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Decision Making Using Fuzzy Cognitive Maps in Post-Triage of Non-Critical Elderly Patients

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Abstract: For patients arriving in the Emergency Departments (EDs) of hospitals a key aspect is to classify patients and identify high-risk patients since they have the potential for rapid deterioration during the waiting time. Triage is a widely applied and well-known process of evaluating and categorizing patients' condition, in EDs. On the other hand, EDs are frequently overcrowded, which makes triage an extremely challenging and demanding process in order to ensure that patients stepping into the ED are given the appropriate medical attention in time. This paper discusses the introduction of a general decision making procedure based on Fuzzy Cognitive Maps so that to create a Medical Decision Support System for Post-Triage decisions. The case of non-emergent and non-urgent elderly patients is examined and the corresponding model is developed.

Keywords: Soft Computing; Medical Decision Support; Triage Assessment; Fuzzy Cognitive Maps

I. INTRODUCTION

Prolonged wait times in the emergency department may lead to significant changes in a patient's state, and most of the time it means deterioration [1-2]. In order to better service patients in a timely fashion, which is critical for severe patients, the independent triage process has been adopted and developed. Triage is a general sorting process, which quickly determines the treating order for patients not only based on the arriving time at the ED but mainly at the severity of their case. It rapidly identifies patients requiring immediate care due to urgent, life-threatening conditions, as well as assessing the severity of the problem so as to ensure that care is appropriate and timely [3]. Medical personnel involved in the ED triage process utilize a general triaging methodology; one such methodology is the Emergency Severity Index (ESI). The ESI triage procedure should yield rapid, reproducible, and clinically relevant stratification of patients into five groups, from level 1 (most urgent) to level 5 (least urgent). The ESI provides a method for categorizing ED patients by both acuity and resource needs [4]. However, there is not any widely accepted automatic tool to perform, or at least to support, medical staff during the ED triage process. Ideally, this process of assignment of severity level is a dynamic one and optimally should involve multiple reassessments and possible reassignments of acuity level.

The importance of prioritization is that, in essence, it determines the time interval until the patient should meet with the doctor on duty.

Elderly patients frequently visit Hospital Emergency Departments (EDs) seeking medical assistance and requiring from critically urgent to non-urgent medical services. Patients over 65 may have atypical clinical presentation and/or higher severity of illness, multiple comorbidities, non-specific presenting symptoms, increased frailty, a high prevalence of chronic-degenerative diseases, which may include cognitive and communication disorders contributing to a higher risk of adverse outcomes [5]. It is reported that about a third of persons aged 65–79 years and 70% at the age of 80 years had at least two chronic conditions [6-7]. More importantly, not all physicians have considerable experience in assessing older adults. Nowadays, this becomes more difficult as the life expectancy is increasing every year and so elderly people of higher age are visiting EDs with increased frequency. Prompt decisions in providing the right and timely medical attention from the medical personnel is extremely hard, as they have to deal with situations characterized by inherent complexity, intrinsic uncertainty and dynamic

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nature, as well as often overcrowding of the ED. These result in frequent hospitalizations, increased healthcare costs and increased short-term mortality.

Independently of age groups, triage decisions in EDs are often made with limited objective data, ambiguous information given by the patient and/or individuals escorting them to the ED, while at the same time there may be a high level of automation and instrumentation, leading to increased quantities of data that the ED triage personnel must consolidate during the decision making process.

Even though there are protocols and scales in place and there is extensive training that triage personnel undergo, studies have shown that agreement between triage personnel in rating of triage levels to be only fair to moderate [8-9]. This holds even when triage is conducted within the same hospital from the same medical staff with the same group of patient case scenarios but in different times.

Additionally, despite the fact that triage, through the use of scales, is a systematic procedure, there is a possibility of "miss"-triaging, since there is a human factor is involved, which is inherently subjective. Therefore, triage personnel are encouraged to lean towards over-triage if patients seem to fall between two levels, thus, a priority is set for patient safety over resource allocation [10]. On the other hand, when ED becomes crowded, in order to reduce waiting times for higher level patients, those that are borderline may be triaged at a lower priority level. These opposing trends result in patients being over- or under-triaged, respectively.

As a result, patients arriving at the ED who do not have a severe/and or life threatening condition are required to wait to receive medical care. These patients are triaged at levels 3-5 and do not normally receive immediate care, even though those triaged as level 3 are treated with higher priority over those with levels 4 and 5, etc.

Normally, post-triage, patients that are triaged at the same level wait to be seen by a doctor in the ED based on a first come first served basis. For the elderly population, where the complexity of problems is increased, a long wait may cause deterioration of their condition on one hand, while on the other due, to atypical illness presentation, they may be under-triaged underestimating the level of urgency of care needed. Therefore, the problem at hand is two-fold; on one hand to be able to provide decision support in order to minimize, as much as possible, under-triaging and on the other hand, it is important that patients are also prioritized after the triage classification within their classification category and not be tended to only on a first-come first-served basis.

To deal with the post-triage dynamically changing patient conditions, this work extends a two-stage Medical Decision Support System (MDSS) to perform two complementary decisions: i) automatically provide assistance in the triage classification and ii) to suggest and update the priority with which patients are seen by the ED doctor at post-triage for patients within an initial triage level. The MDSS is based on the soft computing modeling technique of Fuzzy Cognitive Maps, which is able to handle such complex and dynamic situations and aid in decision making.

II. FUZZY COGNITIVE MAP BASED DECISION SUPPORT MODEL

Medical Decision Support Systems (MDSS) have been introduced and developed to provide automatically, reliable and objective assistance in the decision making process. Most of MDSS are based on human expert knowledge or at least they utilize it. The requirement for a reliable medical decision support system able to model the complex triage decision making process, lead us to the adoption of Fuzzy Cognitive Maps (FCMs). FCMs have been successfully used in modeling of complex systems and developing intelligent decision support systems in a variety of medical domains. They rely on expertise knowledge and experience of a domain and by making associations between domain descriptors they are able to reach conclusions. Fuzzy Cognitive Maps are illustrative causative representation models that are able to abstractly describe complex systems and processes using an interactive set of concepts that are interrelated by cause and effect relationships. An FCM draws a causal graphical representation to model the behavior of a system consisting of interrelated concepts [11]. Cause and effect within FCMs reflects how much a change in one concept influences a change in another concept. FCMs could be considered as fuzzy signed directed graphs permitting feedback and circular interactions, where the weighted edge w_{ij} from causal concept C_i to affected concept C_j describes the amount by which the first concept influences the latter, as is illustrated in Figure 1. The medical expert knowledge and experience over the operation and behavior of a complex system or procedure is embedded in the structure of the FCM and

the FCM developing methodology [9]. The procedure of designing the FCM structure for triage exploits the knowledge, experience and practice of triage personnel in the emergency department to develop a decision making process that follows a similar to their decision making and reasoning approach during triage of a patient.

Fuzzy Cognitive Map MDSSs have been used in a variety of domains including differential diagnosis [13], rehabilitation [14], obstetrics [15] and multiple other applications in biomedical, engineering, environmental, social and business areas. Consequently, FCMs have proven that they can be extremely useful for modeling the complex medical decision making processes following an approach that resembles human reasoning [16]. FCMs consist of interconnected concepts that represent the key modeling aspects, so in the FCM-MDSS, the concepts are of two kinds: the decision

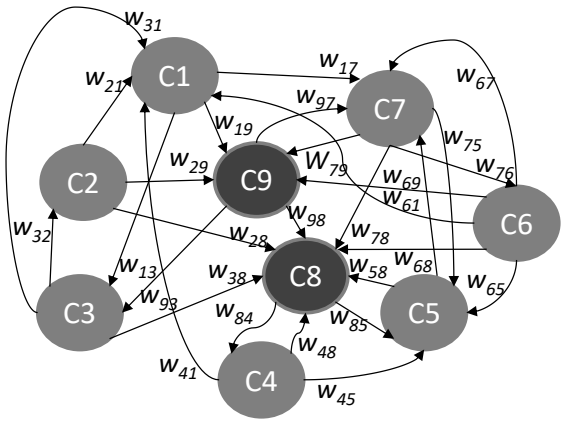

Fig. 1 The Fuzzy Cognitive Map Medical Decision Support model with input nodes C1-C7 and output nodes C8 and C9.

concepts and the factor concepts (direct inputs or intermediate results) that interact and contribute to each one decision. Naturally, factors may influence one another and therefore, some concepts may be connected to one, two or many other concepts and/or to decision concepts. Thus, the overall model is becoming quite complex, but the FCM-MDSS is able to run various scenarios and suggest the best decision for each particular situation.

III. TRIAGE AND POST-TRIAGE FCM-MDSS

The integrated Triage FCM-MDSS consists of two major components, as shown in Figure 2. The first component is a medical decision support system based on FCMs that provides an initial triage level based on the ESI model. The second component is used in cases where the initial decision was ESI 3, 4 or 5 to determine if there should be a change in the priority assigned as a result of triage for patients within the same triage level.

A. FCM-ESI

In the classical ED triage system each patient is assigned one of the 5 ESI levels and therefore, the Fuzzy Cognitive Map ESI has to include 5 Decision Concepts (DC), each one corresponding to an ESI level: DC1 -ESI Level 1, DC2 -ESI Level 2, DC3 -ESI Level 3, DC4 -ESI Level 4, DC5 -ESI Level 5. Authors have already developed and tested a general FCM-ESI, which consisted of 23 factors where the corresponding weights and importance values were also assigned in order to determine the weights between concepts [17]. The 23 Factor concepts are: *FC1* Life threatening, *FC2* Limb threatening, *FC3* Patient chief complaint, *FC4* Vital signs, *FC5* Medical history, *FC6* Other factor, *FC7* Expected # of resources, *FC8* Patient age, *FC9* Required timely intervention, *FC10* Weakness, *FC11* Additional symptoms other than chief complaint, *FC12* Severe pain or distress, *FC13* Patient referred to ED from outside, *FC14* Behavioral or psychiatric issue, *FC15* No additional symptoms to chief complaint, *FC16* Absence of medical history, *FC17* Patient medications, *FC18* Hospital or ED discharge<3 days, *FC19* Patient immune-compromised, *FC20* Alcohol or illicit drug use, *FC21* No recent change mental state, *FC22* Patient can walk or sit, *FC23* Pre-existing communication/cognitive deficits.

Additionally, they have recently updated FCM—ESI model [18], where three additional factors are also included that primarily play a role in non-critical patients: *FC24* Patient likelihood to adhere to treatment, *FC25* Living situation (i.e. at home, alone or with caregiver, or in a care institution) and *FC26* Patient left on previous visit without being seen (LWBS). These factors are considered important with respect to decision in admitting or discharging the patient from ED.

Based on the patient information and the factors, the FCM-ESI proposes a decision on triage, as a second opinion for the staff performing triage – it is not intended to be a completely automated system. If the result of triage is ESI-level 1 (emergent) or ESI-level 2 (urgent), the patient is in need of immediate care, which is provided in the ED. If the results are ESI-level 3

(acute), -level 4 (routine), or –level 5 (non-urgent) the patient is assigned a priority within his level and waits. Here an integrated approach is proposed where a second triage level is introduced based on a second FCM in order toto make sure that adverse outcomes due to waiting will be avoided. As time progresses, patient situations may change; therefore, precautions need to be taken to assist the patient as soon as their situation changes. This emerges the need of the Dynamic priority Post-Triage FCM.

B. Dynamic Priority Post-Triage FCM

As indicated in Figure 2, the Dynamic Priority Post-Triage FCM is a MDSS, which is introduced to continuously evaluate and ensure the ongoing triaging for cases where patients have been triaged as ESI levels 3, 4, or 5 and are waiting to be seen by a doctor. This implies though, that while waiting, there is availability

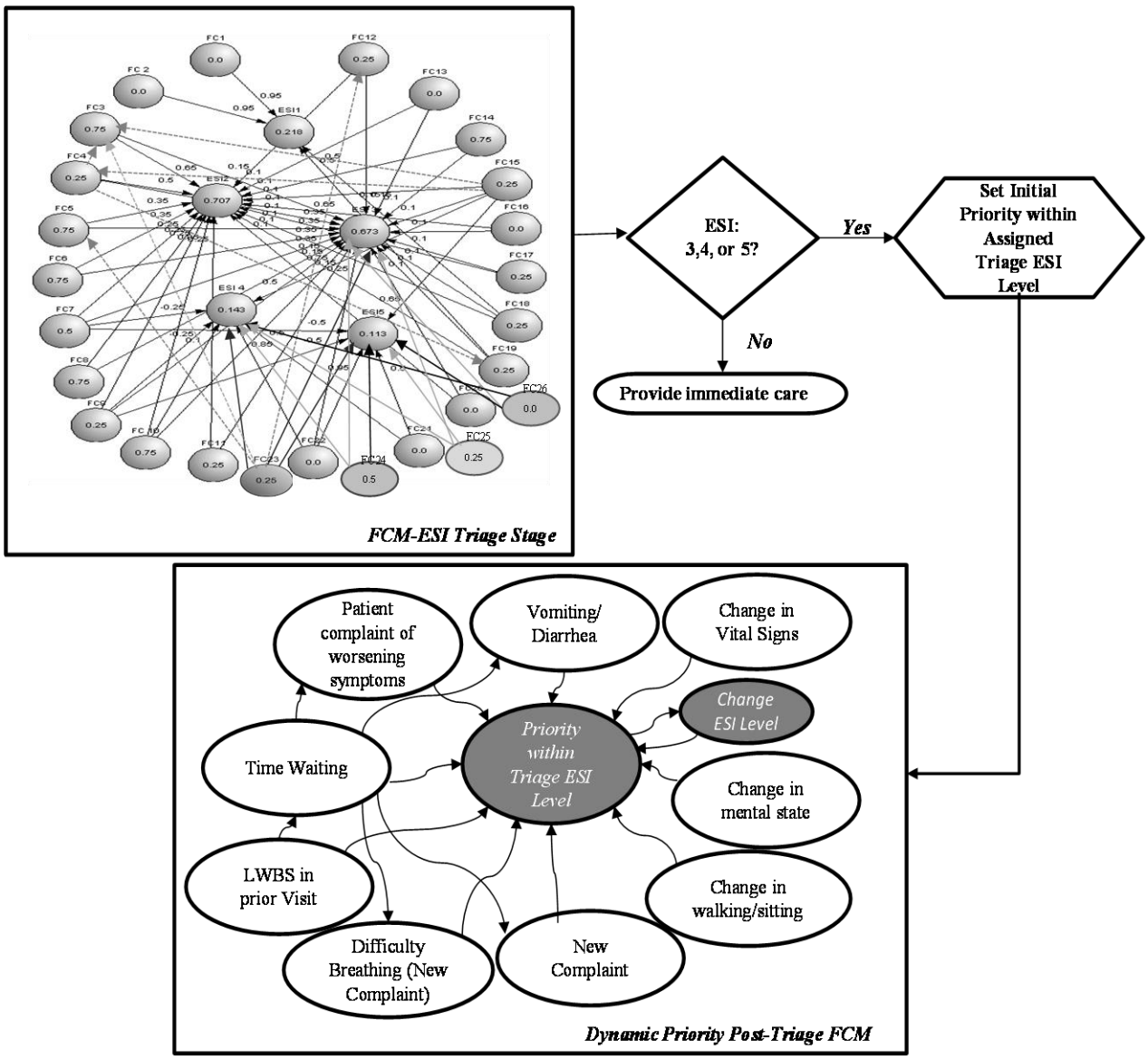

Fig. 2 Two-Stage Triage and Post-Triage FCM Integrated Decision Support System for Non-Critical Elderly Patients

of staff to check up on them from time to time. This is important, in particular for elderly patients, since as time progresses, their situations can become worse. The factors that are included in this second stage FCM are the following:

- Change in vital signs (*FC4*).
- Patient reporting of worsening symptoms.
- Change in mental state (*FC21*).
- Change in patient can walk or sit (*FC22*).
- LWBS (*FC25*)
- Triage ESI level.
- Time spent in waiting area. (This is important for patients that have left on a previous visit without being seen, since extended waiting time may lead to them leaving again.)
- New symptoms presenting during the waiting time that did not exist during the initial triage process.
- Vomiting/Diarrhea – since this can affect dehydration and rapidly change a patient's status.
- Difficulty Breathing (new symptom) – this is usually an "alarm" symptom which frequently needs immediate attention.

Additionally, the factor "time in waiting area" is strongly connected to certain factors included in this second stage, since, as time goes by, the importance of these factors increases, leading to higher priority in the triage system.

For example, patients with a fever of 100°F or more with infections could adversely progress over time, which means their priority should be upgraded. Similarly, patients experiencing vomiting over a prolonged waiting time may get dehydrated leading to delirium etc.

In the proposed second stage FCM, two output concepts are included. The first reflects the change in Priority within assigned Level and the second the change in Assigned Triage Level. The goal is that the second stage will make sure that patients are not waiting for hours without receiving necessary care because of a number assigned to them in an overcrowded ED.

SUMMARY

This work introduces a post triage process, mainly aiming to ensure that waiting time, which influence patient's situation will be taken into consideration. It is an extension of previous work on Decision Support System for ESI Triage, in particular for non-critical elderly patients in the Emergency Department [18].

Triaging of elderly people is characterized by high complexity and it is a very difficult task to assess, determine and assign a decision about their health condition. Additionally, waiting during post triage may lead to rapid deterioration. A two-stage Decision Support System for the ESI Triage and Post- Triage has been introduced and developed:

- 1st stage, a FCM-ESI system categorizes patients according to the 5 levels of the ESI.
- 2nd stage, during post-triage there is a prioritization of non-critical patients within ESI levels 3-5 which is continuously updated, as new information is received, in order to assist in preventing adverse outcomes while waiting.

This work integrates the adoption of FCMs as the main modeling approach for developing reliable MDSS for triage process. It is expected that the proposed approach will be further tested in ED situations and cases.

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