Towards Health 4.0: e-Hospital Proposal Based Industry 4.0 and Artificial Intelligence Concepts

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Abstract. The implementation of the most recent technologies is a requirement in this fast-growing and competitive world, especially in the improvement and development of the healthcare area, that is fundamental in life quality enhancement. This article has as objective the utilization of AI and Industry 4.0 concepts oriented to the optimization of a hospital, using a case study an Emergency Department (ED). This proposal allows the development of a current proposal of e-Hospital based on Health 4.0 features and the use of computational ED models will allow the avoidance and detection of bottlenecks in the workflow. Those blockages are automatically removed using an improved shift management proposal based on control theory, AI, and telemedicine. The results show an optimization in the use of the resources and a reduction of the length of stay improving the service quality. The simulation tools allow the test and validation of novel proposals for e-health.

Keywords: Health 4.0 · Discrete Event Simulation · e-Hospital · Emergency Department · Evolutionary Algorithm · Optimization

1 Introduction

Health 4.0 was created as a response to the demographic and socio-economic changes in the last years. The main design principles are interoperability, virtualization, real-time capability decentralization, service orientation, modularity, safety, security and resilience [1, 2]. Its execution represents a complex challenge that can be solved by the adoption and implementation of concepts like Artificial Intelligence (AI), Cloud Computing, 5G, Internet of Things (IoT), Medical Internet of Things, Precision Medicine and Blockchain. That technology is complemented with healthcare simulation tools, like Discrete Event Simulation (DES), that is the main simulation tool to test and solve management issues.

A problem that can be solved by the implementation of Health 4.0 concepts and the use of simulation tools is the overcrowding in the Emergency Department (ED),

D. Riaño et al. (Eds.): AIME 2019, LNAI 11526, pp. 84–89, 2019.
https://doi.org/10.1007/978-3-030-21642-9_12

recognized as a world-class problem. The overcrowding is a situation that occurs when the number of patients is superior to the available resources. This is an unpredictable situation that occurs only 25% of the total operating time of an ED, it reduces the service quality and the staff productivity, creating agglomerations, increasing the patients waiting time, and others negative social factors [3]. The overcrowding problem is a current problem, making it a good case study to proof the design principles of Health 4.0 and the integration of up-to-date technologies. For its implementation is mandatory an analysis and understanding of the processes in a traditional Hospital, identifying the opportunities to upgrade the tools and improve the resources, for example with the use of teleconsultation, telepresence, and telesurgery, as a solution for remote services [4, 5].

This work has as objective to propose a solution for the overcrowding in a chosen ED, testing the solutions in a DES environment, measuring and performance comparison using the Key Performance Indicators (KPI). The comparison and development of simulation models for a traditional ED and an e-Hospital ED based on Health 4.0 were implemented in DES models, using Matlab-SimEvents®, based in [6, 7], Table 1 and Fig. 1.

Table 1. Service time distributions and staff number [6, 7].

Stage	Distribution (Minutes)	Staff	Abbrev	Current staff
Reception	Uniform (5,10)	Receptionist	R	2
Lab tests	Triangular (10,20,30)	Laboratory technician	T	3
Examination room	Uniform (10,20)	Physician	D	2
Reexamination room	Uniform (7,12)			
Treatment Room (TR)	Uniform (20,30)	TR nurse	TN	1
Emergency Room (ER)	Uniform (60,120)	ER nurse	EN	9

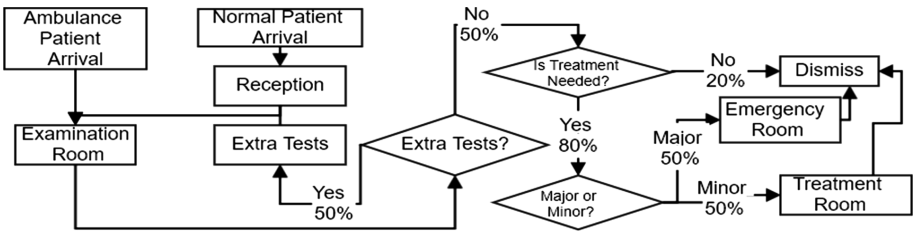

Fig. 1. ED high-level process view [6, 7].

2 Methodology

The proposed methodology for this work takes the study case of ED presented by [6], where a DES model was developed for a chosen ED to optimize the personnel, increasing the Hospital profits. By another hand, this work is the continuation of [7], where a DES model was developed with an automatic method to solve the ED overcrowding issues.

Initially was developed of a DES for the chosen the ED model, it is used for analysis of health services under a certain established condition. The DES ED follows the data presented in Fig. 1. The developed DES follows the implementation and patients arrival rate presented by [6, 7]. The improvement of the traditional ED makes of it an e-Hospital ED, that is achieved based on the analysis of the ED-DES. A bottleneck is detected in the Examination Room because of its high utilization ($99 \pm 1\%$.), it generates overcrowding. Also, other KPI in that stage are abnormal, the queue length and waiting time average of 18.51 ± 4.36 patients/h and 88.41 ± 20.41 min, respectively.

An e-Health ED is proposed based on the implementation of telemedicine, used technically in [5], in order to reduce the detected bottleneck. The proposed telediagnosis solution, based on automatic control, it is a controller that takes as reference the Examination Room queue length, in this case, 6 patients in the waiting line. That controller will automatically choose the moment when a tele-physician will be required.

The implemented controller corresponds to a PID controller [8], that following a mathematical model based on the error signal, it will be able to take some decisions, as it implemented by [7]. In order to set controller parameters (Proportional, Integral, and Derivative), traditional methods used for deterministic dynamic systems are useless, due because of the stochastic nature of the studied system. Instead, an AI technique was used to find the right parameters. An Evolutionary Algorithm was used to solve this problem, more specifically a Memetic Algorithm (MA) based on a Genetic Algorithm (GA).

The MA optimizes the PID controller parameters using metaheuristics, it uses a fitness function to determine how good or bad is a solution. The population size corresponds to 100 controllers with its constants, representing a set of controllers in the solution space. Each solution is graded by a fitness function, where the more fit individuals (better solutions) of the population can survive, mutate, replicate, and reproduce themselves to obtain better results. The implemented MA follows the metaheuristic algorithm of [7, 8].

The used MA follows the training algorithm of [8] and the use of a fitness function like the used by [7]. In this case, the fitness function corresponds to the sum of 3 methods to evaluate PID controllers, the Integral Square Error, Integral Absolute Error and Integral of Time-Weighted Absolute Error. The fitness function (J) is optimized by the MA.

This management optimization proposal brings some features of Health 4.0 to the ED like Virtualization, Real-Time Capability, and Modularity. The implemented solution of the e-Hospital DES model corresponds to an improvement of the Traditional Hospital ED, in Fig. 2. The implementation of the described telediagnosis room

represents the design principle of a Hospital 4.0. This solution is based on the integration of concepts like AI, and Control theory, showing Health 4.0 principles like Virtualization, Real-Time Capability, and Modularity, improving some e-health characteristics like management, efficiency, and equity. Finally, the identification and improvement of the system allowed a KPI comparison of a traditional and an e-Hospital ED-based Health 4.0 concepts.

3 Results and Discussion

The simulation results of the developed DES of a traditional ED [6, 7] and the proposed e-Hospital, in Fig. 2. Table 2 shows the most remarkable obtained KPIs. The results summarize 1000 days of each DES model under different conditions (stochastic simulation). The main difference between the compared systems is the use of a telediagnosis room in the e-Hospital, in order to reduce the ER queue length bottleneck. The main KPI improvements are presented in the Examination Room, where the bottleneck was located. That improvement is reflected in the improvement of the e-Hospital ED performance, with the reduction of the Length of Stay (LOS) and the increased number of Discharged patients.

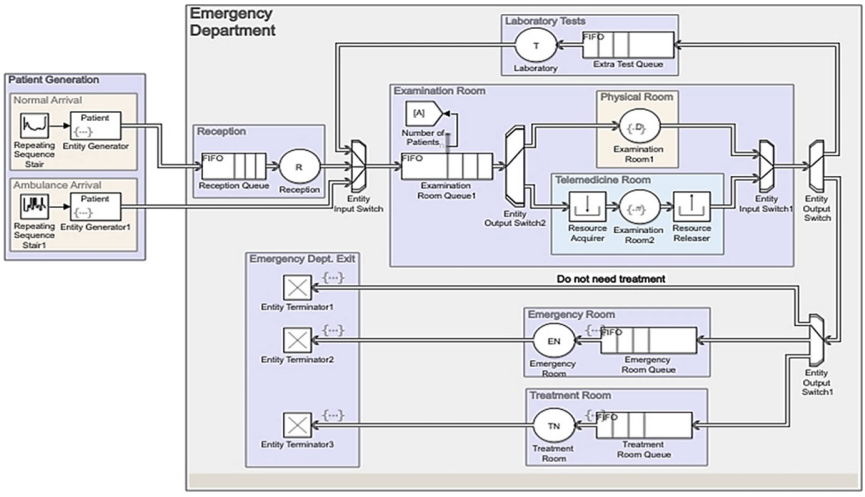

Fig. 2. DES simulator of an ED-based Health 4.0, following [7].

The main difference between the structures of the traditional and the e-Hospital ED proposal is the addition of 1.72 ± 0.96 tele-physicians were scheduled, using the based AI PID controller. The performance of the e-Hospital system showed that a minor improvement makes a difference in the service quality, reflected in the KPIs. Comparing the obtained results with the results of [6], the obtained results were better, since [6] do not consider dynamical shifts during the day. The current work can be also

compared with [7], where following a similar methodology, they added an additional step in the analysis of bottlenecks after the first improvement. That second analysis was avoided in this work to respect the principle of Real-Time Capability of Health 4.0. The improvement in [7] for the LOS was around *23.86 ± 8.85%* adding 9.8 ± *0.94%* of personnel, while in the current work, the LOS improvement was around *13.65 ± 9.79%* adding *10.11 ± 5.64%* of personnel. This comparison showed the importance of secondary bottleneck analysis and improvement.

Table 2. Main KPI of the DES for traditional hospital and e-Health ED.

Key Performance Indicator (KPI)	Traditional ED		e-Hospital ED		Error
	Mean	Std	Mean	Std	
Length of stay (h)	3,88	0,56	3,35	0,38	0,53
Discharged patients (patient/h)	4,59	0,26	5,53	0,27	–0,94
Examination room queue length (patients/h)	18,51	4,36	6,40	0,39	12,11
Examination room queue wait (min)	88,41	20,29	29,34	3,05	59,06
Examination room queue (patients/h)	19,76	4,36	7,08	0,83	12,68
Examination room utilization (%)	0,99	0,01	0,98	0,01	0,01

4 Conclusion and Further Developments

The design principles of Health 4.0 allowed us to identify the current requirements of a traditional hospital, leading us to perceive solutions through the integration of different areas like automatic control and AI, to improve some gaps in the traditional ED. The current study case was a good example of problem identification and solution, following the Health 4.0 bringing valuable features like virtualization, real-time capability, and modularity, improving the ED management, efficiency, and equity. As a further development, a reinforcement learning algorithm can be used to improve management decision making.

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