A Genetic Neuro Fuzzy Approach for Handling the Nurse Rostering Problem

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ABSTRACT

Nurse scheduling is a complex task that arises in everyday activities at hospital system. Most of the scheduling problems are Non Deterministic (NP)-hard. The nurse rostering problem is a subclass of the personnel scheduling problems. Various techniques have been applied to solve this problem but the issue of using constraints to generate roster still exists. In this paper hybrid soft computing technique was proposed, comprising of Genetic Algorithm and Adaptive Neuro Fuzzy Inference System. Genetic algorithm was used in optimizing the roster and the Adaptive Neuro Fuzzy Inference System was used to generate rosters based on the rostering constraints of the hospital. The combination of these soft computing techniques will improve flexibility, increase effective handling of uncertainty in roster generation and allow the generation of nurses roster using constraints.

(Keywords: nurse rostering; genetic algorithm; neuro-fuzzy system)

INTRODUCTION

A shift is a period of time in which a group of employees are rendering services. Most organizations providing a round the clock service divide its daily work into consecutive shifts. In such an organization, an employee is assigned to the set of shifts, which satisfies several constraints that may be set up by staffing requirements and labor contract clauses (Kim, et al., 2014).

The application of shift processes have been explored in several organization and institutions with the health sector having noticeable benefits such as productivity enhancement of each individual nurse due to reduction in working time and work load. It is not new that healthcare organizations have to provide patient with round the clock health care service delivery with health care nurses been at the fore front of such delivery (Gold, et al., 1992). Due to the demand for such nurses and the tremendously growth of patients, a disproportionate work ratio have been created among individual nurses. It has also been observed that fatigue and lack of productivity have hampered efficient healthcare delivery in most hospitals (Tatjana, et al., 2013). Due to the aforementioned issue and the associated costs, adoption and implementation of roster was proposed to enhance nurses' productivity.

A nurse roster is a weekly or monthly plan for all nurses in a hospital, and is obtained by assigning shift categories to the nurses (Balekar and Mhetre, 2013). Creation of a roster is indeed a complex task. Many constraints have to be taken into consideration and their importance carefully balanced. Nurse scheduling represents a task which consists of creating a schedule for the nurses in a hospital.

The Nurse Rostering Problem (NRP) is a common problem every hospital faces every day (Balekar and Mhetre, 2013). NRP belongs to personnel scheduling problems and it requires provision of an optimal schedule based on the working hours of the nurses, their personal choices to shift types, hospital rules and government laws (Burke, et al., 2004). Generally, constraints are put forward by regulations, working practices and the preferences of the nurses (Brucker, et al., 2005).

In the University of Benin Teaching Hospital (UBTH), this problem is not eliminated as observed through survey techniques utilizing interview in eliciting interviewee responds. It is also observed that rostering process is done manually by highly qualified nurse administrator predominantly a Chief Nursing Officer (CNO) whom might also be a ward manager and thus requires time and involvement of the personnel thereby limiting the needed organizational resources. The manual approach has also created some issues such as some employee working more than the stipulated hours while others worked for less and bias in the part of the ward manager. With these issues, there is need to develop an efficient algorithm for generating roster for nurses and obtaining an optimal schedule in shorter time.

Genetic Algorithms (GA) have proved to be an efficient algorithm for finding near optimal solution to a scheduling problem and the Adaptive Neuro Fuzzy Inference System (ANFIS) have shown to be capable of learning and generating predictions based on inputs. In this study, a hybrid model comprising of genetic algorithm and Adaptive Neuro Fuzzy Inference System (ANFIS) for predicting and generating optimal nurses roster for University of Benin Teaching Hospital (UBTH) Nursing Services Department was proposed.

REVIEW OF RELATED WORKS

In nurse rostering, the ultimate aim is to create high quality roster, considering the well-being of nurses and the operational concerns of the employers (Ozcan, 2005). Over the years, researchers have used various techniques to implement solutions for staff scheduling problem.
Previous attempts to solve nurse rostering problems were focused on optimizing integer programming solutions (Warner, 1976; Arthur, et al., 1981; Musa and Saxena, 1984; and Ozkarahan and Bailey, 1988) although attention was placed on constraint programming approach (Lazaro and Aristondo, 1995; Cheng, et al., 1996).

In 1997 John and Abdul proposed an integer programming (IP) approach to develop a flexible and reliable nurse rostering system. In their work the problem constraints were formulated as a set of simultaneous equations using 0 or 1 decision variables. Then they used an IP algorithm to find the maximum value of an objective function, whilst satisfying all hard constraints. The results of the experiment showed that the average schedule generated was considerably close to an ideal 5 days on and 2 days off schedule, than the average manually developed schedule.

More recent attention has been placed on linear programming approach (Satheesh, et al., 2014). In 2014, Satheesh and colleagues proposed a shift sequence for nurse scheduling using linear programming technique. Their aim was to maximize the fairness of the schedule, while respectively satisfying all the constraints. The result showed that the method was able to maximize the fairness of the schedule for 295 nurses. However, It lacks flexibility and is unable to reliably solve larger problems which are the major concerns of mathematical programming techniques (Cheng, et al., 1996; Chow and Hui, 1993; and Dhar and Ranganathan, 1990), coupled with their need for requiring a great deal of computing resources.

GA has been an efficient tool which has been greatly utilized in solving NRP. Past studies sought ways of capitalizing GA in scheduling problems (Brezulianu, et al., 2010; and Heidari and Chalechale, 2012). To Improve Performance of Genetic Algorithm for Nurse Scheduling Problem, Kim, et al. (2014) used a cost bit matrix of which each cell indicates any violation of constraints. In their work a cell with 1 indicates that the corresponding assignment violates constraints and needs no further consideration. The experimental results showed that the suggested method generated a nurse scheduling faster in time and better in quality compared to the traditional genetic algorithm.

Özgür-Kelemci (2015) applied genetic algorithm to solving nurse rostering problem instance at Fatih Sultan Mehmet Hospital in Istanbul, Turkey. The actual data and the hard and soft constraints for generating the schedules were obtained from the hospital and eleven (11) nurses were used. The constraints have weights associated with them. The GA has a population size of 330 and each chromosome has a length of a month, the uniform crossover operator was employed and the maximum number of generation achieved was 5,000. Tournament selection operator and Uniform mutation operator was used. The result showed that weight method increases the weight of the soft constraints exponentially, so the penalty points of soft constraints decrease and it affects the hard constraints which decreases the performance of the entire system.

John (2015) proposed a staff scheduling approach using Genetic Algorithm with a Two-Dimensional Chromosome Structure for scheduling nurses at a hospital. One solution uses a traditional bit-string chromosome structure to represent each schedule. The other solution uses a two-dimensional array chromosome structure to represent each schedule. The experimental results showed that two-dimensional array staff-scheduling implementation performs better than bit-string staff-scheduling implementation.

Genetic algorithm, although being able to find optimal solution, usually needs a decent sized population and a lot of generations before an optimal result can be achieved. It is also incapable of predicting an optimal solution based on constraints.

A study conducted using Bayesian optimization algorithm was carried out by Jingpeng and Aickelin (2005). They introduced Bayesian network for nurses scheduling problem. Fifty-two data instances were used to train the Bayesian network. In the system rule strings was generated at random from the first population and a set of better rule strings was selected. The traditional roulette-wheel selection was applied. New rule strings were generated by using these conditional probability values, and were added into the old population, replacing some of the old rule strings. The result showed that only 38 out of 52 data sets are solved to or near to optimality.

In another study conducted by Jingpeng and Aickelin (2006) they proposed a scalable optimization via probabilistic modeling for nurse scheduling using Bayesian optimization algorithm. Fifty-two real data sets collected from three wards over a period of 24 months and cover a range of scheduling situations was used to train the system. Each data set consists of one week's requirements for all shift and grade combinations and a list of available nurses together with their preference and qualifications. The BOA was coded in Java 2, and all experiments were run on Pentium 4 2.0GHz PC with 512MB RAM under the Windows XP operating system. The result showed that the BOA had a mean of 39.8, flexibility 100% and a runtime of 23.0 seconds which indicated that a feasible solution was found for all the dataset.

Regardless of the huge success achieved by Bayesian Network, the technique is still based on probability and most of the observed values might not be correct. Secondly Bayesian network requires huge number of analysis for every subset of evidence variable.

Most recent study on optimizing nurses roster was carried out by Yahya, et al. (2017). They used Non Linear Great Deluge Algorithm (NLGDA) in handling nurse rostering problem. The proposed method was implemented in Java, and simulations were performed on 2.8 GHz CPU with 8 GB RAM. For each dataset, the algorithm ran for 10 Seconds based on the competition rules time and each instance was tested 30 times. The result showed that NLGDA obtained one best result on every 17 datasets and was able to reach most of the lower bound values under the competition time provided. And just like GA the method needs a decent sized population and a lot of generations before an optimal result can be achieved. It is also incapable of predicting an optimal solution based on constraints.

PROBLEM DESCRIPTION AND FORMULATION

The ward manager prepares the ward's roster and this is done on a monthly basis. Before the roster is prepared, the ward manager must takes into cognizance the number of nurses to handle each shift, public holiday, requests made and leave bookings (annual and maternity leave) made by the nurses. In preparing the roster, the number of nurses running each shift varies from one ward to another depending on the patient load, staff strength and the days of the week. The ward manager also considers the different cadres running the shift in order to ensure that the ward is covered with senior and junior nurses per time.

CONSTRAINTS

Several constraints were identified and analyzed. The analyzed constraints were divided into two groups, hard constraints and soft constraints, which were determined by their effects on the prepared roster. The hard constrains must be met in all circumstance otherwise the roster is considered to be unacceptable. The soft constraints are used to evaluate the equality of the roster, so they are not compulsory but are desired to be satisfied as much as possible. The constraints identified are as follows:

Hard Constraints

Working Hours Constraint (WHC): This constraint defines the total number of working hours for the nurses within the specified time period.

Shift Constraint (SHC): In each ward, during each shift there must be a minimum number of nurses required to run the shift.

Successive Night Shifts Constraint (SNC): A nurse cannot be assigned to more than eight successive night shifts in a month except for the chief nursing officer who does four night shifts.

Successive Shifts Constraint (SSC): A nurse cannot be assigned to two successive shifts. A day shift (morning or afternoon) in one day and a night shift in the following day are considered as successive shifts

Exclude Night Shifts Constraint (ENC): Night shifts cannot be assigned to the most senior chief nursing officer of the ward

On-Duty Constraint (ODC): Each nurse cannot be assigned less than seven shifts per two weeks. Annual Leave Constraint (ALC): Nurses are given 30 days annual leave in a year.

Maternity Leave Constraint (MLC): Pregnant nurses are given 16 week maternity leave

<u>Soft Constraints</u>

Request Constraint (RC): Nurses can define at most five days request preferences.

Extra Day Constraint (EDC): Each nurse is entitled to an extra day off to make up for the public holidays for each month.

PROPOSED SOFT COMPUTING MODEL

The proposed model for optimizing nurses seeks to eliminate the challenges faced in manual implementation of nurses' roster. It employs the use of Genetic Algorithm (GA) and Adaptive Neuro Fuzzy Inference System (ANFIS). The genetic algorithm would be used in optimizing previous rosters (dataset) to ensure that the constraints are satisfied. The GA component will utilize a value encoding method where part of the genes in each chromosome represents the days of the month. The gene representing the days of a month and will contain values such as M, A, N, NO, DO, ED and PH representing morning shift, afternoon shift, Night shift, Night Off, Day Off, Extra day and Public Holiday, respectively.

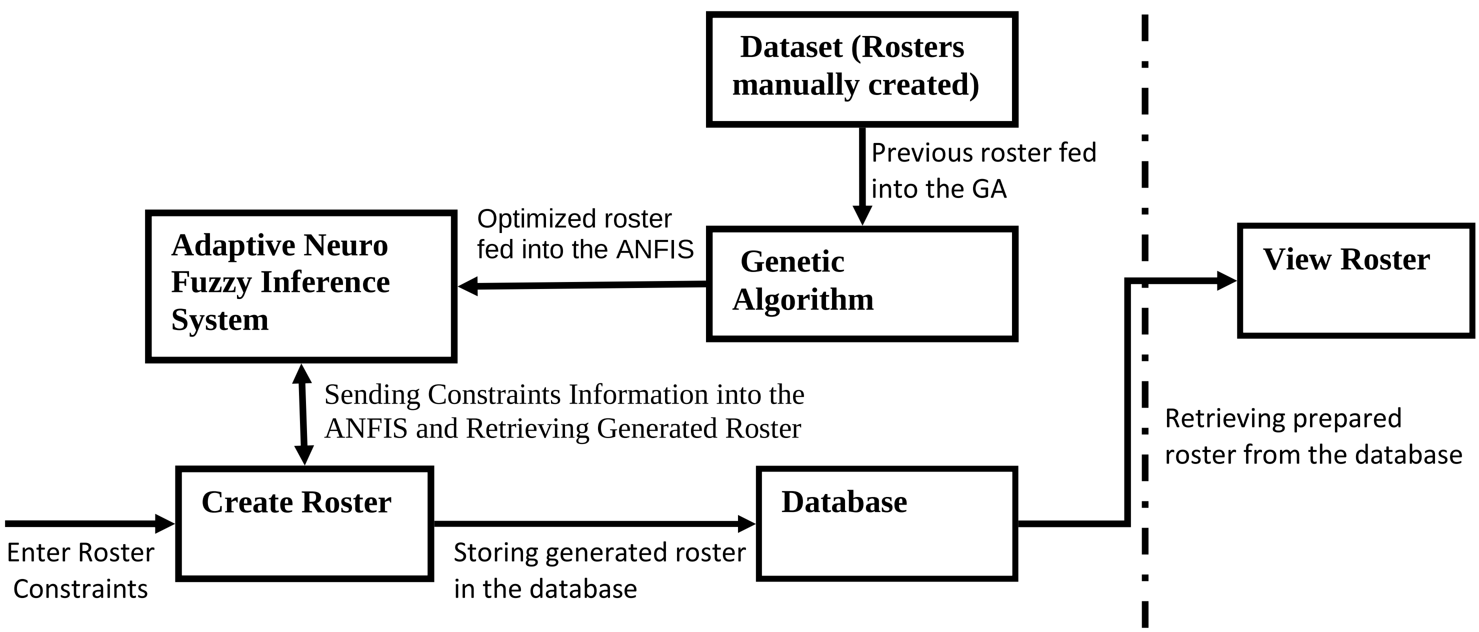

Figure 1: Proposed Soft Computing Model for Optimizing Nurses Roster.

The roulette selection wheel, uniform mutation operator and the two-point cross over method will be employed since it was effective in the study carried out by Kim, et al. (2013). The optimized roster will be used in training the ANFIS. The model will incorporate interface that will allow the ward manager to enter request made by nurses and other constraints for preparing the roster. Using this information the ANFIS generates the rosters and stores it in the database. The proposed model will offer a robust, secure, cost effective and generate efficient nurses roster in a timely and efficient manner.

GENETIC ALGORITHM MODULE

Objective function of the Genetic Algorithm

The objective function will determine if the roster is feasible or not. It will determine if a constraint has been violated and the number of violated constraints. If a hard constraint is violated the roster is regarded as not feasible.

$$\text{WHC (constraint 1)} = \begin{cases} 0 & \text{Workin Hour} \leq 160 \\ 1 & \text{Working Hour} > 160 \end{cases}$$

$$\text{SHC (constraint 2)} = \begin{cases} 1 & \text{number of nurses} < \textit{number required} \\ 0 & \text{number of nurses} \geq \text{number required} \end{cases}$$

$$\text{SNC (constraint 3)} = \begin{cases} 0 & \text{Successive night Shift} \leq 8 \\ 1 & \text{Successive night Shift} > 8 \end{cases}$$

$$\text{SSC (constraint 4)} = \begin{cases} 0 & \text{Not Assigned Successive Shift} \\ 1 & \text{Assigned Successive Shift} \end{cases}$$

$$\text{ENC (constraint 5)} = \begin{cases} 0 & \text{Assigned Night Shift} \\ 1 & \text{Not Assigned Night Shift} \end{cases}$$

$$\text{ODC (constraint 6)} = \begin{cases} 0 & \text{Assigned Shift in two Weeks} < 8 \\ 1 & \text{Assigned Shift in two Weeks} \geq 8 \end{cases}$$

$$\text{ALC (constraint 7)} = \begin{cases} 0 & \text{Granted Annual Leave} \\ 1 & \text{Not Granted Annual Leave} \end{cases}$$

$$\text{MLC (constraint 8)} = \begin{cases} 0 & \text{Granted Maternity Leave} \\ 1 & \text{Not Granted Maternity Leave} \end{cases}$$

$$\text{OFDC (constraint 9)} = \begin{cases} 0 & \text{Rest Days} < 6 \\ 1 & \text{RestDays} \geq 6 \end{cases}$$

$$\text{EDC (constraint 10)} = \begin{cases} 0 & \text{Granted Extra Day Off} \\ 1 & \text{Not Granted Extra Day Off} \end{cases}$$

$$\therefore \text{Objective function} = \sum_{i}^{n} \text{Constraint}_i \,\text{WeightViolation}$$

Where n= total number of constraints i=1,2,3 … n

Fitness Function for the Genetic Algorithm

The fitness function should be able to measure how fit a given chromosome is. The fitness for the proposed model is given below

$$\text{fitness function} = \sum_{i}^{\text{Number of days in a month}} (\text{Shift}_{type} * \text{Shift}_{value})$$

Where

Number of Days in a month=31

I=1,2,3 …, 31

Shift_{type}=Gene representing the days of a month such as M, A, N, NO, DO, ED and PH

Shift_{value} = Hour value for Shift_{type}

Procedure GA

The following algorithm will be used in optimizing the dataset:

1. Start with n nurse roster

2. Calculate the fitness f(y) of each nurse schedule (y) in the population.

3. Repeat the following steps until objective function is achieved.

(a) Select a pair of nurse schedule p1 and p2 from the current population with the probability of selection that is an increasing function of fitness.

(b) With probability Pc (crossover probability), cross over p1 and p2 at the middle to form two children. If no crossover takes place, form two children that are exact copies of their respective parents.

(c) Mutate the two children with probability Pm (mutation probability) and place the resulting chromosomes in the new population.

4. Replace the current population with new population.

5. Go to step 3 until a desirable solution is found or the maximum number of generations is completed.

Adaptive Neuro Fuzzy Inference System Module

This optimized dataset will be fed to this module, the gene values of the optimized dataset will be substituted with numeric value representing the duration of the shifts and in cases with NO, DO, ED and PH the duration will be 0. The ANFIS will have 10 inputs each corresponding to the number of constraint used in creating the roster and 31 outputs corresponding to the maximum number of days in a month. The Gaussian Membership function will be used in the membership function layer because it has been shown to generate the best results in studies conducted by Kavitha and Naidu (2011) and Noureen, et al. (2017).

CONCULSION

The nurse scheduling problem is a Non Deterministic (NP) hard scheduling problem inundated with several fuzzy complicating features. In organizations providing round the clock services, where productivity is of immense significance, conscientious attention must be given to the preparation of staff roster. When considering a medical institution where care that nurses render to patients depends on the quality of the roster then the need for a reliable and efficient rostering model cannot be over emphasized. In this research a model for generating nurse's roster was proposed. The model incorporated Genetic Algorithm (GA) and Adaptive Neuro Fuzzy Inference System (ANFIS) which would both be used for optimizing the roster and training the system respectively.

The proposed soft computing model will be capable of generating efficient rosters based on constraints and this will further improve the quality of services rendered by the nurses.

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