Fuzzy Cognitive Map Hierarchical Triage Decision Support for the Elderly

Voula C. Georgopoulos[1] and Chrysostomos D. Stylios[2]
[1]*School of Health and Welfare Professions, TEI Patras, Patras, Greece*
[2]*Dept. of Informatics and Communications Technology, TEI of Epirus, Artas, Greece*
voula@teipat.gr, stylios@teiep.gr

Keywords: Medical Decision Support, Health System, Modelling, Soft Computing.

Abstract: Fuzzy Cognitive Maps (FCMs) is a soft computing technique that has successfully been used to model complex systems and to develop Medical Decision Support Systems for many medical discipline applications. FCMs have a great ability to handle complexity, uncertainty and abstract inference as is the case in the health care sector. In this work a Hierarchical structure is introduced within an integrated health system where the Supervisor is modelled as an abstract FCM to support the triaging procedure. At the lower level, the FCM-ESI DSS is used to estimate the Triage ESI level of every patient. This FCM-ESI DSS is developed based on a novel approach, which ensures a high degree of inferring from human experts.

1 INTRODUCTION

The significant difficulty of making decisions in the health care area of Emergency Department (ED) service delivery is due to the inherent complexity and intrinsic uncertainty of EDs and their dynamic nature. Taking into consideration the aging population increasingly seeking services at the ED in combination with the limited resources and increased costs lead to the need for development of decision making tools that will effectively and efficiently provide patient care in a timely fashion.

Emergency Departments (EDs) vary from country to country both in terms of range of services offered as well as patients arriving for care in EDs. However, a recent definition provides the essence of what goes on in EDs: “Emergency departments provide unscheduled care for a wide variety of persons for reasons that range from life-threatening conditions to problems that could be treated in a primary care setting” (Nawar, Niska, & Xu, 2007).

Triaging involves an initial sorting of patients who arrive at the emergency room, usually called emergency department (ED), by rapidly identifying 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 (ENA, 2001).

Patients are categorized according to the level of urgency (Fernandes, et al., 2004; Travers, et al., 2002), based on their complaints, their general condition, a brief examination and physiological factors. In this way triage systems permit minimizing of the waiting time for treatment of the most urgent patients, while those not in need of urgent treatment are placed in a waiting area.

Given the constantly increasing age of a population this leads to increased numbers of visits of elderly patients to the ED and as a result to an increased burden on the EDs (Yim, Graham, & Rainer, 2009). The elderly often have multiple and complex diseases (Aminzadeh & Dalziel, 2002] and, as a general rule, undergo more diagnostic testing and have longer length of stays than younger patients. The elderly frequently visit the ED because of their increased prevalence to chronic-degenerative diseases, susceptible to frequent exacerbations.

It is significant to mention that in study of a sample of 50 randomly selected cases of ED admissions patients 65 years or older, discrepancies were found between the medical staff and expert nurses in 20 cases: where staff nurses had undertriaged 13 patients and overtriaged 7 patients (McCall, et al.,2009). According to another study (Grossmann, et al., 2012) of patients over 65, undertriage occurred in 22.5% cases. Main reasons were neglect of high-risk situations and failure to appropriately interpret vital signs.

Since all patients presenting to the ED are not of equal severity and complexity, those that do not have a severe/and or life threatening condition will have to wait to receive care. For the elderly population where the complexity of problems is increased, a long wait may cause deterioration of their condition. Therefore it is important that patients are also prioritized after the triage classification within their classification category and not be tended to on a first-come first-served basis.

Emergency rooms are extremely complex not only in the patient and treatment protocols, but also due to the high level of automation and instrumentation, huge volume of information, and interdisciplinary coordination that is necessary (Christian, et al., 2006). As such the triage decision can be modelled using soft computing modelling techniques such as Fuzzy Cognitive Maps discussed in the next section.

In this paper, a two-level Decision Support System is discussed to automatically assist in the triage classification as well as assign and update priority for patients which must wait according to their classification.

2 FUZZY COGNITIVE MAPS

Fuzzy Cognitive Maps with their modifications integrate aspects of fuzzy logic, neural networks, semantic networks, expert systems and they are usually supplemented by other soft and hard computing methodologies. An FCM is illustrated as a causal graphical representation consisting of interrelated concepts. FCMs are fuzzy signed directed graphs permitting feedback, where the weighted edge w_{ij} from causal concept C_i to affected concept C_j describes the degree by which the first concept influences the latter. FCMs are characterized as fuzzy feedback models of causality, where the weighted interconnections between concepts of the FCMs present causality between concepts by creating an interconnected network of interrelated entities, like an abstract mental model. Feedback interconnections are permitted along with if- then inferencing; that permits FCMs to model complex nonlinear dynamic systems. FCMs have the ability to include hidden nonlinear dynamics.

The concepts of the Fuzzy Cognitive Model stand for the main characteristics of an abstract model of any system, each concept of the FCM represents a granular entity such as state, variable, input, output, event, action, goal, trend of the system that is modeled as an FCM. The value of every concept C_i is A_i and it results from the transformation of the fuzzy real value of the system's variable, for which this concept stands for, in the interval [0,1]. This produces the initial concept value which is then updated as it is computed through the interaction of the interconnected concepts with the corresponding weight. Generally, between two concepts there are three possible types of causal relationships that express the type of influence from one concept to the other. The weight of the arc between concept C_i and concept C_j could be positive $(W_{ij} > 0)$ which means that an increase in the value of concept C_i leads to the increase of the value of concept C_j, and a decrease in the value of concept C_i leads to the decrease of the value of concept C_j. When there is negative causality $(W_{ij} < 0)$ which means that an increase in the value of concept C_i leads to the decrease of the value of concept C_j and vice versa. Finally, there can be no causality $(W_{ij} = 0)$.

The value A_i of concept C_i expresses the degree of its corresponding physical value. FCMs are used to model the behavior of systems; during the simulation step, the value A_i of a concept C_i is calculated by computing the influence of the interconnected concepts C_j's on the specific concept C_i following the calculation rule:

$$A_i^{(k+1)} = f(A_i^{(k)} + \sum_{\substack{j \neq i \\ j=1}}^{N} A_j^{(k)} \cdot w_{ji}) \qquad (1)$$

where $A_i^{(k+1)}$ is the value of concept C_i at simulation step $k+1$, $A_j^{(k)}$ is the value of concept C_j at simulation step k, w_{ji} is the weight of the interconnection from concept C_j to concept C_i and f is the sigmoid threshold function:

$$f = \frac{1}{1+e^{-\lambda x}} \qquad (2)$$

where $\lambda > 0$ is a parameter that determines its steepness. In this approach, the value $\lambda = 1$ has been used. This function is selected since the values A_i of the concepts must lie in the interval [0,1].

Fuzzy Cognitive Maps have been used to develop Medical Decision Support Systems (MDSS). A specific type for Medical Diagnosis is the Competitive Fuzzy Cognitive Map (CFCM) (Georgopoulos, Malandraki & Stylios, 2003; Georgopoulos & Stylios, 2005; Georgopoulos & Stylios, 2008) which consists of two main types of concepts: diagnosis-concepts and factor-concepts. Figure 1 illustrates an example CFCM model that is used to perform medical diagnosis. Here, the concepts of the FCM and the causal relations among them that influence concepts and determine the value of diagnosis concepts indicating the final diagnosis are illustrated.

In the CFCM model each diagnosis concept represents a single diagnosis, which means that these concepts must be mutually exclusive because the main intention is to always infer only one diagnosis. This is the case of most medical applications, where, according to symptoms, medical professionals conclude to only one diagnosis and then decide accordingly concerning the treatment. Actually, this comes from the medical axiom: "every patient has only one disease" but may represent many symptoms related to different diseases but all are results of the primitive disease. The general diagnosis procedure is a complex process that has to take under investigation a variety of interrelated factors, symptoms and functions. In accomplishing any diagnosis process, some of these factors are complementary, others are similar and even others are conflicting.

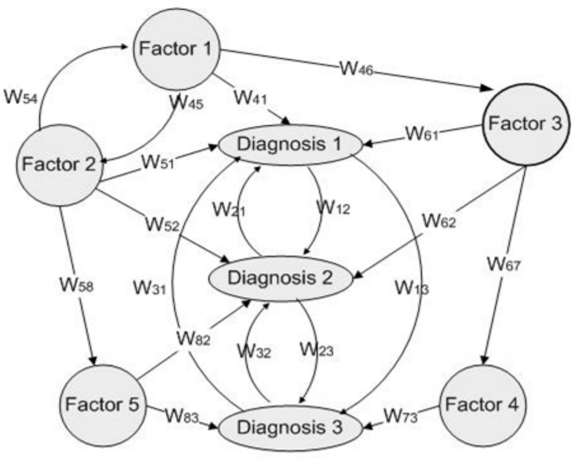

Figure 1: A CFCM model for Medical Diagnosis.

In the Competitive Fuzzy Cognitive Map model, the factor-concepts can be considered as inputs into the MDSS from patient data, observed symptoms, patient records, experimental and laboratory tests etc, which can be dynamically updated based on the system interaction, whereas the decision-concepts are considered as outputs where their estimated values outline the possible diagnosis for the patient.

3 ESI TRIAGE SYSTEM

When a patient first arrives in the Emergency Department, the first stop is triage where a trained and experienced registered nurse typically prioritizes each patient's condition into one of five general categories. This is done according to the Emergency Severity Index (ESI) which was designed for use in ED triage by the US Department of Health & Human Services. The ESI is a five-level categorization algorithm that prioritizes patients into five groups from 1 (most urgent) to 5 (least urgent) on the basis of severity and the number of resources that the patient may need to receive proper care (Wuerz, 2001).

In particular, the ESI uses the following scale based on decision points to determine its categories (Gilboy, et al., 2005; Barbee, et al., 2010):

- ESI category 1- Emergent: patient intubated, without pulse or respiration, or unresponsive. i.e the patient requires immediate life-saving intervention so as to prevent loss of life, limb, or eyesight,
- ESI category 2- Urgent: patient is in a high-risk situation, or confused, lethargic or disoriented, or in severe pain, or danger zone vital signs.
- ESI category 3- Acute: patient is in need of many resources to be taken care of. These may include, for example, Laboratory Tests, ECG, X-rays, CT-MRI-ultrasound-angiography, IV fluids, specialty consultation, com-plex procedures etc.
- ESI category 4- Routine: patient is in need of one resource.
- ESI category 5- Non urgent: patient is in need of no resources.

Due to the dynamic and uncertain nature of the overall triage process in addition to the differentiation difficulty, methods are needed to help the triage nurse to be efficient in making prioritization among the patients with the same acuity classification. Triage is a dynamic process in decision-making and the determination of who needs the most immediate care must be reassessed as contextual factors change and additional patient information becomes available [Patel, et al., 2008].

The triaging procedure requires a continuously monitoring and keeping track of patients waiting to be seen and a prompt assessment of each new patient who arrives at the triage area. All the above mentioned factors have to be taken into consideration and they contribute to the complexity of decision-making and create a degree of uncertainty for the triage procedure. Therefore a Decision Support System on Fuzzy Cognitive Maps for ESI Triage is developed in the next section.

4 FUZZY COGNITIVE MAPS MODEL FOR THE 5-LEVEL ESI TRIAGE SYSTEM

In an ED triage system each patient is assigned one of the 5 ESI levels and therefore, the Fuzzy Cognitive Map ESI will include 5 Decision Concepts (DC) each one for every ESI level:

- DC1 ESI Level 1;
- DC2 ESI Level 2;
- DC3 ESI Level 3;
- DC4 ESI Level 4;
- DC5 ESI Level 5.

The FCM development procedure is based on human experts who have to define the factor concepts that are represented at the FCM. There is group of experts who are asked to select the main factors based on which they conclude to an ESI triage; everyone expert replies with a set of 3-5 factors or even more sometimes.. The frequency with which each factor was chosen by the group of experts as a whole determined the importance weight (iw) between a factor concept and a decision concept.

The 22 factor concepts (FC1-FC22) of the FCM are and their iw have been detailed reported in (Georgopoulos & Stylios, 2012; Georgopoulos & Stylios, 2013) and are mentioned in Table 1.

Moreover, the experts are asked to evaluate the triage stage of specific cases and based on their assessment we infer additional information, which leads to a complementary second weight, the "influence to specific decision" specific weight- sw , which represents how much the specific factor leads towards a specific decision / diagnosis. The procedure to calculate the sw is the following: every expert who considers one factor as important and takes it into consideration, is asked to present the degree with which this specific factor leads the expert to select one decision. Every expert describes the degree of influence of one factor towards one decision using a linguistic variable, such as "very strong influence *vsi*", "strong influence, *si*", "medium influence, *mi*", "weak influence *wi*", "very weak influence *vwi*", as it is depicted at Figure 2.

Table 1: Factors of the FCM.

FC1	Life threatening	0.45
FC2	Limb threatening	0.40
FC3	Patient chief complaint	0.67
FC4	Vital signs	0.4
FC5	Medical history	0.35
FC6	Other factor	0.32
FC7	Expected # of resources	0.31
FC8	Patient age	0.16
FC9	Required timely intervention	0.15
FC10	Weakness	0.20
FC11	Additional symptoms other than chief complaint	0.14
FC12	Severe pain or distress	0.12
FC13	Patient referred to ED from outside	0.08
FC14	Behavioral or psychiatric issue	0.07
FC15	No additional symptoms to chief complaint	0.05
FC16	Absence of medical history	0.05
FC17	Patient medications	0.05
FC18	Hospital or ED discharge<3 days	0.04
FC19	Patient immune-compromised	0.04
FC20	Alcohol or illicit drug use	0.03
FC21	No recent change mental state	0.75
FC22	Patient can walk or sit	0.12

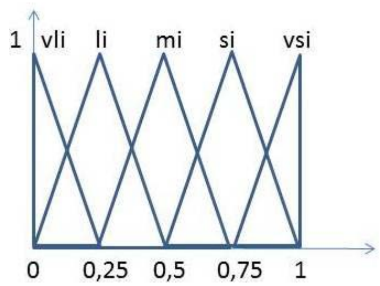

Figure 2: The positive fuzzy linguistic weights.2

Thus, every expert describes the specific weight of each interconnection with a fuzzy linguistic variable from the above mentioned set, which stands for the relationship between the two concepts and determines the grade of causality between the two concepts. Then, all the proposed linguistic weights for one interconnection suggested by experts, are aggregated using the SUM method and an overall linguistic weight is produced. The overall lingustic weight with the defuzzification method of Center Of Gravity (COG), is transformed to a numerical weight , belonging to the interval [-1, 1].

Then, the overall weight describing the influence from one factor concept towards a decision concept is calculated using the form:

$$w_{ji} = \mathrm{sgn}(sw)\left(l_1 * iw + l_2 * |sw|\right) \quad (4)$$

where the two parameters are introduced to represent the participation of the importance weight and the specific weight, on the overall weight describing the influence of every factor concept towards the decision/diagnosis concept. It is mentioned that the value of has to be normalized in the interval [-1, 1], where the weight takes values.

The previously developed FCM-ESI model did not provide for interactions between the various factor concepts. However, because the decision is very complex and there are always cause effect relationships between factors contributing to the triage decision, it is important to extend the previous FCM-ESI DSS system to include such connections between factor nodes.

In the current model these are as follows:

- Vital signs (FC4) and Patient chief complaint (FC3) Vital signs (FC4) and Patient immuno-compromised (FC19) – for example patients that are experiencing fever and are on chemotherapy.
- Over the counter medications (F15) and chief complaint (FC3) – patients using over the counter pain medication may have decrease in their pain level and as a result the severity indicated concerning their chief complaint may be decreased
- Over the counter medications (F15) and vital signs (FC4) – over the counter medications may change vital signs, e.g. reduced fever, increased blood pressure etc

.

Experts were asked to identify the possible interactions among Factor Concepts. At first, every expert is asked to determine the pair of concepts that are coupled. Thus, a set of possible paired factors concepts is created and then all the experts are asked to suggest the degree (using a linguistic weight) of coupling/ influencing among the previously identified pairs of factor concepts. A set of five fuzzy linguistic values are used.

The complete FCM-ESI is illustrated in Figure 3 where the 5 central nodes are the decision nodes (ESI levels). The decision node with the maximum value is the level at which a patient is triaged.

The FCM-ESI for every patient takes the concept factor values from measurements, laboratory test and examination and these values are transformed in the interval [0,1] where concepts take values and then the values of Decision Concepts are calculated, so that to infer the ESI level.

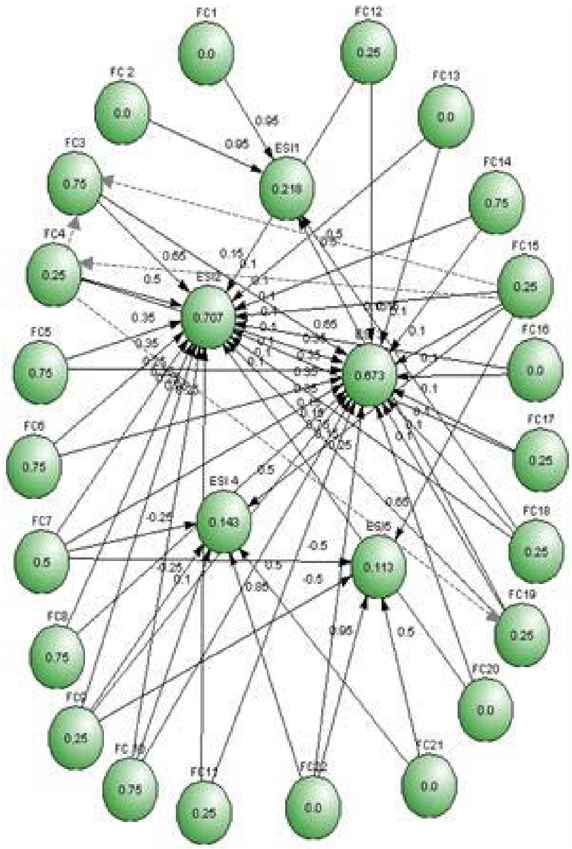

Figure 3: The FCM-ESI model for triaging.

5 PRIORITY BETWEEN EQUALLY TRIAGED PATIENTS FOR ESI LEVELS 3-5

An important issue after initial triage for patients with ESI levels 3-5 in an overcrowded ED is the priority with which patients receive care. Usually, this is on a first come – first served basis. However, this can change over time. For example, in some cases injuries and illnesses that need medical and nursing intervention are time sensitive. The longer the wait, the more damage may occur because of changes for example such in oxygen, blood, electrolytes (potassium, sodium, etc.), sugar, etc. Failure to prioritize triaged patients appropriately may result in very sick patients at risk for deterioration while waiting. Since this is also difficult and critical decision for the personnel in the ED, a supervisory level has been added on the FCM-ESI DSS model, where the outcome is changes in priority for patients within the same ESI level.

In order to develop the supervisor priority FCM-ESI Decision Support Systems, there are selected the most essential factor concepts that may influence the patient status. The supervisor priority FCM-ESI consists of the concepts (Figure 4):

- Change in vital signs (FC4).
- Patient report of worsening symptoms.
- Change in mental state (FC21).
- Change in patient can walk or sit (FC22).
- Triage ESI level.
- Time in waiting area.

Therefore, for each patient where a particular ESI Decision Concept had the maximum value (i.e. the ESI Level with which the patient was characterized) this decision node interacts dynamically with other FC nodes as new information is provided over time and is checked every half hour.

This leads to prioritizing of the patients that have equal or almost equal ESI status in order to avoid adverse events after triage due to long wait in overcrowding. Thus the supervisor priority FCM-ESI is called to prioritize among patients with the same ESI level.

6 CASE STUDY

A 72-year-old woman presented to a busy emergency department (ED). During triage she told the triage nurse that she experienced face and tongue swelling in the last two days. The vital signs at triage, including respiratory rate and oxygen saturation, were normal. No previous history indicated this condition, the patient had not taken medications, was not in any pain, and there were no problems with the patient's mental state, Also the patient was able to sit and walk. Both a triage nurse and the FCM-ESI resulted in ESI-Level 3.

The patient sat in the waiting room for more than 2 hours after which she was placed in a room in the ED. After an additional hour a doctor evaluated her. In the meantime, her tongue and throat had swollen substantially, and she was having difficulty breathing. She was diagnosed with angioedema and required emergency intubation, a potentially dangerous and high-risk procedure accompanied by aggressive treatment with intravenous epinephrine.

On the other hand, using the supervisor priority FCM-ESI DSS, when the patient after 1.5 hours experienced substantial swelling and difficulty breathing the triage the patient priority was increased to Very-Very High and thus, the patient received immediate care without the need for intubation.

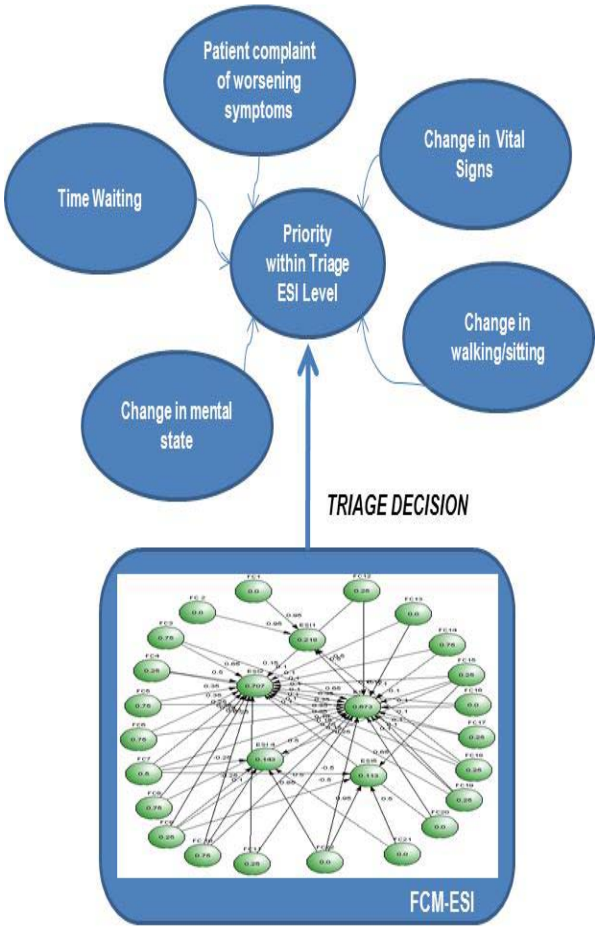

Figure 4: The supervisor priority FCM-ESI DSS

7 SUMMARY

This paper is an extension of previous work and it presents an integrated methodology for developing a hierarchical Decision Support System for ESI Triage. Usually at the Emergency Department (ED) of hospitals medical staff has to cope with many patients, asking for urgent treatment and so they have to assess their health condition under significant time constrains. The case of elderly patients has great importance as they usually are admitted quite frequently at the ED suffering from chronic problems, their health condition is characterized by complementarity and/or controversy and usually with a lack of interaction and low level communication ability. Thus triaging of elderly people is characterized by high complexity and it makes a difficult task the assessment and decision about health condition.

For such cases, Soft Computing methodologies are rather suitable and so Fuzzy Cognitive Maps (FCMs) are proposed here to model and develop a Decision Support Systems for the ESI Triage, which is a significant procedure during patient admission at the Emergency Department (ED) of hospitals. Generally, FCMs have been successfully applied to develop Medical Decision Support Systems for many discipline fields.

Here, there is further expansion of a recently proposed methodology to develop FCMs exploiting and combining knowledge and experience of human experts along with information and bibliographic data. Moreover, a hierarchical two level structure is introduced consisting of a FCM at each level. The introduction of the abstract FCM supervisor prioritizes among the different patients and increases the efficiency of the MDSS.

ACKNOWLEDGEMENTS

This work was supported by the E.U. FP7–PEOPLE–IAPP–2009, Grant Agreement No. 251589, Acronym: SAIL.

REFERENCES

Aminzadeh, F. & Dalziel, W.B., 2002. Older adults in the emergency department: a systematic review of patterns of use, adverse outcomes, and effectiveness of interventions, *Ann Emerg Med*, 39:238-47.

Barbee, G.A. et al., 2010. The effect of provider level triage in a military treatment facility emergency department. *Journal of Emergency Primary Health Care (JEPHC)*, 8:Article 990386.

Christian, C. K. et al., 2006. A prospective study of patient safety in the operating room, *Surgery*, 139:159–173.

Emergency Nurses Association (ENA), 2001. *Making the right decision: A triage curriculum* (2nd ed.). Des Plaines, IL.

Fernandes, C. et al., 2005. Five level triage: A report from the ACEP/ENA Five Level Triage Task Force. *JEN* 31(1):39-50.

Grossmann, F.F. et al. 2012. At risk of undertriage? Testing the performance and accuracy of the emergency severity index in older emergency department patients, *Annals of Emergency Medicine*, 60(3):317–325.e3.

Georgopoulos, V.C., Malandraki G.A., & Stylios, C.D., 2003. A Fuzzy Cognitive Map Approach To Differential Diagnosis of Specific Language Impairment, *Journal of Artificial Intelligence in Medicine* 29(3):261-278.

Georgopoulos, V.C. & Stylios, C.D., 2005. Augmented Fuzzy Cognitive Maps Supplemented with Case Based Reasoning for Advanced Medical Decision Support, In: *Soft Computing for Information Processing and Analysis Enhancing the Power of the Information Technology.* M. Nikravesh, L. A. Zadeh and J. Kacprzyk (Eds.) Studies in Fuzziness and Soft Computing, Springer-Verlag, Vol. 1, pp. 391-405

Georgopoulos, V.C. & Stylios, C.D., 2008. Complementary case-based reasoning, competitive Fuzzy cognitive maps for advanced medical decisions. *Soft Computing*, 12: 191-199.

Georgopoulos, V.C. & Stylios, C.D., 2012. Introducing Fuzzy Cognitive Maps for Developing Decision Support System for Triage at Emergency Room Admissions for the Elderly. *Proceedings of the 8th IFAC Symposium on Biological and Medical Systems,* 29-31 August 2012, Budapest, Hungary.

Georgopoulos, V.C. & Stylios, C.D., 2013. Fuzzy Cognitive Map Decision Support System for Successful Triage to Reduce Unnecessary Emergency Room Admissions for the Elderly. In *Fuzziness and Medicine: Philosophical Reflections and Application Systems in Health Care*, pp. 415-436, Springer Berlin Heidelberg.

Gilboy, N. et al., 2005. Emergency Severity Index, Version 4: Implementation Handbook. *Agency for Healthcare Research and Quality, Publication No. 05-0046-2*, Rockville, MD. http://www.ahrq.gov/research/esi/

McCall, B. et al., 2009. Mistriage of elderly in the emergency de-partment, *Connecting the Dots: Geriatric Nursing, Education, and Clinical Simulation*, Chapel Hill, NC, 2009.

Nawar, E.W., Niska, R.W., & Xu J., 2007. National Hospital Ambulatory Medical Care Survey: 2005 emergency department summary, *Adv Data*, 386:1-32.

Patel, V.L. et al., 2008. Calibrating urgency: triage decision-making in a pediatric emergency department. Advances in health sciences education, 13(4):503-520.

Travers, D.A. et al., 2002. Five-level triage system more effective than three-level in tertiary emergency department, *JEN* 28(5):395-400.

Wuerz, R., 2001. Emergency severity index triage category is associated with six-month survival. ESI triage study grou, *Academic Emergency Medicine*, 8:61–64.

Yim, V.W., Graham, C.A., & Rainer, T.H., 2009. A comparison of emergency department utilization by elderly and younger adult patients presenting to three hospitals in Hong Kong, *Int J Emerg Med*, 2:19-24.