Proposal of a Smart Hospital Based on Internet of Things (IoT) Concept

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Abstract. This article proposes the utilization of the Artificial Intelligence (AI) and Automation techniques oriented to a service-based business. Developing and proposing a methodology for the implementation and development of a smart hospital, taking as a foundation a traditional hospital. The approach is based on the analysis of the studied e-health system, focusing on the patient flow. The use of Discrete Event Simulation (DES) models allows a computational model method for recreating the system and detect the system's bottlenecks. Those blockages are improved by the addition of "smart devices", implemented in the DES model and this improvement of the patient flow attendance and service quality, what directly influence the reduction of mortality in the Emergency Department (ED). Finally, the social implication is the reduction of the mortality in the ED, what is directly related to the improvement of the service quality and the reduction of the waiting time for the patients.

Keywords: E-health · Smart Hospital · Discrete Event Simulation

1 Introduction

Nowadays, due to the technological improvement, our life has been improved considerably, especially in cases like transportation, manufacturing, communications, businesses and other areas. The healthcare area has been improved also, but not as fast as other areas, due to the risks and special care it needs to improve.

The healthcare is highly represented by the medical services that are given in hospitals. Those hospitals offer a different kind of services and specializations, associated with the different patient requirements. In this work, the focus is the Emergency Department of a hospital, due to the critical management operation of the system and the critical need of the users.

The Emergency Department (ED) or Emergency Ward is an area of primary care, that aims to offer initial treatment of different diseases to patients with high priority who present themselves without a prior appointment. According to [1, 2] the EDs around the world show problems of overcrowding. In the study presented by [1], 15 developed countries were studied, and the high attendance produced overcrowding and a reduction of the service quality.

N. Lepore et al. (Eds.): SaMBa 2018, LNCS 11379, pp. 93–104, 2019.
https://doi.org/10.1007/978-3-030-13835-6_11

The overcrowding of patients in an ED is a situation that is presented when the number of patients is superior to the number of resources, whether medical staff, medical devices or hospital care areas. This situation leads to a considerable increase in patient waiting time and a reduction in efficiency and quality of service. The problem of overcrowding in ED is a generalized problem around the world [2, 3], a public health problem that affects everyone in every social class [1]. The key factors that generate the problem are mainly the duration of patients' waiting time, agglomerations, patients' inflow and outflow, physicians' productivity, available physical resources, among other factors [2, 3].

In recent years, different countries have adopted practices and action plans to reduce the effect of overcrowding, as those presented by [1, 2], but the adopted policies are not enough to solve the problem since variables such as uncertainty of patient flow, different types of diseases, and other external factors such as epidemics or natural disasters are difficult to predict.

The main implications of the overcrowding problem in ED are the decrease in quality of service, increased risk of death and social discrimination in the queues [4]. According to [4] the relation between the overcrowding in ED and the mortality rate have a high relation, and in 4 of 6 studies were found that the Late Treatment presents a relation with the mortality of the patients in the ED. Meanwhile, the other presented factors are not conclusive to indicate a considerable relation with the mortality rate in the emergency services.

From another viewpoint, for hospitals, the problem of overcrowding in the ED brings economic profits, since the service provided with overcrowding maximizes the use of resources and thus allows a better use of the available assets and personnel, thus maximizing the profit of the providers of health services [5]. Therefore, the proposals of solution for the overcrowding have as a minimum requirement: the improvement of the service quality and, at the same time, the improvement of the hospital's profit. These constraints make this problem a highly complex problem since it regards the quality of the provision of a high-risk service with the profit and maintenance of the hospital. It is important to highlight that overcrowding is not a daily problem and following one of the studies presented by [5], the problem occurs only in 25% of the total operating time of the ED, which increases the difficulty of the problem, due to the unpredictability of patient flow behavior.

Among the proposed solutions to solve the problem of overcrowding in the ED exists 2 kinds of solutions: the implementation of healthcare politics or the optimization of resources using management operation tools. Between the documented healthcare politics by American College of Emergency Physicians in 2008, the better policies are the reallocation of the admitted patients to free areas, such as corridors and conference rooms; coordination of surgeries scheduling, among other ideas, which, even offering improvements, they are not definitive solutions, presenting inconsistencies in the existing literature [4]. By another hand, the management operations view requires the use of simulation and optimization tools, which are used for an administrative view of healthcare management. The acceptance of the last approach in the healthcare field to test different and new methodologies, policies and operations are increasing; which is reflected in the increase of researches and publications in the area [6].

The different simulation paradigms can identify the complexity of healthcare systems, that are mainly three: Discrete Event Simulation (DES), System Dynamics (SD) and Agent-Based Modeling (ABM). The main difference between those system modeling paradigms is that in the first two (DES and SD) depend on rules defined in the real world, entities are modeled based on these rules. By another hand, the ABM, present an interaction between entities based on defined rules based on the behavior of the systems [7]. The biggest problems in healthcare systems can be optimized using simulation models, managing to improve problems such as high patient flow, patient scheduling, shift scheduling, testing of new health policies, among others [7].

By another hand, the use of the IoT and Industry 4.0 concepts in the healthcare is starting with high importance according to the potentially useful applications in the area [8]. To introduce some concepts, the Internet of Things (IoT), basically proposes a use, processing, and storage of information in the cloud, that can be accessed and used autonomously by intelligent objects with a connection in the cloud through the internet [9]. The goal of the IoT is the sharing of data and processing of them, to achieve a smart integration of the objects aimed at improving the life quality.

By the other side, the concept Industry 4.0 is based on the IoT principle of an intelligent connection of objects, in this case, information technologies (IT) and operational technologies (OT), to facilitate the development of each company's own services and processes. Industry 4.0 can also be called the Industrial Internet of Things (IIoT) following the vision proposed by the company General Electric [10].

In general, it is possible to realize that the IoT is a very extensive concept, the reason why the concept of Industry 4.0 presented as IIoT, is a study area that applies the concepts of the IoT in the industry, making both concepts complementary and highly related. In this work, the IoT and IIoT concepts are used as synonymous due to the similarity of the concept in the healthcare area.

The main idea of this work is to propose and present with a study case the convergence of the IoT concept and healthcare management. That convergence could be ambiguous, but in a wide view, the healthcare management using as input data the collected data by the IoT objects, related to the patients, can be extremely useful to know the state of the system and the possible improvements. Obtained information like queues lengths, waiting time and related data are extremely valuable for the implementation of a smart, connected and optimal solutions in hospital management, what will bring an improvement of quality in the different healthcare areas due to the better use of the resources.

The proposal of this study is to propose a potential solution to improve the main problem of the ED services, the overcrowding, due to its direct impact on the mortality rate in the ED. The methodology needs the use of the concept of IoT, a simulation tool as the DES, and other secondary concepts, like telemedicine and automatic control notions to achieve the goal.

2 Methodology

The following methodology is based on the data obtained from the ED model presented in [11], where the author developed a DES model of an ED and treated it as an optimization problem. In that project, the hospital data and information were summarized the into stochastic data, later reflected on the ED DES. After the collection of the dataset and the implementation of the DES model in Matlab 2017a® (SimEvents®), it is possible to reproduce the simulation and verify the improvement of the system.

Subsequent, the DES allows reading the different management data of the system. That information can be compared with some of the information obtained by the IoT system, following each patient in the ED, information like queue length in each station, the average waiting time of patients, and so on. That data is enough to observe the system as the IoT would look at it, with an administrative management perspective, allowing the implementation of an online control for the current system requirements.

Finally, the identification and improvement of the principal bottlenecks in the system. The simulation allows the detection of the main system bottlenecks and with that knowledge is possible to propose a feasible solution to solve that problem. The proposed solution is based on telemedicine and principles of automatic control, to control the flow of patients. Also, the additional investment in hospital personnel and the use of a service of telemedicine requires a little investment, compared with the hospital quality improvement.

2.1 Discrete Event Simulation (DES) for an Emergency Department (ED) Study Case

The implementation of the ED using DES is based on the data and simulation presented in [11], follows the stochastic data presented in Table 1 and Fig. 1.

Table 1. Service time distributions at each stage of the process.

Stage	Distribution (Minutes)
Reception	Uniform (5,10)
Lab tests	Triangular (10,20,30)
Examination room	Uniform (10,20)
Reexamination room	Uniform (7,12)
Sala De treatment room	Uniform (20,30)
Emergency room	Uniform (60,120)

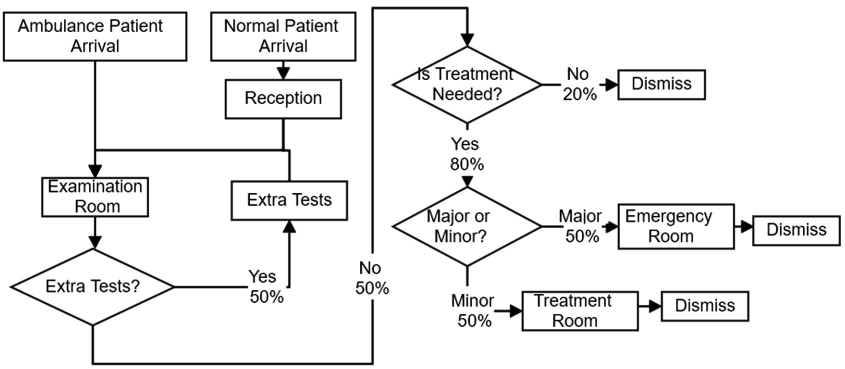

Fig. 1. Emergency department high-level process view, following the presented by [11]

As the Fig. 1 shows the inputs of patients correspond to a receptionist arrival and an ambulance arrival. The receptionist arrival corresponds to a non-homogenous Poisson process with an estimate of $\lambda(t)$ given in Fig. 2. Another hand gives the ambulance arrival process given by a Poisson process with a rate of 2 per hour.

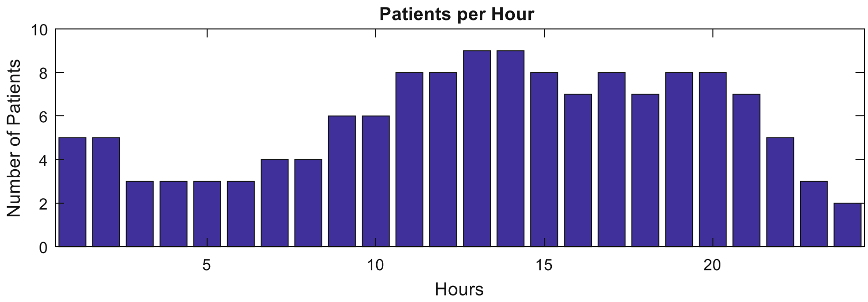

Fig. 2. Plot of the estimated rate function $\lambda(t)$ in patients per hour for the arrival process

The implementation of the simulation was made using Simulink® (SimEvents®) in Matlab 2017. The constants of the system that corresponds to the staff servers are presented in Table 2, as is presented in Fig. 3. The results obtained by the system, after 1000 simulations, can be observed in Table 3, where appears the main statistical information of the system behavior.

Table 2. Constant values for each staff server of the Fig. 3.

Staff server	Abbreviation	Current value
Reception	R	2
Doctor	D	2
Laboratory technician	T	3
TR nurse (Treatment room)	TN	1
ER nurse (Emergency room)	EN	9

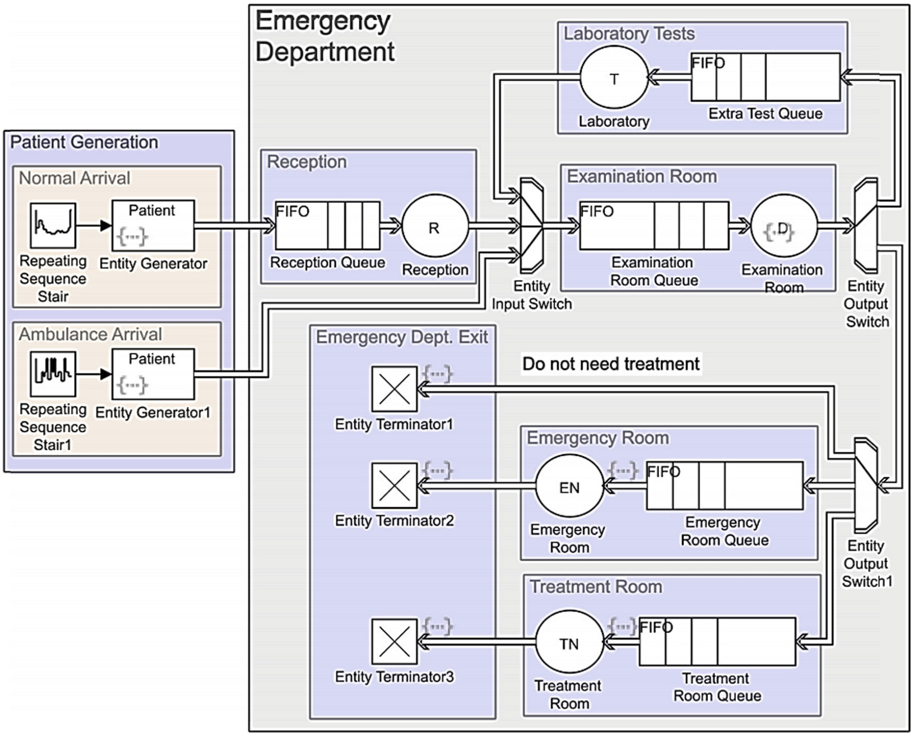

Fig. 3. Implementation of the ED in the DES using SimEvents® in Matlab 2017.

Table 3. Information about the main processes of the system presented in the Fig. 3.

Result	Value	Standard deviation
Expected patient time in system (h)	3.99	0.77
Expected number out (patients per hour)	4.85	0.35
Average waiting time (min): Reception	0.00	0.00
Average waiting time (min): Laboratory	0.70	0.50
Average waiting time (min): Doctor	**85.01**	**25.81**
Average waiting time (Min): Emergency room	0.03	0.34
Average waiting time (min): Treatment room	19.77	11.13
Average queue length: Reception	0.00	0.00
Average queue length: Laboratory	0.05	0.03
Average queue length: Doctor	**18.07**	**5.67**
Average queue length: Emergency room	0.00	0.01
Average queue length: Treatment room	1.00	0.54
Utilization (%): Reception	28.00	1.00
Utilization (%): Laboratory	5.00	5.00
Utilization (%): Doctor	**96.00**	**1.00**
Utilization (%): Emergency room	34.00	4.00
Utilization (%): Treatment room	64.00	9.00

2.2 Detection of the Bottlenecks and Proposed Solution

Based on the Table 3 can be observed that the utilization of the Examination Room is 96 ± 1%, what is too high. Also, the queue length and the waiting time of patients there are so high, the queue length an average of 17.83 ± 5.55 patients and the waiting time an average of 84,67 ± 25,62 min, showing it as the main bottleneck in the system.

The proposed solution is based on the concept of telemedicine, specifically the use of Doctors using telepresence for the Examination Room. The concept of telemedicine has been applied in [12, 13], consequently currently with the implementation of concepts as IoT, that concept and use can be highly used with the inclusion of the new technologies in the society.

The proposal is an alternative Examination Room based on telepresence, what will allow that some doctors in a remote center be able to diagnose the patients. That idea will remove the detected bottleneck of the system.

2.3 Implementation of the Solution

The Smart Hospital concept is primarily based on the implementation of the telediagnosis room in the DES is introduced as a finite resource that depends on the queue length. The selected queue length is of 5 patients in the waiting line, the reason of that choice is that the current number of doctors in the physical room is 2 and the tele-doctors is 2, so a waiting line of 5 leaves only 1 person waiting in line. The remote diagnosis center can maximumly assign 2 tele-doctors per turn, each turn is around 13,25 min, what is the average time a doctor diagnoses a patient.

For the control of the required number of doctors was used a concept of automatic control, the implementation of a PID (Proportional, Integral, and Derivative) controller what is highly used in robotics, industrial processes and others [14–16]. The implementation of that concept will allow a mathematical model to take some decisions according to the system error, the equation what model the implemented PID controller in the DES model is presented in the Eq. (1), where *u(t)* is the control output signal, *e(t)* the error signal, *P* the proportional control constant, *I* the integral control constant and *D* the derivative control constant.

$$u(t) = P\,e(t) + I \int e(t)dt + D\frac{de(t)}{dt} \tag{1}$$

To set the PID parameters of this system with stochastic and unknown dynamic model has been used an Artificial Intelligence technique, a Genetic Algorithm (GA) what is a metaheuristic optimization Evolutionary Algorithm. The GA optimizes by a metaheuristic the PID controller constants *P*, *I* and *D*, using a fitness function. A population of 100 PID constants represents the feasible solutions, that are evaluated by a fitness function where the more fit individuals of the population can survive, mutate, replicate, and reproduce themselves to obtain better results. Examples of optimization of different controllers in different applications and with different controllers or neuro-controllers using GAs can be found in [17–19].

The used GA follows the proposal made by [17], where the fitness function corresponds to the algebraic sum of 3 methods to evaluate PID controllers, the Integral

Square Error (ISE), Integral Absolute Error (IAE) and Integral of Time-Weighted Absolute Error (ITAE) methods is cost or fitness function (*J*) that the GA should optimize. The fitness function (*J*) follows the Eq. (2).

$$J(P, I, D) = \int_0^\infty [e(t)]^2 dt + \int_0^\infty |e(t)| dt + \int_0^\infty t|e(t)| dt \quad (2)$$

The genetic algorithm implemented in this proposal follows the procedure shown in Fig. 4.

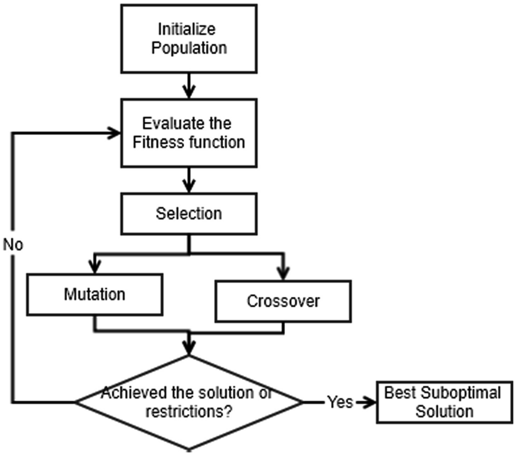

Fig. 4. Flow diagram of the genetic algorithm.

By another hand, the implemented PID controller has a limited and rounded output. The rounded output is given because the number of doctors is an integer positive number. The minimum number obtained can be 0 and the maximum is 2, it is a constraint for the number of tele-doctors.

3 Results and Discussion

The implementation of the Smart Hospital ED is based in the traditional hospital ED, just adding a PID controller to requiring the telepresence doctor service. After the implementation of the telediagnosis center, it was possible to identify the creation of a new bottleneck in the Treatment Room (TR), so a treatment nurse was added to improve this new issue.

The implementation of the PID controller to control the number of required doctors allowed to improve the results given by [11], that was also presented in Table 3. The PID controller was adjusted with the following constants: *P = 0.3012, I = 0.00984* and *D = 0.000498*. The results after 1000 simulations with the proposed controller are presented in Table 4.

Table 5 presents the differences between the traditional hospital and the Smart Hospital proposal, the values in bold located in the *Difference* column show the improved data.

Table 4. Information on the key performances of the Smart Hospital (1000 simulations).

Result	Value	Standard deviation
Expected time in system (h): Total	2.54	0.33
Expected number out (patients per hour): Total	6.20	0.47
Average waiting time (min): Reception	0.00	0.00
Average waiting time (min): Laboratory	6.15	4.59
Average waiting time (min): Doctor	**23.13**	**1.80**
Average waiting time (min): Emergency room	0.44	1.10
Average waiting time (min): Treatment room	3.87	2.30
Average queue length: Reception	0.00	0.00
Average queue length: Laboratory	0.69	0.62
Average queue length: Doctor	**5.45**	**0.75**
Average queue length: Emergency room	0.02	0.07
Average queue length: Treatment room	0.25	0.12
Utilization (%): Reception	29.00	1.00
Utilization (%): Laboratory	58.00	8.00
Utilization (%): Doctor	94.00	2.00
Utilization (%): Emergency room	39.00	6.00
Utilization (%): Treatment room	39.00	5.00

Table 5. Comparison of the key performances of a traditional and the Smart Hospital proposal.

Result	Hospital value	Smart Hospital value	Difference
Expected time in system (h)	3.73	2.84	**0.89**
Expected number out (patients per hour)	4.72	6.38	**–1.66**
Average waiting time (min): Reception	0.00	0.00	0.00
Average waiting time (min): Laboratory	0.59	6.05	–5.47
Average waiting time (min): Doctor	85.02	23.15	**61.87**
Average waiting time (min): Emergency room	0.03	0.44	–0.41
Average waiting time (min): Treatment room	19.91	3.89	**16.02**
Average queue length: Reception	0.00	0.00	0.00
Average queue length: Laboratory	0.05	0.69	–0.64
Average queue length: Doctor	18.22	5.39	**12.83**
Average queue length: Emergency room	0.00	0.02	–0.02
Average queue length: Treatment room	0.77	0.30	**0.47**
Utilization (%): Reception	28.00	29.00	–
Utilization (%): Laboratory	5.00	58.00	–
Utilization (%): Doctor	96.00	94.00	–
Utilization (%): Emergency room	34.00	39.00	–
Utilization (%): Treatment room	64.00	39.00	–

Based on Table 5 is possible to see the improvements of the hospital in different ways, between the most remarkable results, are the reduction of the user time in the system by 0.89 h, the increased number of output patients by 1.66 patients more per hour, the reduction by 61.87 min of the average waiting time for the doctors are the most remarkable changes in the system.

By another hand, some results were negatively affected, but the decreased behavior is not significant to affect the system or to reduce the quality of the obtained results. Therefore, the patients will see a significant improvement in the ED, reducing the mortality rate according to [4].

The comparison between the used resources by each case is presented in Table 6, where is possible to see the modifications between the systems and understand the additional required staff to improve the ED quality according to the Table 5.

Table 6. Comparison of the Staff Number in 24 h of service.

Staff server	Abbreviation	Hospital	Smart Hospital
Reception	R	2	2
Doctor	D	2	2
Telepresence doctor (Dynamically controlled)	**–**	**–**	**0.6683 ± 0.1672**
Laboratory technician	T	3	3
TR nurse (Treatment room)	TN	1	**2**
ER nurse (Emergency room)	EN	9	9

By observing the Table 6 is possible to infer that the Smart Hospital system added 1 Nurse of TR and the equivalent of a 0.6683 ± 0.1672 tele-doctors (in a day). That increase in the staff number has improved the ED system as is presented in Tables 4 and 5. Those improvements affect directly the system performance by reduction of the user time in the system by 1.18 h and the increased number output patients by 1.66 patients more per hour, what are significant changes from the patients' viewpoint, helping to save lives in risk and allowing a higher quality service in the ED services.

4 Conclusion and Further Developments

The IoT and IIoT concepts can be used in different areas for different purposes, for example in the performance improvement of any service-based system. In this case, a healthcare system was presented, and by the example of an ED was shown the implementation possibilities and uses of connected things to obtain data and improve the administration and management of a queue-based system with the help of current technological solutions.

The perspective of the IoT and IIoT used in a simulation, as it was presented in this work using DES, allowing the possibility to prototype real solutions without the implementation of real smart objects, making feasible a simulated environment to test smart policies based IoT captured data.

The inclusion of robotics and other current technologies in smart environments, using this simulation approach is feasible when the system can be approached as a stochastic system. The multi-agent-based simulation will be an opportunity to simulate and test in depth the concept of connected smart devices in a more realistic and controlled environment.

By another hand, the improvement of the ED, in the smart hospital case was successful, using not many additional resources and a concept as telemedicine and IoT, the system improved by around 30% in the expected number of output patients and patient expected time in the system. Those significant changes were obtained by an addition of 10% of the old staff, according to the presented results.

Finally, it was possible to present a work were the IoT, IIoT, the DES, and other current technological concepts converged in the result of an improved environment, what leads to a futuristic and not so distant world, where the smart connected devices will allow an improvement of the resources uses improving the life quality of the society.

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