- ORIGINAL ARTICLE -

Impact of the Population Pyramid on the Emergency Department

Impacto de la Pirámide Poblacional en el Servicio de Urgencias Hospitalarias

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Abstract

A country's population pyramid can affect the quality and demand for emergency departments (ED) in several ways. EDs may need specialized resources and equipment to meet the population's needs. In this research, we present an analysis of scenarios through agent-based modeling and simulation. We analyzed the population pyramids of Spain, Argentina, and Paraguay to provide insight into how demographic structure impacts the length of stay (LoS) and the need for medical and nursing staff. This can help policymakers and health managers better plan health resources and services in each country. We verified the evolution of the parameters, length of stay (LoS), and the occupation of doctors and nurses depending on different scenarios, such as the age of the patients and the number of patients arriving, and how it can lead to saturation of the ED. Through several scenarios analyzed using simulations of the age pyramids of Spain, Argentina, and Paraguay, we conclude that the age pyramid of patients treated in ED affects the demand for services, the need for specialized care regarding human and material resources, and waiting time. Implementing measures to manage demand and optimize available resources is essential to ensure adequate patient care.

Keywords: agent-based model, emergency department, KPI, population pyramid, simulation.

Resumen

La pirámide poblacional de un país puede afectar la calidad y la demanda de los servicios de urgencias hospitalarias de varias maneras. En esta investigación, presentamos un análisis de escenarios mediante modelado y simulación basados en agents. Analizamos las pirámides poblacionales de España, Argentina y Paraguay para proporcionar información sobre cómo la estructura demográfica impacta la duración de la estancia (LoS) y la necesidad de personal médico y de enfermería. Esto puede ayudar a los responsables y a los gestores sanitarios a planificar los recursos y servicios sanitarios. Verificamos la evolución de los parámetros, la duración de la estancia (LoS) y la ocupación de médicos y enfermeras en función de diferentes escenarios, como la edad de los pacientes y el número de pacientes, y cómo puede conducir a la saturación de los servicios de urgencias hospitalarias. A través de varios escenarios analizados mediante simulaciones de las pirámides de edad de España, Argentina y Paraguay, concluimos que la pirámide de edad de los pacientes en urgencias afecta a la demanda de servicios, la necesidad de atención especializada, y el tiempo de espera. Implementar medidas para gestionar la demanda y optimizar los recursos es esencial para garantizar una atención adecuada al paciente.

Palabras claves: modelo basado en agentes, servicio de urgencias, KPI, pirámide poblacional, simulación.

1 Introduction

Emergency departments are essential in different health systems because they help people who are not in good condition and provide immediate and vital medical care in case of emergency. They help save lives, prevent complications, and ensure the health and well-being of the community. Improving services and quality of care in EDs is one of the most significant challenges in ensuring everyone receives the quality medical care that each person deserves. A country's population pyramid can impact the quality and demand for emergency services in several ways. The demographic distribution of the population, particularly the proportion of older and younger people, can influence the demand for emergency services.

Population composition can also affect the ability of emergency services to provide high-quality care. A broad-based population pyramid, indicating a young and growing population, may result in increased demand for emergency services related to accidents, childhood injuries, and pediatric illnesses. Expanding and improving emergency services may be necessary in areas with a growing young population to meet the needs of an increasing population. A population pyramid with a higher proportion of older people can result in a different and more complex demand for EDs. Older people tend to present with a variety of chronic medical conditions and acute illnesses, which may require more specialized care and a faster response from the ED. EDs may need specialized resources and equipment to meet the population's needs.

Understanding the demographic makeup of the population can help hospitals and health systems better anticipate and plan for the demand for emergency services and implement strategies to manage it effectively. The population pyramid can also influence public health policy planning at the national and local levels [1, 2, 3].

In this research, we present an analysis of a set of scenarios based on a population pyramid analysis model for Spain, Argentina, and Paraguay. We verify how the population pyramid impacts patients' length of stay (LoS) and the occupation of doctors and nurses based on different scenarios and explain how these demographic changes can affect ED demand. Key performance indicators (KPI) refer to a series of metrics used to synthesize information on the effectiveness and productivity of actions, make decisions, and determine which are most effective in meeting the set objectives. In this work, we will study the following KPIs: length of stay (LoS), patient waiting time (Lowt), and the occupation of different resources such as doctors, nurses, laboratory, imaging, triage, and admission based on different scenarios, such as patient aging and variation in the number of resources (doctors and nurses). We examine how variations in the population pyramid influence patients' length of stay (LoS) and the workload of doctors and nurses across different scenarios. Additionally, we analyze the implications of these demographic shifts on the demand for emergency department (ED) services.

There is an ED simulator, which has been developed as part of previous research work by the High-Performance Computing for Efficient Applications and Simulation (HPC4EAS) research group of the Autonomous University of Barcelona (UAB) [4, 5, 6, 7]. The simulator allows the model's behavior to use different parameters. It will serve as a decision-making support system that Hospital administrators can use.

The paper is organized as follows: section II explains related works. In section III, the methodology. Section IV the results and discussion. Section V presents the conclusions and future work.

2 Related works

Some studies carried out on the analysis of the population pyramid in EDs are the following:

In the study by Mielczarek and Zabawa [8], population dynamics are modeled using a hybrid simulation approach. The objective is to present a population submodel developed using the system dynamics approach. Preliminary findings confirm the hybrid simulation approach's validity in further exploring demographic-dependent health policy issues.

In the study conducted by Wiinamaki and Dronzek [9], the research aimed to project the bed requirements for expanding the emergency care center. The model was used to analyze the increasing impact of the aging population in terms of length of stay and bed capacity for a hospital in Florida; the model applied a longer length of stay to older patients. As a result, it indicates that the simulation provided significant benefits in terms of projected financial savings and improved operations.

In the study conducted by Garcia [10] presents research carried out in Sweden, where the influence of population aging on health systems is analyzed. The model they propose can be used to simulate real situations and prevent specific problems, such as a lack or excess of resources and long waiting times, which could lead to critical situations in an emergency health system. They used DES and arena simulation software.

In the study conducted by Baril et al. [11] analyzes the length of stay of outpatients in a hospital ED in the province of Quebec (Canada). The average was just over 7 hours, exceeding the average for all EDs in that locality. The waiting time has generated constant dissatisfaction among patients. A discrete event simulation (DES) was performed using the Arena software [12] to analyze this problem. The results obtained were that by giving more responsibility to nurses, patients' average length management in light of demographic changes. The case study wash of stay was significantly reduced with less financial effort than adding new physicians.

In the study by Hajłasz and Mielczarek [13], the authors analyze a case study using discrete event simulation (DES) to support decision making in hospital bed management in the light of demographic changes; these studies were done using real hospital data. The case study was developed for one of the Polish district hospitals. The influence of demographic changes such as societies' aging and how that affects admissions to the emergency department in age and sex cohorts was investigated, examining factors such as bed availability. It was concluded that simulation is beneficial for checking various scenarios, such as the availability of the number of beds and what aspects should be considered, such as the case of demographic changes. This research shows how demographics influence patient admissions to the emergency department and bed utilization.

In the study by Squires et al., [14], DES was used to test the impact of different change options, such as reducing the number of low or mild-acuity patients in the ED by diverting low-acuity patients at triage to a general medicine service at the exact location, simulation testing was performed before making actual changes to the system to analyze the reduction in patient waiting time.

The study by Mielczarek and Zabawa [15] describes a hybrid simulation model that integrates the system dynamics approach with discrete time control to formulate projections of population evolution. The preliminary results show promise in using the hybrid simulation approach for a more advanced exploration of health policy issues that depend on demographics.

Most work done on ED simulation has used DES. This approach is popular because it allows modeling and analyzing systems where operations occur at specific points in time, providing a detailed representation of processes and workflows. However, our work is based on agent-based modeling. In contrast to prior studies that employ discrete event systems as a formalism for simulating healthcare environments, our methodology leverages agent-based models. These models are relatively underrepresented in the current literature for this type of study, yet they offer significant advantages. Agent-based models can capture individual behaviors and interactions between agents within the simulated model, allowing for a better and more dynamic overview of the simulated environment.

An advantage of the system we propose is the ease of analyzing different KPIs as specified, such as the length of stay (LoS), patient waiting time (Lowt), occupation of doctors, nurses, laboratory, imaging, triage, LoS by triage level, and admission based on different scenarios, such as patient aging and a decrease in the number of resources (doctors and nurses). No recent studies have been identified that address the simulation of the age pyramid within emergency departments (EDs). Our model allows us to analyze the age pyramid of emergency department patients through simulation. Studying the age pyramid of a population helps to understand the demand and workload of emergency departments since requirements and usage guidelines may vary depending on the age distribution of patients attending the emergency department. No current studies have been conducted on the age pyramid of the population, which is a very important topic that cannot be ignored, especially by governments, for future planning of human or material resources in emergency departments. The lack of current studies highlights an important gap in research, the analysis of which can greatly improve the organization and management of resources in the emergency department(ED).

3 Methodology

Our research group has developed and validated a simulator using an agent-based model for an ED in NetLogo [16]. An agent-based model (ABM) has two essential components: the agents and the environment. Everything resides under a series of rules that describe the interaction between those crucial components.

The agents represent the active elements of the model, while the environment is an abstract representation of a real space where a group of individuals can interact. NetLogo plays a crucial role as a simulation environment for agent-based models. It serves as the basis for the agent-based system, driving the agents' behavior through a state machine that guides all interactions during the simulation.

Individuals in an ED move from one place to another, interacting with other agents. During this time, as a result of interactions and due to the patient's conditions, each agent changes its state. A state machine effectively represents this behavior and models a system with distinct and separate states. A set of state variables represents these states; each variable can take one of a series of possible values at each moment in time, and each set of different values represents a different state.

An ABM approach is used to simulate the ED, where the agents are the patients, the health personnel, and the physical resources of the ED (see Fig. 1). The patient flows are registration, triage, diagnosis, and treatment (i.e., clinical and nursing evaluation in both areas) and the dependent service processes (medical imaging tests and laboratory tests), and the duration of each service process is different from other processes.

It has two separate areas: for urgent patients (zone A) and non-urgent patients (zone B) (Fig. 1). Each zone operates with its personnel, functioning independently of the other groups [17]. A critical aspect of stochastic simulation is the reliability and quality of the random number generator used for random operations. NetLogo uses a number from the random series for each patient's arrival (to calculate the time between patients according to the Poisson process). Patient arrival intervals follow a Poisson process distribution, with the process mean changing by the time of day modeled.

Although the method and means do not change between simulations, the effect of a change in the randomness seed of a simulator run will change the intervals, and this property allows the model to be analyzed statistically, using several different values for this seed. The Poisson process means that other values are given depending on the time of day. Several values in the literature have been adapted for the simulator analysis [18].

When patients arrive at admissions, they are added

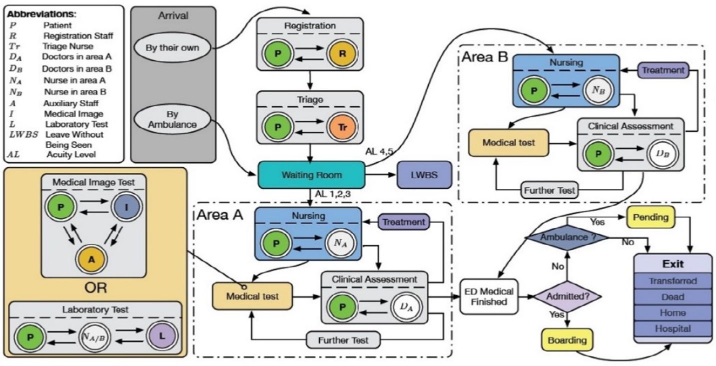


Figure 1: Workflow of ED and the interaction between its components elements.

to a queue. When it is their turn, the patient approaches one of the admissions staff, who asks for the personal details necessary to register them in the computer system. Patients are often directed to a waiting room after this interaction. Triage is the first place where a triage nurse examines a patient. The nurse then assigns a severity number to the patient.

Most hospitals worldwide utilize a five-level triage system, with level one representing the most severe cases and level five the least severe. All patients are divided into five acuity levels (AL): I-resuscitation, II-emergent, III-urgent, IV-less urgent, and V non-urgent, according to the Spanish triage system [19], and [20], by prioritizing incoming patients and identifying those who cannot wait to be seen based on patient condition and resource needs. Patients with a higher level of severity (level I or II) have a higher priority to receive treatment and use physical ED resources.

A patient's triage results also determine her treatment area in the ED. Patients with severity levels I, II, and III are hospitalized/treated in zone A and remain in their care boxes during all diagnosis and treatment processes. In contrast, patients with severity levels IV and V are hospitalized/treated in zone B. The simulator's advantage is that it obtains the overall average LoS of the service and each severity level, allowing for the development of more appropriate policies.

The same nurses and healthcare personnel carry out all patients' admission and triage phases. After triage, in the diagnosis and treatment stages, different doctors and nursing assistants serve each area while sharing the same testing services resources, such as X-rays, laboratory tests, etc. [17]. In typical cases, after triage, the patient returns to a waiting room before seeing a doctor. If the patient has a severe health condition, they will be taken directly for diagnosis and treatment. The diagnosis and treatment area is where doctors see patients and consider their ailments or injuries. Patients, their companions, doctors, and emergency nurses interact within this environment there.

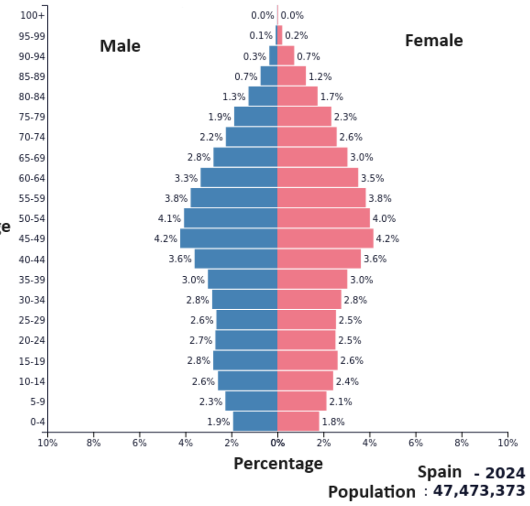
There are designated offices where doctors attend to patients who do not require a stretcher for immediate diagnosis. In contrast, stretchers are reserved for patients expected to have a more extended stay in the emergency room. Emergency nurses rotate between stretchers to ensure patients have everything they need. Individuals in an ED move from one place to another, interacting with other agents. Each agent changes its state during this time due to interactions and patient conditions.

Agents in the ED are modeled as Moore machines [21], where each state corresponds to a distinct output. In our system, we can measure the LoS or Lowt by triage level or patient severity level and the occupation of the healthcare personnel. This could be very useful for hospital administrators. Analyzing which critical resource is causing the LoS to increase is essential. The output of our agent-based simulator, which tracks the status of ED agents (sensors), delivers essential such as length of stay (LoS) and patient waiting time (Lowt) for each stage, offering valuable insights for optimizing ED management. Time is divided into identical discrete intervals and periods at each time step of the agent's operating system.

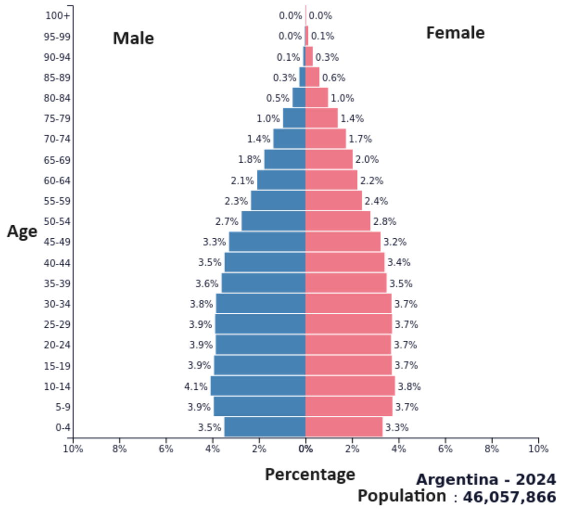
Each time step is divided into two phases. Assuming the simulator is at the time, the phases are as follows: First, each agent processes the inputs from the last phase, and according to that input and the state as it was in the previous step and, changes to its new state. Second, each agent emits its output to its current state. This output uses receivers to change to the next state. Over time, each agent changes state. It may change to the same state it was in previously, but there is a change anyway.

4 Results and discussion

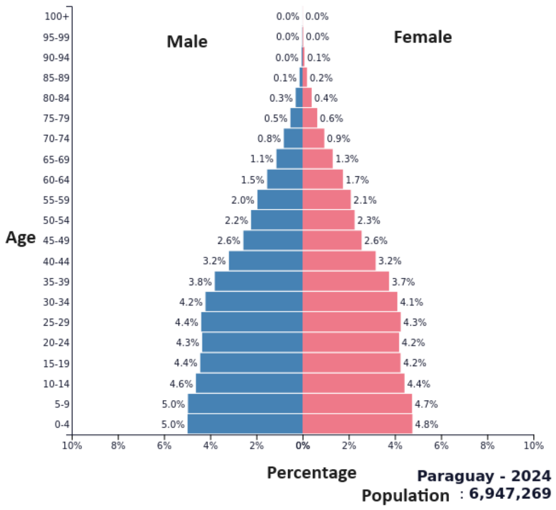
In our emergency simulator, we use data from the patient's age [22] distributions as inputs to the model to generate the patient agent. These data were obtained from the global population pyramid of each country [22] and can be seen in the following 2, 3, 4, and 5 what will the population pyramids of Spain, Argentina and Paraguay looks like in 2024, 2029, 2034, and 2039.



(a) Spain

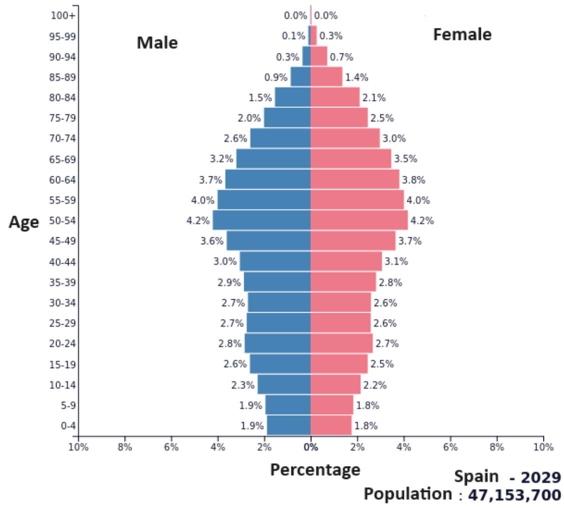


(b) Argentina

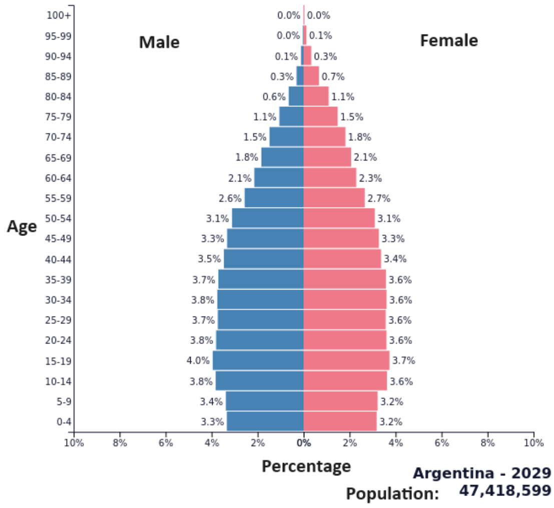


(c) Paraguay

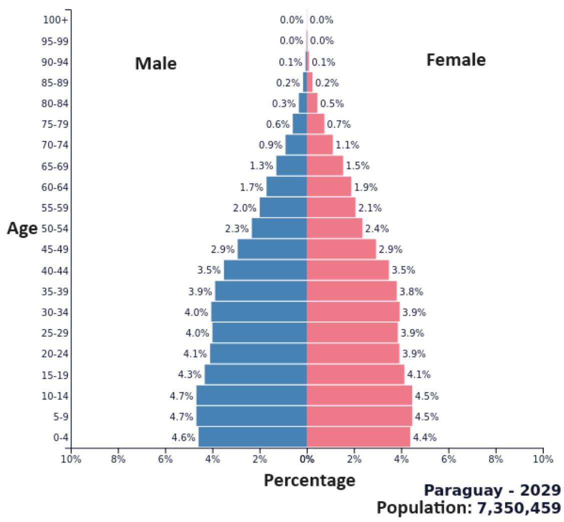
Figure 2: Population Pyramids of the World for the year 2024 for Spain, Argentina and Paraguay [22]



(a) Spain

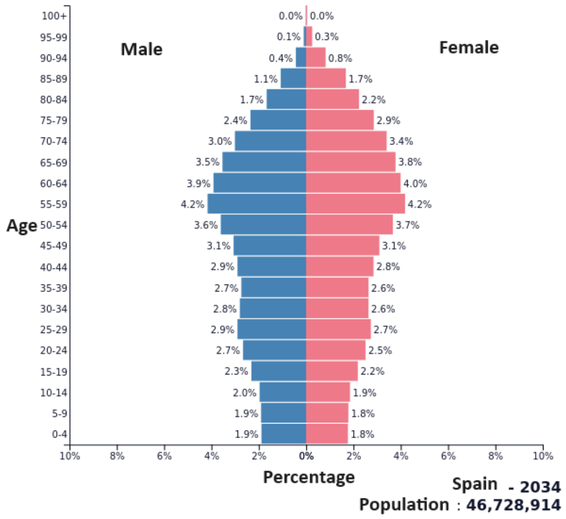


(b) Argentina

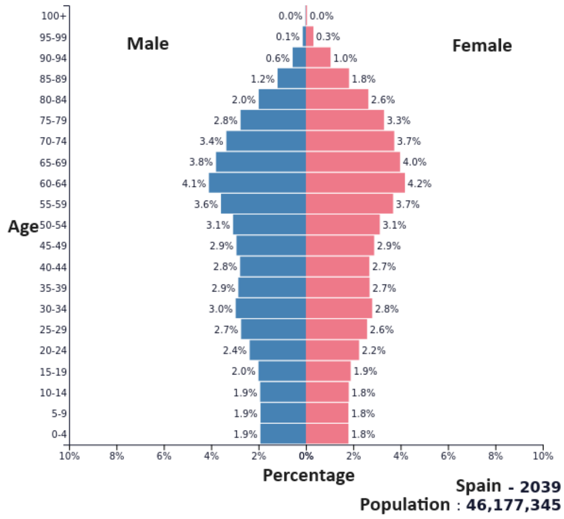


(c) Paraguay

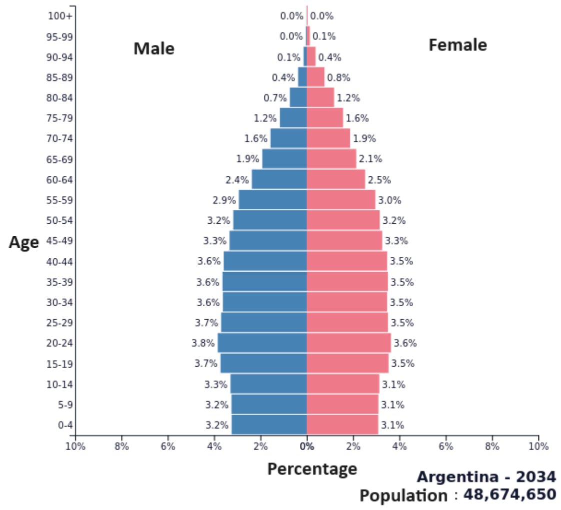
Figure 3: Prediction pyramids of the World for the year 2029 for Spain, Argentina and Paraguay [22]



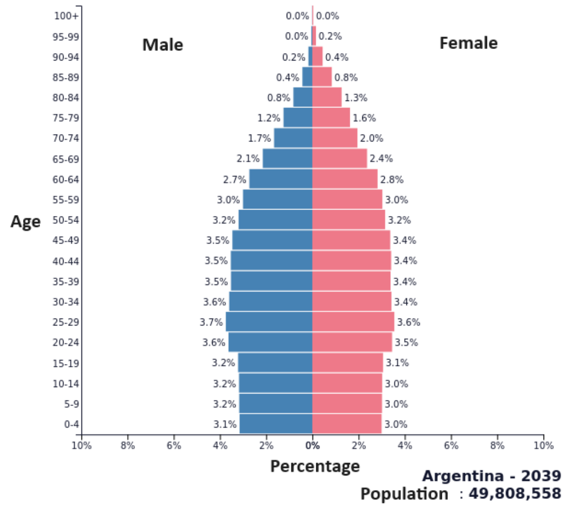
(a) Spain



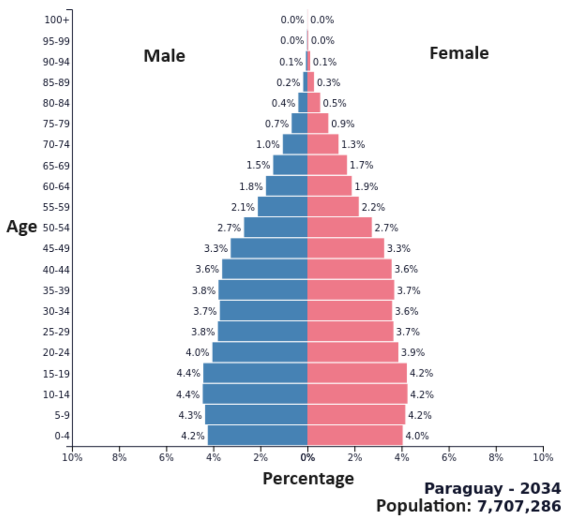
(a) Spain



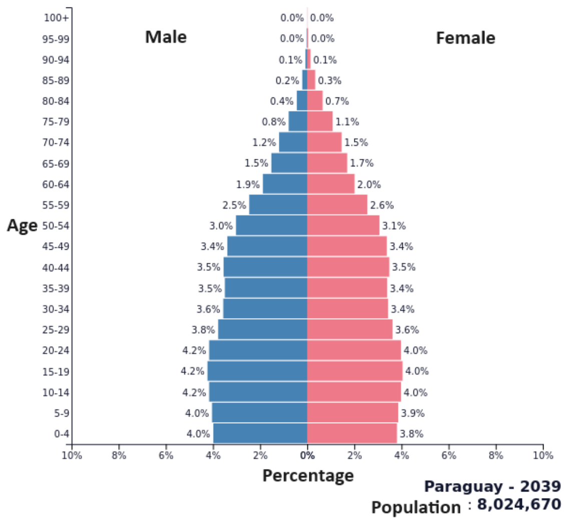
(b) Argentina



(b) Argentina



(c) Paraguay



(c) Paraguay

Figure 4: Prediction pyramids of the World for the year 2034 for Spain, Argentina and Paraguay [22]

Figure 5: Prediction pyramids of the World for the year 2039 for Spain, Argentina and Paraguay [22]

We analyze scenarios based on Spain, Argentina, and Paraguay's age pyramids. We can analyze different age distributions because they are different age pyramids with more or less aged or young populations. These data were derived from the global population pyramids of each country [22]. We verify the evolution of the parameters based on different scenarios and explain how these demographic changes can affect the demand for EDs. Some KPIs we selected to analyze are significant for the patient: length of stay (LoS) and length of wait (Lowt), and essential for management: the occupancy of doctors, nurses, and admission.

With the input data from the age pyramid of Spain, Paraguay, and Argentina, we conducted 100 simulations with an average of 300, 320, 340, 360, 380, 400, 420, and 450 patients per day for three months for each simulation. We analyze the LoS parameters and the occupations of the different hospital resources with these simulations. In Table 1 and Table 2 present the average Length of Stay (LoS) for LoS 2 and LoS 3 in 2024 for Spain, Argentina, and Paraguay, with patient numbers progressively increasing from 300 to 450 to avoid abrupt variations. The data reveal that Spain, the country with the oldest population, exhibits the highest LoS.

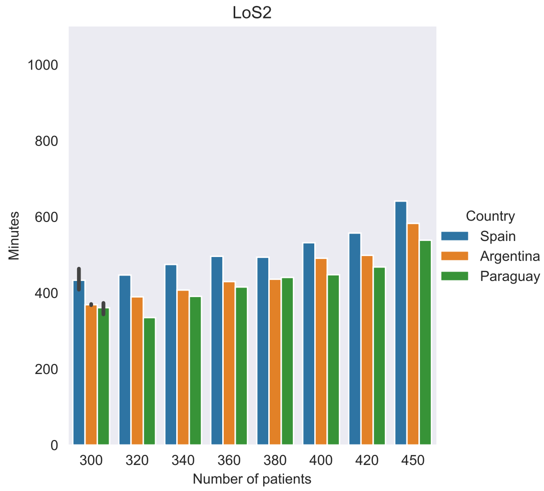
Table 1: Comparison of the length of stay for severity level 2 according to the number of patients from 2024.

Number of patients	Spain LoS2 (minutes)	Argentina LoS2 (minutes)	Paraguay LoS2 (minutes)
300	433	369	361
320	447	390	335
340	475	407	391
360	496	430	415
380	494	436	441
400	532	491	448
420	557	499	468
450	641	583	539

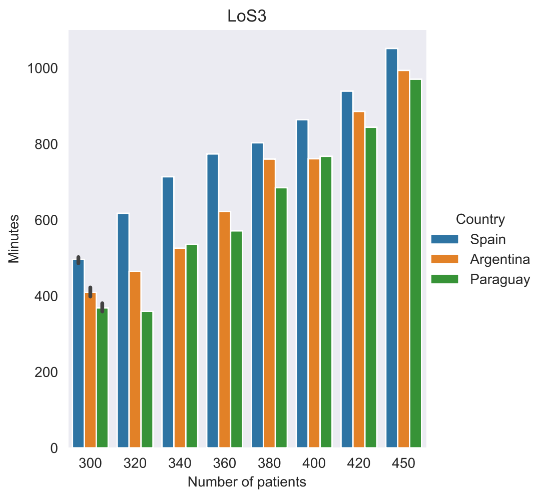
Table 2: Comparison of the length of stay for severity level 3 according to the number of patients from 2024.

Number of patients	Spain LoS3 (minutes)	Argentina LoS3 (minutes)	Paraguay LoS3 (minutes)
300	496	409	369
320	618	464	359
340	714	526	536
360	774	622	571
380	803	760	685
400	864	761	768
420	939	886	844
450	1051	994	971

In Fig. 6, you can see the analysis of the results after performing the simulation with a gradual increase in patients from 300, 320, 340, 360, 380, 400, 420 to 450. For the countries of Spain, Paraguay, and Argentina, the age pyramid for the year 2024 will be used. The Length of Stay (LoS) gradually increases across all countries as the number of patients arriving at the emergency service rises. In the graphical representation, Spain is described by the blue bar, Argentina by the orange bar, and Paraguay by the green bar. We analyze the LoS results for severity levels 2 and 3. It was not analyzed for level 1 due to a low number of patients.



(a) LoS2



(b) LoS3

Figure 6: Comparison of the length of stay for severity level 2,3 according to the number of patients from 2024; The blue bar corresponds to Spain, the orange bar to Argentina, and the green bar to Paraguay.

The age pyramid of Paraguay has a broad base, which indicates that the population has a relatively higher number of young people. This shows a higher birth rate and a younger population. The age pyramid can show a more even distribution in the younger age groups and a decrease in the older age groups. According to the age pyramid, Argentina seems more stable than Paraguay, with a narrower base. This suggests a more balanced birth rate and a more constant population regarding age distribution. Argentina has experienced an aging population for some years, with a higher percentage of older people.

The population pyramid in Spain shows a narrower base and a broader top in the older age groups compared to Paraguay and Argentina, where the base is broader and the top narrower. This reveals that Spain has lower birth rates and a higher longevity rate, resulting in an aging population. Spain has experienced a marked population aging process in recent decades, with a significant increase in the percentage of older people and a relatively smaller proportion of young people.

With the input data from the age pyramid of Spain, Paraguay, and Argentina countries, we conducted simulations with 300, 320, 340, 360, 380, 400, 420, and 450 patients for three months for each simulation. We analyze the LoS parameters and the occupations of the different hospital resources with these simulations.

The blue box plot represents the orange and green LoS of Spain, Paraguay, and Argentina. LoS 2, 3, 4, and 5 in Spain are more significant than in Paraguay and Argentina. With an older population, patients in Spain may have a lower prevalence of mild diseases and a chronic illness and a higher prevalence of multiple comorbidities, which could prolong their stay in the emergency services.

Additionally, older patients may require more extensive evaluation and care and greater coordination with specialized hospital services, which could increase the LoS in EDs. Patients in Paraguay and Argentina may have milder illnesses, fewer serious illnesses, and associated morbidity than in Spain.

Age is modeled based on each country's population pyramid, which affects the number of treatments and severity levels of patients. For example, in more chronic patients, treatments will take longer; therefore, the length of stay in the hospital ED will be longer.

Although each country's age pyramid can influence the length of stay in EDs, other factors also play an essential role. These include the disease burden of the population, the availability of healthcare resources, the efficiency of the overall healthcare system, the lack of doctors, nurses, laboratories, accessibility to hospital care, and delays in receiving care and treatment, which may also influence the time the patient spends in the ED.

Argentina exhibits a more balanced age distribution in its population pyramid than Paraguay and Spain, resulting in a mix of younger and older patients in the emergency department (ED). The LoS in EDs in Argentina could vary depending on the severity level of the patient's medical conditions, the availability of resources, and the efficiency of the healthcare system.

As an example of an analysis that can be performed, considering the sensors in Fig. 7 and Fig. 8, we present the results of our research. We compared the effects of the parameters of the age pyramid of the year 2024. We analyzed the occupations of doctors in Area B and nurses in Area A in Spain, Paraguay, and Argentina.

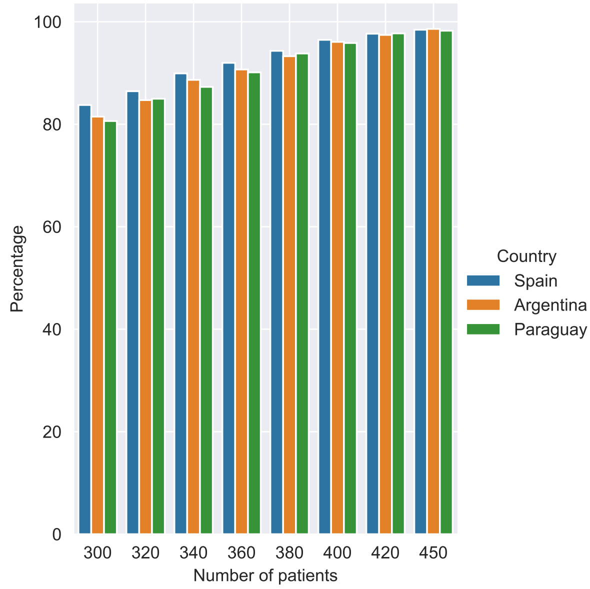


Figure 7: Comparison of the occupation of doctors in Area B in the countries of Spain, Argentina, and Paraguay from 2024; The blue bar corresponds to Spain, the orange bar to Argentina, and the green bar to Paraguay.

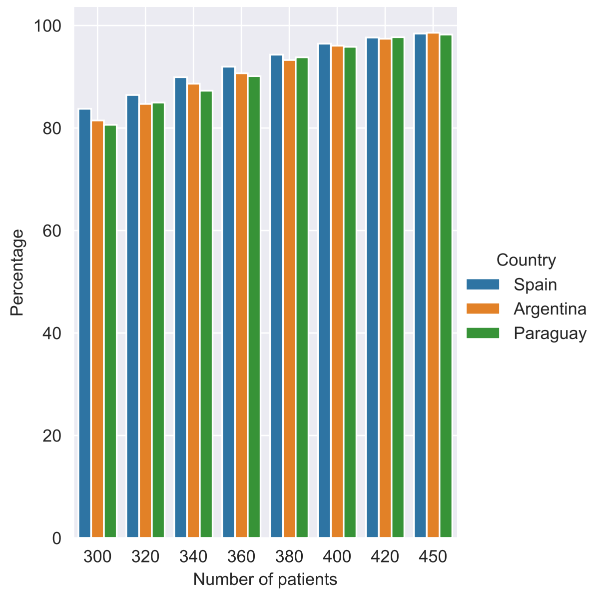


Figure 8: Comparison of the occupation of nurse A in the countries of Spain, Argentina, and Paraguay from 2024; The blue bar corresponds to Spain, the orange bar to Argentina, and the green bar to Paraguay.

The simulations were conducted over multiple three-

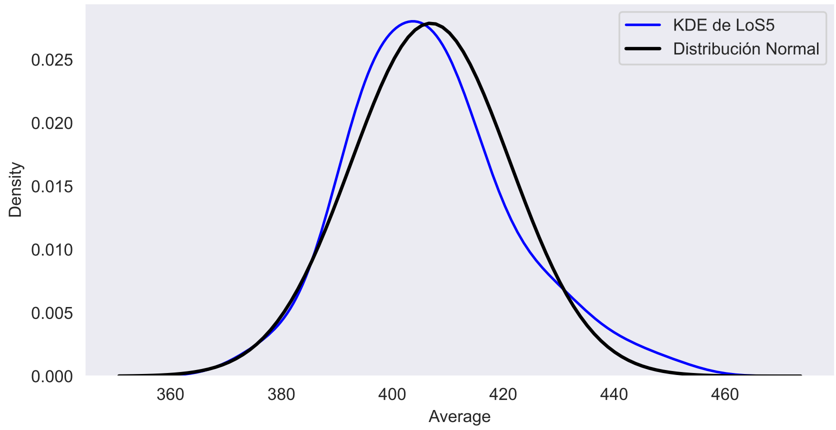


Figure 9: Normal distribution of LoS5.

month periods, with the number of patients progressively increasing from 300 to 450, offering a comprehensive overview of the scenario. The LoS for Spain is a little higher; this may be because the aging population can increase the workload of doctors in EDs. Due to the greater prevalence of chronic, highly complex diseases, the higher risk of complications, the complexity of the cases, the need for geriatric evaluation, or the coordination of post-discharge care.

The length of stay in the ED increases when the number of patients arriving at the emergency department increases, whether due to epidemics, pandemics, flu, or other types of diseases or disruptions such as earthquakes, accidents, or other reasons. Multiple variables, such as congestion, arrival of patients with more complex cases, and a shortage of resources, such as doctors and nurses, can contribute to patients remaining hospitalized for longer, increasing the patient's length of stay.

We took the country of Spain to experiment and see what happens. We did several simulations, with over three months for each simulation, from 300 to 450 patients. We compared the results with our original simulation. In one variation, we added one doctor to Area B and one nurse to Area A; in another, we added only one doctor to Area B; and in a third, we added only one nurse to Area A.

For all cases, we analyzed whether the length of stay (LoS) for each severity level is a normal distribution, as seen in Fig. 9, by performing 100 simulations. In this case, for patients with severity level 5. The x-axis shows the average in minutes, and the y-axis shows the density. In a typical distribution graph, the density represents the height of the probability curve for a specific value of the random variable. The probability density function details the relative probability that a numerical value resulting from a random experiment will take on a particular value.

Fig. 10 shows the result of simulating the doctor occupancy behavior in Zone B by replacing the 2024 age pyramid in the different countries.

The simulations were carried out over several three-month periods of each simulation, gradually increasing the number of patients from 300 to 450, which provides a global perspective on the problem. The Los for Spain is a little higher; this may be because of the aging population can increase the workload of doctors in EDs due to the greater prevalence of chronic, highly complex diseases, the higher risk of complications, the the complexity of the cases, the need for geriatric evaluation, or the coordination of post-discharge care. An increase in LoS is also observed in EDs as the the number of patients increases. This may be due to several factors, such as increased congestion, delays in care, case complexity, and resource limitations, all of which may contribute to increased length of patient stay.

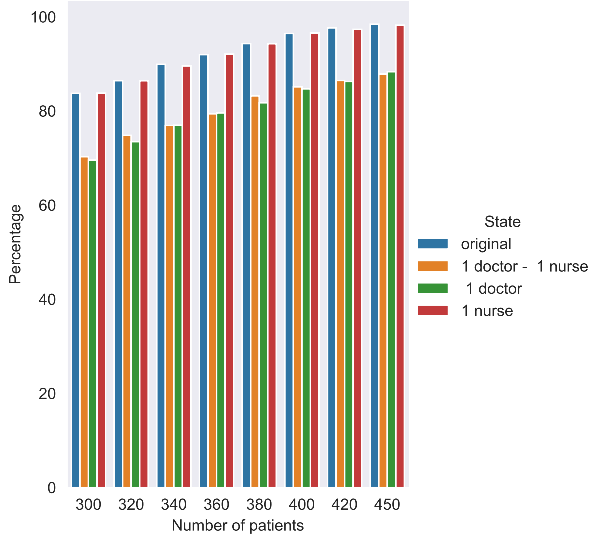


Figure 10: Increases in resources for the case of the country Spain, case analysis of doctors in Area B occupation, from 2024.

We took the country of Spain to experiment and see what happens. We did several simulations with over three months for each simulation, from 300 to 450 patients. We compared the original simulation we had done previously, and in one of the simulations, we added one doctor in Area B and one nurse in Area A.

On the other, we said only one doctor in area B and Another, there is only one nurse in area A. Fig. 10 shows the result of simulating the doctor occupancy behavior in Zone B by replacing 2024 age pyramid in the different countries. The original simulation case we had previously run for 300 patients reached approximately 80 percent occupancy, as seen in the blue bar, and the orange bar represents the scenario where a doctor and a nurse are added.

In that case, doctors' occupancy in Area B decreases from 80 to approximately 70 percent. The green bar represents the scenario where a doctor is added, which can also reduce the doctor's occupancy rate by 10 to 15 percent. The red bar represents when a nurse is added. In the case of doctors in Area B, adding a nurse does not affect the doctor's occupancy rate. You can see how the number of patients gradually increases from 300 to 450.

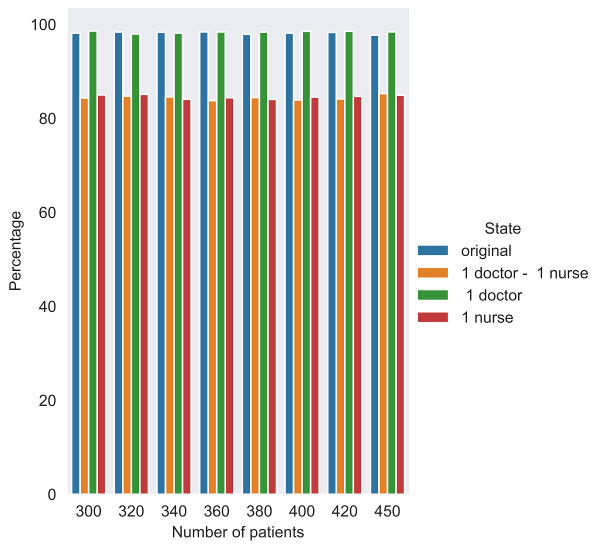


Figure 11: Increases in resources for the case of the country Spain, case analysis of nurses in Area A occupation, from 2024.

Fig. 11 shows the result of the simulation of the behavior of the nurse's occupancy in area A by replacing the 2024 age pyramid for the case of the country Spain. For the original case of the simulation that we had previously done for 300 patients, it reached approximately 98 percent occupancy, which represents the blue bar, and the orange bar represents the scenario of when a doctor and a nurse are added in area A, in that case, it can be observed that the occupation of the nurse in area A decreases from 98 percent to approximately 85 percent.

The green bar represents the scenario when one doctor is added, which can be seen in the fact that the nurse's occupation percentage does not change practically. The red bar represents when a nurse is added to area A, which is observed to decrease the nurse's occupancy from 98 percent to approximately 85 percent occupancy.

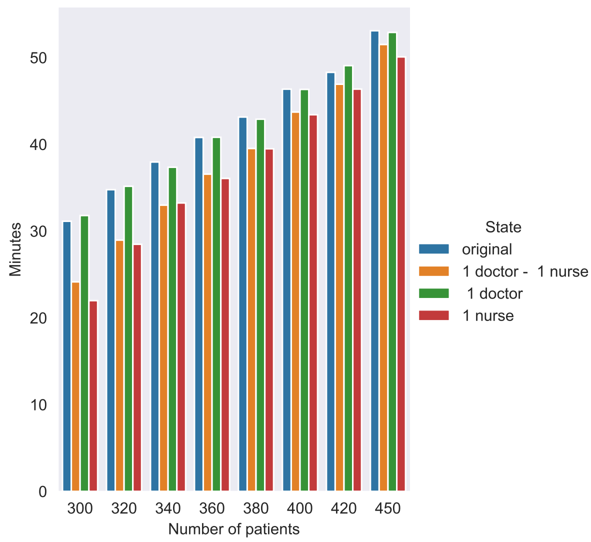


Figure 12: Carebox waiting time length for the case of Spain, from 2024.

Fig. 12 shows the result of the simulation using the age pyramid of the year 2024 for the case of Spain, studies the behavior of the length of the waiting time for a care box in minutes; it can be seen that the waiting time of the care box increases as the number of patients increases.

The x-axis represents the number of patients arriving at the ED, increasing from 300 to 450 in increments of 20 for Spain, while the y-axis shows the percentage of patients waiting for a care box, measured in minutes.

The original case of the simulation we had previously done for 300 patients reached approximately 30 minutes, representing the blue bar. The orange bar represents the scenario when a doctor and a nurse are added in area A; in that case, it can be observed that the waiting time decreases when adding these resources. The green bar represents the scenario in which a doctor is added.

What can be verified is that adding a doctor does not affect the waiting time in the care box. The red bar represents when a nurse is added to area A; what is observed is that adding a nurse decreases the occupation of the care box time. This indicates that adding a nurse reduces waiting time more than adding a doctor.

Fig. 13 shows the result of the simulation of the behavior of a comparison of the analysis of the length of stay of patients with severity level 2 (LoS2) in the countries of Spain, Argentina, and Paraguay in the years 2024, 2029, 2034, and 2039 using the world age pyramid [22]. It can be observed that the LoS of patients with severity level 2 in Spain is much higher than in Argentina and Paraguay due to the more significant number of chronic patients in Spain. Patients with severity level 2 are the most urgent and are located in zone A.

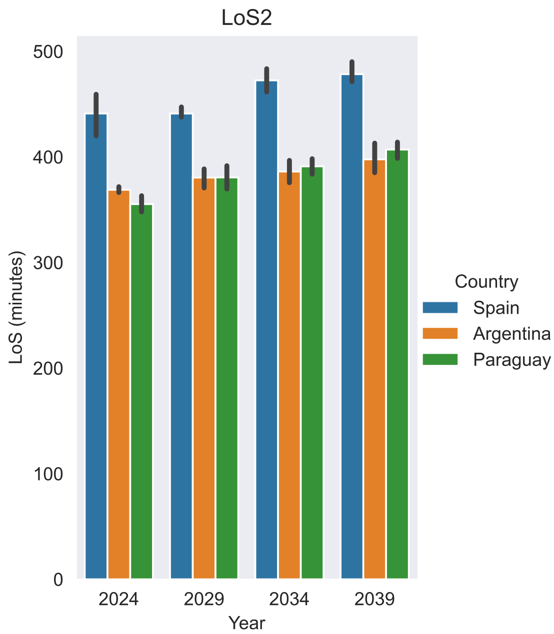


Figure 13: Comparison of LoS2 countries from 2024 to 2039; The blue bar corresponds to Spain, the orange bar to Argentina, and the green bar to Paraguay.

The blue bar represents Spain, the orange bar represents Argentina, and the green bar represents Paraguay. The x-axis displays the years selected for the simulation—2024, 2029, 2034, and 2039—with the age pyramid for each corresponding country and year applied. The y-axis represents the average waiting time (LoS) in minutes for severity level 2. The simulation reveals that patients in Spain stay longer than those in Argentina and Paraguay. This is attributed to the more significant number of elderly patients in Spain, which increases the length of hospital stays.

Fig. 14 shows the result of the simulation of the behavior of a comparison of the analysis of the length of stay of patients with severity level 3 (LoS3) in the countries of Spain, Argentina, and Paraguay in the years 2024, 2029, 2034, and 2039 using the world age pyramid [22]. The x-axis indicates the years chosen for the simulation—2024, 2029, 2034, and 2039—using the age pyramid specific to each country and year. The y-axis shows the average waiting time (LoS) in minutes for severity level 3.

It can be observed that the LoS of patients with severity level 3 in Spain is much higher than in Argentina and Paraguay due to the more significant number of chronic patients in Spain. The bars are color-coded to represent each country: blue for Spain, orange for Argentina, and green for Paraguay.

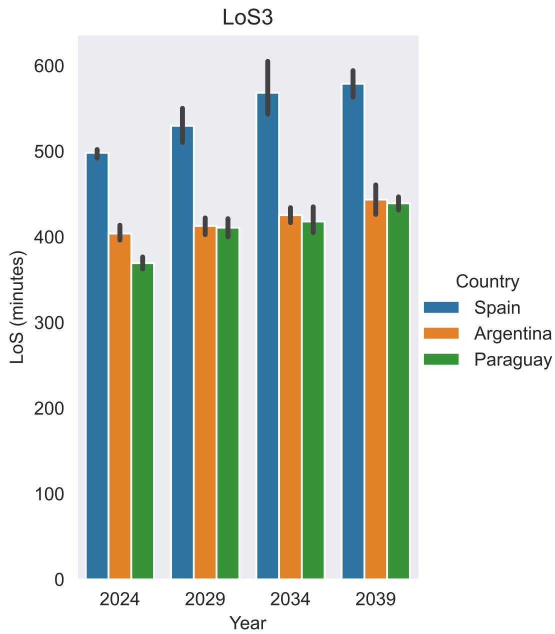


Figure 14: Comparison of LoS3 countries from 2024 to 2039; the blue bar corresponds to Spain, the orange bar to Argentina, and the green bar to Paraguay.

Comparing the graphs of LoS 2 and 3, that is, the length of stay of patients with severity levels 2 and 3, it can be observed that the length of stay is longer for patients with severity level 3 compared to 2. This may be because there are more patients with severity level 3. Patients with severity level 3 are in zone A of the ED and are considered among the most serious patients, along with patients with severity levels 1 and 2.

In Fig. 15, we observe the comparison of the results of the average LoS after performing the simulation with the parameters of the age pyramid of patients with severity levels 2, 3, 4, and 5 of Spain, Paraguay, and Argentina with the age distribution world age pyramid [22], that we entered as a parameter, for the years 2024, 2029, 2034 and 2039.

On the x-axis, you can see the different severity levels of each LoS; these are severity levels 2, 3, 4, and 5. Severity levels 2 and 3 are the patients in Zone A and are the most severe, and the patients with severity levels 4 and 5 are those in Zone B and are the mildest. On the y-axis, you can see the average in minutes for the severity of each level. You can see that the LoS of patients in Spain is much higher than in Argentina and Paraguay due to the significantly higher number of chronic patients in Spain. The bars plot represents a color for each country; for example, the blue bar represents Spain, the orange bar represents Argentina, and the green bar represents Paraguay.

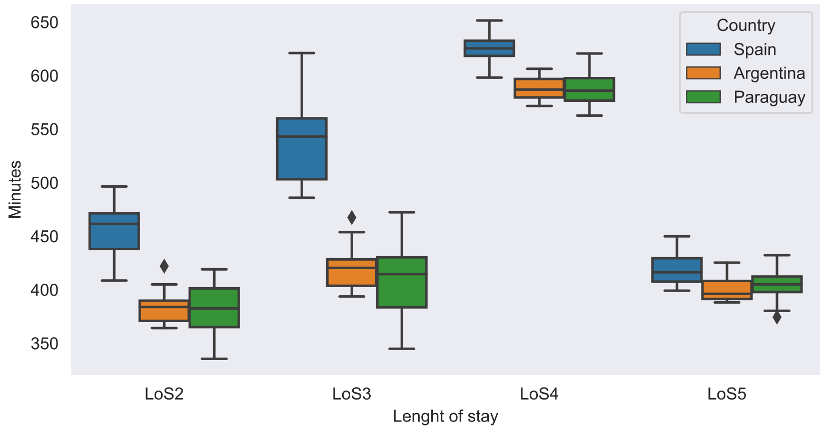


Figure 15: Comparison of the length of stay (LOS) for severity levels 2-5 in Spain, Argentina, and Paraguay from 2024 to 2039; The blue bar corresponds to Spain, the orange bar to Argentina, and the green bar to Paraguay.

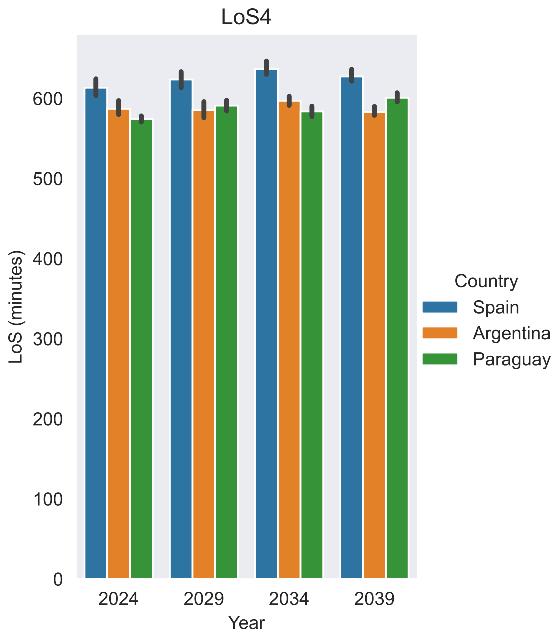


Figure 16: Comparison of LoS4 countries from 2024 to 2039; The blue bar corresponds to Spain, the orange bar to Argentina, and the green bar to Paraguay.

Fig. 16 shows the result of the simulation of the behavior of a comparison of the analysis of the length of stay of patients with severity level 4 (LoS4) in the countries of Spain, Argentina, and Paraguay in the years 2024, 2029, 2034, and 2039 using the world age pyramid [22].

It can be observed that the LoS of patients with severity level 4 in Spain is much higher than in Argentina and Paraguay due to the more significant number of chronic patients in Spain. The x-axis represents the years selected for the simulation—2024, 2029, 2034, and 2039—using the age pyramid corresponding to each country and year. The y-axis displays the average waiting time (LoS) in minutes for severity level 4.

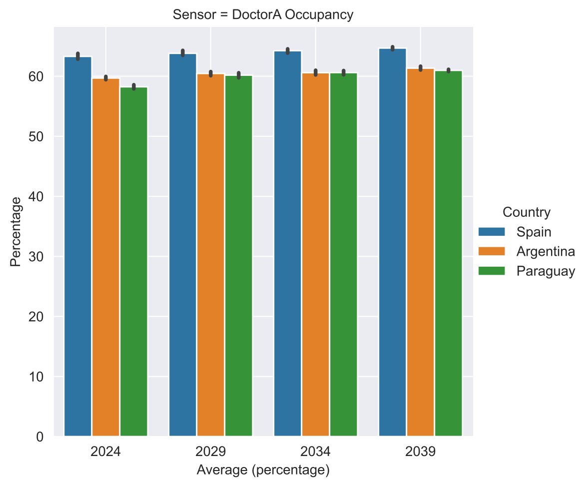


Figure 17: Comparison of the occupation of doctors in Area A in Spain, Argentina, and Paraguay; The blue bar corresponds to Spain, the orange bar to Argentina, and the green bar to Paraguay.

It can be observed that the LoS of patients with severity level 4. Patients with severity level 4 are those patients who are in area B of the hospital emergency department and are among the mildest patients, along with patients with severity level five. Generally, these types of patients spend less time in the hospital but sometimes take longer to be treated. The bars plot represents a color for each country; for example, the blue bar represents Spain, the orange bar represents Argentina, and the green bar represents Paraguay.

Fig. 17 shows the result of the behavior simulation of how the age pyramid of different countries in EDs influences the occupation of resources. In the case of Spain, the blue bar for the occupation of doctors in area A in 2024, 2029, 2034, and 2039 is slightly higher due to the more significant number of patients. Spain has the oldest population and, therefore, more chronic patients compared to Argentina and Paraguay.

On the x-axis, you can see the years for which the simulation was selected, 2024, 2029, 2034, and 2039, and from which the age pyramid for that country and that year was used. The y-axis represents the percentage of doctor occupancy in Area A for the specified years.

The bars represent a color for each country; for example, the blue bar represents Spain, the orange bar represents Argentina, and the green bar represents Paraguay.

5 Conclusions

This research presents a scenario analysis using agent-based modeling and simulation; we examine the population pyramids of Spain, Argentina, and Paraguay from 2024 to 2039 to understand how demographic structure affects the length of stay (LoS) of patients in EDs and the need for medical and nursing staff.

The different scenarios suggest that patients' length of stay (LoS) increases with an older population and decreases otherwise. This aligns with logical reasoning, as older populations typically require more complex and prolonged care. The results also show that the occupancy of doctors, nurses, and examination boxes increases as more patients arrive. Since Spain has a slightly older population than the others, the length of stay was a little longer than in Argentina and Paraguay.

Hospital administrators can benefit from an ED simulator based on the age pyramid of countries such as Paraguay, Spain, and Argentina from 2024 to 2039.

Proactive long-term planning is critical to predicting how the demand for emergency services will change over time due to population aging and other demographic factors.

Resource allocation helps determine the future need for medical personnel, equipment, and supplies, ensuring that resources are aligned with projected demand.

It will facilitate policy establishment by enabling the development of public health policies and emergency management strategies based on accurate data and simulated scenarios.

By improving the quality of care, the simulator allows for identifying periods of high demand and designing interventions to reduce waiting times, thereby directly improving patient care.

Impact assessment helps to evaluate how different strategies and policy changes affect the quality and efficiency of emergency services. Research in this area is valuable as it enables the analysis of how varying age structures impact the workload of emergency departments.

Simulation can help assess the current capacity of EDs and decide whether they will be able to meet the anticipated future requirements. It is an efficient tool for predicting and planning various scenarios in emergency departments, in multiple contexts, or specifically, as is the case with the changing population pyramid and increased patient arrivals. This includes evaluating the availability of beds, medical and nursing staff, equipment, supplies, and physical space.

This approach provides policymakers and healthcare managers with critical information and the tools to effectively plan and allocate physical, material, and human resources and healthcare services appropriate to each country's needs.

As a future direction, the aim is to develop digital twins of the emergency departments (EDs) in the analyzed countries, validate the results against real-world scenarios, and thoroughly explore the unique parameters of each country's ED.

Authors' contribution

The authors confirm their contribution to the article as follows: RG: Conducting experiments, Performing graphics, and Writing-Preparing the original draft; AW: Investigation, Supervision, Software, Validation, Correction; DR: Investigation, Supervision, Software, Validation, Correction; RS: Investigation, Writing, review, editing; EB: Investigation, Correction; EL: Design of experiments, Supervision, Software, Validation; FE: Validation. All authors reviewed the results and approved the final version of the manuscript.

Competing interests

The authors have declared that no competing interests exist.

Funding

This research has been supported by the Agencia Estatal de Investigacion (AEI), Spain, and the Fondo Europeo de Desarrollo Regional (FEDER) UE, under contract PID2020-112496GB-I00 and partially funded by the Fundacion Escuelas Universitarias Gimbernat (EUG).

This publication is supported under contract PID2020-112496GB-I00, funded by the Agencia Estatal de Investigacion (AEI), Spain and the Fondo Europeo de Desarrollo Regional (FEDER) UE and partially funded by a research collaboration agreement with the Fundacion Escuelas Universitarias Gimbernat (EUG).

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Citation: R. Galeano, A. Wong, D. Rexachs, R. Suppi, E. Bruballa, F. Epelde and E. Luque. *Impact of the Population Pyramid on the Emergency Department*. Journal of Computer Science & Technology, vol. 25, no. 1, pp. 53-67, 2025.
DOI: 10.24215/16666038.25.e05
Received: April 15, 2024 **Accepted:** November 25, 2024.