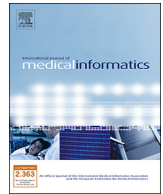




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## Decision support system for triage management: A hybrid approach using rule-based reasoning and fuzzy logic



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## ABSTRACT

**Objectives:** Fast and accurate patient triage for the response process is a critical first step in emergency situations. This process is often performed using a paper-based mode, which intensifies workload and difficulty, wastes time, and is at risk of human errors. This study aims to design and evaluate a decision support system (DSS) to determine the triage level.

**Methods:** A combination of the Rule-Based Reasoning (RBR) and Fuzzy Logic Classifier (FLC) approaches were used to predict the triage level of patients according to the triage specialist's opinions and Emergency Severity Index (ESI) guidelines. RBR was applied for modeling the first to fourth decision points of the ESI algorithm. The data relating to vital signs were used as input variables and modeled using fuzzy logic. Narrative knowledge was converted to If-Then rules using XML. The extracted rules were then used to create the rule-based engine and predict the triage levels.

**Results:** Fourteen RBR and 27 fuzzy rules were extracted and used in the rule-based engine. The performance of the system was evaluated using three methods with real triage data. The accuracy of the clinical decision support systems (CDSSs; in the test data) was 99.44%. The evaluation of the error rate revealed that, when using the traditional method, 13.4% of the patients were miss-triaged, which is statically significant. The completeness of the documentation also improved from 76.72% to 98.5%.

**Conclusions:** Designed system was effective in determining the triage level of patients and it proved helpful for nurses as they made decisions, generated nursing diagnoses based on triage guidelines. The hybrid approach can reduce triage misdiagnosis in a highly accurate manner and improve the triage outcomes.

### 1. Introduction

Hospital emergency departments (EDs) attempt to provide a timely service for clients who do not plan ahead. Compared with other health centers, the ED is a unique environment with limited resources and a wide range of patients in need of care [1]; it is considered one of the most important departments among all health care systems. However, as overcrowding in EDs threatens the health of patients, triage is performed as an effective solution to tackle this problem [2].

The triage process is the first critical step in giving care to the clients of EDs by prioritizing patients at different triage levels based on the severity of their clinical conditions. Triage servers prioritize patients for urgent care based on a short initial clinical assessment usually performed by emergency nurses. In some hospitals, in addition to treatment priority, triage determines the visiting location of patients; for

example, interior room, trauma room, cardio-pulmonary resuscitation room, or an outpatient room [3,4]. In emergency situations, fast and accurate patient triage for the response process is critical in the co-ordination of medical services with hospital sources since there is a high mortality rate. In many hospitals, the triage process is often performed using a paper-based mode; however, this method intensifies workload and difficulty, wastes time, and is open to human errors [5,6].

Triage decision-making is an important task that should be conducted for each patient referring to the ED. However, the characteristics of the triage server, such as his or her evaluation and experience, the patient's clinical history, and the availability of necessary resources all contribute to the complexity of the triage process. The most important task to accomplish in the ED is enabling the available physician to quickly and accurately recognize the patient's medical needs to avoid costs of unnecessary surgeries and other medical treatments [7]. For

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more accurate recognition, some standardized classification systems were developed for the triage process. For example, the Emergency Severity Index (ESI) is a standard instrument for classifying patients based on the estimated acuity and resource consumption [2]. Research findings have shown that the ESI triage method is regarded as one of the best ways to prioritize patients in many countries, including Iran, and that this method is considered a valid and accurate system for improving the access to medical care that is used in the ED of Iranian hospitals [2].

Levels 1 and 2 of the ESI have been respectively assigned for emergency and urgent situations requiring the immediate assessment and intervention by service providers to prevent death. Clients at triage levels 3, 4, and 5 are less urgent, and they are classified based on the prediction of required resources. Version 4 of the ESI triage system, which has been approved by the Agency for Healthcare Research and Quality (AHRQ), is derived from evidence-based research [8,9].

Nurses routinely perform the triage process since they have received extensive practical and academic training on the employment of the ESI rules and the assessment of patient acuity. In such situations, the occurrence of miss-triage arises in the form of under-triage or over-triage, which might result in negative outcomes for patients waiting to receive care [10].

However, the challenge of increased demand against the reduced quality of the emergency care system has led hospital administrators to attempt to devise an efficient solution for offering timely and high quality services. In the healthcare sector, the use of information systems is undeniably necessary to ensure an efficient, effective, and quality service and employee and client satisfaction. Today, most countries have implemented modern and emerging technologies in hospital EDs. Clinical decision support systems (CDSSs) can provide a suitable solution to the aforementioned challenges [11,12]. CDSSs can also assist with information management to support clinicians' decision-making abilities, reduce workload, and improve clinical workflows. When they are well designed and implemented, CDSSs have the potential to improve health care quality, increase efficiency, and reduce health care costs [13].

The correct realization of emergency patients' triage level is considered a serious decision-making challenge in the conduct of the triage process. In this regard, a high number of studies undertaken in this domain have reiterated the positive impact of CDSSs because error minimization is among the main advantages of this system [14,15]. However, in practice, CDSSs are not adequately used in clinical centers and very few successful uses of this system have been reported [16]. Nevertheless, it is difficult for a researcher or expert in this area to convince medical practitioners to bridge the gap between physicians and the CDSS. In an evidence-based mode, experts should make physicians aware of the suitability and effectiveness of this powerful tool for improving the care-giving services and patient conditions, and reducing costs [17].

Clinical triage practices and guidelines have suggested criteria for the correct diagnosis of the triage levels. These systems are accurate tools and approaches for implementing the guidelines and can boost compliance with clinical practices [18]. Hence, CDSSs are implemented mostly based on clinical solutions and the expert opinion of those integrating these solutions. Although clinical solutions are beneficial for healthcare provision and health outcomes, they suffer from pitfalls such as vagueness and ambiguity. Fuzzy logic can obviate such ambiguity and vagueness in DSSs [15]. The main advantage of a fuzzy logic rule-based classifier is its effectiveness in its predictive power of diagnostic accuracy [19].

Another advantage of data management and DSSs is their ability to improve the quality of the documentation of medical records, which is a legal and professional requirement. In addition to the certainty about the care given to patients and facilitating the exchange of patient information for healthcare team members, quality of documentation measure can be used for research, qualitative assessments, and forensic

purposes. However, the status and quality of the documentation have not currently reached desirable levels in Iran's hospital EDs [20]. Because employing computer systems increases the quality of documentation, allows access to up-to-date information, enhances completeness, and diminishes workload [21], assessing the quality of the information being entered into electronic systems is of paramount importance.

Accordingly, this study aims to design and assess a DSS that not only determines patients' triage levels but can also be used as a patient data management system and provide a diagnosis module, which employs combined decision methods. We also assess the accuracy of the diagnoses and the error reduction rate.

## 2. Methods

Using a hybrid approach, we developed a CDSS based on the ESI triage guidelines. To achieve this, we first observed the triage workflow in some EDs. We administered surveys and conducted interviews with four clinicians (emergency medicine experts and triage nurses) and three technical experts who were members of the CDSS team and were responsible for implementing the system on embedding ESI rules in a clinical environment. To examine the current efficiency of paper-based triage, team experts carried out a focus group discussion that was facilitated by a health information technology expert. Unstructured interviews were held with the participants to determine the major weak and strong points of the existing system and to survey the flow of triage and the available strategies and guidelines. The participants were asked about their perceptions, opinions, beliefs, and attitudes toward the shortcomings of paper-based triage. The potential strong points of implementing a triage DSS were explained to them. To use the ESI, a nurse starts at the top of the algorithm process (Fig. 1), which encompasses four decision points (A, B, C, and D) on assigning patients to one of five triage levels. Fig. 1 shows the four key questions for this task. For ESI 1 and 2, the nurse considers only a patient's acuity in accomplishing an ESI assignment. If the answer to these initial questions is "no," then the nurse proceeds down the algorithm process to the questions regarding resources and moves on to decision point C. In this decision point, emergency department nurses are required to clearly understand that available resources should be estimated before a patient is assigned to ESI level 3. The nurse then needs to look at the patient's vital signs. If the vital signs exceed acceptable parameters, the triage nurse should consider upgrading the triage level to ESI 2. The triage nurse is responsible for determining whether a patient should be upgraded to this level on the basis of vital sign abnormalities. Patients classified under ESI level 4 are predicted to require one resource, and patients assigned to ESI level 5 are predicted to require no resources [22,23]. In the implementation phase of the hybrid triage DSS, nurses in the emergency department periodically completed paper-based documentation in different work shifts as a routine task. In the same shift, two triage nurses were randomly selected to use the triage DSS independently. No differences existed between the nurses' seniority levels in both groups, thus reducing the Hawthorne effect. The ethics committee of Tabriz University of Medical Sciences approved the procedures of the study.

We used a combination of the Rule-Based Reasoning (RBR) and Fuzzy Logic Classifier (FLC) approaches to predict the triage level of patients based on the triage specialists' opinions and ESI guidelines. In the proposed method, the RBR method was applied to model the first to fourth decision points of the ESI algorithm. Table 1 shows a summary of the triage levels based on the ESI algorithm. With this triage algorithm, patients are assigned an ESI level ranging from 1 (most urgent) to 5 (least urgent), considering the patients' acuity, pain, and resource needs. Finally, the data regarding the vital signs (heart rate, SPO2 [Saturation of Peripheral Oxygen], respiratory rate, and triage level as an output) were used as input variables in specific conditions and modeled using the FLC.

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