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ANALYSIS OF THE RESILIENCE OF AN EMERGENCY DEPARTMENT: THE CASE OF ACCIDENT WITH MULTIPLE VICTIMS

Mariela Rodriguez

Faculty of Engineering
National University of Jujuy
10 Italo Palanca
Jujuy 4600, ARGENTINA

Francesc Boixader
Eva Bruballa

Escoles Universitaries Gimbernat (EUG),
Computer Science School, Universitat Autonoma de Barcelona
Sant Cugat del Vallès,
Barcelona 08174, SPAIN

Francisco Epelde

Consultant Internal Medicine
University Hospital Parc Tauli
Universitat Autonoma de Barcelona
Sadabell, Barcelona 08208, SPAIN

Armando De Giusti

Faculty of Informatics
National University of La Plata
Calles 50 y 120 - La Plata,
Buenos Aires 1900, ARGENTINA

Alvaro Wong
Dolores Rexach
Emilio Luque

Computer Architecture and Operating Systems Department
Universitat Autonoma de Barcelona
Edific Q Campus UAB
Bellaterra, Barcelona 08193, SPAIN

ABSTRACT

The care of multiple victims such as in natural disasters in an Emergency Department is critical. This differs from ordinary care by the number of patients that arrive, their severity and insufficient staff for these events. Designing and simulating this real life scenario will be useful for disaster management decision makers. The objective of this simulation is to model a system with resilience to critical situations. To model the input of this research, we worked with the percentage of patients received by Cauquenes Hospital during the Chilean Earthquake on February 27th, 2010. A comparison of two situations has been carried out: the admission of patients before an earthquake with normal daily attention versus the admission of patients before an earthquake and the activation of the relief chain. The latter situation allows the system to be resilient and adapt quickly to its new reality.

1 INTRODUCTION

According to the World Health Organization, around two earthquakes of differing magnitudes occur in the world every minute (PAHO 2023). When these earthquakes reach a high magnitude and occur in large urban populations, they cause major natural catastrophes. Recently, an earthquake of magnitude 7.8 affected the countries of Turkey and Syria, where more than 45,000 deaths are were reported (OCHA 2023). These acts of nature cannot be avoided, but there are public organizations, private organizations, and researchers that who carry out studies and actions to reduce the effects that occur. It is important to plan the actions of the primary action units, as is the case of an Emergency Department (ED), which has specialized personnel for daily care, but in situations of natural catastrophes, the service collapses due to the arrival of many patients.

The objective of this study is to analyze the performance of an ED when events occur that exceed the normal flow of care. In particular, the model will be adapted to the earthquake that occurred on February 27th, 2010, in Chile and the evacuation of patients to Cauquenes Hospital (Contretaras and Abarza 2010). For this purpose, three possible scenarios will be considered: normal care before the event occurs, care during the event and for a considered period when the victims arrive, and a third scenario that corresponds to the actions necessary to adapt the ED system until it recovers its normal operation. An agent-based model (ABM) will be used to model this system. The simulator model used was developed by the HPC4EAS research group at UAB (Zhengchun et al. 2015) in collaboration with Tauli Hospital, Sabadell (Spain) and modified for this project.

2 RELATED CONCEPTS

To approach this project, it is necessary to describe in which area it will be developed, the necessary concepts and existing documentation. First of all, it will be detailed that it is an ABM system, in which the ED simulator is developed. This model has phases that will be taken as a reference for the development of the project. The different types of existing emergency situations that allow determining the seriousness of a particular event are detailed below. In the most serious events, such as natural disasters, patients must be rescued immediately, so there is a type of triage exclusively for these situations and a relief chain is activated for a more efficient work.

To evaluate the model to be designed, the appropriate key performance indicators are established for this project and this helps the system to be resilient to earthquakes.

2.1 Agent-based Model

Agent-based modeling is a popular method that can explain social structures in a virtual environment. An ABM makes it possible to analyze and report on complex dynamic systems such as public health (Gilbert, 2008; Tracy 2018).

To develop a model and simulate it using an ABM, two phases must be distinguished (Gerritsen 2015). The first one is the design phase. In this phase, the model is built, and it is decided what is to be modeled. After this phase, the second phase is the simulation of the process and the evaluation of the model. Finally, the model must be evaluated, it is checked that it provides a representation of reality, the validation can be internal through theories or external with empirical data.

2.2 Emergency Situations

Globally there are different events of a natural or provoked nature that put people's lives in danger and require attention in an ED. The type of situation that requires attention at hospital level is related to the resources necessary for its attention, which range from the least serious to the catastrophic. Table 1 classifies three emergency situations according to the type of injuries suffered, from the least serious to the most serious. Situation 1 deals with minor emergencies such as traffic accidents, fires or similar where the number of injured does not affect the assistance service in an ED. Situation 2 is when there are emergencies that alter the normal flow of care in an ED and for this scenario, less priority should be given, and care should be given to minor injuries and more serious injuries. Situation 3 is when a major disaster occurs, in this case only patients with serious injuries are treated and with priority (Lopéz Jaramillo 2021). Cases 2 and 3 are determined according to the place and the response capacity for receiving the injured from acting hospitals.

Table 1: Emergency situations (Lopéz Jaramillo 2021).

Type of Injury	Situation 1	Situation 2	Situation 3
Not injured	yes		
Simple fractures	yes	yes	
Multiple and severe fractures	yes	yes	yes
Shortness of breath	yes	yes	yes
Rib cage hemorrhages	yes	yes	yes
Severe organ involvement	yes	yes	
Brain trauma	yes		
Death			

The care of multiple victims in an ED from a Situation 2 or 3 incident means that the care resources are overwhelmed by the number of patients who arrive and measures must be adopted to help mitigate the situation, which is when we refer to care in disaster situations. The definition of disaster that contemplates acts of nature, such as hurricanes, floods, and earthquakes give McFarlane and Norris (McFarlane and Norris 2006) is "*a potentially traumatic event that is collectively experienced, has an acute onset, and is time delimited; disasters may be attributed to natural, technological, or human causes.*"

Disaster care stands out for the characteristics of performance and efficiency provided in the service. Moreover, it is in disaster care when staff or material resources are insufficient to care for patients. (Lopéz Jaramillo 2021)

2.3 Triage and Relief Chains

For efficient care in EDs, organization is important; for this, it is necessary to guarantee an efficient triage system. Triage is the process that enables clinical risk management to adequately and safely manage patient flows when clinical demand and needs exceed resources (Ganley and Gloster 2011). The classification of the patient according to the triage scale is based on the concept that what is urgent is not always serious and what is serious is not always urgent (Mondragón et at. 2013). There are five recognized models of structured triage with wide implementation (Christ et at. 2010). The triage used for the simulator model is the Manchester Triage System (MTS). Although, in cases of natural disasters, the situation is different from the conventional one, the efficiency and performance of care must be taken into account, thus, priority care must be given to those patients who are most likely to survive.

To carry out medical care, a relief chain is carried out, which is a structure of an emergency plan to guarantee health care for the affected people. The coordinated relief chain should combine routine and emergency actions to facilitate flexible activation and hierarchical rescue (Wang et al. 2022). Three links are established in the chain. Link 1: Impact Zone, Link 2: Care and Coordination Zone, which is where the Stabilization and Classification Module (SCM) is located, and Link 3: Hospital Units (PAHO 1995). In Figure 1, it can be seen that the first level is the one carried out at the impact site, which is a classification based on the need for immediate treatment carried out by emergency personnel. The second level is the one carried out in the SCM, which is a classification based on the urgency of evacuation for definitive treatment. The third level is carried out in the ED to the people who were referred from the previous level. The initial prehospital triage that is efficient at the impact site is SHORT (Peláez Corres et al. 2005), which is classified as 1. Red: first priority for assistance and transfer, people are very critical, hemodynamically unstable and require immediate stabilization. 2. Yellow: they are victims of moderate severity, hemodynamically stable and who can wait a few hours to be treated. 3. Green, third priority, light casualties who can walk, can wait at least six hours or so, can be sent to hospital or to outpatient treatment. 4. Black: without priority, corresponding to the deceased or those with irrecoverable injuries.

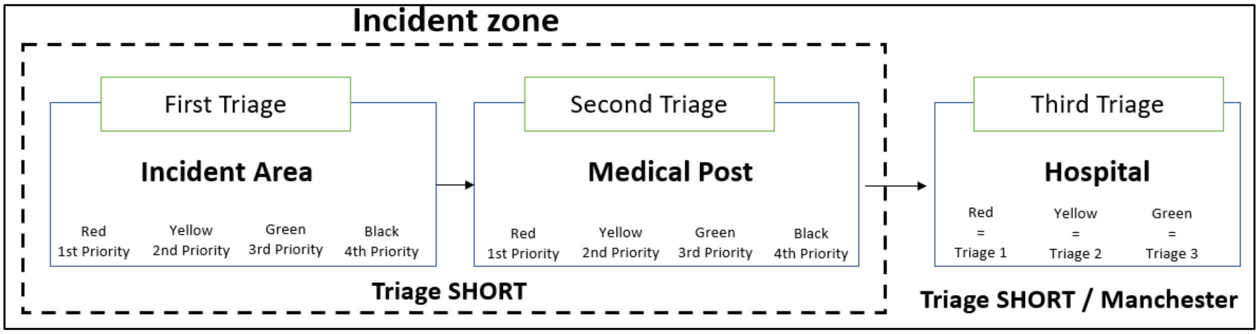

Figure 1: Triage SHORT action sequence (Peláez Corres et al. 2005; Zaboli et. al. 2023).

2.4 Key performance indicators in medical care

Key performance indicators (KPIs) are used by hospitals to monitor and evaluate performing gainst benchmark values or standards. KPIs can be defined to measure the usefulness of a given service provided in healthcare over a period of time (Khalifa and Khalid, 2015). KPIs can capture both quantitative and qualitative information. There are several factors that influence the performance of an ED, of which it is interesting to measure:

- Mean Length of Hospital Stay (LoS): This is a general healthcare metric that tracks how much time elapses between a patient's admission to the hospital and discharge. LoS can be calculated on an all hospital or therapy area basis. (Healthcare 2023)
- Care box occupancy rate: This metric measures the care box occupancy rate during a given period.

2.5 Resilience

In a disaster situation where a community exceeds its capacity to cope with the situation using its own resources, as happens when natural events such as floods, earthquakes, or tsunami occur, disruptions are caused to health systems.

Resilience is the ability of the system to cope with the impacts of unspecified and possibly unforeseen disruptive events. Resilience is the ability to resist, absorb, adapt and respond to negative impacts (Carlson et al. 0012).

The study of resilience in a health system allows strengthening its capacities to better cope with disasters that are unforeseen in time and the number of patients that may arrive. So, resilience generates a set of skills and strategies that are activated in the face of disaster. (Anholt and Boersma 2018).

2.6 Current Emergency Department Model

The ED model designed in the simulator in the Netlogo software (developed by (Zhengchun et at. 2015) has active agents, non-active agents, and an environment in which they operate.

The active agents interacting in the model are: patients, health technicians, administrative staff, doctors, nurses and triage nurses. Doctors and nurses are distinguished according to their area of work and professional experience (senior or junior).

The passive agents of the model that act reactively, when used by an active agent, are: the diagnostic laboratories (Radiology and Laboratories), the computer system (contains patient information and is useful for administrative staff, doctors, nurses).

The ED has six identified areas: admission area, triage area, patient waiting area and laboratory, Zones A and B as shown in Figure 2. The patient enters the admission area and the necessary data for care is recorded. The patient is then evaluated by a physician in the triage area and, depending on the severity of the patient, is treated in: Zone A (care box) patients with triage 1, 2 or 3 (1. resuscitation, 2. urgent or 3. emergency) and in Zone B patients with triage 4 or 5 (4. less urgent and 5. non-urgent). If necessary, the patient may be transferred to the diagnostic laboratories and then returned to the care area. Patients seen in Zone A will remain in their own care box during the entire diagnostic and treatment process. In Zone B, there are several doctors and nurses interacting with patients, and patients wait in a room while they are not being seen.

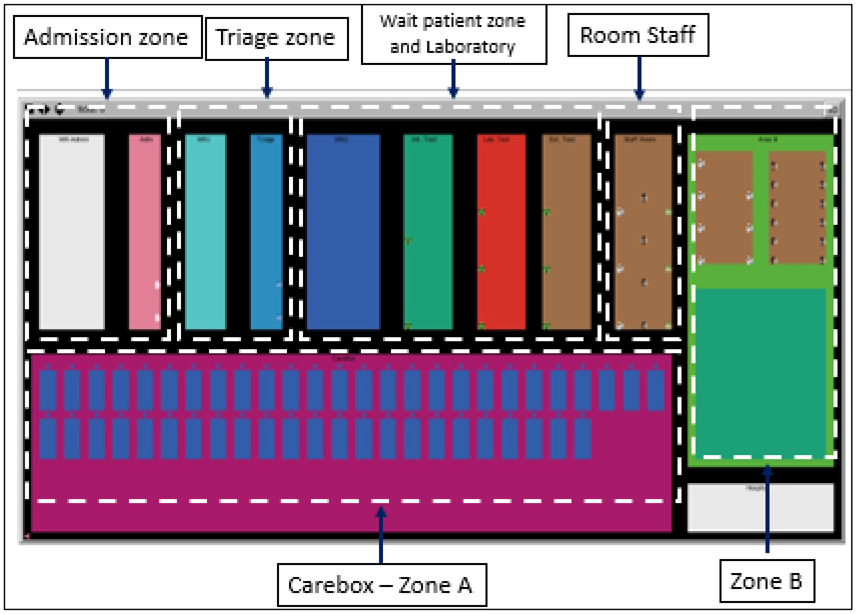

Figure 2: ED simulator – Netlogo. (Zhengchun et al. 2015).

3 MODEL DESIGN

The work to be carried out aims to adapt the ED simulator detailed in Section 2.6 so that it can represent a disruptive event that causes the decline of the health care service. Of the emergency situations raised in Section 2.2, the study will be contextualized in Situation 2, where care is stopped for those patients who have minor injuries and the most seriously injured with little probability of survival. When a type 2 disaster occurs, the relief chain is activated, as shown in Section 2.3, which begins in the area of the incident. Here, the first classification of patients is carried out through Short triage, according to the colors: red, yellow, green and black indicating the severity of the patient. As a general rule, or in most cases, patients with red, yellow and green triage will arrive at the ED, who, after their admission, will become code 1, 2 and 3 patients according to Manchester triage.

For In the care of patient care when disasters occur, fast care is prioritized in order to achieve the greatest possible amount of care. When an earthquake occurs, the number of patients who arrive exceeds the average levels of a normal day and, depending on its severity, it will normalize over the following days. For this reason, a care process is designed to begin when the relief chain is activated and patients are treated with triage 1, 2 and 3. When the system adapts to the new reality, it becomes resilient, that is, it enables Zone B of the ED. Zone B will be enabled when the balance of the average LoS KPI per day is achieved. The time a patient spends in the ED depends on admission times, triage time, waiting time to get a care box, and time spent in actual treatment. When the relief chain is active, admission and triage times are reduced, monitoring the queue waiting for care box is of interest since it is the factor that increases patient length of stay. The procedure is visualized in Figure 3.

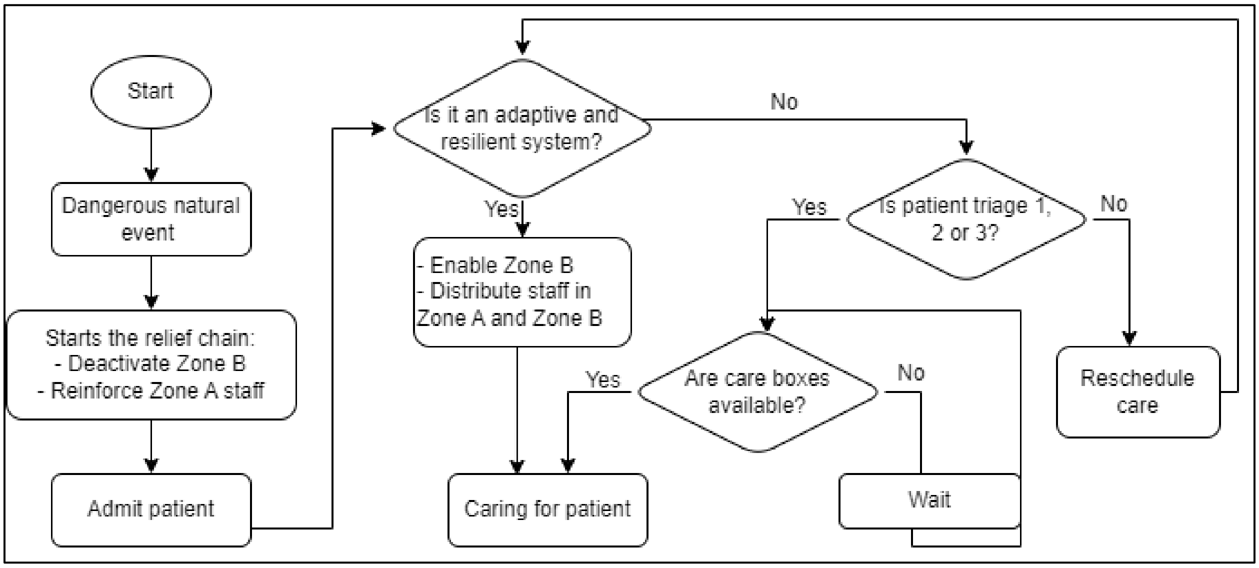

Figure 3: Patient care procedure in ED disaster situations.

4 FORMALIZATION

Once the model with which we will work on patient care has been designed, it is necessary to establish the scenarios that are presented in the ED to compare its performance and development in a normal situation and when the earthquake occurs, three possible scenarios are proposed:

Scenario 1: In this instance, the ED performs in normal situations, with the daily flow of patients, and standard human and material resources. There are a total of 49 beds available in the ED for the care of triage 1, 2 and 3 patients. The distribution of resources for patient care in areas A and B are shown in Table 2.

Scenario 2: In this scenario, the occurrence of an earthquake and the normal development of the ED are evaluated. That is, without activating the relief chain, accepting all patients according to Manchester triage and with the human resources and beds available according to scenario 1. This scenario is proposed to evaluate how the system reacts to an earthquake and without changes.

Scenario 3: In this scenario, we work with the model designed in Section 3. The disaster relief chain is activated and when that happens, speed of attention must be prioritized and care for as many people as possible. So, service times are reduced in certain areas of the ED that allow optimizing this service, such as admission time.

It is kept in mind that in the incident area, rescuers work hard to rescue people, but limited by nature, the greatest volume of work is carried out during daylight. This is reflected by configuring the arrival of patients between the hours of 6:00 a.m. to 8:00 p.m.

Table 2 shows the distribution of staff who attend areas A and B. In the event of an earthquake (critical service), Area A is reinforced and doctors and nurses from Area B are made available in that area.

Table 2: Distribution of staff in Area A and B.

	Regular Service			Critical Service			Distribution
Staff category	**6 am**	**2 pm**	**10 pm**	**6 am**	**2 pm**	**10 pm**	
Area A junior nurse	2	2	2	7	7	7	exponential
Area A senior nurse	2	2	2	9	9	9	exponential
Area B junior nurse	5	5	5	0	0	0	exponential
Area B senior nurse	7	7	7	0	0	0	exponential
Area A junior doctor	2	2	1	7	7	6	exponential
Area A senior doctor	3	3	2	6	5	5	exponential
Area B junior doctor	5	5	5	0	0	0	exponential
Area B senior doctor	3	2	2	0	0	0	exponential

Patient arrivals were modeled using a time-dependent Poisson process. The quantity is given by the work scenario as shown in Table 3. Scenario 1 responds to a normal arrival, with which the ED of the simulator works. On the other hand, Scenarios 2 and 3 show the percentage of patients that Cauquenes Hospital received due to the 8.8 magnitude earthquake that occurred on February 27th, 2010, during the 7-day period following the earthquake.

Table 3: Arrive of patient.

Day	Regular Patient	Percentage Increase	Earthquake Patient
1	297	179 %	827
2	261	10 %	284
3	262	8 %	279
4	263	77 %	466
5	257	1 %	257
6	238	86 %	441
7	248	73%	431

5 RESULTS

This section presents the results obtained from the simulations proposed with the variants of Scenario 2 without the activation of the emergency chain and Scenario 3 with the activation of the emergency chain. The flow of patients can be seen in Figure 4.a., the first 7 days represent a normal daily flow and on day 8 the occurrence of the earthquake can be seen, which is when the flow rises and reaches a peak of 827 patients.

The length of the care box waiting line for treatment is one of the factors that makes it possible to measure the performance of an ED, added to the number of patients admitted daily. Then, when this number grows, it can be said that the system is fully occupied.

The first phase of simulations was carried out to analyze the behavior of the ED in the event of an earthquake and to accept all the patients that arrive, from the most severe to the mildest. In this scenario, there are 49 care boxes that were available in the initial configuration, which, in the case of more patients arriving, are increased to 10 ambulatory care boxes. The nurses and doctors each work in their area and Areas A and B are enabled.

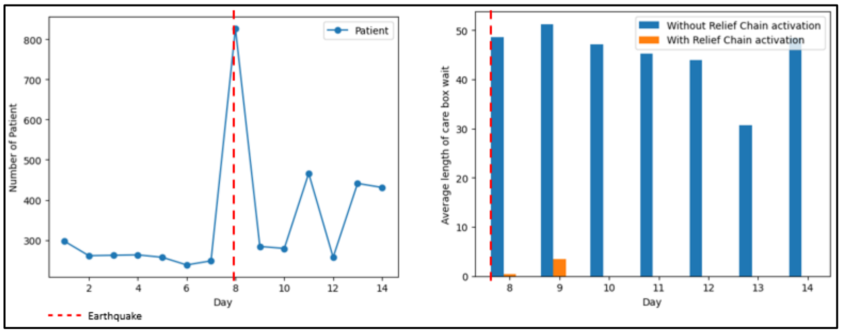

Figure 4: a. Flow of patients before and after the earthquake. b. Queue length of care box with and without Relief Chain activation

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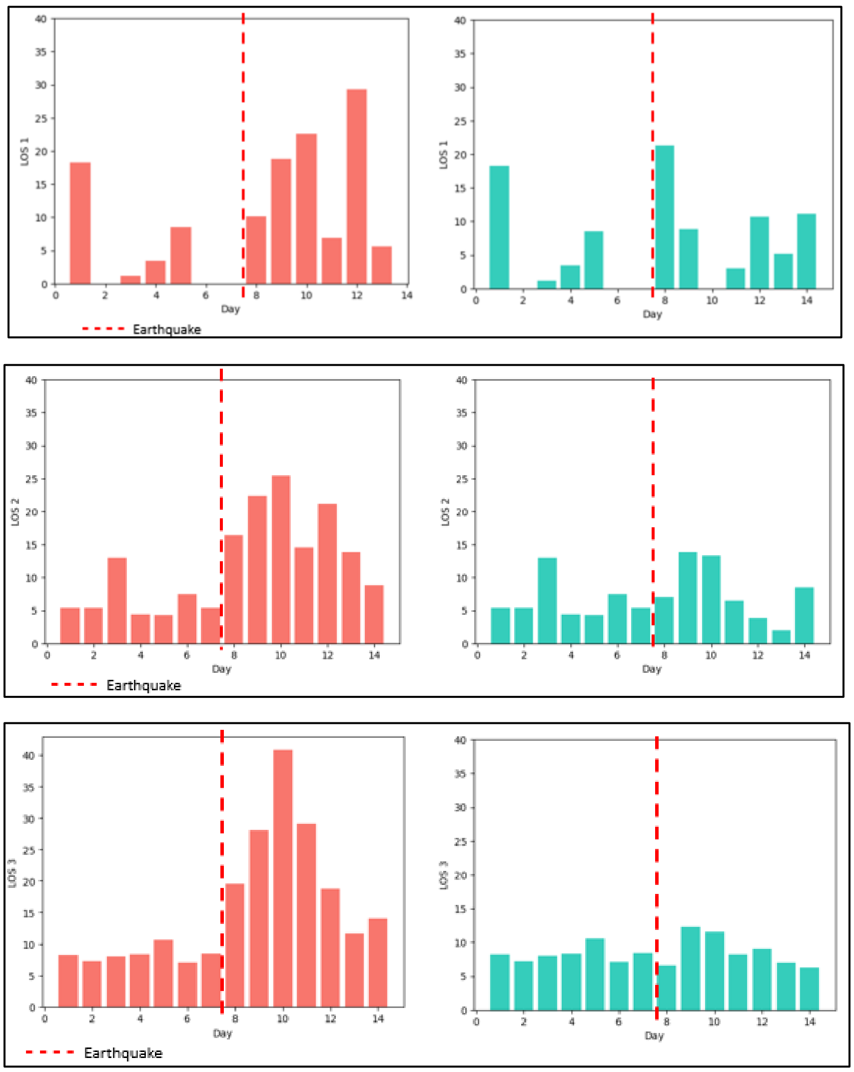

Figure 5: a. (left) Scenario 2 ED without activation of Distress Chain and b. (right) Scenario 3: DA with Succor Chain activation

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From the results of this simulation, it can be seen that there are long queues for triage 1, 2 and 3 patients to get a care box, as shown in Figure 4.b. On average, the length of waiting for the care box is 45 patients per day. This causes patient length of stay in an ED to be considerably increased. In Figure 5.a., the LoS for triage 1 patients in a normal case reaches a peak of 18 hours, but after the earthquake, it reaches a peak 29 hours. Before the earthquake, triage 2 patients had a maximum LoS time of 13 hours. yet after the earthquake, a peak of 25 hours is recorded. Finally, before the earthquake, triage 3 patients had a maximum LoS time of 11 hours, yet after the earthquake, the LoS time is 41 hours.

The second phase of the study responds to the case in which the relief chain is activated and patients from triage 1, 2 and 3 are received. In this scenario, several simulations were carried out to obtain the number of beds necessary for care, allowing LoS times to be as low as possible and the occupation level of doctors and nurses to remain optimal. The number of care boxes in this scenario is 65. Area B was disabled to concentrate efforts in Area A, where triage patients 1, 2 and 3 arrive, doctors and nurses from Area B go to work in Area A. After this configuration, significant changes were seen in the length of the queue waiting for beds and length of stay of patients. As shown in Figure 4b., the bed waiting length is reduced to 0 on the third day after the earthquake. However, the flow of patients continues to be higher than the standard, which is why the study is maintained for the period of 7 days after the earthquake. Regarding the LoS time for triage 1 patients, the maximum period that was spent is 21 hours and, on average, it is a time of 10 hours in which a patient is in the ED.

6 CONCLUSIONS

This article presents the analysis of an ED when situations occur that alter the flow of patient admissions which is important for decision making. Seismic movements that occur in the world are daily, but sometimes the high magnitude and the occurrence in large cities cause a large number of injuries and deaths, added to material losses. This study is a contribution to the performance of an ED when earthquakes occur. The percentage of patients received by Cauquenes Hospital as of February 27th, 2010, for a period of 7 subsequent days was taken as the income flow and was adapted to the number that is prepared to receive the simulator developed by the research group. HPC4EAS at UAB.

The proposed Scenario 2 is an unlikely situation in reality, given that each ED adopts the necessary measures for their care when the flow of patients increases considerably, such as outpatient or virtual care for milder cases, but it is a point of reference to what would happen if all patients were accepted for care.

Scenario 3, instead, comes from an action protocol that is carried out when earthquakes occur, which can vary according to the country or the existing action regulations in each hospital, which is the implementation of a relief chain where the patients have a chance of survival and require hospital care.

The investigation carried out demonstrated how important it is to plan how an ED should act in earthquake situations. The prioritization of patients is carried out in order to attend more patients with serious pathologies. In this way, it was possible to demonstrate that the length of stay of patients in the ED is considerably reduced in a situation where all patients are cared for. The ED model will be useful for management to assess the impact of such an event and to identify the critical resources they need to incorporate recovery. The simulator model has the flexibility that it can be used in another scenario in which the flow of patients and the number of ED staff changes.

Resilience in a system is a broad concept. This time, we studied the resilience that the ED system must have in the event of an earthquake and which allows it to adapt to the flow of patients it will receive during the disaster period, a study that has been carried out through the measurement of the kpi LoS according to the type of patient triage. Resilience is not going back to the previous state but rather adapting to this new situation, which is how the LoS times increased, but with the simulations carried out, it was possible that the values were not excessive.

Future work will follow the line of work presented here, so it is important to study to what extent patients with milder injuries (triage 4 and 5) should be accepted into the ED system until a functional system is achieved with both A and B Areas enabled.

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AUTHOR BIOGRAPHIES

MARIELA RODRIGUEZ is an assistant professor at the Faculty of Engineering of the University of Jujuy. She holds a PhD(c). in Computer Science from the University of La Plata. Her research interests include agent-based simulation, data mining, gender violence. She focuses on the analysis of resilience in an ED through simulation. Her email is mariela.rodriguez@fi.unju.edu.ar

FRANCESC-JOSEP BOIXADER ESTÉVEZ is Director of the University School of Information Technology Tomàs Cerdá (Gimbernat University Schools). He has a Bachelor of Science (Physics) from the Autonomous University of Barcelona (1986); Master in Physics from the Autonomous University of Barcelona in 1990 and earned his Ph.D. in Sciences (area of Physics) from Autonomous University of Barcelona in 1995. He collaborates with the HPC4EAS group, from the Department of Architecture of Computers and Operating Systems from the Autonomous University of Barcelona. His research interest includes the analysis of the applications of the "Computation of High Benefits", specifically, the research being carried out aims to the design and development of a simulator for the Hospital Emergency Service, which can be used as a DSS (Support System for Decision Making). For this, modeling techniques are being applied and Simulation based on Individuals. His email address is francesc.boixader@eug.es

FRANCISCO EPELDE is a Doctor specialist in Internal Medicine, Master in Ischemic Heart Disease from the Central University of Barcelona (UB), Master in Hospital Management from the UB, Master in Cardiovascular Diseases from the UB, Master in Patient of Advanced and Pluripatological Age from the UB, Master in clinical Management from the Catholic University of Murcia. Currently is consultant internal medicine department. He was a Medical Coordinator of the Short Stay Unit of the Parc Taulí de Sabadell University Hospital and Coordinator of the Emergency Working Group of the Spanish Society of Internal Medicine. In education, he is an associate professor of the Department of Medicine of the UAB, where he is responsible of Emergency Medicine. He has been an external consultant in emergency medicine at WHO. Author of 250 publications and 7 book chapters. His email addres is fepelde@gmail.com.

ALVARO WONG is Associate Researcher. He has worked in performance prediction of HPC applications in the ITEA 2 European Project No 09011, research centers & industries. He has a PhD High Performance Computers. Focused lines of research: Parallel Computing & Parallel Applications. He has co-authored a total of 20 full-reviewed technical papers in journals and conference proceedings. His email address is alvaro.wong@uab.cat

EVA BRUBALLA EVA BRUBALLA is currently an Associate Professor with the Computer Science School, Escoles Universitaries Gimbernat i Tomàs Cerdà, University Autonoma of Barcelona (UAB), and an Associate Researcher with the Computer Architecture and Operating System Department, UAB, Spain. She has coauthored eight fully reviewed articles. Her research is on the use of simulation to improve emergency departments' operation. Her email address is eva.bruballa@eug.es.

ARMANDO DE GIUSTI is Professor at the Faculty of Computer Science of the National University of La Plata (Argentina). Extraordinary Professor with Emeritus status by the UNLP (2019). Principal Researcher CONICET (until 2021). He was Director of the Institute for Research in Informatics LIDI (III-LIDI). He is currently Vice President of the Academy of Engineering of the Province of Buenos Aires. He has been Dean of the Faculty of Computer Science for 3 terms (2001-2004, 2007-2010 and 2014-2018). He has published 6 books on Computer Science topics and more than 470 articles in journals, book chapters and annals of national and international conferences. He has supervised 24 PhD Theses in Computer Science and numerous Master Theses in Computer Science. His main research topics are Distributed and Parallel Systems, Cloud Computing, Real-Time Systems, Edge Computing, Information Technology applied in Education and Technology for Digital Transformation. He is the Postgraduate Coordinator of the Faculty of Computer Science at the National University of La Plata where he directs the Master in High Performance Computing and the Specialization in High Performance Computing (accredited by CONEAU). His email address is degiusti@lidi.info.unlp.edu.ar

DOLORES REXACHS is Professor at the Computer Architecture and Operating System Department at University Autonoma of Barcelona (UAB), Spain. She is a PhD in computer engineer. She is co-coordinator of the master in Artificial Intelligence and Big Data in Health - UAB. She has been Coordinator of the postgraduate course in Big Data processing for life sciences - UAB. She has been the supervisor of 9 PhD theses. Her research interests include parallel computer architecture, parallel Input/Output subsystems, performance, and fault tolerance in parallel computers, and social applications. She is co-author of more than 65 full-length technical papers in journals and conference proceedings. Doctor Honoris Causa by the National University of La Plata (UNLP) Argentina (2022). Her email address is dolores.rexachs@uab.cat.

EMILIO LUQUE is currently an Emeritus Professor of Computer Architecture and Technology in the Computer Architecture and Operating Systems (CAOS) Department at University Autonoma of Barcelona (UAB), Spain. Since 1994 he has been involved, leading his group, in several research projects founded by the European Union (EU), the Spanish government, and different industries. His major research areas are: parallel computer architecture, parallel and distributed simulation, performance prediction and efficient management of multi-cluster-multi-core systems and fault tolerance in parallel computers and has published more than 40 papers in technical journals and more than 180 papers at international conferences. He has supervised 20 PhD thesis. Honorary Professor by the National University of San Agustín de Arequipa (UNSA) Perú (2008). Doctor Honoris Causa by the National University of La Plata (UNLP) Argentina (2017). His email address is emilio.luque@uab.cat