Chapter 1

A Cognitive Model for Emergency Management in Hospitals: Proposal of a Triage Severity Index

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Additional information is available at the end of the chapter

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Abstract

Hospitals play a critical role in providing communities with essential medical care during all types of disasters. Any accident that damages systems or people often requires a *multi-functional* response and recovery effort. Without an appropriate emergency planning, it is impossible to provide good care during a critical event. In fact, during a disaster condition, the same "critical" severity could occur for patients. Thus, it is essential to *categorize* and to *prioritize* patients with the aim to provide the best care to as many patients as possible with the available resources. Triage assesses the severity of patients to give an order of medical visit. The purpose of the present research is to develop a *hybrid algorithm*, called triage algorithm for emergency management (TAEM). The goal is twofold: First, to assess the priority of treatment; second, to assess in which hospital it is preferable to conduct patients. The triage models proposed in the literature are qualitative. The proposed algorithm aims to cover this gap. The model presented exceeds the limits of literature by developing a quantitative algorithm, which performs a numerical index. The hybrid model is implemented in a real scenario concerning the accident management in a petrochemical plant.

Keywords: emergency management, triage, hospital location, petrochemical plant, safety

1. Introduction

The continuous evolution of production processes has resulted in increased effectiveness and process efficiency. On the other hand, however, the systems are much more complex and difficult to manage [1, 2]. For this reason, to handle any emergencies that are created, it is necessary to develop a proper plan to respond to emergencies. The emergency can be caused: by a fault of a system, by a human error, or by natural factors [3]. The National Governor's Association designed four phases of disaster: (1) *mitigation*, (2) *preparedness*, (3) *response*, and (4) *recovery*. Each phase has particular needs, requires distinct tools, strategies, and resources and faces different challenges [4]. One of the most important phases is the *response phase* that addresses immediate threats presented by the disaster, including saving lives, meeting humanitarian needs, and starting of resource distribution. In this phase, a particular process involves the *triage efforts* that aim to assess and deal with the most pressing emergency issues. This period is often marked by some level of chaos, a period of time that cannot be defined a priori, since it depends on the nature of the disaster and the extent of damage [5]. It is obvious that it is necessary to assess the conditions of the patients during the response phase and to reduce waiting time for medical services and transport [6]. A timely and quickly identification of patients with urgent, life-threatening conditions is needed [7]. Accurate triage is the "key" to the efficient operation of an emergency department (ED) to determine the severity of illness or injury for each patient who enters the ED [8]. The term triage comes from the French verb trier, meaning to separate, sift, or select. A system for the classification of patients was first used by Baron Dominique Jean Larry, a chief surgeon in Napoleon's army [9]. Originally, the concepts of triage were primarily focused on mass casualty situations. Many of the original concepts of triage remain valid today in mass casualty and warfare situations. Triage is a dynamic and complex decision-making process [10]. In general, patients should have a triage assessment within 10 min of arrival in the ED in order to ensure their proper medical management. However, it is not always possible to achieve this purpose. Some weaknesses characterize the classic triage models. It is worthy to underline that several methods of triage exist for evaluating the condition of a patient and treat him/her accordingly. The triage methods most commonly used are *Australasian Triage* scale (ATS), the *Canadian Triage and Acuity Scale (CTAS), Manchester Triage System (MTS)*, and *Emergency Severity Index* (ESI) [11]. As highlighted by Lerner *et al*. [12], each protocol may be very different from another in terms of methods of care, treatments, and strategies. Furthermore, the medical staff has to analyze several factors to decide in which hospital the patient has to be admitted but qualitatively [13]. The *effective triage* is based on the knowledge, skills, and attitudes of the triage staff. However, despite this knowledge, it is evident that the use of one triage algorithm is limited [14]. Thus, the definition of an integrated triage system is an important research priority. This study aims to cover this research gap. The aim of the research is twofold. First, the model provides a hybrid algorithm to define the priority of treatment. Second, a multi-criteria model is developed to evaluate the most suitable hospital where patients can be admitted. The hybrid algorithm exceeds the literature limits, developing a numerical model for the evaluation of triage hospital. The study helps to expand the knowledge on emergency management and also develops a standard algorithm that can be used in emergency situations, to evaluate the patient's condition, and choose the most suitable hospital. The model can be used in different conditions, both for major emergencies and in emergency conditions, medium-low. In the present work, the model is applied during an emergency simulation in a petrochemical company.

The chapter is organized as follows. Section 2 presents an overview of the four triage models most used in the world. Section 3 describes the proposed hybrid algorithm. Section 4 presents a real case study. Finally, Section 5 summarizes conclusions and future developments.

2. The four principal triage models

2.1. The Australasian Triage scale (ATS)

The Australasian Triage scale (ATS) was developed in the 1994 in an Australasian emergency department [15, 16]. All patients presenting to an emergency department should be assessed by a nurse or a doctor. The triage assessment generally goes on no more than 2–5 min. Patients who are waiting are processed again, to see if their condition deteriorated. The nurse or the doctor may also initiate the assessment or initial management, according to organizational guidelines. **Table 1** shows the Australasian Triage scale. Each category is rated with a number between 1 and 5 and a color scale. The second column represents the maximum time within which it is necessary to cure the patient. The third column describes the reference category, and finally the fourth column describes the patient's symptoms.

Table 2 incorporates the classification of **Table 1** and shows the performance indicator threshold. The indicator threshold represents the percentage of patients assigned ATS categories, who commence assessment and treatment within the relevant waiting time from their time of arrival.

2.2. The Canadian Triage and Acuity Scale (CTAS)

The Canadian Triage and Acuity Scale (CTAS) is based on the ATS and was developed in the 1990s in Canada [10]. In the CTAS, a list of clinical symptoms is used to determine the triage level. CTAS defines a five-level scale with level 1, representing the worst case and level 5, representing the patient with less risk. The CTAS establishes a relationship between patient's presenting symptoms and the potential causes. Other factors called modifiers refine the classification [17–19] as follows:

1. *Resuscitation*. Conditions expecting the risk of death. These are patients that have their heart arrested, or are heart pre-arrest, or heart post-arrest. Their treatment is often started in the pre-hospital setting and further aggressive or resuscitative efforts are required immediately upon arrival at the emergency department;

Category	Response	Category description	Clinical descriptors
1	Immediate simultaneous assessment and treatment	Immediately life-threatening	Cardiac arrest, respiratory arrest, immediate risk to airway
2	Assessment and treatment within 10 min	Imminently life-threatening	Airway risk, severe respiratory distress, circulatory compromise
3	Assessment and treatment within 30 min	Potentially life-threatening	Severe hypertension, moderate severe blood loss, vomiting
4	Assessment and treatment within 60 min	Potentially serious or urgency situation	Mild hemorrhage, vomiting, eye inflammation, minor limb trauma
5	Assessment and treatment within 120 min	Less urgent	Minimal pain, low risk, minor symptoms, minor wounds

Table 1. Australasian Triage scale.

ATS scale	Treatment acuity (maximum waiting time for medical assessment and treatment)	Performance indicator threshold
1	Immediate	100%
2	10 min	80%
3	30 min	75%
4	60 min	70%
5	120 min	70%

Table 2. ATS performance indicator threshold.

2. *Emergent*. The patient risks his/her life because of serious injuries and requires quick cures. The doctor must act to stabilize the vital conditions;
3. *Urgent*. The patient is not life-threatening, but his/her condition could worsen. The vital signs are normal, but it is necessary to act soon to avoid being impaired;
4. *Less urgent*. The patient has no serious injuries. His condition depended on the strain, age, and little pain. The medical examination is not required;
5. *Non-urgent*. The patient's condition is not pejorative. They may be due to a chronic problem. Then, the patient can go home if the hospital resources do not allow the visit.

The CTAS is developed in several steps (**Figure 1**):

- **Quick look:** The first step of the CTAS analysis. When the symptom is obvious it is simple to evaluate the level;
- **Presenting complaint:** The second step is to analyze the symptoms. As with the "Quick Look," the symptom should only be used to evaluate if the patient is into CTAS Level 1;
- **First-/second-order modifier**: In many cases, the "Quick Look" is not sufficient to analyze the complaint. To refine the assessment, modifiers are analyzed. This makes it possible to better assess the patient.

Figure 1 describes the CTAS analysis step to assess the patient's condition.

2.3. The Manchester Triage System (MTS)

The Manchester Triage System (MTS) is used in emergency departments in Great Britain [20, 21]. The MTS model has a scale with five levels (**Table 3**). The time is relative to a maximum time to response. **Table 3** shows the Manchester Triage scale. Each category is rated with a number between 1 and 5 and a color scale. The second column describes the name of the assessment. The third column represents the maximum time within which it is necessary to cure the patient. The fourth column describes the patient's symptoms.

The MTS uses 52 diagrams which represent symptoms, with which to evaluate the patients. When a patient reports symptoms, the nurse examines his/her situation and he/she determines

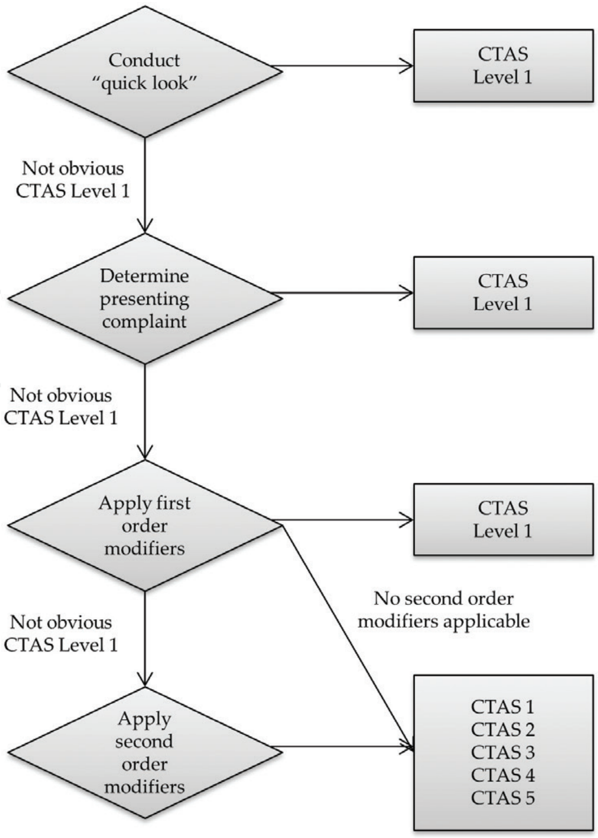

Figure 1. CTAS approach.

the treatment priority according to the triage scale. It utilizes a series of flow charts that lead the triage nurse to a logical choice of triage category also using a five-point scale [22]. The MTS model is a powerful tool to evaluate patients. Its discriminatory power is not equal for medical and surgical specialties, which may be linked to the nature of inbuilt discriminators [23].

2.4. The Emergency Severity Index (ESI)

The Emergency Severity Index (ESI) is a triage algorithm that was developed in the USA in the late 1990s [24]. The priority depends on the patient's severity and the necessary resources. Initially, the nurse analyzes the vital signs. If the patient is not in critical conditions (level 1 or 2), the decision maker has to evaluate the expected resource necessary to determine a triage level (level 3, 4, or 5). Algorithms are frequently used in emergency care. The ESI model is based on a four-point decision. **Figure 2** shows the four decision points reduced to four key questions [25]:

A. Does this patient require immediate lifesaving intervention?

B. Is this a patient who shouldn't wait?

C. How many resources will this patient need?

D. What are the patient's vital signs?

Category	Name	Time (min)	Symptoms
1	Immediate	0	Airway compromise Inadequate breathing Shock
2	Very urgent	10	Severe pain Cardiac pain Abnormal pulse
3	Urgent	60	Pleuritic pain Persistent vomiting Significant cardiac history
4	Standard	120	Vomiting Recent mild pain Recent problem
5	Non-urgent	240	Vomiting Recent mild pain Recent problem

Table 3. Manchester Triage scale.

Figure 2 represents the structure of the ESI model. The decision responds to certain questions and based on the answers you associate a different assessment.

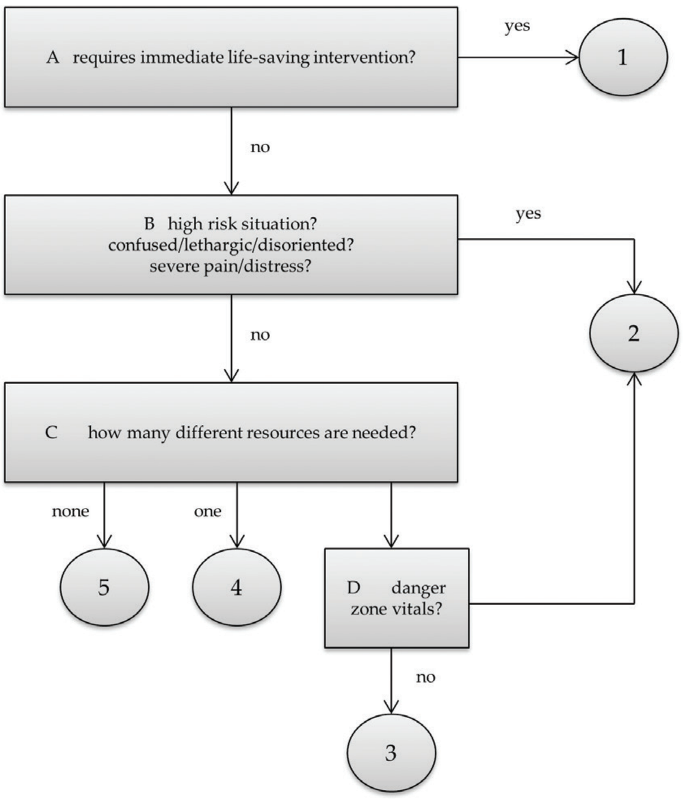

Figure 2. ESI approach.

Table 4 describes the action considered lifesaving and those that are not, for the purposes of ESI assessment level 1 [26]. Classifications are present in the first column, the second column describes the interventions that save lives, while in the last column, there are interventions that do not save lives.

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	Lifesaving	**Not lifesaving**
Airway/breathing	BVM ventilation	
	Intubation	Oxygen administration
	Surgical airway	Nasal cannula
	Emergent CPAP	Non-rebreather
	Emergent BiPAP	
Electrical therapy	Debrifillation	
	Emergent cardioversion	Cardiac monitor
	External pacing	
Procedures	Chest-needle decompression	ECG
	Pericardiocentesis	Laboratory tests
	Open thoracotomy	Ultrasound
	Intraoseous access	FAST
Hemodynamics	Significant fluid resuscitation	Access
	Blood administration	Saline lock
	Control of major bleeding	
Medications	Naxolone	ASA
	D50	Antibiotics
	Dopamine	Nitroglycerin
	Atropine	Heparin
	Adenocard	Pain medications

Table 4. Lifesaving interventions.

In the first point (A), the decision maker assesses whether the patient needs immediate care. In this case, the patient is valued as level 1; otherwise, it goes to decision point B. The triage nurse verifies if the patient is at high risk. The patient's age and the past medical history influence the triage nurse's determination of risk. This patient has a potential condition of a threat to his/her life. The nurse recognizes a patient at high risk, when he/she realizes that the vital signs may get worse. The triage nurse assesses this patient as level 2 because the symptoms are dangerous. The decision maker should ask, "*How many different resources do you think this patient is going to consume in order for the physician to reach a disposition decision*?" The patient can be discharged, leaving the hospital or transferred to another hospital. Nurses assess the need for resources for each patient, comparing it to the capacity of the hospital. The nurse again examines the patient's symptoms. If the symptoms have worsened, then the patient is evaluated for level 2, or level 3. If the patient needs few resources, he/she is estimated level 4; otherwise it is evaluated level 5. This is decision point D. The limit of the literature about the hospital triage is the qualitative approach used.

3. The rationale: TAEM algorithm

Studies of the reliability and validity of triage models underline that existing models are very qualitative [27–29]. However, it is important to standardize a model and to measure the degree with which the measured acuity level reflects the patient's true acuity at the time of triage. Thus, the proposed model developed in our research aims to be "quantitative." It uses numerical indicators to measure the patient's acuity level. The hybrid model evaluates the condition of patients (triage) and the hospital to conduct the patients; it mixes qualitative aspects (defined in the literature) with quantitative/numerical elements. Emergency management is divided into three phases:

1. Phase#1: Emergency start;
2. Phase#2: Triage algorithm for emergency management (TAEM);
3. Phase#3: Rating hospitals.

Figure 3 represents a scheme of the new hybrid model that we have developed, starting from the four previous models analyzed. Classical approach requires that the decision maker assesses different questions before to achieve at an evaluation of the patient. Our model allows a quantitative numerical evaluation of the patient's condition and better hospital choice. TAEM algorithm is proposed to be used by medical staff during an emergency management situation. The model can be used in different and more or less serious emergency conditions.

The subsequent text provides detailed description of the TAEM algorithm.

3.1. Phase#1: emergency start

The present phase aims to measure emergency preparedness in order to predict the likely performance of emergency response systems. This is a critical phase to define actions to be implemented. When an accident occurs, an emergency condition is manifested. Depending on the type of emergency, the internal emergency plan is triggered. The internal emergency plan provides implementing all the preventive and protective systems to prevent the emergency situation from becoming worse. If the emergency is serious, the external aid has to be alarmed (medical personnel, policeman, and firemen). Thus, it is essential to define the number of relief efforts and the type.

3.2. Phase#2: triage algorithm for emergency management (TAEM)

The TAEM model identifies five levels of emergency. The basic structure is acquired by ESI model. However, different from ESI model, the TAEM algorithm associates a score to each element, obtaining a total coefficient (numerical approach). The colors are taken from the Manchester methodology and the operation times are taken by the Australasian methodology. **Figure 4** shows the methodological flowchart for the TAEM algorithm. It is a part of the complete pattern shown in **Figure 3**. In particular, the model that we developed involves the use of an algorithm to identify the patient's classification.

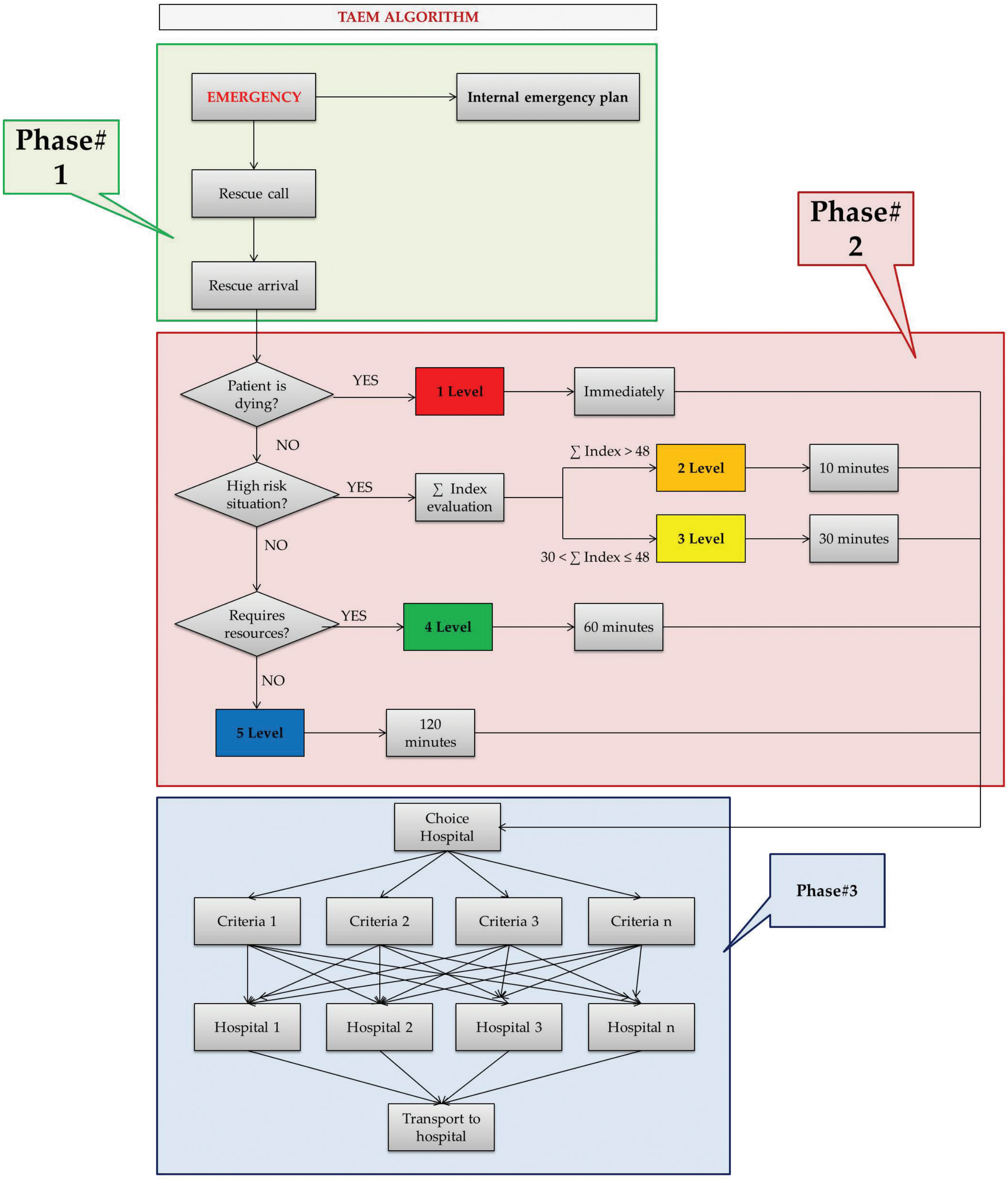

Figure 3. Emergency management research flowchart.

Patient assessment is carried out by the nurse through three different steps (**Figure 5**), which are described below. The model that we have developed considers the structure of the ESI model, the MTS model colors, the response times described by the ATS method, and the inclusion of a quantitative numerical approach

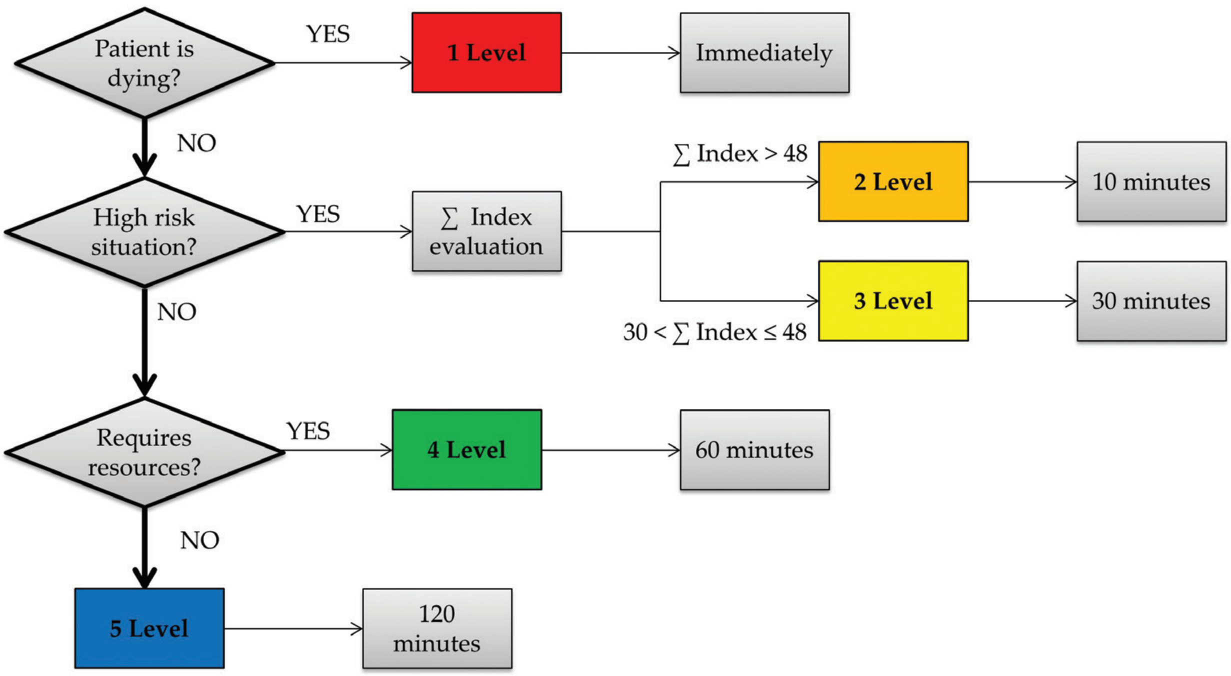

Figure 4. TAEM approach.

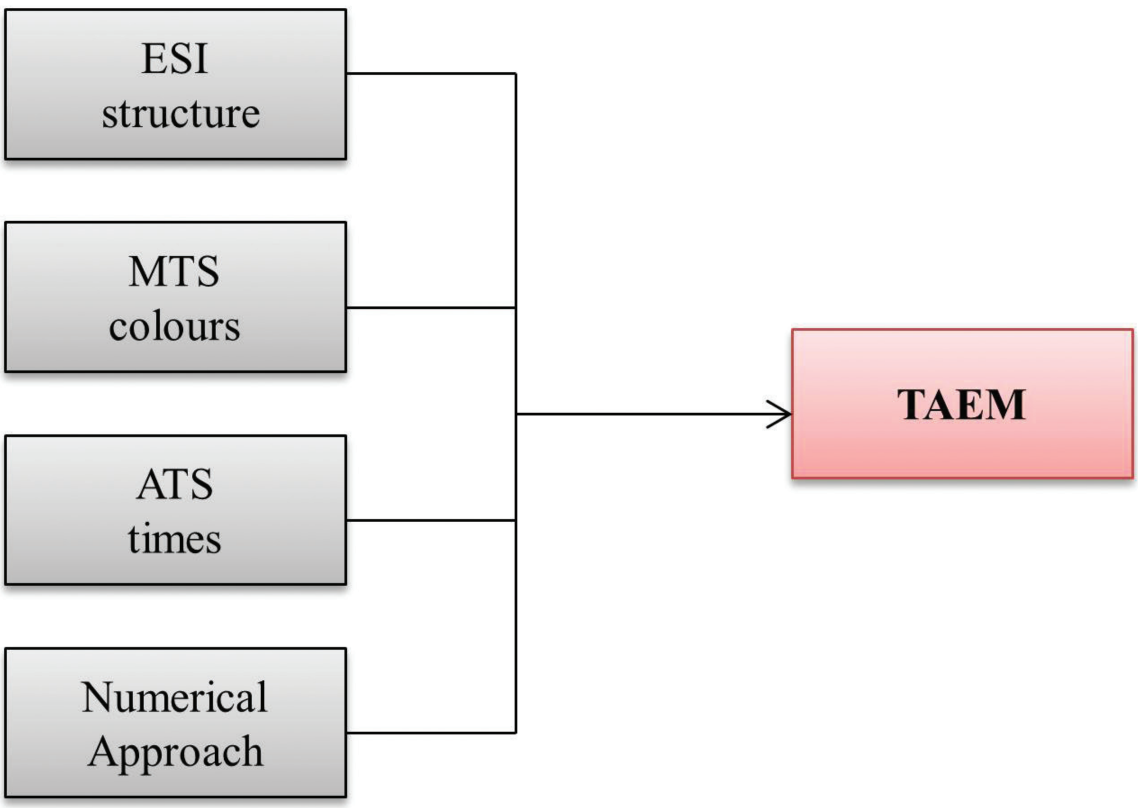

Figure 5. TAEM algorithm flowchart.

In addition to the development of TAEM structure, we have developed a new standardization to identify the classification of patients. **Table 5** summarizes the triage scale of the TAEM algorithm. Each category is rated with a number between 1 and 5 and a color scale. The second column describes the name of the assessment. The third column represents the maximum time within which it is necessary to cure the patient. The fourth column describes the patient's symptoms.

If one of the main vital functions is not active, then the patient is assessed level 1. **Table 6** shows the vital functions analyzed in the death-danger analysis, to assess the patient level 1. The symptoms of a patient in critical condition are as follows:

- Cardiac arrest;
- Respiratory arrest;
- Severe respiratory distress;
- Child who is unresponsive to pain;
- Hypoglycemic with a change in mental status;
- Severe bradycardia;
- Critically injured, patient unresponsive.

If the patient has none of these symptoms, it is not evaluated for level 1. The nurse must decide whether the patient is level 2. We have developed a numerical algorithm that allows evaluating an index for the patient severity. The algorithm has been represented in **Table 6**.

For the assessment, it considers various factors, and it associates with each of these factors increasing a value according to severity. Each factor has a predetermined weight, depending on the importance of the factor. The values shown in the table have been proposed by analyzing the literature on triage procedures.

For each factor, the index (Eq. (1)) is calculated. Then, add up the indexes (Eq. (2))

Category	Name	Time (min)	Symptoms
1	Immediate	0	Airway compromise Inadequate breathing Shock
2	Very urgent	10	Severe pain Cardiac pain Abnormal pulse
3	Urgent	30	Pleuritic pain Persistent vomiting Significant cardiac history
4	Standard	60	Vomiting Recent mild pain Recent problem
5	Non-urgent	120	Vomiting Recent mild pain Recent problem

Table 5. TAEM scale.

Factors	Severity			Weight			Index
	1	**2**	**3**	**0.5**	**1.5**	**5**	
Level of consciousness					x		
Heart beat						x	
Breathing						x	
Pain				x			
Panic				x			
Injury						x	
Age					x		
Pressure level					x		
Past medicals				x			
							∑ index

Table 6. Index triage.

$$Index = Severity \times Weight \quad (1)$$

$$\sum Index = \sum (Severity \times Weight) \quad (2)$$

The minimum value of $\sum$ Index is 21, then the maximum value of $\sum$ Index is 63. In detail,

- If $\sum$ Index > 48, the patient is evaluated level 2.
- If 30 < $\sum$ Index ≤ 48, the patient is evaluated level 3.
- If the patient is not level 2 or 3 and is not an urgent situation, then the nurse should assess the resources available to define the triage level.

The triage nurse should ask, "*How many different resources do you think this patient is going to consume in order for the physician to reach a disposition decision*?" The nurse to answer these questions must take into account the routine practice in the particular emergency department. The resources that are considered by the nurse are as follows:

- Blood laboratories;
- Urine laboratories;
- Electrocardiogram (ECG);
- X-rays;
- Computed tomography-magnetic resonance imaging (CT-MRI) ultrasound angiography;
- Fluids hydration;
- Specialty consultation;
- Sedation.

If the patient requires different resources, it is catalogued level 4, otherwise level 5.

3.3. Phase#3: rating hospitals

The present phase aims to determine the best choice of the hospital, according to predetermined criteria. For the hospital evaluation, it has adopted a multi-criteria algorithm, which takes into account the criteria listed in **Table 7**. For each criterion, a weight (*W*) is associated, and for every hospital, an evaluation (*E*) is associated. The product $W \times E$ greater determines the optimal solution (**Table 7**). The sum of the weight values is 100. The evaluation value is between 0 and 90.

		Evaluation (*E*)				$W \times E$			
Criteria	**Weight criteria (*W*)**	**Hospital 1**	**Hospital 2**	**Hospital 3**	**Hospital n**	**Hospital 1**	**Hospital 2**	**Hospital 3**	**Hospital n**
Departments									
Distance (km)									
Secondary road									
Beds									
Transport									
Tot									

Table 7. Quantitative model.

4. The experimental scenario

The case study is related to a management of emergency, after an accident, which occurred in a petrochemical company plant. The emergency is related to the explosion of a hydrogen sulfide tank. **Figure 6** shows the petrochemical plant layout and the hydrogen sulfide tank under study. Immediately after the explosion, the foreman activates the emergency management practices. During the explosion, one operator was located near the tank and he was affected by the fire. The manager called health aid.

The medical staff checked the vital functions to see if the two operators were dying. The evaluation was negative. So, the medical staff verified the other functions (**Table 8**) to assess the patient's condition. The severity index was 32; this means that the patient was level 3 and must be taken care of within 30 min. It is important to note that the values reported in **Table 8** are related to a real simulation of an incident occurred in the petrochemical company.

In 30 min it would be possible to reach four different hospitals. Thus, it was necessary to evaluate the best hospital in which to carry the injured. **Table 9** shows the criteria adopted

Figure 6. Chemical plant and hydrogen sulfide tank.

Factors	Severity			Weight			Index
	1	**2**	**3**	**0.5**	**1.5**	**5**	
Level of consciousness		x			x		3
Heart beat	x					x	5
Breathing	x					x	5
Pain	x			x			0.5
Panic		x		x			1
Injury		x				x	10
Age		x			x		3
Pressure level		x			x		3
Past medicals	x			x			1.5
						∑ index	**32**

Table 8. Triage index.

	Hospital 1	Hospital 2	Hospital 3	Hospital 4
Departments	Resuscitation surgery orthopedics emergency room dermatology	Resuscitation surgery emergency room dermatology	Resuscitation orthopedics emergency room dermatology	Resuscitation orthopedics emergency room dermatology
Distance (km)	3.4	4.5	6	6.8
Secondary road	2	3	4	4
Beds	370	165	221	234
Transport	3	1	2	3

Table 9. Criteria values.

for the choice of the hospital. Each criterion is given a weight (*W*) and each criterion on the hospital is given one vote (**Table 10**). The numbers shown in **Table 9** are real values, relative to the nearest hospital's petrochemical plant.

		Evaluation *(E)*				*W* × *E*			
Criteria	**Weight *(W)***	**Hospital 1**	**Hospital 2**	**Hospital 3**	**Hospital 4**	**H 1**	**H2**	**H3**	**H4**
Departments	24	90	72	72	72	2160	1728	1728	1728
Distance (km)	24	90	80	75	70	2160	1920	1800	1680
Secondary road	19	45	68	90	90	855	1292	1710	1710
Beds	19	90	40	54	57	1710	760	1026	1083
Transport	14	90	30	60	90	1260	420	840	1260
Total						**8145**	**6120**	**7104**	**7461**

Table 10. Hospital choice.

Table 10 calculates through the multi-criteria approach to the importance of each hospital according to different criteria presented in **Table 9**. **Table 10** shows that the best result is hospital 1, where the patient is cured.

5. Conclusion

Emergency management plays an increasingly important role, in order to safeguard the human life. The present research proposed a hybrid model for the emergency management. The model is completely innovative and exceeds the limits of the literature. Starting from triage models known in literature, we have developed a hybrid algorithm (TAEM algorithm) for the evaluation of the patients. TAEM algorithm aims to evaluate both qualitative and quantitative factors that may influence the final decision in the rescue of patients. Thus, a quantitative index is defined to achieve this goal. In particular, the algorithm allows defining a patient's subjective assessment analyzing the subjective aspects that are translated into numbers. In this way, it is possible to define an index that represents the patient assessment. Furthermore, it is possible to define the severity of the patient and treat him/her accordingly. In addition, the TAEM algorithm aims to complete the emergency management through a multi-criteria approach in order to define in which hospital it is proper to conduct the injured. Different criteria in different hospitals, associating a numerical value, have been evaluated. The hospital that has a higher rating is the best choice. This model allows avoiding long lines and long waits in emergency rooms in case of serious emergency situations in which there are many injured. The validity of the model is demonstrated applying it in a real case study. The model presented assumes an important role in research because it exceeds the qualitative limits of existing triage models; it is also useful for practical purposes, during emergency situations.

The future developments of the work aim to develop a software tool to implement the TAEM algorithm. The final result will be an application that can support various types of emergency triage at the point of care using mobile devices. The system will be designed for use in the emergency department of a hospital and to aid physicians in disposition decisions. The system will facilitate patient-centered service and timely, high-quality patient management.

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