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Design of an Information System for optimizing the Programming of Nursing Work Shifts

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Abstract. Health institutions operate twenty-four hours a day, seven days a week. They face a demand that fluctuates daily. Unlike jobs with fixed hours and obligatory days off, in health, operational continuity is required. The allocation for nursing shifts generates a rotation of people for health services according to legal and casuistic guidelines. Assigning and planning shifts results in a workload that takes an average of five to six extra hours. Existing applications offer a partial solution because they do not consider the news and contingencies of a health service. A web application is presented that, given a list of nurses, historical shifts and restrictions, a work shift planning is generated. This application comes to support the current shift allocation method based on electronic spreadsheets. The development consists of two modules. The first module has a shift allocation algorithm developed in C ++ and the second module has a graphical interface. As a case study, a set of health services from Chile and Colombia was used. The services have a defined number of nurses, who work different shifts according to the role and need of the institution. The results obtained are similar to a historical one. The proposed system takes less time and delivers various files and parameters that can be useful for nurses, the service and the health institution.

1. Introduction

Health institutions are facing various challenges, in which they increase economic pressure and demand for care challenges. One of the outstanding problems in health care operations is the problem of the allocation of work shifts [1].

The Nurse Rostering Problem (NRP) is a problem of the NP-Hard class [2].The problem involves making the allocation of work shifts, days off and vacations for nurses [3] [4]. The NRP faces a variety of constraints that hinder the goal of optimizing shift allocation [5]. Among them are number of personnel versus required personnel; maximum monthly work hours; maximum number of workable hours and days off [6].

There are several restrictions that vary according to the country and corresponding labour legislation [7]. Therefore, there are various solutions to the NRP, each according to the needs of each institution and country [8] [9].

NRP has been the focus of study since the 1970s when the first studies on the problem emerged [10]. In [10] after studying a hospital unit, they propose a solution focused on minimizing an objective function that balances compensation of personnel coverage and personal time preferences. That same year, [11] proposes a solution to the problem, whose objective function to quantify the preferences of

the staff versus the time of work estimation, with rotation patterns and requests for free days, takes as restrictions the number of personnel and the change of rotation [12].

For NRP, new algorithmic approaches and developments of computer systems that facilitate the task of assigning shifts to arise. In spite of the above, the personnel in charge of assigning shifts prefer to perform this task manually [13]. The task of assigning shifts takes five hours on average, this scenario is affected when a nurse must be absent [14] [15]. Thus, an immediate reprogramming is required without overloading the remaining staff [16]. Based on the foregoing, it can be assumed that a quick way to deal with this situation is to offer extra shifts to the rest of the staff, but this sometimes exceeds the legal limit and may even generate additional costs for the institution [2] [17].

The research focus of this study is focused on contributing to improving the efficiency of the work shift programming and scheduling tasks through the development and implementation of a web application that automates the process and significantly reduces the time spent on this task.
This document presents in its structure a case study used for the analysis, the solution technique used, then the graphical interface and the technical architecture used are presented, finally, the results and conclusions are presented.

2. Case Study

The base scenario for the development of the web application, establishes a nursing service with five nurses, each with their own preferences for the request of free days and vacations [18] [19] [20] [21] [22][23][24]. It must be considered that any nurse at any time may present a medical license of an indeterminate length. External constraints define labor laws and the number of nurses available versus the minimum number of nurses for the service to function normally [6] [25] [26]. These restrictions will serve as input to develop an algorithm that performs a shift assignment taking into account the available constraints [27]. Figure 1. shows an example of how the work shift programming was carried out without any computational help. This manual assignment included Day Shifts (D), Night Shifts (N) and days off (-).

ENERO	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	L	M	M	J	V	S	D	L	M	M	J	V	S	D	L	M	M	J	V	S	D	L	M	M	J	V	S	D	L	M	M
Francisca Torres	D	N			D	N			D	N			D	N			D	N			D	N			D	N			D	N	
Africa Fuentes	N			D	N			D	N			D	N			D	N			D	N			D	N			D	N	
Inés Tapias		D	N			D	N			D	N			D	N			D	N			D	N			D	N			D	N
Mariela Capurro			D	N			D	N			D	N			D	N			D	N			D	N			D	N			D
Francisca Torres	D	N	-	-	D	N	-	-	D	N	-	-	D	N	-	-	D	N	-	-	D	N	-	-	D	N	-	N	-	-	-
Africa Fuentes	N	-		D	N	-	-	D	N	-	-	D	N	-	-	D	N	-	-	D	N	-		D	N	-	-	D	N	N	-
Inés Tapias	-	-	N	N	-	D	N	-		D	N	-	-	D	N	-	-	D	N	-	-	D	N	-	-	D	N	-	-	D	N
Mariela Capurro		D	D	-	-	-	D	N	-	-	D	-	-	-	D	N	-	-	D	N	-	-	D	N	-	-	D	-	D	N	D
Margarita Vásquez																															
Vanessa Quispe												N																			

Figure 1. Example of a manual work shift programming.

3. Methodology

3.1 Solution Architecture

A three-layer architecture was defined as shown in Figure 2, the presentation layer corresponds to the user interface, displayed in the web application format. The second layer corresponds to the logical layer, where the allocation algorithm generates the monthly and weekly planning for the nurses of a service. The first two layers communicate with a third layer, where the data of an Access control list is stored according to the case study, this ensures that users cannot see information and plans from other users of other health institutions.

We chose to use this type of architecture because it offers extensible benefits to the needs of health services. The three-layer architecture allows developers to modularize and expand the application, in addition, the costs of implementing new functionalities are reduced, this is because the implementation of three independent layers between them allows making changes on one of them without unnecessarily affecting the others [28].

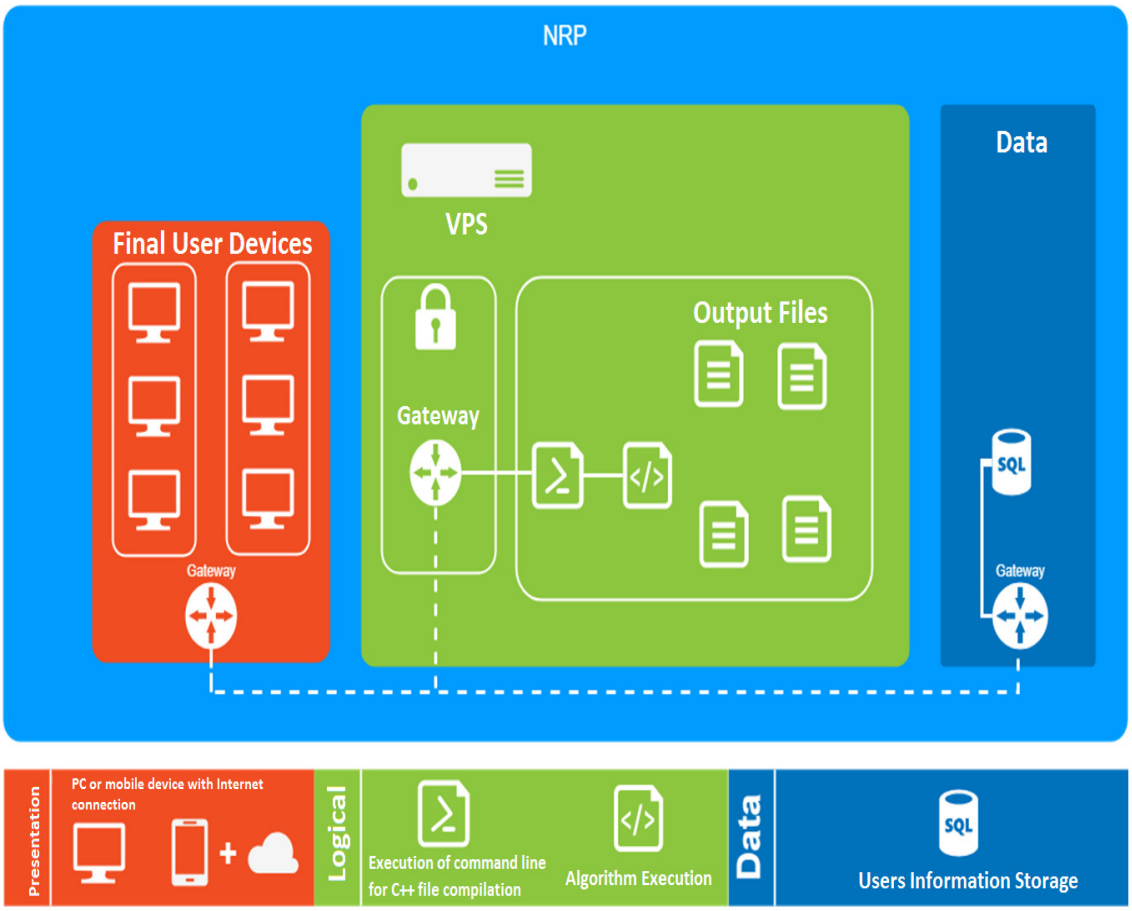

Figure 2. Technological architecture.

3.2 Solution Algorithm – Logical Layer

The proposed solution consists of an algorithm developed in C ++, whose pseudocode is shown in Figure 3, which receives 2 files as input, one of them corresponds to the nurses list with their respective preferences and the second, a configuration file, the which defines the internal variables of each service as shown respectively in Table 1.

3.3. User interface – Presentation Layer

A web module was developed (figures 4 and 5) to facilitate the use of the system by final users.

The web application is completely in Spanish. The interfaces were designed for data acquisition the content and functionality, complying with the quality standard established by ISO 25000 [29].

As shown in Figure 3, the option is shown when selecting a file to upload, there is the option to modify it, in a more intuitive way than to modify the input file directly, prioritizing the usability of the system, in addition to this way the nurse in charge of the assignment of shifts does not make mistakes when entering the desired information.

Attributes of functionality, maintainability, efficiency, usability, and portability stand out as attributes of quality. This in relation to the non-functional requirements developed.

```
1   Inputs: personal.csv, config.
2   Output: planification.csv
3   Start
4   While Last day of the month condition is not met Do
5       While Unassigned nurses in a daily work shift > 0 Do
6       If the nurse is available for assignment Then
7           If the nurse has no assignments Then
8               Assign a work shift
9               Go to Line 5
10          End If
11          If the nurse has assignments Then
12          Analyze if assignment is possible according hours and consecutive work shifts.
13          Assign work Shift
14          Go to Line 5
15          End If
16      End If
17      If Number of nurse and the work shift have no changes Then
18      Assign an extra work shift to the nurse with less hours and less extra works shifts.
19      End If
20      If No extra shifts was assigned Then
21      Update the list of required float nurses
22      End If
23      If there is remaining nurses with no assignments Then
24      Schedule the nurse as Day Off.
25      End If
26      End While
27      Go to the Next day of the month
28  End While
29  End
```

Figure 3. Proposed Solution Algorithm

Table 1. Available configurations

Type of configuration	**Data**
Maximum number of hours per day	Integer number between 0 and 24
Maximum number of hours per week	Integer number between 0 and 168
Types of shifts	List of elements separated by comma, in the following order: ShiftID (integer), the name of shift (String), Duration in hours (integer)
Shifts that cannot be preceded by other shifts (combinations not valid)	List of elements separated by comma, in the following order: ShiftID, ShiftID which cannot precede.
Combinations of valid turns	List of elements separated by comma, in the following order: new ShiftID, ShiftID 1, ShiftID 2, ..., ShiftID n
Requirements of shifts per day	List of elements separated by comma, in the following order: ShiftID, integer number indicating the number of nurses for shift on Monday, integer number indicating the number of nurses for shift on Tuesday, integer number indicating the number of nurses for shift on Wednesday, integer number indicating the number of nurses for shift on on Thursday, integer number indicating the number of nurses for shift on Friday, integer number indicating the number of nurses for shift on Saturday, integer number indicating the number of nurses for shift on Sunday

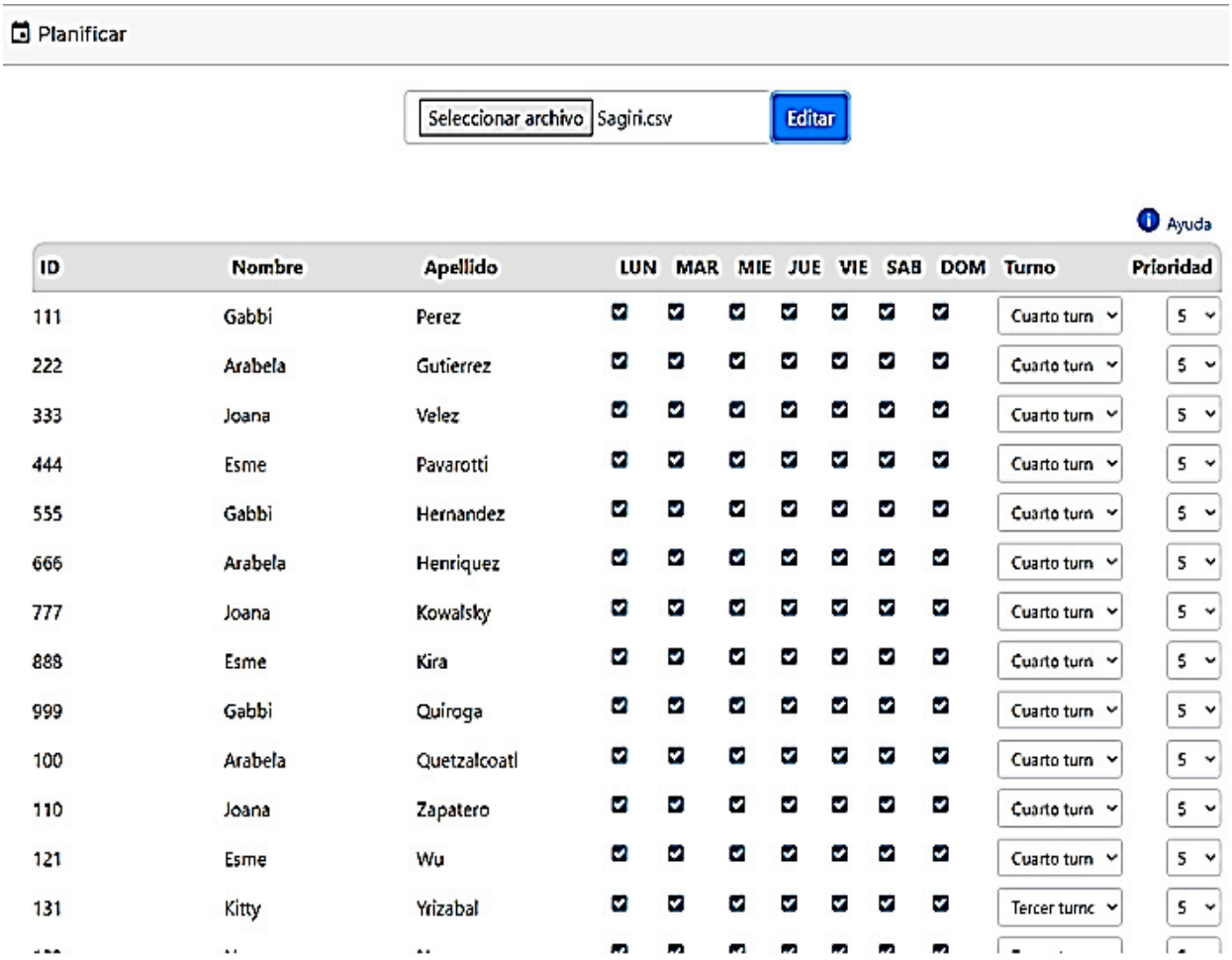

Figure 4. Input file example.

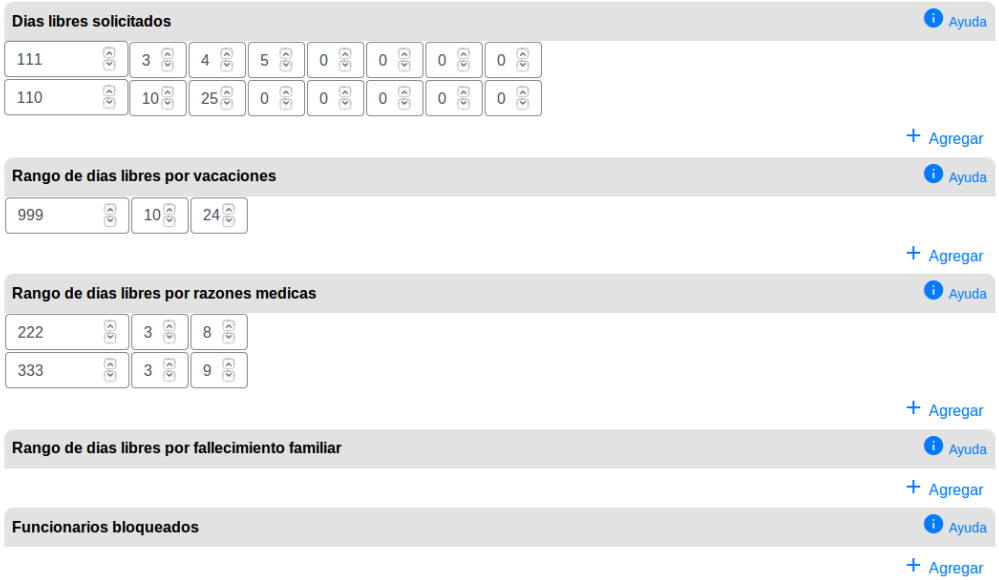

Figure 5. User interface example.

4. Results

To carry out a validation of the system, a real nursing service was used, the objective was to obtain results similar to a manual assignment.

Figure 1 shows hand-made planning, the top part shows what was planned at the beginning of the month and in the part below it shows the result at the end of the month.

An input file was defined with the list of nurses and some constraints like the one shown in figures 2 and 3 to obtain a monthly shift plan.

ID	Nombre	VIE	SAB	DOM	LUN	MAR	MIE	JUE	VIE	SAB	DOM	LUN	MAR	MIE	JUE	VIE
2		NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE
3		LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE
4		LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE
5		LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO
6		DIA	LIBRE	LIBRE	DIA	DIA	DIA	DIA	DIA	LIBRE	LIBRE	DIA	DIA	DIA	DIA	DIA
7		LIBRE	LIBRE	SOLICITUD	SOLICITUD	LIBRE	LIBRE	SOLICITUD	SOLICITUD	LIBRE	LIBRE	SOLICITUD	SOLICITUD	LIBRE	LIBRE	SOLICITUD
8		LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE

Figure 6. Output file (1/2).

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
SAB	DOM	LUN	MAR	MIE	JUE	VIE	SAB	DOM	LUN	MAR	MIE	JUE	VIE	SAB
LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE
LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO
LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE
NOCHE	LIBRE	LIBRE	INCAPACIDA	INCAPACIDA	INCAPACIDA	INCAPACIDA	INCAPACIDA	INCAPACIDA	INCAPACIDA	LIBRE	LARGO	NOCHE	LIBRE	LIBRE
LIBRE	LIBRE	DIA	DIA	DIA	DIA	DIA	LIBRE	LIBRE	DIA	DIA	DIA	DIA	DIA	LIBRE
LIBRE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LARGO	NOCHE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE
LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE	LIBRE

Figure 7. Output file (2/2).

When uploading the generated file to the system, resulting in a plan as shown in illustrations 6 and 7, which, when comparing both schedules, the system delivered similar results to the planning done in Figure 1.

When performing a more detailed analysis, it can be seen in figure 1, that the assignment for the first nurse of the list is that corresponding to the nurse with ID 2 of figures 4 and 5, it is exactly the same, with the difference that Figure 1 shows an anomaly in the structure of shifts between days 28 and 31, where the nurse performs a night shift when it does not correspond and is assigned an extra day off.
Another case to analyze is that of the nurse with ID 5 of figures 6 and 7, which corresponds to the fourth nurse of the list in figure 1, by way of proof this nurse was assigned a medical license between days 19 and 25 (figure 6) this medical license was specified by the system as shown in figure 5 , the objective of this was to observe the behavior of the allocation algorithm to adapt to the minimum personnel requirements required daily, in this case it was not necessary allocation of extra work shifts to other nurses.

5. Conclusions and Future Work

The software architecture is portable, manageable, with reusable components, and allows modifications and extensibility, as well as being scalable. This is due to a set of layers interacting with each other, which have interfaces to communicate with other services.

The developed product is extensible and can be implemented in similar areas. As future work, it is planned to include new restrictions such as the time an nurse takes from his home to his place of work, work with historical records to avoid repeating the same shifts from one year to the next in an nurse and implement new functionalities to the Web Application.

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