matrix ($\tilde{D}$) of experts is constructed.

$$\tilde{D} = \begin{bmatrix} 0 & \cdots & \tilde{D}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{D}_{n1} & \cdots & 0 \end{bmatrix} \tag{2}$$

$$\tilde{d}_{ij} = \left(l_{ij}, m_{ij}, r_{ij}\right) \tag{3}$$

Step 4: In this step, benefiting from the initial direct-relation matrix, the normalized direct-relation fuzzy matrix is constructed.

$$\gamma = \max\left(\sum_{j=1}^{n} r_{ij}\right) \tag{4}$$

$$\tilde{E} = \begin{bmatrix} \tilde{E}_{11} & \cdots & \tilde{E}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{E}_{n1} & \cdots & \tilde{E}_{nn} \end{bmatrix} \tag{5}$$

$$\text{Where } \tilde{e}_{ij} = \frac{\tilde{d}_{ij}}{\gamma} = \left(\frac{l_{ij}}{\gamma}, \frac{m_{ij}}{\gamma}, \frac{r_{ij}}{\gamma}\right) \tag{6}$$

Table 1
Adapted check-list item set for accessibility.

Item ID	Description of the item
A1	Is the ED located within the main hospital building?
A2	Is the ED entrance located in the most easily accessible part of the hospital?
A3	Do patients arrived at the ED find easy parking?
A4	Is there any reserved parking area for doctors of the ED?
A5	Is the ED entrance easily visible and remarkable?
A6	Are separate entrances available for ambulance and walk-in patients?
A7	Is the entrance easily visible and remarkable for walk-in patients?
A8	Is the triage room clearly visible for the walk-in patients?
A9	Is the triage area represented by lights or lines?
A10	Are patients separated according to different triage colors?
A11	Is the ED patient reception area easily identified and recognized?
A12	Is the ED waiting area in a position that the nurse/doctor at the triage can directly observe?
A13	Is the treatment area easily and quickly accessible from the reception area?
A14	Is a resuscitation area quickly accessible from the ambulance entrance?
A15	Is the critical care area in direct access to the treatment area, waiting room, and the reception area?
A16	Is access to a trauma care area quickly feasible from the entrance?
A17	Is there easy access to the intensive care unit (ICU) from the ED?
A18	Is there a specially reserved route from the ED to the ICU?
A19	Is there a lift available from the ED to reach other departments?
A20	Are the corridors suitable for wheelchairs and stretchers to be used to move patients to the main hospital building?
A21	Is the orthopedic examination and plaster room away from the first treatment area?
A22	Is the orthopedic examination and treatment room close to the radiological examination unit?
A23	Is there any direct access from the treatment area to the resuscitation and radiological imaging units?
A24	Is the laboratory easily accessible from the examination area?
A25	Are there different windows available in the laboratory for the delivery of emergent lab samples?
A26	Is there access to the psychiatric ward within the same building as the ED?
A27	Is there a psychiatric room close to the ambulance entrance?
A28	Is the nurse station positioned in a place where one can observe all patients?
A29	Is the equipment in the nursing station easily accessible to the nursing staff?
A30	Is the equipment and equipment stock at the nursing station adequate?
A31	Is it possible to directly observe the pediatric care staff in the treatment area?
A32	Are the toilets well isolated from the treatment area?
A33	Are the fire exits clearly depicted?
A34	Is the fire exit located in an easily accessible location?
A35	Are all doors in the ED at least 1.5 m wide?
A36	Are there patient admission and admission to the waiting room for outpatients?
A37	For outpatients, is the Eye and ENT clinic close to the ED entrance?
A38	Is the security station located in a location that can see 360° of the ED and allow emergency intervention?
A39	Are there camera-observation devices in the police station that can monitor every part of the ED?

Table 2
Adapted check-list item set for physical spaces, structures and equipment.

Item ID	Description of the item
PSE1	Is the ED building resistant to a major earthquake?
PSE2	Is the total area of the ED capable of responding effectively to the varying number of arrivals?
PSE3	Is the total number of beds in the ED capable of responding effectively to the number of arrivals?
PSE4	Is the number of examination rooms in the ED capable of responding effectively to arrivals?
PSE5	Is the number of toilets capable of responding to varying number of arrivals?
PSE6	Is there enough space in the ED to be converted to bed in the event of a crisis?
PSE7	Are a disinfection and shower area available near the ED entrance for a possible chemical and radioactive occurred?
PSE8	Are the electrical panels outside the ED entrance?
PSE9	Is there a triage room?
PSE10	Are there two nurses in the triage area?
PSE11	Does the triage area have enough space to respond to a high number of arrivals?
PSE12	Is there a pediatric treatment room available for children?
PSE13	Is there an isolated obstetrics and gynecology (OB-GYN) treatment room?
PSE14	Is there an orthopedics and casting room in the ED?
PSE15	Is there a room available for minor injuries?
PSE16	Is there a room where public staff supervising the ED is constantly present?
PSE17	Is the room where the officer in charge is adequate in terms of light, sound and lighting?
PSE18	Is the security station located in the entrance of the ED?
PSE19	Is there a treatment area for walk-in patients?
PSE20	Is there a pharmacy inside the ED?
PSE21	Are there separate toilets for men and women in the reception area?
PSE22	Are there software-related infrastructures available to allow access to the patient's medical history in the reception area?
PSE23	Is there a quarantine room to block infectious diseases?
PSE24	Is there a laboratory and blood bank in the ED?
PSE25	Are there separate examination rooms for inpatients?

(*continued on next page*)

Table 2 (*continued*)

Item ID	Description of the item
PSE26	Is there adequate equipment in the examination rooms reserved for inpatients?
PSE27	Is there an Ear-Nose-Throat (ENT) treatment room?
PSE28	Is there enough equipment in the eye clinic?
PSE29	Is there a waiting area in the ED?
PSE30	Is there a head nurse room available in the ED?
PSE31	Is there a burn unit in the ED?
PSE32	Is there an administration office in the ED?
PSE33	Is there a designated administration area away from the treatment areas?
PSE34	Is there a silent or counseling room designated within the ED?
PSE35	Is there sound insulation between the consultation area and the examination rooms?
PSE36	Is there a morgue?
PSE37	Is the height of the stretchers 75 cm from the ground?
PSE38	Is the square meter area per bed in the ED greater than 11.15 m^2?
PSE39	Are there outpatient care areas between 0.5 and 2.3 m^2?
PSE40	Is the area of the trauma room at least 23.23 m^2?
PSE41	Are the critical care and cardiopulmonary resuscitation (CPR) room larger than 23.23 m^2?
PSE42	Is the height of the nurse station box office at least 1 m above the ground?
PSE43	Is a generator available for the ED?
PSE44	Is there a separate isolated ventilation system for each treatment room?
PSE45	Are there panels from floor to ceiling separating examination rooms?
PSE46	Can the panels be removed for treatment area?
PSE47	Is the lighting enough for the treatment area?
PSE48	Is continuous monitoring of the isolated treatment rooms possible?
PSE49	Are fixed or portable oxygen cylinders available for each bed?
PSE50	Is there a sink in every examination and treatment area?
PSE51	Is there a multi-phone line at the nurse station?
PSE52	Is it possible to access the internet from the ED?
PSE53	Is the telecom system installed in the ED?
PSE54	Is there an emergency button in the restrooms?
PSE55	Is the call system installed for the cardiac resuscitation unit?
PSE56	Is the fire alarm system installed for different areas of the ED?
PSE57	Are fire extinguishers available in all ED spaces?
PSE58	Are there enough electrical outlets for each area?
PSE59	Do electrical outlets have a height of 36 cm?
PSE60	Is there a system to report directly to the police or to the police?
PSE61	Is there a portable X-ray in the cardiac resuscitation unit?
PSE62	Is the laboratory capable of responding to routine tests (electrolyte level, blood sugar, urea, creatine)?
PSE63	Are the different work and treatment areas of the ED under surveillance?
PSE64	Is there a clean and dirty warehouse?

Table 3
Adapted check-list item set for patient accommodation.

Item ID	Description of the item
PATA1	Is the waiting area enough to respond effectively to the number of patient demand?
PATA2	Is there a caregiver available to assist patients at the ED entrance?
PATA3	Are the heating and cooling systems in the waiting area adequate?
PATA4	Is there a water dispenser in the waiting area?
PATA5	Are there a few seats or chairs that can respond to the number of patient admissions in the waiting area?
PATA6	Is there a newspaper magazine in the patient reception area?
PATA7	Are the heating and cooling systems of the treatment area adequate?
PATA8	Is there a nurse call system in each bed?
PATA9	Does the waiting area paint consist of natural and vivid colors?
PATA10	Are enough staffs working to meet patient expectations in the ED?
PATA11	Is there a playroom for pediatric patients?
PATA12	Are there enough seats or chairs for the companions?
PATA13	Is there a mosque for relatives and patients?

Table 4
Adapted check-list item set for personnel accommodation.

Item ID	Description of the item
PERA1	Is there a place specifically allocated to receive the results of radiological imaging results?
PERA2	Do doctors have separate rest areas?
PERA3	Is the heating and cooling systems of the resting area adequate?
PERA4	Are there personal cabinets reserved for staff in the rest area?
PERA5	Are restrooms available for staff in the rest area?
PERA6	Are there private shower areas available for the staff to take a shower in the rest area?
PERA7	Is there a refrigerator, sink and microwave in the rest area?
PERA8	Is there a necessary communication infrastructure for telephone and internet access in the rest area?
PERA9	Is there a dining area located within the rest area?
PERA10	Is there a sleeping area within the rest area?
PERA11	Is the lighting of the resting area adequate?
PERA12	Is there a mosque in the resting area?

Table 5
Adapted check-list item set for patient privacy.

Item ID	Description of the item
PATP1	Is the visual and auditory privacy of the patient secured in the examination area?
PATP2	Is the elevator allocated to a separate place from the waiting room?
PATP3	Do the documents containing the patient's medical history be kept out of the reach of other patients?
PATP4	Are the areas designed suitable for establishing a reliable relationship between the doctor and the patient?

Table 6
Adapted check-list item set for personnel privacy.

Item ID	Description of the item
PERP1	Is the staff work area properly isolated from the patient care area?
PERP2	Are the locker rooms and cupboards for employees away from the patient care area?
PERP3	Is the rest of the staff located in a place that patients cannot see?
PERP4	Is there an appropriate space for staff to put personal belongings?
PERP5	Are there separate entry-exit doors for personnel?

Step 5: Hereafter the matrix $\tilde{E}$, a total-relation fuzzy matrix is calculated as follows.

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \dots & \tilde{t}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \dots & \tilde{t}_{nn} \end{bmatrix} \quad (7)$$

where $\tilde{t}_{ij=} = (l''_{ij}, m''_{ij}, r''_{ij})$

$$Matrix\left[l''_{ij}\right] = E_l \; x \; (I - E_l)^{-1} \quad (8)$$

$$Matrix\left[m''_{ij}\right] = E_m \; x \; (I - E_m)^{-1} \quad (9)$$

$$Matrix\left[r''_{ij}\right] = E_r \; x \; (I - E_r)^{-1} \quad (10)$$

Step 6: After the computation of matrix $\tilde{T}$, $\tilde{ro}_i + \tilde{co}_j$ and $\tilde{ro}_i - \tilde{co}_j$ are computed. Here, $\tilde{ro}_i$ and $\tilde{co}_j$ show the sum of the rows and columns of matrix $\tilde{T}$. Whilst $\tilde{ro}_i + \tilde{co}_j$ shows the importance of criterion *i*, $\tilde{ro}_i - \tilde{co}_j$ shows the net effect of criterion *i*.

Step 7: Thereafter, $\tilde{ro}_i + \tilde{co}_j$ and $\tilde{ro}_i - \tilde{co}_j$ are defuzzified by using centre of area defuzzification style to determine the best non-fuzzy value with Eq. (11).

$$BNV_{ij} = \frac{u_{ij} - l_{ij} + m_{ij} - l_{ij}}{3} + l_{ij} \quad (11)$$

Step 8: In the last step, the cause and effect relation diagram are drawn by the aid of $\tilde{ro}_i + \tilde{co}_j$ and $\tilde{ro}_i - \tilde{co}_j$.

Proposed two-stage methodology

The process flow of the proposed two-stage methodology is given in Fig. 1. Based on the framework presented, the problem is structured in two stages. The first stage is to implement adapted check-list. In the second stage, items responded as "Yes" (means that the criterion is met) were also reviewed. The ones responded as "No" (means that the criterion is not met) were removed from the evaluation of the second stage. The first group items were transformed into a criterion set for the second stage. The selected criteria were then analyzed using FDEMATEL method in order to determine the most critical criteria affecting ED ergonomic design and their interactions.

Case study

In this section, the two-stage methodology is applied to evaluate ED ergonomic design of a training and research hospital ED in Istanbul, Turkey.

Organization of the observed ED

The hospital where the observed ED is located has a history of 111 years. It is an educational and research hospital in Istanbul. The ED has three main areas, yellow, green and red, where about thirteen patients can be treated at the same time. The ED face many shortcomings regarding ergonomic design. The ergonomic evaluation criteria can be monitored and analyzed in conjunction with the causal-effect relations of the FDEMATEL method.

Application of the two-stage methodology

Check-list implementation results and recommendations for the ED

Due to the scarce of data, the methodology uses experts' judgments. The linguistic assessment of experts is practical in dealing with conditions that are defined in quantitative expressions. Therefore, to obtain a linguistic assessment, it was contacted with a group of medical staff. The group comprises of doctors, nurses and technicians. The experts were asked to assess the relationships among the evaluation criteria (simplified item definitions) according to the linguistic scale. Since there were several medical experts assessed the criteria, a group consensus is followed through the study. Firstly, experts designed the item sets for each of six headings and implemented it. At the end of the implementation, 63 items have not been met (about 46% of all items). The ED has met the expectations in terms of 74 items which approximately correspond to 54% of all items. According to the results, 20 yes and 16 no answers were taken in the accessibility subheading. In order to understand the ED ergonomic design and suitability, items have been examined more closely.

Accessibility. The ED building consists of three buildings within the hospital. The illuminated plates depicting the location of the ED are available and visible from all areas of the hospital. There is no sign inside the ED demonstrating the patient reception area. A welcome desk and triage area are located on the left side of the entrance. Corridors and doors are in anthropometric dimensions suitable for stretcher and wheelchair passages. Orthopedic examination and plaster room are located within the yellow area and easy to reach. Also, a radiological imaging unit is positioned directly opposite the orthopedic examination room. It is possible to reach the yellow area directly with the doors from the resuscitation located in the section called red area and from the patient reception areas. There is no fire exit door in the ED. The entrance and exit are realized through a single door. New points must be created for the fire exit and personnel entry/exit. There is no psychiatry, eye or ENT clinic in the ED. Children are placed in an emergency place because the issues related to pediatrics are automatically disabled.

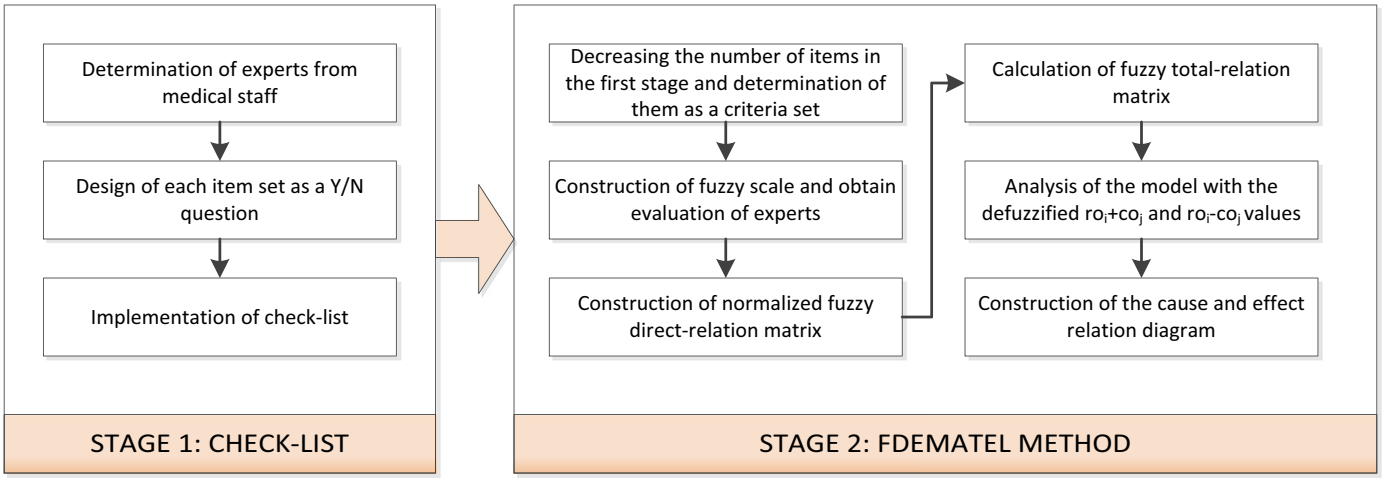

Fig. 1. Flowchart of the two-stage methodology.

The security unit is positioned in a room opposite the ED entrance. Therefore, there is no way to see it anywhere. In summary, it is not possible to consider the ED of the observed hospital as ergonomically accessible. Yet, ergonomic intervention is required in many areas.

Physical spaces, structures and equipment. According to the results obtained from the check-list implementation, under the physical spaces, structures and equipment, 41 yes and 23 no answers were received. Earthquake strengthening and physical restoration of the ED building was performed in 2011. In the light of this information, the building is earthquake-resistant. Although the total area of the ED is large, the waiting area and outpatient admissions area are not large enough to meet patient demand. The number of examination rooms for outpatient admissions is insufficient. The toilet is situated in the yellow area just opposite the patient treatment units and is not dedicated for staff. That is not isolated from the treatment areas. No emergency button is available in the toilets.

There is a triage area in the ED. However, only one responsible nurse works in the triage process. The triage area serving only two tolls is not capable of responding to the number of patients with varying demand. There is one duty officers' room in the ED. It is functional in terms of fundamental ergonomic criteria such as heat, lighting and sound. In the ED, a yellow area is available. The nurse station in the yellow area is located on the left side of the entrance. It is not possible to observe all the treatment rooms from this area. Only two nurses serve in this area. According to the interviews with working nurses, they indicate that the yellow area is insufficient in terms of personnel and equipment. There is no dedicated management office for the ED. The management office is located within the main hospital building, away from the ED. The red area contains burn and revitalization unit. There are four beds and four electroshock devices in the revitalization unit.

Furthermore, 15 beds are fully equipped in the emergency intensive care unit located in the red area. For each bedside area, 3 m^2 is arranged. According to the international standards of 11.52 m^2 per bed, it is ergonomically wholly inadequate. The laboratory located in the yellow area is capable of responding to all required tests. The personnel in charge mentioned the absence of the system to inform the security units directly in the ED. The morgue of the hospital is located on the minus third. Within the yellow area, direct access to other departments is possible via the lift. In summary, although the ED contains the necessary equipment in terms of physical spaces, structures and equipment, it does not provide a good picture in terms of ergonomic suitability of the equipment.

Patient accommodation. Under the patient accommodation subheading, three yes and ten no responses were received in the check-list. There are two waiting areas at the entrance of the ED. The first one is the waiting area where the patients are hospitalized. The heating system in this area is adequate. There is no small mosque in the ED.

Personnel accommodation. Six yes and six no responses were received regarding the personnel accommodation. In the ED, there is a room with 30 m^2 in size for the physicians to rest in the yellow area. There is no separate dining area and sleeping area in the room. The room can meet the basic ergonomic criteria such as heat, light and sound.

Patient privacy. Relating to patient privacy, only four yes responses were received. It can be said that patient privacy is well protected. In the ED, the patient's medical history and personal records can be accessed via a computer in the patient reception area.

Personnel privacy. On the other hand, only five no responses were received regarding personnel privacy. There are separate lockers in the restroom for doctors and nurses. However, there is no closet for patient-carrying staff where they can put their personal belongings. There are no particular entry-exit doors for the personnel in the ED. In order to ensure the privacy of the staff, the resting rooms should be located outside the treatment areas. Personal cabinets must be provided for all personnel. Briefly, it is inferred that the ED is not in a good position in terms of personnel privacy.

Implementation of FDEMATEL and cause-effect relation analysis

After implementing check-list, we reviewed the items that were met the expectations in the first stage. In this context, the evaluation criteria determined for the second stage of the study were given in the Appendix. Abbreviations of "A, PSE, PATA, PERA and PATP" denote criterion identity code given by the headings of "Accessibility, Physical spaces, structures & equipment, Patient accommodation, Personnel accommodation and Patient privacy".

First, the evaluation criteria for ED ergonomic design as provided in the Appendix are assessed in terms of the relationship using the fuzzy linguistic scale of Table 7. According to the consensus of evaluators consisting of ED stakeholders (ED executive, doctors, nurses, laboratory technicians), Table 8 shows the linguistic

Table 7
The evaluation scale of ED ergonomic design with triangular fuzzy numbers.

Linguistic terms	Triangular fuzzy numbers
No influence (No)	(0, 0, 0.25)
Very low influence (VL)	(0, 0.25, 0.5)
Low influence (L)	(0.25, 0.5, 0.75)
High influence (H)	(0.5, 0.75, 1)
Very high influence (VH)	(0.75, 1, 1)

assessments of evaluators' consensus on the accessibility criteria for ED ergonomic design. The results of FDEMATEL for the accessibility criteria for ED ergonomic design are only given in the paper due to the space limitations. Accordingly, Table 9 demonstrates the initial direct-fuzzy matrix. After having established the initial direct-fuzzy matrix, the normalized direct-relation fuzzy matrix is constructed by using the Eqs. (4)–(6), respectively. Table 10 illustrates the normalized initial direct-relation fuzzy matrix. After that, the total-relation fuzzy matrix can be calculated by applying Eqs. (7)–(10). In that context, Table 11 provides the total-relation fuzzy matrix accordingly.

In the light of the above outcomes, the fuzzy values of $\tilde{ro}_i$, $\tilde{co}_j$, $\tilde{ro}_i + \tilde{co}_j$ and $\tilde{ro}_i - \tilde{co}_j$ can be obtained as illustrated in Table 12. After this step, defuzzification process is performed to convert the fuzzy numbers into crisp values. By using Eq. (11), the crisp values of the $\tilde{r}_i$, $\tilde{c}_j$, $\tilde{ro}_i + \tilde{co}_j$ and $\tilde{ro}_i - \tilde{co}_j$, provided in Table 13, can be found to build up cause-effect relation diagram. In the last stage, the cause and effect relationship diagram can be depicted based on the above outcomes.

In conclusion of the results of defuzzified values of $\tilde{ro}_i$, $\tilde{co}_j$, $\tilde{ro}_i + \tilde{co}_j$ and $\tilde{ro}_i - \tilde{co}_j$, Fig. 2 provides the cause-effect relation diagram. According to the diagram, two groups named cause and effect factors are analyzed in terms of ED ergonomic design.

In the next section, the detailed discussion on these two groups about to what degree they are crucial for ED ergonomic design.

Discussion

ro_i values demonstrate the effects of each criterion on other criteria as given in Table 8. The largest impact on ED ergonomic design has been observed by "A35: Determination of all door widths in the ED at least 1.5 m" (2.15), "PSE6: Sufficiency of the surge capacity for a possible crisis or disaster" (1.88), "PATA2: Availability of assistance staff at reception for guiding patients" (1.89), "PERA2: Availability of a separate physician resting area" (2.42) and "PATP3: Availability of a designated area for storing patient files away from another patients' reach" (0.12). "A22: Closeness of the orthopedic examination and casting rooms to the radiology suite", "PSE16: Availability of a room for the public staff supervising the ED", "PATA3: Availability of an air-conditioning system in the waiting area", "PERA1: Availability of a dedicated area for viewing imaging results" and "PATP1: Securability of the patients' visual, auditory, and olfactory privacy within each treatment area" had the lowest impact on ED ergonomic design.

co_j values represent the effect of other criteria on each criterion. The results showed that, as compared with other criteria, "A12: Availability of the entrances and the waiting area in direct observation area of the triage nurse/doctor" (2.26) and "PERA1: Availability of a dedicated area for viewing imaging results" (2.46) had the most significant impact while "PSE6: Sufficiency of the surge capacity for a possible crisis or disaster" (0.76) had the smallest impact.

Regarding level of interaction ($ro_i + co_j$), "A12: Availability of the entrances and the waiting area in direct observation area of the triage nurse/doctor" (4.01), "PSE62: Be equipped of the lab

Table 8
The linguistic assessment of evaluators' consensus on the accessibility criteria for ED ergonomic design.

Criteria	A1	A4	A5	A6	A7	A8	A10	A12	A14	A15	A17	A19	A20	A22	A23	A24	A25	A29	A35	A36
A1	No	VH	H	No	L	L	VL	L	VL	VL	L	No	L	No	No	L	VL	L	VL	VL
A4	L	No	L	L	L	L	VL	L	L	No	No	No	No	L	L	L	No	No	L	VL
A5	VH	H	No	VH	VH	VH	H	VH	L	L	L	L	H	L	L	L	L	No	L	L
A6	VH	H	VH	No	H	H	L	H	L	L	VL	L	H	L	L	L	No	No	L	L
A7	H	L	VH	H	No	L	L	H	VL	VL	VL	VL	VH	H	H	VL	L	L	VL	VL
A8	L	L	VH	VH	VH	No	VL	VH	L	L	VL	VL	VL	No	No	No	L	VL	L	L
A10	VH	H	H	VH	H	H	No	L	VH	H	H	L	L	VL	VL	H	No	VH	L	H
A12	VL	L	VL	L	L	H	VL	No	No	No	No	L	VH	VH	H	L	VH	VH	VH	VH
A14	VH	VH	H	VH	H	L	VH	L	No	VL	H	No	No	No	No	VL	VL	H	No	No
A15	H	H	H	H	H	L	VH	VH	VH	No	VH	VL	No	VL	VL	L	No	No	No	No
A17	L	H	L	L	H	L	VH	H	VH	H	No	VH	H	H	H	L	L	L	No	No
A19	VL	VL	No	No	No	No	L	H	L	L	VH	No	VH	VH	VH	VH	VH	L	H	H
A20	L	L	No	L	L	No	VL	VH	VL	VL	VL	No	No	H	VH	L	VL	No	VL	H
A22	VL	L	No	No	L	VL	VL	L	No	No	No	VL	L	No	VH	H	VL	No	No	No
A23	VH	H	H	L	VH	VH	L	L	L	VH	VH	No	L	L	No	No	L	H	L	L
A24	H	L	H	VL	H	H	VL	H	H	VH	VH	L	No	No	VH	No	No	No	VL	No
A25	VL	VL	L	L	VL	L	VL	H	H	H	VH	H	VH	VH	VH	VH	No	VH	VL	VL
A29	No	VL	L	No	No	VL	H	H	H	VH	VH	H	L	L	VH	H	H	No	No	VH
A35	H	H	VH	H	H	H	VH	VH	VH	H	VH	VH	VH	L	H	VL	No	L	No	VL
A36	L	H	L	H	VH	VL	H	VH	VH	VH	VH	No	No	L	VL	H	No	No	H	No

Table 9
The fuzzy initial direct-relation matrix.

Criteria	A1	A4	A5	A6	...	A25	A29	A35	A36
A1	(0,0,0.25)	(0.75,1,1)	(0.5,0.75,1)	(0,0,0.25)	...	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0.25,0.5)
A4	(0.25,0.5,0.75)	(0,0,0.25)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	...	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)	(0,0.25,0.5)
A5	(0.75,1,1)	(0.5,0.75,1)	(0,0,0.25)	(0.75,1,1)	...	(0.25,0.5,0.75)	(0,0,0.25)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
A6	(0.75,1,1)	(0.5,0.75,1)	(0.75,1,1)	(0,0,0.25)	...	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
...	...	...	...	...	...	...	...	...	...
A25	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	...	(0,0,0.25)	(0.75,1,1)	(0,0.25,0.5)	(0,0.25,0.5)
A29	(0,0,0.25)	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0,0.25)	...	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0.75,1,1)
A35	(0.5,0.75,1)	(0.5,0.75,1)	(0.75,1,1)	(0.5,0.75,1)	...	(0,0,0.25)	(0.25,0.5,0.75)	(0,0,0.25)	(0,0.25,0.5)
A36	(0.25,0.5,0.75)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0.5,0.75,1)	...	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)

Table 10
The fuzzy normalized initial direct-relation matrix.

Criteria	A1	A4	A5	A6	...	A25	A29	A35	A36
A1	(0,0,0.01)	(0.04,0.06,0.06)	(0.03,0.04,0.06)	(0,0,0.01)	...	(0,0.01,0.03)	(0.01,0.03,0.04)	(0,0.01,0.03)	(0,0.01,0.03)
A4	(0.01,0.03,0.04)	(0,0,0.01)	(0.01,0.03,0.04)	(0.01,0.03,0.04)	...	(0,0,0.01)	(0,0,0.01)	(0.01,0.03,0.04)	(0,0.01,0.03)
A5	(0.04,0.06,0.06)	(0.03,0.04,0.06)	(0,0,0.01)	(0.04,0.06,0.06)	...	(0.01,0.03,0.04)	(0,0,0.01)	(0.01,0.03,0.04)	(0.01,0.03,0.04)
A6	(0.04,0.06,0.06)	(0.03,0.04,0.06)	(0.04,0.06,0.06)	(0,0,0.01)	...	(0,0,0.01)	(0,0,0.01)	(0.01,0.03,0.04)	(0.01,0.03,0.04)
...	...	...	...	...	...	...	...	...	...
A25	(0,0.01,0.03)	(0,0.01,0.03)	(0.01,0.03,0.04)	(0.01,0.03,0.04)	...	(0,0,0.01)	(0.04,0.06,0.06)	(0,0.01,0.03)	(0,0.01,0.03)
A29	(0,0,0.01)	(0,0.01,0.03)	(0.01,0.03,0.04)	(0,0,0.01)	...	(0.03,0.04,0.06)	(0,0,0.01)	(0,0,0.01)	(0.04,0.06,0.06)
A35	(0.03,0.04,0.06)	(0.03,0.04,0.06)	(0.04,0.06,0.06)	(0.03,0.04,0.06)	...	(0,0,0.01)	(0.01,0.03,0.04)	(0,0,0.01)	(0,0.01,0.03)
A36	(0.01,0.03,0.04)	(0.03,0.04,0.06)	(0.01,0.03,0.04)	(0.03,0.04,0.06)	...	(0,0,0.01)	(0,0,0.01)	(0.03,0.04,0.06)	(0,0,0.01)

Table 11
The fuzzy total-relation matrix.

Criteria	A1	A4	A5	A6	...	A25	A29	A35	A36
A1	(0,0.03,0.13)	(0.05,0.08,0.18)	(0.03,0.07,0.17)	(0,0.03,0.08)	...	(0,0.03,0.11)	(0.02,0.04,0.13)	(0,0.03,0.12)	(0,0.03,0.12)
A4	(0.02,0.05,0.15)	(0.01,0.03,0.13)	(0.02,0.05,0.15)	(0.02,0.05,0.07)	...	(0,0.01,0.09)	(0,0.02,0.1)	(0.02,0.04,0.12)	(0,0.03,0.11)
A5	(0.05,0.11,0.22)	(0.04,0.09,0.23)	(0.01,0.05,0.18)	(0.05,0.1,0.12)	...	(0.02,0.06,0.16)	(0.01,0.03,0.14)	(0.02,0.06,0.17)	(0.02,0.06,0.17)
A6	(0.05,0.1,0.21)	(0.04,0.09,0.22)	(0.05,0.1,0.21)	(0.01,0.04,0.11)	...	(0,0.02,0.13)	(0.01,0.03,0.13)	(0.02,0.06,0.16)	(0.02,0.06,0.17)
...	...	...	...	...	...	...	...	...	...
A25	(0.01,0.06,0.18)	(0.01,0.06,0.19)	(0.02,0.07,0.19)	(0.02,0.07,0.08)	...	(0.01,0.03,0.13)	(0.05,0.09,0.17)	(0.01,0.04,0.14)	(0.01,0.05,0.15)
A29	(0.01,0.05,0.16)	(0.01,0.06,0.19)	(0.02,0.07,0.19)	(0.01,0.04,0.08)	...	(0.03,0.07,0.16)	(0.01,0.03,0.13)	(0.01,0.03,0.13)	(0.05,0.08,0.17)
A35	(0.04,0.1,0.23)	(0.04,0.1,0.24)	(0.06,0.11,0.22)	(0.04,0.09,0.11)	...	(0.01,0.03,0.14)	(0.02,0.06,0.17)	(0.01,0.04,0.14)	(0.01,0.05,0.16)
A36	(0.03,0.08,0.19)	(0.04,0.09,0.21)	(0.03,0.07,0.19)	(0.04,0.08,0.12)	...	(0.01,0.02,0.12)	(0.01,0.03,0.13)	(0.03,0.07,0.17)	(0.01,0.03,0.13)

Table 12
The fuzzy values of $\tilde{ro}_i$, $\tilde{co}_j$, $\tilde{ro}_i + \tilde{co}_j$ and $\tilde{ro}_i - \tilde{co}_j$.

Criteria	ro_i			co_j			ro_i+co_j			ro_i-co_j		
A1	0.24	0.85	2.78	0.60	1.48	3.69	0.85	2.33	6.46	−0.36	−0.63	−0.91
A4	0.23	0.76	2.53	0.60	1.51	3.92	0.83	2.27	6.45	−0.37	−0.75	−1.39
A5	0.64	1.53	3.77	0.61	1.43	3.68	1.25	2.96	7.44	0.03	0.09	0.09
A6	0.51	1.30	3.64	0.55	1.32	1.88	1.07	2.62	5.52	−0.04	−0.02	1.76
A7	0.43	1.25	3.22	0.66	1.54	3.88	1.09	2.79	7.1	−0.23	−0.29	−0.65
A8	0.41	1.13	3.04	0.50	1.30	3.52	0.91	2.43	6.56	−0.09	−0.17	−0.49
A10	0.67	1.56	3.83	0.46	1.28	3.41	1.13	2.85	7.24	0.21	0.28	0.43
A12	0.57	1.36	3.30	0.79	1.77	4.23	1.36	3.13	7.53	−0.22	−0.41	−0.92
A14	0.46	1.11	2.97	0.55	1.35	3.50	1.01	2.45	6.47	−0.09	−0.24	−0.52
A15	0.51	1.20	3.13	0.49	1.22	3.30	0.99	2.42	6.43	0.02	−0.02	−0.18
A17	0.63	1.46	3.74	0.60	1.38	3.44	1.23	2.84	7.18	0.02	0.08	0.30
A19	0.60	1.37	3.39	0.31	0.87	2.73	0.91	2.23	6.12	0.29	0.50	0.65
A20	0.31	0.94	2.75	0.55	1.26	3.29	0.86	2.2	6.04	−0.24	−0.33	−0.54
A22	0.19	0.63	2.34	0.47	1.16	3.24	0.66	1.79	5.58	−0.28	−0.54	−0.90
A23	0.62	1.47	3.72	0.60	1.39	3.53	1.23	2.86	7.25	0.02	0.08	0.19
A24	0.49	1.18	3.27	0.45	1.20	3.40	0.94	2.38	6.66	0.04	−0.02	−0.13
A25	0.61	1.50	3.53	0.28	0.81	2.65	0.89	2.32	6.18	0.33	0.69	0.88
A29	0.59	1.36	3.46	0.39	0.93	2.82	0.98	2.29	6.28	0.21	0.42	0.64
A35	0.78	1.73	3.95	0.28	0.88	2.79	1.06	2.61	6.74	0.50	0.85	1.16
A36	0.59	1.36	3.44	0.34	0.96	2.89	0.94	2.32	6.34	0.25	0.40	0.55

for routine lab tests" (3.69) and "PERA2: Availability of a separate physician resting area" (4.40) had the most significant level of interaction with other ED ergonomic design criteria, respectively. On the other hand, "A22: Closeness of the orthopedic examination and casting rooms to the radiology suit" and "PSE17: Adequateness of the officer room in terms of sound, lighting etc." had the smallest level of interaction with other criteria. Regarding the type of interaction ($ro_i - co_j$), criteria with minimum ro_i value and co_j value are considered as effect criteria (Fig. 3). In summary, the ED ergonomic design criteria can be assessed under four different zones, as proposed in the study of Mohammadfam et al. [13].

The most important criteria affecting ED ergonomic design are placed in zone-1. For the accessibility of the ED, "A35: Determination of all door widths in the ED at least 1.5 m", "A10: Following of a line system", "A17: Accessibility of the ICU from the ED", "A23: Availability of direct access to the imaging suit, and the resuscitation room from the treatment area" and "A5: Visibility of entrance at the ED" are the most crucial criteria and therefore, actions plan and corrective-preventive activities must be fulfilled to improve these criteria. As in Çelik and Oğulata [4], compliance of the entrance doors to the relevant standards has been observed as the first priority in the solution proposals . In zone-2, there exist five cause criteria that are less important than the first group placed in zone-1. These include "A25: Availability of a different window for delivery of emergent lab samples at the laboratory", "A6: Availability of separate entrances for ambulance and walk-in patients", "A19: Availability of dedicated elevators in case facilities are not in the same level as the ED", "A29: Readiness and accessibility of the equipment in the nursing station to the nursing staff" and "A36: Availability of direct access of the reception and waiting areas to the hospital for outpatient referral". These criteria should be considered secondary in the priority ranking of corrective actions. "A25: Availability of a different window for delivery of emergent lab samples at the laboratory" is the second most crucial causal criterion since it ranks second place among all criteria with an $ro_i - co_j$ value of 0.63. It also has a significant influence on the whole ED ergonomic design process in terms of accessibility.

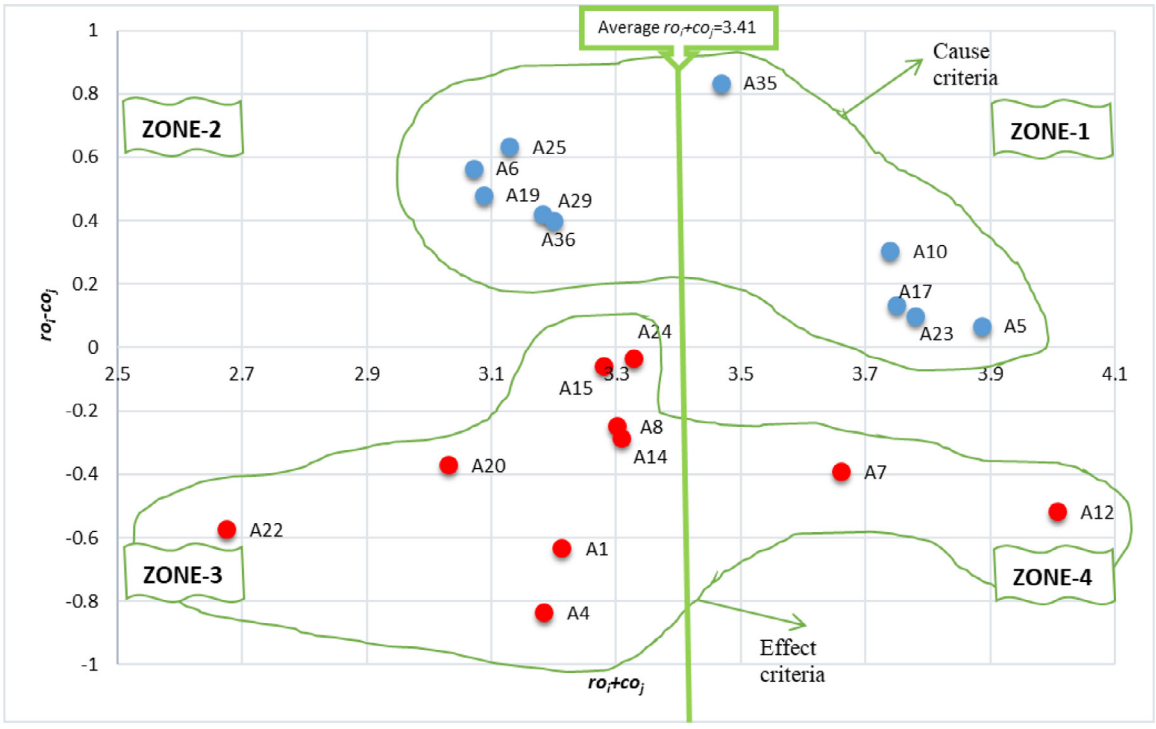

Fig. 2. The cause-effect relation diagram of accessibility criteria for ED ergonomic design.

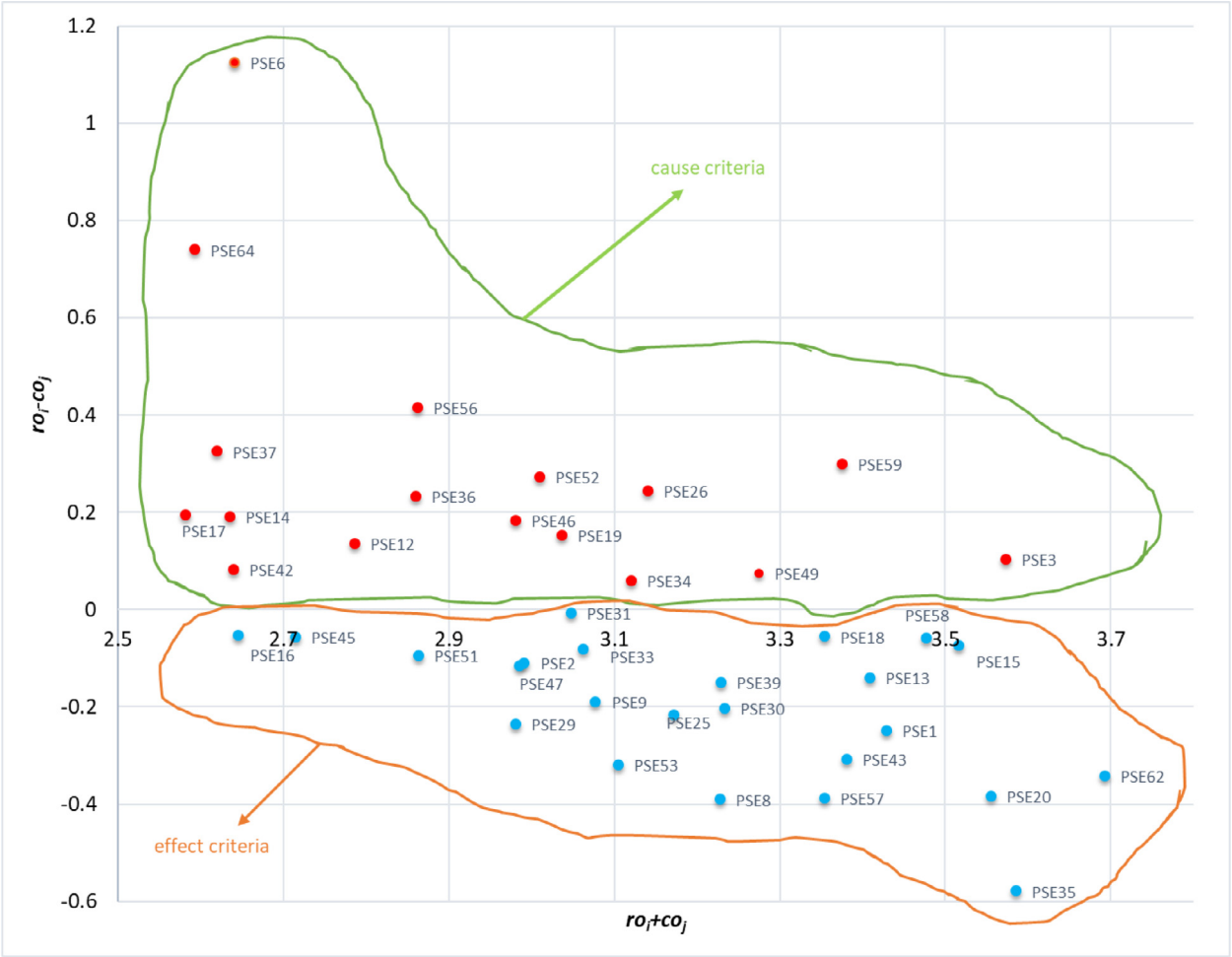

Fig. 3. The cause-effect relation diagram of physical spaces, structures & equipment criteria for ED ergonomic design.

Table 13
The defuzzified values of $\tilde{ro}_i$, $\tilde{co}_j$, $\tilde{ro}_i + \tilde{co}_j$ and $\tilde{ro}_i - \tilde{co}_j$.

Criteria	ro_i	co_j	ro_i+co_j	ro_i-co_j
A1	1.29	1.92	3.21	−0.6
A4	1.17	2.01	3.18	−0.8
A5	1.98	1.91	3.89	0.07
A6	1.82	1.25	3.07	0.57
A7	1.63	2.03	3.66	−0.4
A8	1.53	1.77	3.3	−0.2
A10	2.02	1.72	3.74	0.31
A12	1.75	2.26	4.01	−0.5
A14	1.51	1.8	3.31	−0.3
A15	1.61	1.67	3.28	−0.1
A17	1.94	1.81	3.75	0.14
A19	1.78	1.3	3.09	0.48
A20	1.33	1.7	3.03	−0.4
A22	1.05	1.62	2.68	−0.6
A23	1.94	1.84	3.78	0.1
A24	1.65	1.68	3.33	−0
A25	1.88	1.25	3.13	0.63
A29	1.8	1.38	3.18	0.42
A35	2.15	1.32	3.47	0.83
A36	1.8	1.4	3.2	0.4

In zone-3, there are criteria which are affected zone-1 and zone-2 criteria while they affect zone-4 criteria. Since effect criteria are easily impacted by the other criteria and, it may be still necessary to analyze effect criteria which can lead to severe consequences in the accessibility aspect of ED ergonomic design. With respect to the cause-effect relation diagram, for example, the effect criteria of "A24: Accessibility of the ED lab from all treatment areas", "A15: Availability of the critical care area in direct access of the treatment area, waiting room and the reception", "A8: Visibility of triage room and location in the path of walk-in patients' entrance" and "A14: Availability of a resuscitation area" have high $ro_i - co_j$ value which indicates that they are slightly affected by the other criteria among the whole process. For zone-3 criteria, the third line of corrective-preventive action plans must be considered for ED ergonomic design. In zone-4, there exist two effect criteria depicted as "A7: Visibility of entrance for walk-in patients" and "A12: Availability of the entrances and the waiting area in direct observation area of the triage nurse/doctor". These criteria are placed at the last priority order, and they may be improved indirectly.

Similar analysis and discussion are performed for the remaining criteria set provided in Table 8. According to the results obtained, "PATP1: Securability of the patients' visual, auditory, and olfactory privacy within each treatment area" and "PATP3: Availability of a designated area for storing patient files away from another patients' reach" are considered in casual criteria group. On the other hand, each of "PATA2: Availability of assistance staff at reception for guiding patients", "PATA3: Availability of an air-conditioning system in the waiting area" and "PATA7: Availability of an air-conditioning system in the treatment areas" are placed in effect criteria group. They all have a higher score of $ro_i + co_j$. When the ED ergonomic design is considered in terms of personnel accommodation, it is seen that all the criteria are placed in the effect group. They all have a positive $ro_i + co_j$ value. "PERA2: Availability of a separate physician resting area" and "PERA4: Availability of private lockers reserved for staff in the resting area" have scores of 4.40 and 4.37, respectively. It means that these criteria are affected more than others. According to the results obtained from the cause-effect relation diagram of physical spaces, structures & equipment criteria for ED ergonomic design (Fig. 3), the following implications are obtained: "PSE3: Sufficiency of the number of beds for annual patient demand" has more impact on the entire ED ergonomic design process. Following this result, "PSE59: Placement of the electrical outlets properly at a height of 36 cm" is the second most important causal criterion since it ranks second place among all criteria with an $ro_i + co_j$ value of 3.38.

In the light of cause-effect relation diagram, "PSE62: Be equipped of the lab for routine lab tests" and "PSE35: Isolation of the counseling room acoustically from the treatment areas" have the first and second highest $ro_i + co_j$values in the whole process. Therefore, they are the most important effect criteria.

The obtained findings from the two-stage methodology are so close to the results of the guidelines that include procedures and policies regarding the use and design of emergency departments. In a guideline by the Department of Health and Human Services [5] in State of Victoria (Australia), standards about the room design and equipment are described too close to our results. According to that guideline, doors should be either extra-wide or 1½ door size with a viewing panel and be outward opening. Also, door handles should move in a downward motion or can be non-ligature. In the current study, the criterion of "A35: Determination of all door widths in the ED at least 1.5 meters" was identified as a criterion that affected mostly accessibility of the ED. Also, other cause criteria have emerged as important criteria that were drawn up in many guidelines [2,5,10].

For practical implications, this study provides a guide for stakeholders in ED ergonomic design. The two-stage methodology, with its four-zone structure, determines the most important ED ergonomic design criteria and their interactions. Therefore, decision-makers of the observed ED may consider the corrective-preventive actions towards the most important criteria and improve their ED performance. The methodology of this study can also be adapted for any EDs apart from Turkey and design recommendations can be useful for the EDs of other countries. To this end, it can be obtained more efficient processes of *emergency care delivery*.

Evaluation of ED ergonomic design can be performed by various multi-criteria decision-making (MCDM) methods. In this study, we prefer FDEMATEL since it can identify the interdependence among criteria. Unlike DEMATEL, AHP is another choice. However, there is an assumption in AHP that elements are independent. One of the advantages of FDEMATEL is its demonstrating ability of the causal relationships between criteria in a visual style. This ability of FDEMATEL enables stakeholders understanding the results and quantifying the strengths of relationships [1,7,13]. Benefiting from the usefulness of adapted check-list method and the strengths of FDEMATEL, this study is composed of a two-stage methodology. It is the first attempt in the literature that determines the most important criteria and their interactions in ED ergonomic design based on expert's assessments and FDEMATEL's causal and effect diagrams.

Conclusion

In this study, a two-stage methodology is proposed for the evaluation of ED ergonomic design. In the first stage of this methodology, an adapted check-list was implemented to evaluate ED ergonomic design in a training and research hospital ED located in Istanbul, Turkey with 137 items on six main headings with the opinions of medical staff. In the second stage, a fuzzy decision-making method called FDEMATEL is applied to determine casual and effect criteria for the observed hospital ED through a decreased number of items assessed in the first stage. Considering the interdependence among items, FDEMATEL method reflects the causal and effect relationships among criteria.

In conclusion of the first stage of the methodology, several suggestions are offered that the ED needs interventions on accessibility, patient and personnel accommodations and personnel privacy. The findings of the second stage show what the most important

casual and effect criteria in the categories of accessibility, physical spaces, structures and equipment, patient and personnel accommodation, and patient and personnel privacy are. Moreover, a four-zone structure on the results of FDEMATEL makes it easy to understand the most serious criteria affecting ED ergonomic design, their interactions with other criteria and their priority levels in suggesting possible corrective actions. The obtained results revealed that the most important causal criteria regarding accessibility concern determination of all door widths in the ED at least 1.5 m and direct connection of the entrances and the waiting area with triage nurse/doctor. In the category of physical spaces, structures & equipment, sufficiency of the number of beds for annual patient demand has been appeared as the most impacted criterion on the entire ED ergonomic design process. Besides, obtained results are found so close to the results of the guidelines, including procedures and policies regarding the use and design of emergency departments in some developed countries as the USA and Australia. The methodology and application results of this study can be adapted to any emergency departments from other countries.

The study has an important limitation. The number of criteria assessed through the FDEMATEL stage exceeds twenty in both accessibility and physical spaces, structures & equipment criteria. For this reason, the number of pair-wise questions that experts needed to respond has increased considerably. It may adversely affect the willingness of experts and the accuracy of their responses. Therefore, more decreased criteria pool can be considered for future studies.

Author Statements

Funding: None.

Competing interests: None declared.

Ethical approval: Not required.

APPENDIX. Evaluation criteria for ED ergonomic design

Criteria	Definition of the criteria
A1	Location of the ED within the main hospital building
A4	Availability of particular parking areas reserved for on call physicians close to the entrance
A5	Visibility of entrance at the ED
A6	Availability of separate entrances for ambulance and walk-in patients
A7	Visibility of entrance for walk-in patients
A8	Visibility of triage room and location in the path of walk-in patients' entrance
A10	Following of a line system
A12	Availability of the entrances and the waiting area in direct observation area of the triage nurse/doctor
A14	Availability of a resuscitation area
A15	Availability of the critical care area in direct access of the treatment area, waiting room and the reception
A17	Accessibility of the ICU from the ED
A19	Availability of dedicated elevators in case facilities are not in the same level as the ED
A20	Suitability of corridors for wheelchairs and stretchers
A22	Closeness of the orthopedic examination and casting rooms to the radiology suit
A23	Availability of direct access to the imaging suit, and the resuscitation room from the treatment area
A24	Accessibility of the ED lab from all treatment areas
A25	Availability of a different window for delivery of emergent lab samples at the laboratory
A29	Readiness and accessibility of the equipment in the nursing station to the nursing staff
A35	Determination of all door widths in the ED at least 1.5 m
A36	Availability of direct access of the reception and waiting areas to the hospital for outpatient referral
PSE1	Earthquake-resistance of the ED building
PSE2	Sufficiency of the total area of the ED for annual patient demand
PSE3	Sufficiency of the number of beds for annual patient demand
PSE6	Sufficiency of the surge capacity for a possible crisis or disaster
PSE8	Placing of the electrical panels outside the ED entrance
PSE9	Availability of a triage room
PSE12	Availability of an examination room for pediatric patients
PSE13	Availability of an isolated OB-GYN treatment room
PSE14	Availability of an orthopedics and casting room in the ED
PSE15	Availability of a procedure or minor operating room designated in the ED
PSE16	Availability of a room for the public staff supervising the ED
PSE17	Adequateness of the officer room in terms of sound, lighting etc.
PSE18	Location of the security stationed in the ED at the entrance
PSE19	Availability of a treatment area for walk-in patients
PSE20	Availability of a pharmacy near the ED
PSE25	Availability of separate examination rooms for the inpatients
PSE26	Availability of enough equipment in the examination rooms reserved for the inpatient patients
PSE29	Availability of a designated waiting area
PSE30	Availability of a head nurse room in the ED
PSE31	Availability of a burn care room in the ED
PSE33	Availability of a designated administration area away from the treatment areas
PSE34	Availability of a silent or counseling room designated within the ED
PSE35	Isolation of the counseling room acoustically from the treatment areas
PSE36	Availability of a morgue
PSE37	Height of gurney as 75 cm
PSE39	Availability of outpatient care areas as 0.5 to 2.3 m2 areas
PSE42	Setting the height of the nursing station counter at least 1m
PSE43	Availability of a generator for the ED
PSE45	Availability of separating wooden panels from ceiling to the floor available in the treatment area
PSE46	Be removed of the panels to increase the available treatment area
PSE47	Sufficiency of lighting in the examination and treatment areas
PSE49	Availability of a central O2 supplying system with outlets available at least for every high-acuity bed
PSE51	Availability of access to multiple phone lines in the nurses' station
PSE52	Availability of access to the internet in the ED
PSE53	Availability of a telecom system installed in the ED
PSE56	Availability of a fire alarm system installed in different areas of the ED
PSE57	Availability of fire extinguishers in all ED spaces
PSE58	Availability of enough electrical outlets in each treatment area
PSE59	Placement of the electrical outlets properly at a height of 36 cm
PSE62	Be equipped of the lab for routine lab tests
PSE64	Availability of proper storages for clean and dirty equipment within the ED
PATA2	Availability of assistance staff at reception for guiding patients
PATA3	Availability of an air-conditioning system in the waiting area
PATA7	Availability of an air-conditioning system in the treatment areas
PERA1	Availability of a dedicated area for viewing imaging results
PERA2	Availability of a separate physician resting area
PERA3	Adequateness of the heating and cooling systems of the rest area
PERA4	Availability of private lockers reserved for staff in the resting area
PERA8	Be equipped of the resting area with communication facilities such as phone and internet
PERA11	Sufficiency of lighting in the resting area
PATP1	Securability of the patients' visual, auditory, and olfactory privacy within each treatment area
PATP2	Separateness of the path to the elevator from the main crowded areas
PATP3	Availability of a designated area for storing patient files away from another patients' reach
PATP4	Availability of a designated area for confidential patient-doctor interactions

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