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Fuzzy logic applied to a Patient Classification System

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Abstract— **The optimization of the clinical staff resources is a very complicated task that can be supported by a set of tools called Patient Classification Systems (PCS). These methods allow the evaluation of the correct number of nurses and healthcare workers needed in order to guarantee an appropriate care level.**

In this study a PCS tool called MAP is presented, able both to support the staff allocation and to assess the complexity level of each single patient. This method, applicable in all clinical fields, is based on the analysis of the patient state by means of a set of physiological variables characterizing his clinical conditions and his environment.

Moreover, we introduce an evolution of MAP based on Fuzzy Logic, in order to produce an instrument more suitable to the daily clinical applications.

I. Introduction

The healthcare process is a very complex task because is influenced by a large number of factors. Its efficient and effective management will benefit of specific support tools. In particular the balance between demand and supply of nursing care is a very challenging aspect, that is widely faced in literature [1-3]. In this context, an objective method, able to assess the adequate nurse staffing needs based not only on the number of patients to be cared, but also on the level of their care complexity, will be very useful.

Patient Classification Systems (PCS) identify a set of tools for grouping patients according to the amount of nursing care required [4]. These instruments allow a deep analysis of the care complexity and an optimization of the human resources in order to maintain appropriate care levels. Several methods for complexity assessment were proposed in the last decades in order to face the increase in the requests of healthcare support in different clinical fields. Two main categories of PCSs could be identified: activity-based systems and dependency-based systems [5]. The first group includes those methods that relate each patient care activity to a given time duration and obtains the nursing staff need from the sum of all times (e.g. the Workload Indicators of Staffing Need [6]). The second group classifies patients according to the level of dependency on the nurse support and associates a nurse workload to each class, as in the Functional Independence Measure [7].

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The Italian healthcare system evolved, during the '90s, from a management of the clinical employees related to the number of ward beds to a staff administration based on the Diagnosis-Related Groups (DRGs) [8] that classify patients according to their diagnosis. Obviously, the use of an indicator connected with the patient diagnosis rather than directly to the patient needs has been widely criticized [9].

However, from a deep analysis of proposed approaches for patient classification it emerges that most of them are not able to reveal both the patient care needs and the human resources required. Moreover, the same PCS methods are usually applied in different clinical fields without any relevant adaptation, as for the obstetrical field [10].

In this study we present a methodology for the nursing care complexity assessment called MAP [11] (*Metodo Assistenziale Professionalizzante – Professionalizing Healthcare Method*) able to guide nurses in the analysis of each patient healthcare path and to indicate the contribution due by the other members of the clinical staff. Moreover, we present an evolution of the MAP based on Fuzzy Logic (FL) [12], in order to allow a better use of the method in daily clinical applications.

II. Materials and Methods

A. *The model for nursing care complexity assessment*

MAP is a patient-centered instrument for the nursing care complexity assessment. It allows the evaluation of the patient state by means of the physiological variables characterizing his clinical conditions and his environment. Specifically, MAP identifies, in addition to the *environment* elements, three main factors:

- *Clinical Stability*;
- *Responsiveness*, i.e. his capability to define his own needs and to choose the right behaviors to be performed;
- *Self-sufficiency*.

The environment and the three factors are called *dimensions.* To each dimension MAP associates a set of *characteristics* to be used to assess the patient care complexity. For each characteristic is defined a score proportional to its importance for the final patient assessment. In particular, five levels of importance are defined and associated to specific scores: weak importance (2), sufficient importance (4), moderate importance (6), normal importance (8) and high importance (10). Only even numbers are used as scores to simplify following calculations. In MAP system a total 60 characteristics applicable to all clinical fields are defined and further 6 characteristics to be used only for the obstetric evaluations. The following list contains the characteristics related to each dimension:

- Clinical Stability: heart rate, cardiac rhythm, blood pressure, respiratory rhythm, oxygen saturation, body temperature, blood glucose level, dermis conditions, urinary function, bowel movement, emesis, upper gastrointestinal bleeding, lower gastrointestinal bleeding, upper breathing tract bleeding, lower breathing tract bleeding, urinary tract bleeding, genital bleeding, membrane condition after birth (only for obstetric applications), pain level, sleep condition.
- Responsiveness: consciousness level, orientation, emotional state, ability to communicate, ability to understand, ability to take decisions, ability to take care of himself.
- Self-sufficiency: fecal continence, urinary continence, capability to make basic movements in bed, capability to get up, walking, capability to wash himself, eating.
- Environment: presence/absence of caregivers, breast-feeding (only for obstetric applications), oral – inhalation – rectal – vaginal - topical therapy, intramuscular therapy, labor induction (only for obstetric applications), intravenous therapy, epidural therapy, enteral therapy, oxygen therapy, blood transfusions, measurement of body temperature, measurement of heart rate-blood pressure, measurement of fetal heart rate (only for obstetric applications), wound medications, pressure ulcer medications, vascular cannula, central venous catheter, epidural catheter, feeding tube, percutaneous endoscopic gastrostomy - percutaneous endoscopic jejunostomy, urinary catheter, ostomy, mechanical ventilation, surgery, type to birth (only for obstetric applications), laboratory procedures, instrumental - radiological - endoscopic procedures, biopsy procedures, cardiotocography (only for obstetric applications), preparation for diagnostic procedures, surgery preparation, discharge.

Finally, a list of *variables* is used to describe the possible patient conditions relative to a specific characteristic. A percentage weight is associated to each variable, according to the level of criticality of the condition. For example for the characteristic *body temperature*, that has a score equal to 6, four variables are considered with their relative weights: normal temperature (0%), hyperthermia (50%), hyperpyrexia (100%), hypothermia (100%).

The final patient complexity is obtained summing the weighed scores for all characteristics and assigning the patient in one of the four complexity classes: low complexity, medium-low complexity, medium-high complexity, high complexity.

Moreover, the patients' distribution into the four complexity classes permit the evaluation of the minimum and the recommended number of nurses and healthcare workers needed to assure an adequate care quality. This calculation is based on a coefficient c_i related to the number of workers required for each complexity level i in a day and obtained according to the following equation:

$$c_i = \frac{care\ amount[min/day] \cdot responsibility\ rate[\%]}{shift\ duration[min] \cdot 100}$$

where the $care\ amount$ and the $responsibility\ rate$ are experimentally determinate for each complexity level, both for nurses and for healthcare workers, and reported in [11].

The number of workers needed is then calculated as:

$$\#workers = \sum_{i=1}^{4} (c_i \cdot n_i)$$

where n_i is the number of patients in the *i-th* complexity class.

A more detailed description of MAP and the assessment of the clinical staffing needs is reported in [11] .

B. Model evolution with Fuzzy Logic

A preliminary MAP validation was conducted on a sample of about 700 patients belonging to 15 hospital wards distributed all over the Piedmont region [11]. This phase demonstrated the suitability of MAP to assess patient complexity but it was also evident that a method that could express the uncertainty could improve the performances of MAP.

For this reason FL was used in order to introduce gradual information in the evaluations of the characteristics. A Fuzzy Inference System (FIS) was built for each dimension. The characteristics associated with the specific dimension became the FIS inputs and each variable (the possible alternatives relative to a single characteristic) was modeled in terms of membership function (MF). These MFs were built so that the original meaning of the characteristic was maintained and, in the same time they give the nurse the possibility to describe patient conditions in a more realistic way than what is possible with only a few fixed values. An example of the original variables compared with the fuzzy ones is reported in Fig 1 for the *body temperature* characteristic. It can be seen that the four initial fixed variables (hypothermia, normal temperature, hyperthermia and hyperpyrexia) are converted into four MFs with the same meaning of the original conditions but admitting as input all possible body temperature values.

The outputs of the four FISs, representing the amount of alteration for a specific dimension, were used as inputs for a further FIS returning the complexity of the single patient. In Fig. 2 the input and the output MFs of the final FIS are presented.

For the definition of the rules for each FIS, several members of the nursing staff were interviewed and asked to report a large set of examples of possible patients belonging to a specific complexity classes.

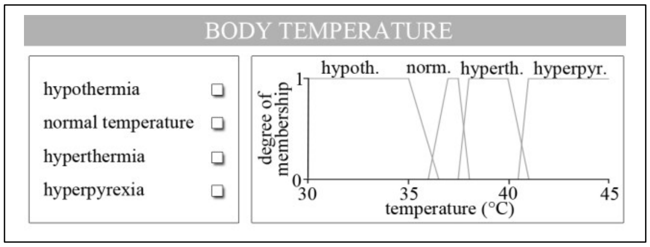

Figure 1. Example of the *body temperature* characteristic as defined in the original MAP version (left) and in the new version based on FL (right).

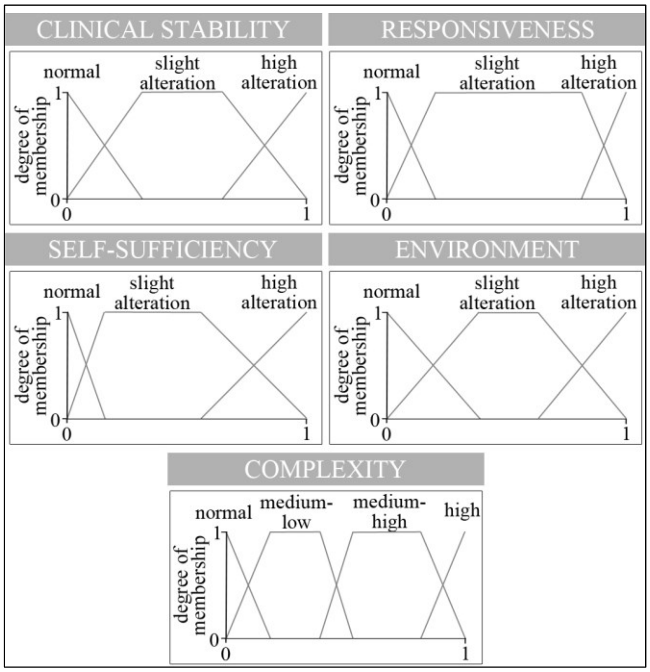

Figure 2. Input (clinical stability, responsiveness, self-sufficiency, environment) and the output (complexity) MFs of the final FIS.

The Mandami Inference was chosen as method to aggregate the set of inputs into a single or a set of outputs. The Fuzzy Logic Toolbox supplied in Matlab was used to implement the five FISs.

An example of rule activation and final patient classification is reported in Fig. 3 for an elderly patient suffering from hypertension and diabetes, non-fully responsive and self-sufficient, with urinary catheter and intravenous fluid therapy. In the FL-based MAP the rule that is activate in the final FIS is: IF *clinical stability* IS *slight alteration* AND *responsiveness* IS *high alteration* AND *self-sufficiency* IS *high alteration* AND *environment* IS *slight alteration* THEN *complexity* IS *high.*

This result is coherent with the one obtained using the original version of MAP according to which the same patient obtained a total score of 80 that was associated with an high complexity level.

The validation of the new FL-based approach is actually underway. We are now collecting a large data set of real patients data. For each patient we will compare the output of FL-based MAP with the one of the standard version.

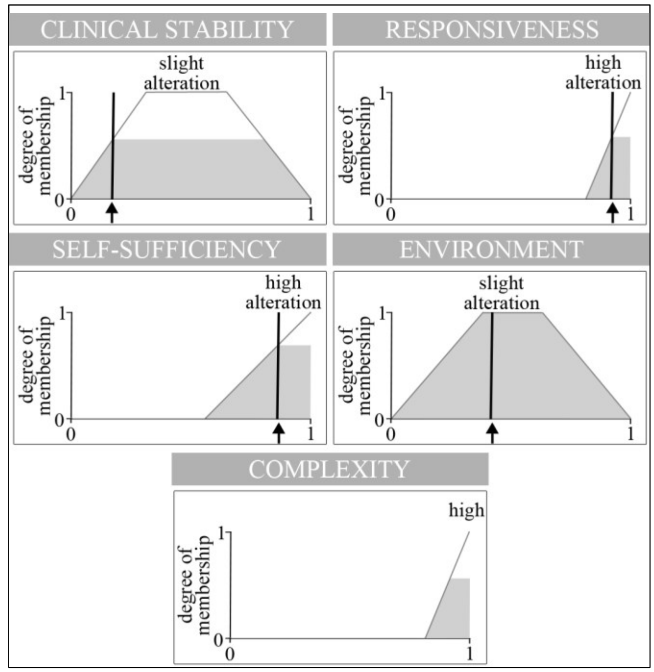

Figure 3. Example of rule activation and patient classification in the final FIS. In this rule the four input variables are connected among them with the AND operator.

III. Conclusions

The correct scheduling of the staff resources in a clinical facility is a very difficult task. Moreover, the possibility to assess the care complexity of each patient could be useful in order to decide and to program the correct actions in relation to the real clinical needs.

In this study we proposed a new method for the assessment of the nursing care complexity that is centered on the patient and not on the healthcare professionals. The evolved version of MAP, based on FL, allows to nurses evaluating the single patient healthcare path in a more efficient way, taking into account also their professional experience. Furthermore, such a method can be employed as support tool for the hospital managers for the optimization of the clinical resources according to the real workloads, for the budget planning and in the assessment of the nursing activities.

Moreover, a specific software is actually under construction, to calculate the patient complexity and the staff needs based on the last evolution of MAP approach. Such a software will be able to automatically acquire the clinical parameters from the nursing records while the remained values will be inserted manually by means of specific interfaces.

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