Information Technologies and Analytics as Decision Support Systems in Hospital Logistics: Four Research Experiences in the Colombian Case

VICTORIA EUGENIA OSPINA, ANDRES FELIPE CARDONA
Escuela Colombiana de Ingeniería Julio Garavito
AK.45 No.205-59, Bogotá.
COLOMBIA
Victoria.ospina@escuelaing.edu.co
Andres.cardona@escuelaing.edu.co

WILLIAM J. GUERRERO
Facultad de Ingeniería, Universidad de la Sabana
Campus del Puente del Común, Km. 7, Autopista Norte, Chía
COLOMBIA
William.guerrero1@unisabana.edu.co

Abstract: - This article presents four research experiences in hospital logistics using simultaneously mathematical models and information management. The cases analyzed included the efficient scheduling of nursing shifts, kidney exchange programs, the design of medical equipment maintenance policies, and the design of rapid response tools for cardiovascular accidents. The problems found are presented and the technological solutions developed are described. The results obtained show the importance of combining information management and optimization models in the four cases in question. Future work includes the collection of historical data to fine-tune and improve the performance of the solutions developed, and as such to predict the behavior of the logistics systems studied.

Keywords: - **IoT, healthcare, analytics, hospital logistics, knowledge management, optimization**

1. Introduction

Information technology (IT) plays an increasingly important role in the health sector. A multitude of technological solutions are available to health establishments, service providers, patients, and the general population. Amongst the solutions cited are health organizations' clinical management systems, patient management, health service management, diagnostic support applications, and medical treatments [1]. There is also an impressive ensemble of tele-medicine, tele-appointments, tele-diagnosis, and tele-treatment that seek to offer greater access to health services to geographically-scattered patients. See [2] [3].

Finally, there are multiple mobile applications that enable access and information transmission for patients, physicians, nurses, ambulances, and devices from anywhere. The internet of things (IoT) and cell phones are another important component in technological support for medical assistance; a huge volume of data is generated by the aforementioned applications and may be very useful in decision making. [4].

Finally, a collection of optimization models has been developed to design and manage hospital supply chain processed and the provision of health services [5]. Amongst these, hospital logistics models seek efficient and effective management of resources, people, and information in order to provide health services. Included in these models there are medication inventory management models and models for blood-derived products, as well operation room scheduling models and models for patient transport, etc. [6]-[7]. Nonetheless, few of these models take into account knowledge management theories or the business architecture required for the application of the models themselves. Nor do they take complete advantage of data in the way that analytics models do.

The integration of technological solutions into optimization models strengthens health solutions in which the safety of patients' private information and efficiency when making decisions that may affect patients' quality of life and the speed of their recoveries is of utmost importance.

This article's contribution is to present four research experiences in which analytics, IT, and mathematical models in the health service provision sector has significant room for improvement in their logistics systems' main performance indicators. The solutions developed can be seen on the corresponding webpage:

http://decanatura.is.escuelaing.edu.co/~nodosalud/nodo-salud/.

In section two of the article a technological tool for the optimization of nursing shift scheduling is described. Section three analyses the context of organ exchange programs, with an emphasis on kidney exchange. Section four describes a model for the optimization of medical equipment maintenance policies. Section five summarizes the experience acquired with regards to the logistics required for rapid responses to cerebrovascular accidents (CVA) (strokes) that occur outside of medical institutions. Finally, section six presents conclusions and future work to be done.

2. Experience 1: IT Solutions for Nursing Shift Scheduling

Nurses are a resource of utmost importance for operations in any clinic or hospital. The problem with nursing shift scheduling consists of determining the sequence of shifts that each nurse will work within a timeline of seven (7) to ten (10) days. Nurses in Colombia are regularly assigned a morning shift (6:00am to 2:00pm), an afternoon shift (2:00pm to 10:00pm), or a night shift (10:00pm to 6:00am) every day. Clearly, a nurse who has worked a night shift must not then work the following morning shift. Additionally, rest shifts must be scheduled to prevent personnel burnout.

There are also other conditions that must be taken into account. For example, for each shift and work unit must have sufficient nursing staff to cover patient needs and to support the doctors on shift.

This issue is of special interest for Latin American hospitals where nursing personnel is scarce, and professional absenteeism, and staff turnover are relatively high among nurses. An effective scheduling method must find a balance between personnel workloads, must ensure that the same nurses are not always assigned to night shifts, and must enable nurses to obtain a balance between their personal and professional lives. Moreover, scheduling should also provide nurses with shift stability so that they can regulate their sleep cycles.

The scientific literature presents a range of mathematical models and algorithms focused on shift scheduling for nurses and, in general, for all types of personnel [6], [8].

The use of information technology for this predicament is relevant given the complexity of the problem when there is a large number of staff involved. Many hospitals used methods based on the head nurses' experience to schedule shifts. In our experience, few institutions use applications and technology that allow medical staff management or have optimization algorithms associated with decision making related to staff shifts.

The solution that we have developed is a tool that adapts to the needs of hospital institutions and ensures that nurses' subjectivity is not needed to choose work shifts. On the contrary, this system seeks a balanced workload for all nurses and minimizes burnout. In addition, the tool can be adapted to different institutional policies. For example, the percentage of nurses desired for assignation to each shift can be set as can breaks. The number of work days and days off per nurse can also be fixed. The tool can also be adjusted so that nurses can not be assigned shifts for more than four consecutive days (or more).

Mathematically, the main decision variable is a binary variable that indicates if a specific shift should be assigned for each nurse [9]. Fig. 1 shows an example of a solution found for the problem, shown in the application. For each day of the week, each nurse is assigned a unique shift or shift off in such a way that burnout is minimized.

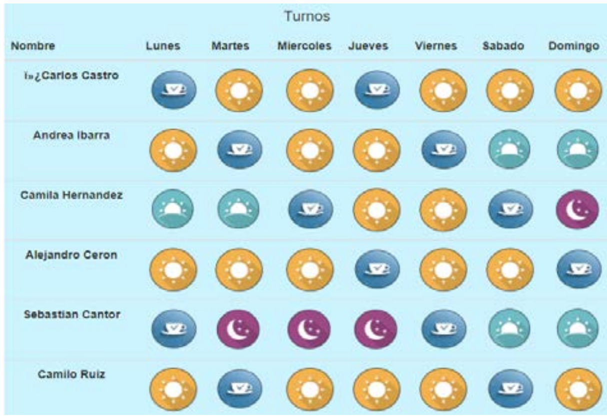

Fig 1. Example of a solution obtained for the scheduling of eight (8) nurses' shifts.

The tool developed permits automatic and efficient scheduling of shifts for each nurse in a matter of seconds. This tool is flexible in terms of the inclusion and exclusion of restrictions, and also permits changes to be made in the penalty factor to be considered in the objective function. The fact that a solution is arrived at in just a few seconds will enable decision makers to evaluate different scenarios to find the schedule that is most suitable for their hospitals' needs, rapidly analyzing various optimal scenarios. Moreover, the interface allows easy viewing of the resulting schedule for each nurse. We are currently working on the development of a mobile application that will permit the automatic and confidential sharing of the final schedule with all nurses.

3. Experience 2: IT Solutions for Kidney Exchange Programs

Kidneys are vital organs and their deterioration causes serious issues in other bodily systems and a decrease in the affected individual's quality of life. Faced with irreparable damage to this organ, there are two frequently used medical treatments. The first of these two options is dialysis consists of extracting blood from the patient's body and then removing waste and excess water from the blood before returning it to the patient's body, thereby replacing the kidneys' natural functions. This procedure is difficult for patients as it must be carried out several times a week at a specialized health center. This interrupts patients' normal activities and prevents them from leading normal lives.

The second treatment option is a kidney transplant, which is a surgical procedure in which a functioning kidney is transferred from one body to another. In the long term this option is much more economical than dialysis and also enables patients to live normal lives. Additionally, the life expectancy for a patient who receives a kidney transplant increases by approximately ten years [10]. Kidney donors can be deceased or live. Despite the fact that the majority or donations come from deceased donors, the wait time for this type of donation can be several years.

Kidney exchange programs (KEP) have been extensively studied in scientific literature and are already used in countries such as the United States of America and some European countries. The idea of a KEP is to generate a bank of kidney recipients who have family members or friends who are willing to donate one of their kidneys. Unfortunately, in many cases these donors and recipients are incompatible due to blood type or immune system issues. The donor and recipient bank is put together in order to find compatible donor-recipient pairs and to carry out more successfully kidney transplants. This strategy significantly increases the number of kidney donors and reduces patients' wait times. Moreover, the program reduces the national health systems' operational costs as dialysis treatments are reduced. The ethics of KEPs are discussed in [11].

The solution we have developed is a platform that enables donors to join the program in order to find other donor-recipient pairs with whom they can voluntarily exchange kidneys. The platform developed calculates the complete compatibility matrix between all the donors and recipients in the system. Once the database of program members has been set up, the organ exchange cycles that maximize the number of participating couples are calculated. The optimization issues and a review of recent literature on entire programming models is described in [12]. Fig. 2 shows an example of a solution obtained via the platform in which possible exchanges between ten couples participating in the program were identified.

To date, our experiments have been theoretical, given that there is no legislation on KEPs in Colombia. Nonetheless, this study will give us the operational foundations needed to start a necessary debate on legislation to regulate such a program.

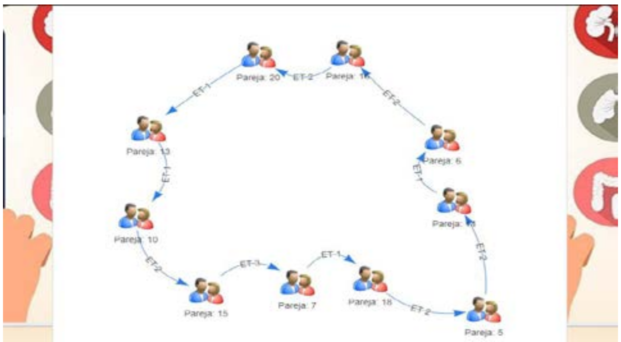

Fig. 2. Example of a KEP solution obtained.

4. Experience 3: Maintenance of Medical Equipment

Medical equipment is an important resource in guaranteeing quality healthcare services. The time needed to repair equipment, its maintenance, updating of equipment, and downtime due to damaged equipment all have significant impacts on the time that a physician takes to diagnose a patient and to treat an illness, and also affects a hospital's handling capacity. This time takes on more importance when the possibility of a late diagnosis is considered, which in turn affects the efficacy of the treatment given to a patient.

The piece of medical equipment studied is the computerized topography scanner (CT or CAT scanner). This tool is used in several diagnostic processes and by different medical specialists, given that it enables non-invasive exploration. This equipment can be used to take images of the head, thorax, and limbs.

In general, hospital do not have large numbers of CT scanners, as each of these costs more than USD$50,000. Taking into account that significant number of individuals who require a timely diagnosis, hospitals' equipment must be available to support the diagnostic process as much of the time as is possible.

There are different methodologies to reduce the time during which a CT scanner is out of service due to some type of damage, or the instances in which a scanner is working at a suboptimal level because it requires maintenance or calibration. A review of the scientific literature is presented in [13]. It is concluded that of the 34 research documents reviewed, 64% of them contain empirical models and 19% are prioritization models, while only 17% are optimization models. The following Markov Chain model is proposed to represent the impact of decision frequency for corrective and preventative maintenance of medical equipment. *X(t)* is equal to the number of machines working at moment *t*. *Y(t)* is equal to the number of machines operating in suboptimal conditions because they require maintenance at moment *t*. *Z(t)* is equal to the number of machines detained due to requiring corrective maintenance at moment *t*. The *S* space state is defined by the $(X_{(t)}, Y_{(t)}, Z_{(t)})$ trio where *X(t)* + *Y(t)* + *Z(t)* is equal to the total number of machines.

The solution we have developed optimizes the speed with which damage to a piece of equipment can be repaired and the frequency with which preventative maintenance needs to be carried out to make the CT scanner available as much of the time as possible and in the best possible conditions while taking hospitals' budgetary restrictions into account. The objective function evaluates the benefit of the average number of machines working, plus the benefit of the average number of machines working that require preventative maintenance, minus the cost of machine downtime due to damage, corrective maintenance, and preventative maintenance. Fig. 3 shows an example of a solution obtained for a system of ten (10) CT scanners.

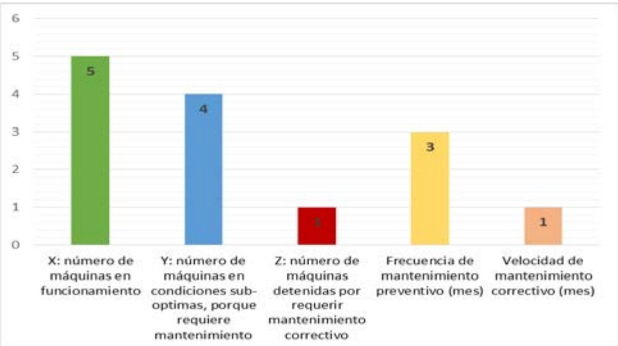

Fig. 3. Example of a solution obtained for a system of ten (10) CT scanners.

The tool developed enables the automatic and efficient calculation of the frequency with which preventative maintenance needs to be carried out and the speed with which repairs must be done. This tool enables hospital staff to define the budget destined for maintenance; a parameter considered in the objective function. As the solution is calculated in a short time, decision makers are able to evaluate different contexts to schedule maintenance in accordance with a piece of equipment's use.

5. Experience 4: Rapid Responses to Cerebrovascular Accidents

In nosological classifications, a cerebrovascular illness is a condition in which damage occurs in the brain's blood vessels, which generally causes a permanent neurological deficit or even death, in the worst cases. Within this group of illnesses is the ischemic stroke in which a cerebral artery is obstructed by fat or a clot. If the blood vessel in question is not redirected, the cerebral parenchyma irrigated by the artery will progress to necrosis in a matter of time (approximately 4.5 hours). Luckily, in 2005, the use of a drug (tissue plasminogen activator) was approved. The administration of this medication within the first three hours of an ischemic stroke seeks to remove the obstruction created by the thrombus inside the artery and as such to facilitate the reperfusion (the action of restoring the flow of blood to an organ or tissue) of damaged tissue and in doing so avoid cerebral damage or at least slow it down, which is what is known as "Thrombolysis in acute ischemic stroke" [14]

Cerebrovascular illness is a real problem in public health given that it is second-leading cause of death around the world, according to the World Health Organization, and the third-leading cause of death in Colombia [15], according to the Ministry of Health and Social Protection. In addition to this, it is the leading cause of disability in the world. For all of these reasons, any initiative that seeks to modify the evolution of this condition will have a global impact. Specifically, when thrombolysis in acute ischemic stroke is spoken of, despite the fact that this is the best management option available, it continues to be a scarcely used tool. One of the main reasons for this underuse is a lack of awareness on the part of patients and a significant number of health staff. As a result of this, there are excessive delays in the timely remission of patients to centers where thrombolysis is administered which is very serious in the case of a stroke, where the patient's brain is progressively lost with every passing second. Despite these limitations, the national health system in Colombia has slowly begun to implement thrombolysis programs but with very low percentages of beneficiaries compared to the overall number of patients. One of the three programs that most uses thrombolysis is that at the San Rafael Hospital in Tunja, where, despite the fact that there are various institutions with emergency care services, San Rafael is the only of these which administers thrombolysis. It was seen during the study carried out that there are still delays of an average of three (3) hours after a patient has begun to present symptoms. It is for this reason that the application developed enables the first health professional who has contact with the patient to apply a scale that provides direction as to whether or not the patient is suffering an ischemic stroke and, if so, if he or she is a candidate for the thrombolysis procedure. This application also serves as an alarm so that the thrombolysis network can contact the hospital and quickly transfer the patient to the referral center. The tool contributes to benefitting more patients within the area of influence and could used nationally, as well as globally, at different thrombolysis centers. Fig. 4 shows the form used to score the patient according to the National Institutes of Health Stroke Scale (NIHSS).

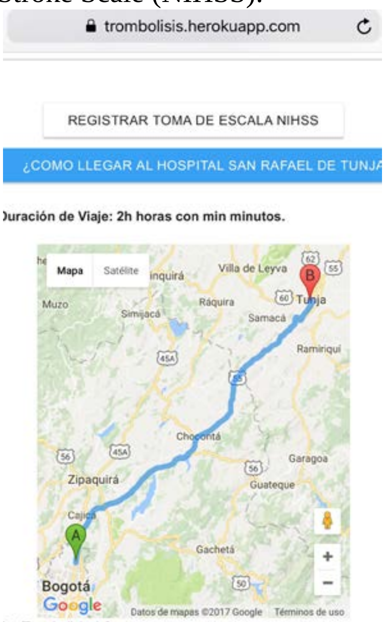

Fig. 4. Example of a form used to take the NIHSS.

Another benefit of the tool is that it calculates the shortest route to take the patient in question to the health center where the procedure can be administered to him or her, thereby ensuring more timely treatment. This time saved via application will contribute extremely effectively to timely treatment in specific health services, such as in the aforementioned case.

6. Conclusions and Future Research

This article presents four (4) research experiences in which the integration of optimization models and information management has generated technological tools for decision making in hospital logistics. The first case study looks at the issue of nursing shift scheduling, in which a minimization of nurses' burnout is sought. The second case study summarizes out experience in technological development to optimize kidney donation and exchange programs. The third case is a mathematical model based on Markov Chains for the optimization of medical equipment maintenance policies for machines such as the CT scanner. Finally, the last case study presented is focused on generating technological tools to ensure rapid responses to cerebrovascular accidents (strokes), integrating a diagnostic text and actions to be taken (including the shortest route to get to the closest treatment center to provide the corresponding treatment) in each case into one sole tool.

In conclusion to the research carried out, we see the importance of integrating information management and optimization models to generate technological applications in the health sector. The examples given enable us to conclude that the data being generated in these health systems can be used to support decision making. While scientific literature is rich in models and methods, the real application of these technologies is scarce and there is still a significant gap between academic developments and their actual application.

In terms of future research, we propose the structuring of systems and devices, in the style of the IoT, capable of storing and analyzing the data that is collected via the tools developed. These systems could boost resource use with optimization models and technology capable of making predictions and carry out simulations based on historical data.

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