Expert system for appointment generation in a medical center using fuzzy logic

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Abstract. This work describes an algorithm that optimizes the actual way of programming appointments in a first level health service. It integrates specialities, X-ray department, clinic laboratory, social work and cures. The schedule assignation was supported on the fuzzy logic theory which offers the advantage of working with wider decision ranges than the traditional logic based on true-false. The design methodology of the algorithm, the definition of the input and output variables and rules were proposed based on a specific case, then the system was tested with a simulated database. A web page was proposed to create and update recurrent appointments into the departments considered. This system is designed modular, so it is in a single place and diminish the required time of the traditional multipoint methodology of assignation. Implementation can be adapted to the specific medical center.

Keywords: fuzzy inference system, informatics, medical appointments, healthcare system

1 Introduction

The applications of medical informatics are very important because the analyzed and structured information becomes knowledge that allows improvements in the quality of health services and also in a better use of the resources. Besides, the development of intelligent systems that help the systematization of the information can improve the performance and automatization of the care process of the patients providing a better service.

The present work was created thinking on any medical center where the amount of patients to be attended sometimes overpasses the capacity of the clinics available. For instance, in Mexico City there are 20.4 million people, according to an ONU report in 2012. There are several institutions that provide health services, either public, such as IMSS, ISSSTE, ISSEMYM and SEDESA-DF, or private. For instance, SEDESA, attends more than 5 million medical consultations, 145 thousand hospital stays and more than 750 thousand urgencies are attended around a wide range of health centers [1, 5].

It is therefore necessary for health providers to optimize economic resources and staff and also to optimize the time spend by the patient in the clinic. This is the reason of being interested in the automatization of the patient attention process. Moreover, once the information is digitized, many interesting possibilities open up allowing a better use of resources assignation in an intelligent form, such as the medical and laboratory appointments.

The present work describes the design and implementation of a technologic solution that makes use of a Fuzzy Inference System, taking as inputs the priority of the next appointment and if necessary other appointments such as clinic analysis, X-ray and social work, depending on the indications of the medical doctor or specialist. An intelligent system was developed to generate a clinic diary in order to assess an optimized generation of appointments, which takes into account the particular needs of each patient according to the medical specialities, medical studies requested as well as the status of availability, capacity and special requirements in each of the department considered.

2 Description of the problem

Nowadays, in the clinics, the information of the patients are concentrated into medical records and on the other hand, the administrative management of the healthcare center contains data about the capacity and availability of the different resources associated to each department. However, this information is not concentrated in one department and when the patient needs to request several appointments at different offices, it has to be done independently. Therefore, the process of generating the next appointments becomes complicated when results of other departments have to be available for the next visit to the doctor. In these cases, it is necessary to coordinate the availability of medical staff and all the resources to prevent the patient from wasting time generating separated appointments and taking the risk of visiting the doctor without the required studies. The probability of having this kind of problem is high since the patient does not have all the information about the availability and delivering times of all the departments.

A solution to this problem could be the use of a specific place to do all the appointments needed, where the information from all the departments can be consulted, not only about availability but also taking into account the delivering times and specific needs of the patient and doctor. In this kiosk, a few number of persons could help the patient to choose the optimum schedule for the next appointment, using the inference system result as a start point in the decision.

The system for appointment generation considered one kiosk that has access to all the departments' information. A Fuzzy Inference System was developed, whose inputs are all the patient's needs and resources conditions, availability of each department, and the output is an optimum day and hour that is proposed to the patient and he can decide if that suits him or he prefers another day or time. The algorithm takes information from a data base that contains medical records of the patient and also the characteristics of each department such as schedule and resources availability of the medical staff and facilities of the medical center. The departments considered in the fuzzy inference system are: medical specialities office, clinical laboratory and X-ray service. The social work and cures department was not included in the fuzzy system because non subsequent appointments are needed. However, they are also monitored and stored. The proposed date represents the optimum value according to the specifications in the inference rules. Then, according to the decision of the patient the system register the dates in a data base to schedule the appointments for each of the required departments. The system is then ready for the next assignation. Figure 1 shows the general structure of the proposed system for the appointment generation.

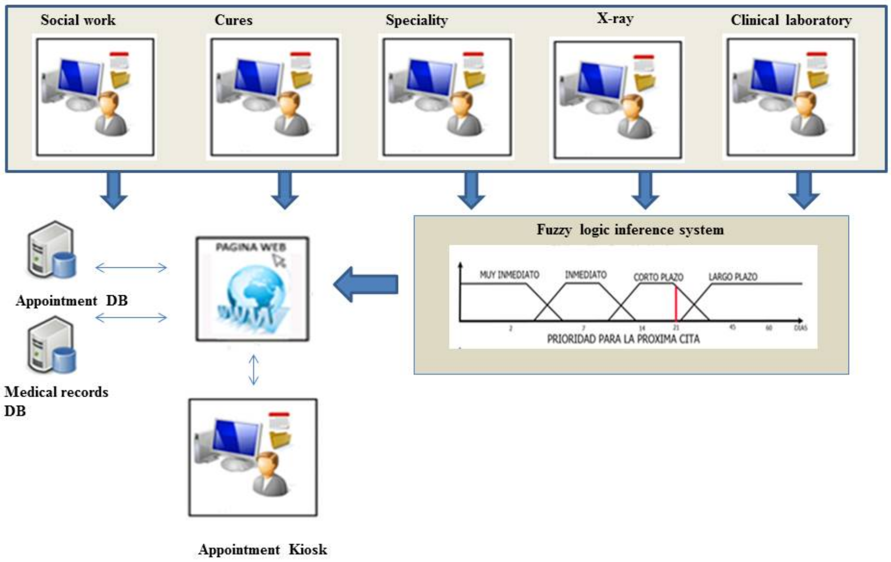

Fig. 1. Structure of the appointment system

All the system will be communicate in a transparent way through a Web page between the different modules, achieving that each module receives the needed information for its correct functioning in the required format and that the data base is updated every time a new appointment is assigned.

3 Theoretical considerations

Fuzzy logic is a tool, branch of artificial intelligence, whose characteristic is that instead of having only two possible values, 1 and 0, all possible values in between are allowed to define the membership value in a set [6,7]. A fuzzy set expresses a membership value of an element in the set. Therefore, if the universe X is a collection of objects denoted as x, then the fuzzy set A in X is defined as a set of ordered pairs as shown in equation 1.

$$A = \{(x, \mu_A(x)) | x \epsilon X\} \tag{1}$$

Where $\mu_A(x)$ is the membership function (MF) for the fuzzy set. The MF maps each element of X to a membership value between o and 1. Usually X is called discourse universe or simply universe and it may consist of discrete objects into a continuous space. In practice, when X is a continuous space, usually X is segmented in several fuzzy sets whose membership functions cover X in a uniform way overlapping with the surrounding functions. It means that any value in X has a different membership value for each of the sets, becoming ambiguous or uncertain. Actually, this is the way in which humans describe variables in the common language. Figure 2 shows an example of five sets defined as trapezoidal functions. It has a membership value of 0.8333 in the 'young', a membership value of 0.2667 in 'middle age' and zero for the rest of the sets.

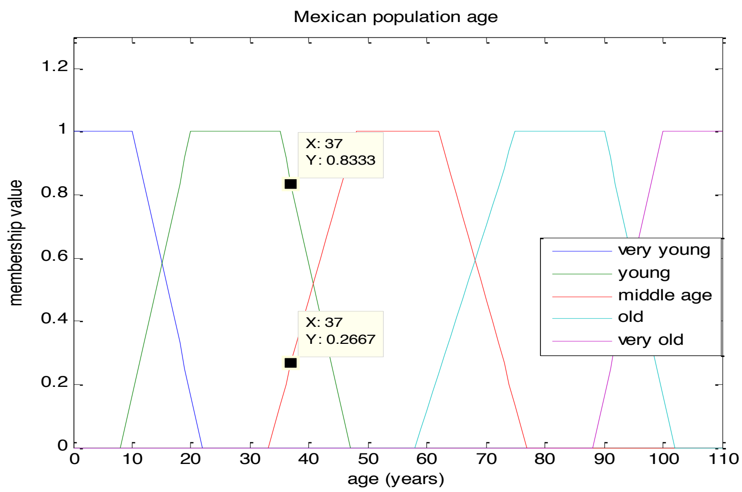

Fig. 2. Example of membership values for 5 fuzzy sets representing the age of Mexican population

The fuzzy system described in this work uses trapezoidal functions because they appropriately represent the fuzzivity of the cases used with a low computational cost. The trapezoidal function is defined with 4 parameters {a, b, c, d} as described in equation 2 [6]; where the parameters {a, b, c, d} determine the four corners that define the trapezoid.

$$trapezoidal(x; a, b, c, d) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ 1, & b \leq x \leq c \\ \frac{d-x}{d-c}, & c \leq x \leq d \\ 0, & d \leq x \end{cases} \quad (2)$$

A fuzzy inference system is based on the concepts of fuzzy sets, If-Then rules and fuzzy reasoning. Due to the multidisciplinary nature of its applications, a fuzzy inference system (FIS) is also known as fuzzy expert system, fuzzy model, fuzzy associative memory, system based on fuzzy rules or simple fuzzy system [6,7].

A FIS allows grouping several If-Then rules based on fuzzy systems. In this work a Mamdani method was implemented, using the max-min composition method to fuzzify and the centroid method to defuzzify. The rules in the Mamdani method take the form shown in equation 3.

$$R_j\text{: } If\ x\ is\ A_j \text{ then } u \text{ is } B_j,\ j = 1,2,\dots,r \qquad (2)$$

Where $x = (x_1, \dots, x_n) \in X\ and\ u \in U,\ y\ A_j(x) = min_{i=1\dots n}\{A_{ji}(x_i)\}$ for $A_j = A_{1j}x$

The Mamdani method is based then on a set of antecedents that trigger a specific consequence by means of a collection of k propositions of the type If-Then.

4 Development

This section describes the methodology of the algorithm's design. The methodology considered for the development is:

A. Identification of the involved departments for the generation of appointments and to stablish their specific characteristics as well as the general characteris tics of the healthcare center.

The departments to be considered and the general requirements of the system were stablished based on the analysis of the information of a healthcare center in Mexico City, this is shown in Table 1.

Table 1.Requierements of the considered departments.

Department	Schedule	Turn	Assigned appointments
Speciality 1 room	07:30 – 15:00	Morning	In case of first appointment the duration is 45 minutes, for the subsequent is 30 minutes
Speciality 1 room	14:30 – 20:30	Afternoon	
Social work	07:00 – 15:00	Morning	Depends on the number of cases
Cures	07:00 – 15:00	Morning	15 per day
X-ray	08:00 – 18:00	Complete turn (morning and afternoon)	30 per day
Clinical analysis lab	07:00 – 15:00	Morning	50 per day

It is important to determine the facilities and staff available according to the attention level of the clinic. In this case the considered case is a level 1 center with the characteristic shown in table 2 decided based on reported statistics [1-5]. The system was designed to be scalable.

B. To identify the variables involved in each of the departments

Once the information about facilities and attention capacity was known and the requirements of each department analysed, the next step was to stablish the procedure to assign an appointment. The procedure starts with the first appointment of the patient that wants to be attended in the clinic where it is decided the required speciality. Therefore the first appointment is always programmed in manual form. The patient is assigned to a specialist according to the availability. Then, the subsequent appointments will depend on the medical diagnosis.

Table 2. Typical facilities for a level 1 clinic in Mexico City.

Department	Number of consulting rooms
Clinic Records	1 attention module
Speciality 1	3 consulting rooms
Speciality 2	5 consulting rooms
Speciality 3	4 consulting rooms
Social work	1 area
Cures	1 area
X-ray	1 room
Clinical laboratory	1 laboratory shared with another speciality clinic

The FIS takes into account only level 1 clinics, with 3 different specialities. Urgencies do not exist, however, in some cases the specialist wants his patient to be attended in a specific manner due to the disease. This is the reason of proposing a priority index in which the attention times were categorized for the three specialities as shown in Table 3.

Table 3. Ranges of priority per speciality

Priority function	Time
High	1 day
Normal	1 week
Low	1 month or more

The generation of automatic appointments was limited to those subsequent because it is case when there is several department consideration. In order to know the needs, a visit to a public health clinic, in Mexico City, was made to observe the care protocol. Table 4 shows the considerations for the generation of appointments.

C. Definition of the input variables for the FIS and information reconditioning.

After stablishing the medical departments in which the appointments will be generated it is necessary for the specialities to fix the period according to the treatment, diagnosis and particular characteristics such as age or severity of the disease and also if the patient needs X-ray plates and/or laboratory analysis. All this information will be given by the specialist. The input variables of the FIS were five: 1) Priority for the next appointment; 2) Delivery time for requested clinical analysis; 3) Availability of clinical laboratory; 4) Time for requested clinical analysis and 5) X-ray availability. All these variables are given in time and were defined according to the specifications of the clinic.

Table 4. Considerations for the appointment generation

Department	Turn	Appointments per turn	Duration of the appointment	Appointments attended at the same time
Speciality 1	Morning	34	1 hour	4
Speciality 2	Morning y Evening	17	30 minutes	1
Speciality 3	Morning y Evening	17	30 minutes	1
Laboratory	Queue system	50	Depends on the type of study	Queue system
X Ray service	Queue system	30	20 minutes	1

For instance, the ranges in time for the input Priority for the next appointment were stablished as: 1) *Very immediate*: limits the appointments between 1 to 3 days after the last generated and confirmed appointment; 2) *immediate*, limits the appointments between 2 to 14 day; 3) *Short term*, limited between 10 and 30 days; 4) *long term*, all those generated for 35, or more, days after the last appointment. These 4 intervals are transformed into trapezoidal membership functions to be inputs for the fuzzy inference system.

The ranges in time for Delivery time for requested clinical analysis were: 1) *None*: when no analyses are requested; 2) *Less than a week*: when the analyses requested take less than a week to deliver results and 3) *More than a week*: when the analyses requested take a week or more. In a similar manner, the other 3 variables ranges in time were stablished.

D. Definition of the output variables

The identified outputs for the system were three: 1) Speciality office optimum schedule, 2) Clinic laboratory optimum schedule and 3) X-ray service optimum schedule. The first and the third variables are given in minutes since the appointments are given in specific times and the duration of each appointment depends on the characteristics of the department, facility and capacity, as shown in table 4. The time of laboratory optimum schedule is given in days since the laboratory works only the first hour in the morning and all patients are asked to be at 7 o´clock. The three output variables were separated in three trapezoidal membership functions as short-term, mid-term and long-term.

E. Generation of the inference rules of the FIS

In order to generate the outputs is was necessary to generate 576 inference rules that correspond to the combination of all membership functions from each input variable. The max-min method was selected to fuzzify and the centroid method to defuzzify. The inference rules were created considering all the requirements and also the official work schedule in Mexico to take into account the days off.

F. Integration of the FIS to the general system for appointment generation

The FIS was design modular so it can be integrated, when it is required, to the general system responsible for the generation of appointments in the kiosk.

A quality of the algorithm is the use of the concept of priority in the clinical laboratory since the appointments are generated according to the specialist indications and at the same time taking into account the time needed to have the analysis results and X-ray result which are defined by the staff availability and capacity of the equipment. All of them define the next appointment and not as commonly done, according to the patients' arrival.

5 Results and evaluation

The integration of the system allows managing the appointments according to the traditional way of patients' care but considering three specialities, clinic laboratory, X-ray, social work and cures specific conditions.

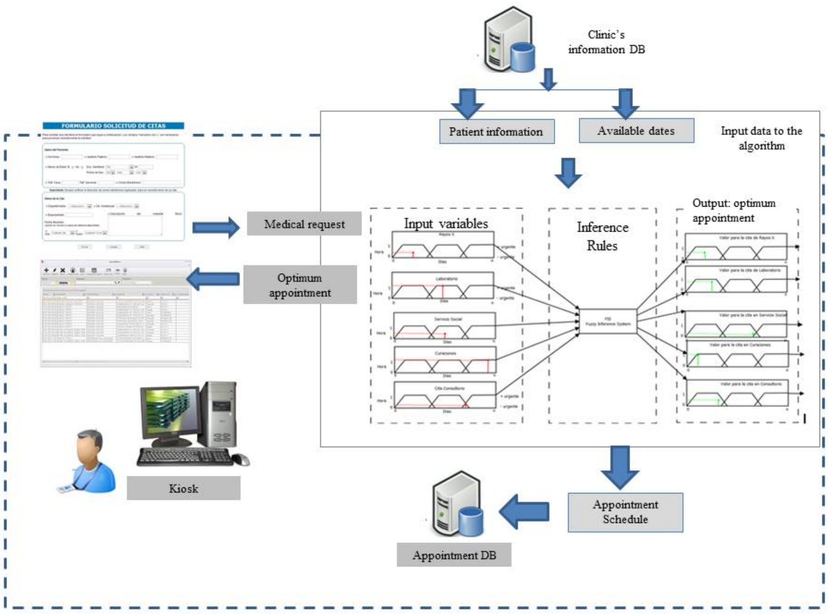

Fig. 3. Design of the informatics system for appointment generation.

Once the department criterion was stablished, the membership functions ranges were defined for the five input variables and the three output variables summarized in tables 5 and 6. For the definition of the inference system 576 rules were used the Mamdani method [6,7]. The algorithm of the FIS module was simulated and evaluated in an exhaustive way using a simulated clinical database, which allowed to adjust the membership functions and the rules according to the priority, capacity of the department and schedule for the next appointment request of the physician.

The appointment assignation was proposed consulting the database of the simulated clinical records, administrative records of the specific department and then evaluating the algorithm's inputs. The kiosk has several simultaneous tasks that modify the status of the of the appointment data base, until it is confirmed by the person in charge. The complete process is done through a Web page as shown in Figure 3.

Table 5. FIS Input Variables

Priority for the next appointment	
Very immediate	Trapezoidal(0,0,1.5,3)
Immediate	Trapezoidal(1.5,2,10,14)
Short term	Trapezoidal(10,14,21,30)
Long term	Trapezoidal(35,40,60,60)
Delivery Time for requested clinical analysis	
None	Trapezoidal(0.5,0.5,1
Takes less than a week	Trapezoidal(0.5,1,29,32)
Takes a week or more	Trapezoidal(29,32,35,35)
Availability of clinical laboratory	
Short term	Trapezoidal(0,0,7,14)
Mid term	Trapezoidal(10,20,30,40)
Long term	Trapezoidal(30,40,50,50)
Time for requested clinical analysis	
Short term	Trapezoidal(0,0,10,15)
Mid term	Trapezoidal(12,15,25,32)
Long term	Trapezoidal(28,33,50,55)
Very long term	Trapezoidal(50,55,60,60)
X-ray availability	
Short term	Trapezoidal(0,0,14,20)
Mid term	Trapezoidal(15,20,30,40)
Long term	Trapezoidal(35,40,55,65)
No plates	Trapezoidal(55,65,70,70)

Table 6. FIS output variables

	Speciality Optimum Schedule (minutes)	Clinical Analysis Optimum Schedule (days)	X-Ray Optimum Schedule (minutes)
Short term	Trapezoidal (0,0 ,14400,20160)	Trapezoidal (0,0,7,12)	Trapezoidal (0,0,10080,17280)
Med term	Trapezoidal (14400,20160,30240,43200)	Trapezoidal (7,12,19,28)	Trapezoidal (10080,17280,27360,40320)
Long term	Trapezoidal (20240,43200,86400,86400)	Trapezoidal (14,28,60,60)	Trapezoidal (27360,40320,86400,86400)

The person in charge observes in the monitor a calendar that allows him to move among the days and choose the optimum schedule provided by the algorithm or a further time. The displayed information is the day and time of the appointment, complete name and identification number of the patient, complete name of the specialist and the department for which the appointment is generated. As an additional tool the system allows to generate an appointment for social work and register it in the appointment database.

The user of the system is the person in charge of the kiosk, who is able to generate the appointment and also the personal in charge of the different departments and the specialists that can consult the appointments. Every time an appointment is generated, the patients' card is updated and also the appointment data base. The obtained result from the algorithm is the optimum according to the established rules, but it may be the case that the patient does not accept the schedule because personal reason so a manual selection can be carried out for a later day or time.

6 Conclusion

The proposal of modular design permits the creation of new departments or the selection of those that will be included in the algorithm. The procedure here described was based on a real case but tested with a simulated database. This allowed to evaluate the feasibility of the design both, from the expert system based on a FIS system, and from the complete system as a service algorithm for appointment generation.

The preliminary test, with the simulated data base from the clinical and administrative recordings from the analysed healthcare center was a valuable tool for the evaluation of the design.

The proposed system design counts with a Web page but the expert system can be integrated to another service as a modulus, which permits to evaluate the real efficiency in any specific healthcare center.

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