Simulation of an Emergency Department to assess resources capacity to attend future demands

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Abstract:

The senior population has been increasing worldwide throughout the years as well as the Emergency Department (ED) demand. Consequently, resources consumed by the patients, such as X-Rays, Computed Tomography Scans, Blood Tests and other tests performed in the ED, are also increasing. This situation happens due to the increase in the current ED demand associated with the increase in aged patients, who are normally assigned with higher priorities in the ED triage, leading to a higher consumption of resources.

This research aims to forecast the future ED demand according to the future demographic evolution, to understand the resource consumption in the future. Therefore, a population evolution projection is performed by a system dynamics simulation model. Furthermore, the current ED patients are evaluated according to the demographic characteristics (age and gender) and the needs in the ED, i.e. priority level and resource consumption in the ED visit. Future ED patients' needs are met by projecting the current ED demand characteristics in the future population projection.

Therefore, the number of future ED visits by priority and resource consumption is reached and is used as input in a discrete event simulation model to evaluate the performance of the ED. The method is tested in the context of the *Complejo Hospitalario de Navarra*. The results show an increase of patients with higher priority levels, leading to a higher consumption of resources. Furthermore, the results also show that an additional physician should be scheduled in one shift to meet future demand.

Keywords: Emergency Department, Population Transition, Resource's Consumption, System Dynamics Simulation, Discrete Event Simulation, Forecasting.

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I. Introduction:

Overcrowding in Emergency Department (ED) is a current problem in numerous hospitals around the world (Aboagye-Sarfo, et al., 2015). This problem is a consequence of the increase in demand in this department, since the ED visitors have been increasing throughout the past years. Overcrowding compromises the level of performance and the efficiency of this department since it leads to an increase in the patients' waiting time in order to be attended by a physician, as well as the increase in the physicians' working hours (Aboagye-Sarfo, et al., 2015). Thus, it is important to identify potential sources of the overcrowding problem in order to increase the level of efficiency in this department and to contribute to the patients' satisfaction.

One of the sources of the ED's overcrowding is the aging population, since aged patients have a higher impact on the ED performance (Liu, et al., 2017): they are the main patients of this department and they also consume more medical resources (aged patients require more medical tests and require more medical attention). As the senior population has been increasing worldwide in the past years, the number of aged ED patients has also been increasing, which has led to an overcrowding problem (Reeder, et al., 2002). In this context, this study aims to forecast future ED demands and their needs based on the future demographic transition. The idea is to evaluate the current needs of the ED patients according to their demographic characteristics (age and gender)

and the future patients' needs are achieved based on the demographic characteristics of the future patients.

To achieve a future population projection, different population trajectories are created and the impact of each one in the ED is studied. Future ED patients are assessed according to their clinical characteristics, which cover the priority level that is expected to be assigned the future ED patients as well as the resources that they will consume in the ED: X-Rays, Computed Tomography (CT) Scans, Blood tests and other medical tests. With this analysis, the future capacity required for the ED, according to the future patients' needs, can be forecasted. The performance of the ED is also evaluated, where the future patients' characteristics are compared with the current ones to find the potential differences in the ED to meet the future demand. The method developed in this study is conceptualized and generalized to be applied in several ED contexts with different patients' characteristics. In this study, the method is applied in the context of *Complejo Hospitalario de Navarra* (CHN) in order to achieve the future ED demand and their clinical needs (priority levels and resource consumption). The CHN is the main hospital in the Navarra and it is the hospital with the highest impact in this region. Besides, an increase in the ED visits at CHN has been observed throughout the past years, as well as an increase in the senior population in Navarra. Therefore, the main service directors and administrators of CHN are interested in forecast future ED demand to plan the ED resources according to the future demand.

The present document is organized as follows: the first chapter is an introductory chapter; the current problem at the ED of CHN that inspired the present study is presented in the second chapter; the Literature Review is developed in chapter 3, where are shown studies that focus on the demographic transition, patients' characterization and the prediction of future patients and their impact in the ED; the multimethodology is shown in chapter 4, detailing each step: (1) for the population projection, (2) for the characterization of the current ED patients, (3) for the projection of the future ED patients and (4) to evaluate the ED performance; chapter 5 discusses the results achieved for each step and chapter 6 covers the main conclusions of the study.

II. Case Study:

CHN is a recent organization that was created in 2014 due to the merger of two different hospitals in Pamplona: *Virgen del Camino* and *Hospital de Navarra*. This new organization covers specialized services for all the population of Navarra, and it has only one entity for the management of services. The merger of the two old hospitals has led to the creation of a new ED where the main goal of this department is to provide medical attention for all the patients in Navarra with urgent conditions, since this is a specialized centre (Gobierno de Navarra, 2019). Although this department covers all adult urgent patients from Navarra (patients aged 15 years or more), the level of resources used in the ED is different according to the patients' situation (priority level): the priority levels are assigned using a range of 1 to 5, where the level 5 represents the least severe situation and the level 1 represents the most complex case. Thus, the ED of the CHN has two main circuits: one that attends the least urgent patients (circuit A) and the other that attends the most urgent patients (circuit B). Besides this, there is also a resuscitation room, which is covered by circuit B, for those patients who need medical attention immediately (considered as circuit C) (Sánchez & Pérez, 2014). There are several fluctuations is demand during the day and the resources planned for each circuit can be adapted in order to achieve a higher efficiency in the other circuits, decreasing the patients waiting time since each circuit can attend different levels of priorities. Besides, an increase in the ED demand at CHN in past years due to the aging population in Navarra's region is verified, which means that the planning of resource consumption is fundamental to attend the future demand.

Aged patients tend to present more complex cases in the ED and to have a higher consumption of resources (Liu, et al., 2017). Based on that, the ED patients are characterized according to the age and gender (demographic characteristics). Furthermore, the priority level assigned (on a scale of 1 to 5), and the resources consumed in the ED (X-Rays, CT Scans, ECGs, Blood Tests and consultations with a specialist), are also evaluated. This study is based on these two main concepts: the increase in the ED visits in CHN and the increase in the senior population in the Navarra region. The aim of

this study is to forecast the future ED demand at CHN and to assess the resource capacity in the near future. The idea is to use the demographic evolution of the Navarra population to forecast the clinical needs of the future ED patients and to study the impact of the future patients in the ED.

III. Literature Review:

Demographic transition is a pattern resulting from the different rates responsible for the population growth, such as fertility and death rates (Sterman, 2000). These demographic factors have been widely used to study the impact of future healthcare demand. Characteristics and needs of future patients can be forecasted based on the age of the future population, by multiplying historical health data of an age group by the future population in the same age group, considering that the demand by the age group will continue the same (Vrhovec & Tajnikar, 2016).

Forecasting future healthcare needs according to the patients' age is very important due to the aging population that has been verified. There are several diseases that are related with the patients' age and, knowledge about the evolution of the population's age in the future can be helpful to predict the incidence of several diseases. The impact of cancer on the future population is one of the most common issues covered by the future demographic changes because it helps to plan the future resource consumption associated with this disease and to prevent the evolution of cancer (Poirier, et al., 2019). Besides this, as older people have a higher probability of developing cancer, forecasting the future senior population helps to forecast the future cancer impacts on society (Liu, et al., 2019). Furthermore, as cancer disease is related with surgery, predicting the impact of this disease can help to forecast the number of surgeons required by future patients with cancer (Ellison, et al.,2018). Besides cancer, the future impact of other diseases can also be achieved, such as osteoarthritis (Turkiewicz, et al., 2014), diabetes (Panton, et al.,2018) and strokes (Faiz, et al., 2018) in society. Regarding to the ED, there is a study that uses the ED patients' age to characterize their needs during the ED visit of the Hospital Taulì de Sabadell in Spain (Liu, et al., 2017). In this paper, the priorities assigned in the triage, the number of tests and the number of consultations, are evaluated based on the patients' age group, where each age group has an interval of 5 years. Results show that the aged patients are assigned with more severe situations and consume more resources in ED.

Based on this, to meet future patients' needs it is necessary to understand the evolution of the demographic characteristics of the general population, since these characteristics show the needs of the future population while patients. A projection of the future population can be achieved using different methodologies. Recorded data is a method where the general population projection is reached using data from statistical offices (Roskos & Wilber, 2006). Cohort-component method is a technique where a model is created to study the demography evolution, according to the distribution of the ages: fertility, migration and death rates are used in this model to forecast the future population and by changing these rates in the model it is possible to achieve different trajectories for the population evolution (Beilman, et al., 2004). Simulation methods can perform populations projections covering the evolution of the demographic characteristics as well as clinical characteristics. For example, to predict the incidence of dementia in future populations, a system dynamics simulation model is used, where the fertility, mortality and death rates are added to the model as well as the rates of dementia incidence for each age group (Vickland, et al., 2011).

There has been an increase in the study of the characteristics of the ED patients, to find the potential sources of the ED overcrowding and the characteristics most studied are: the age and gender of the ED patients, the priority level assigned, the medical resources used in ED visits, the diagnosis and the place the patient comes from. Some studies analyze statistically recent trends to create relationships between the demographic characteristics of the patients and the ED visits (Aboagye-Sarfo, et al., 2015), (Roskos & Wilber, 2006), (Beilman, et al., 2004).

Predicting future ED patients' characteristics as well as the incidence of certain diseases in future societies, such as diabetes or cancer, are the main reasons to predict the future impact on healthcare services. With this type of forecast, it is possible to predict future resource consumption and to manage the department accordingly (Ordu, et al.,2019). Future demand can be achieved using forecasting techniques, such as autoregressive integrated moving averages (ARIMA), exponential

smoothing (ES) and multiple linear regression (MLR) (Ordu, et al., 2019). Another method is to use the past trends of the demand, to forecast the future demand. For example, it is possible to perform a stroke mimics projection using the incidence rates achieved by the recorded data of the stroke mimics, for each age group and gender, and using the population projection (Faiz, et al., 2018). Another study that forecasts future cancer patients uses a similar methodology: the number of future cancer cases is forecasted by multiplying the incidence rates forecasted by the population (Stock, et al., 2018). Another study uses the current prevalence of osteoarthrosis by gender and age group to predict the future prevalence of this disease due to the changes in the population (Turkiewicz, et al., 2014). Similar methodology can be applied to forecast the future trauma volume: current trauma rates are achieved by consulting past data and applied the projection of population created, to estimate changes in the trauma volume (Beilman, et al., 2004). Besides, the contribution of the demographic changes in the ED utilization can be evaluated by forecasting the number of visits, using the forecasted population multiplied by the ED visit rate for each age group (Aboagye-Sarfo, et al., 2015). This study evaluates the rates for each priority level, which leads to a deeper analysis of the impact of the complex cases in the future. The results show an increase in the ED visits, particularly in urgent cases that is explained by the population growth and aging (Aboagye-Sarfo, et al., 2015).

Regarding to the evaluation of the performance of the ED, a study measures the efficiency of several EDs using Data Envelopment Analysis (DEA) that indicates which input and output should be evaluated to study the ED's performance (Akkan, et al., 2019). Another method used to evaluate the ED's efficiency is the use of simulation techniques, since the ED is a complex system and it can be modelled using simulation. The simulation method most used to evaluate the ED is the Discrete Event Simulation (DES). However, some studies use the Agent Based Simulation to evaluate the ED (Liu, et al., 2017), (Kaushal, et al., 2015) and one study uses System Dynamics Simulation (Hajjarsaraei, et al., 2018). Regarding the DES, there is a study that models the ED at the University of Colorado Hospital, to design efficient EDs by measuring the impact flow and physical design interventions (Easter, et al., 2019). The model implements the ED layout, the medical staff, the patients' characteristics (age, gender and complaint) and the resources consumed in the ED and the output achieved by the model refers to the length of stay, bed utilization rate, number of movements per patient among others (Easter, et al., 2019). Besides, there are studies that uses DES to cover specific issues in the ED: the number of patients that arrive by ambulance (Lin, et al., 2012) and the presence of the residents in the ED (Silberholz, et al., 2013) are some examples.

IV. Methodology:

In the ED visit, the patient has a level of severity that specifies how long the patient can wait for medical attention. Furthermore, the patient can do some tests in that ED visit, such as X-Rays, CT

Table 1: Input, output and methodology implemented in each step of this study.

Step/ Goal	Input	Methodology	Output
1. **Population Pyramid Projection**	Current population pyramid	Simulation	Future Population Pyramid
2. **Characterization of current ED visits**	Current ED visits	Ratio/Proportion method and regression analysis	Regressions (for each gender) between patients' age and ratios for ED visits, priorities and resources
3. **Projection of future ED visits**	Future Population Pyramid Regressions (for each gender) between patients' age and ratios for ED visits, priorities and resources	Regression analysis	Future ED visits by priority and future resources consumption
4. **The impact of future patients on the ED**	Future ED visits by priority and future resources consumption	Simulation	Future ED requirements

scans or others, which are considered as resources. This study characterizes each patient's visit with a priority level and the resources used in that visit, based on the age and gender of the patient. To forecast future ED patients and the resources required for that demand, four steps are necessary. Detailing each step: (1) forecast the future population, (2) characterize current patients according to the demographic characteristics and medical needs, (3) forecast the needs for the future patients and use the future needs to assess the resource capacity of the ED and (4) evaluate the ED performance.

Each step has its specific methodology, however, some of them need the output of the previous steps. Table 1 represents the input and output for the different steps, and the methodology implemented in each one, where the same colour represents the same values: the input of step three is the output obtained in steps one and two (orange and blue colours, respectively); the input of step four includes the output of step three (green colour). Besides the relation between some steps, the methodology implemented in each one is different. Each methodology is described with more detail below.

- **Step 1: Population Pyramid Projection**

To obtain the future population pyramid, a simulation model is used to study the population evolution throughout the years. The tool used to perform this simulation is the *Anylogic* simulation software since it can perform simulation with system dynamics. System dynamics simulation is a simulation method that can represent discrete items by their quantities (Grigoryev, 2018) and, in the present model, each age group and each gender of the population pyramid is defined as a discrete item with a certain quantity. Each age group is represented in a pyramid layer and each layer has two different quantities, one for each gender. The pyramid's layers have intervals of 5 years each. The quantities that represent each pyramid layer, are represented in *Anylogic* as *stock* (one for each gender). As each *stock* represents the population for each age group and for each gender, the simulation model has two diagrams, one for each gender. Thus, each diagram has 21 *stocks*, where the first *stock* corresponds to the age group of 0 to 4 years, the second *stock* represents the age group of 5 to 9 years and so on. *Flows* can add quantities to or extract them from the *stock* concerned and these quantities vary depending on the quantity of the *stock* and the rate associated with that *flow*. *Flows* are formulated as: Maturation: it is the quantity of population that belongs in the *stock* (age group) that mature for the next *stock* (next age group) in the end of the year. The model assumes that the average residence time of the population in the *stock* is the number of years that each stock represents, which is 5 years (Sterman, 2000). Therefore, the maturation is considered as one fifth of the population that belongs to the *stock*. Deaths: it is the amount of the population that belongs in the *stock* that dies during the year. This quantity is the result of the population in the *stock* multiplied by the death rate of that *stock*, that is the ratio between the deaths and the population in that *stock* (Pordata, 2018). Migration: net migration is the difference between immigrants and emigrants. The migrations of each *stock* are the amount of population in the *stock* concerned multiplied by the migration rate of that *stock* (Pordata, 2018). Births: the number of births in each gender is the quantity added to the first *stock* of each diagram. To obtain the total births, it is necessary to know the fertility rate and the female population that is in childbearing years. The total fertility rate is the average number of children that a woman will have during her childbearing years, and the childbearing years are considered to be those between 15 and 49 years of age (Sterman, 2000). As the fertility rate is different in each childbearing year, the age-specific fertility rate (ASFR) of a specific age group is obtained by dividing the number of births whose mothers belong to that age group in a given year, by the total number of women that belong to that age group in the same year (United States Census Bureau, 2018), and the number of births per year is (United States Census Bureau, 2018):

$$\text{Births} = \sum_{i=4}^{10} \text{ASFR}(i) \times \text{FemalePopulation}(i) \quad (1)$$

The summation starts at pyramid layer 4 and ends in pyramid layer 10 because it corresponds to the childbearing years (from 15 to 49 years of age). The yearly number of births in the simulation model is controlled by the female population in childbearing years and by the total fertility rate. This rate is

obtained by the sum of ASFR by five years age group multiplied by 5, once each layer is composed by 5 years age (Pordata, 2018). Therefore, the yearly number of births are obtained. As the simulation model created is applied in the context of the Navarra region, the data of this specific population are implemented in the model: fertility, death and migration rates and initial population of the Navarra region. Thus, it is possible to achieve the projection of the population pyramid of Navarra.

- **Step 2: Characterization of current ED visits**

Regarding the characterization of the current ED visits, the patients' characteristics studied are: age, gender, priority level assigned, and the resources consumed in the ED visits. The data evaluated covers the years of 2015-2017 and ED patients are evaluated inside the general population (according to their demographic characteristics), the priorities assigned in the ED are evaluated inside the ED visits and each resource consumption is evaluated inside each priority level. The data is grouped according to the patients and population's ages: the data is yearly (2015-2017) grouped in groups of population with an age range of 15 years each [15,29], [30,44], [45,59], [60,74], [75,89] and [90,100+]. After that, a ratio/proportion method is performed on the groups created to achieve the ratios according the patients' age, for each characteristic evaluated. For example, regarding 2015, the ratios for the visits are achieved by comparing the ED visits and the population in the same age group, gender and year. For example, the ratio of female ED visitors aged between 75 and 89 years for 2015 is formulated as:

$$\text{Ratio of female ED visits aged between 75 and 89 year} = \frac{\text{ED visits by female aged between 75 and 89 years}}{\text{female population aged between 75 and 89 years}} \quad (2)$$

These ratios are obtained for the other age groups, for the male population and for the data recorded for 2016 and 2017. After displaying the ratios according to the age, an average of the ratios concerned of the three years is performed, since the behavior of the graphs of the three years is similar. The ratios achieved by the average of the three years are displayed according to the patients' age, and the best regression for each gender that fits each set of points is selected. This regression can be linear or nonlinear and it is selected according to the coefficient of determination (R^2) that accounts for the variability of the data (Montgomery & Runger, 2011). Consequently, the regression selected is the one with the higher coefficient of determination and an equation that represent each set of points is achieved. The methodology is the same for the ED visits by priority and for the ED visits by priority and resource consumed: the ratios for the ED visits by priority are obtained by dividing the ED visits in each priority by the total ED visits (in each gender and age group) and the ratios for the ED visits by priority and resource consumed are obtained by dividing the ED visits in each priority and with each resource consumed by the total ED visits by the priority concerned (in each gender and age group). With this, the regressions that relate the ratios for the ED visits, for the ED visits by priority and for the ED visits by priority and resource consumed according the patients' age, are obtained.

- **Step 3: Projection of Future ED visits**

The characteristics for the future ED patients are achieved by implementing the ratios from regressions in the population projection obtained: for example, to obtain the future ED visits, it is necessary to multiply the ratio obtained from regressions for the ED visit, of each gender and of each age group, by the population projection concerned. The same is applied to find the quantity of visits in each priority and the quantity of resource consumed in each priority. With this, the amount of ED visits, the ED visits by priority and the quantity of resource consumed in each priority are projected.

- **Step 4: The impact of future patients on the ED**

To evaluate the performance of the ED at CHN a discrete event simulation (DES) model that simulates the ED at CHN is used, since the ED can be seen as a set of processes with a sequence of operations that agents can perform (Grigoryev, 2018). The simulation model used to evaluate the ED's performance covers circuit A, characterized by the patients with the least severe cases, i.e., patients assigned with priorities 3, 4 and 5. The input of this simulation model is the patients' characteristics (gender, age, priority level and resource consumption) and the number of physicians in each shift. The results obtained with this model are the patients' waiting time and the physicians'

working hours. To evaluate the impact of the future demand in the ED, the results obtained with the future demand are compared with the results achieved with the current demand.

V. Results:

The simulation model created to perform the projection of the population is flexible to create different trajectories of the population evolution by changing the rates (fertility, death and migration) defined in the model. The scenario 1 is the base scenario and considers that the population does not change through the simulation years until 2030: the fertility, death and migration rates are the same as the rates of 2016. These results show that the structure achieved does not look like a pyramid (where it is supposed to have a much larger bottom) because the fertility rate currently verified in Navarra is 1.43 and it does not cover the replacement level, which is 2.1 (Pordata, 2018). The second scenario implements a gradual increase in the fertility rate through the simulation years, until the value

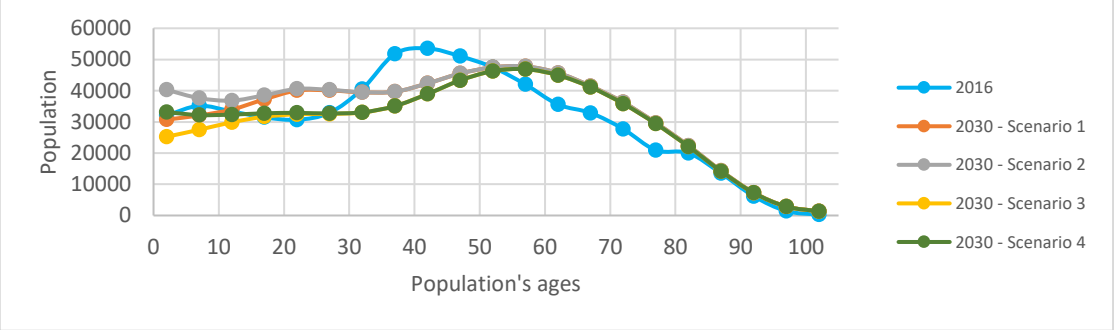

Figure 1: Comparison between the current (2016) and the future (2030) population, according to the age.

of 2.1. An increase of the first layer and in the following layers of the pyramid is verified. In the third scenario, the fertility and death rates are the same as the rates from 2016 through the simulation years, but the migration rates are null since 2017. In the fourth scenario, the fertility rate increases gradually until 2.1 and the migration rates are null since 2017. Comparing the results obtained with the population in 2016 (Figure 1), it is verified that scenario 2 and scenario 4 have a higher number of young people at the beginning of the graph (left side), due to the increase of the fertility rate. Furthermore, in the year of 2016, there is a higher amount of the population between 35 and 50 years of age (light blue plot) and in 2030, it is expected that there will be a higher amount of the population between 45 and 80 years of age, increasing the senior population in the Navarra.

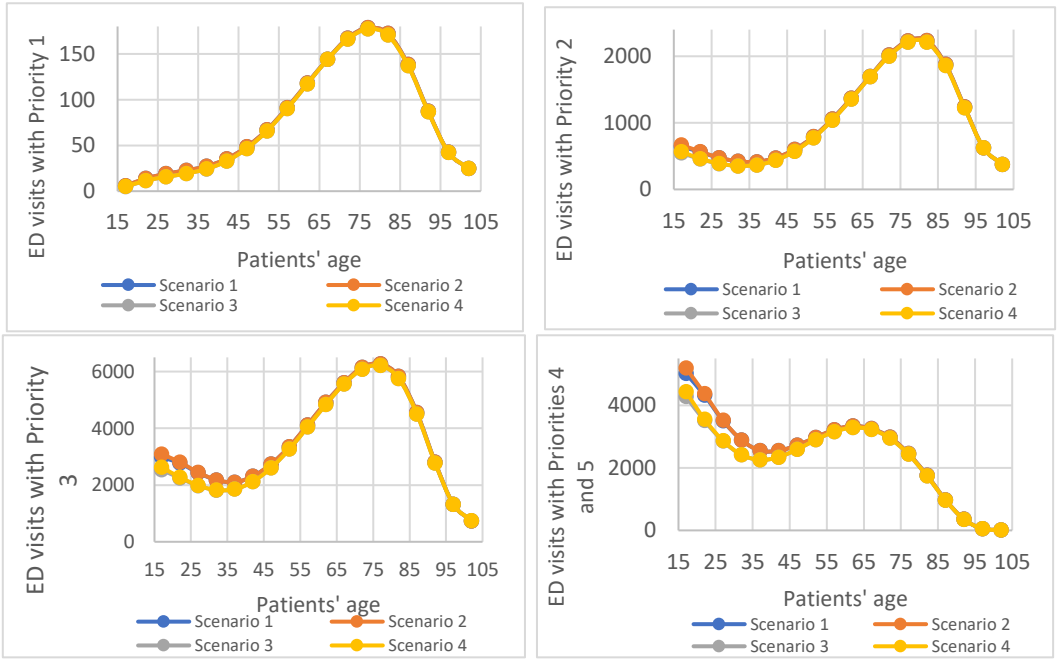

Figure 2: ED visits by priority forecasted for 2030, according patients' age.

Regarding the characteristics of the current ED patients, a regression for the ED visits, for the ED visits by priority and for the ED visits by priority and resource consumed is obtained and applied in each scenario for the population projection created, to achieve the quantity of ED visits, ED visits by priority and resource consumed in 2030. The characterization of the current ED visits shows a strong dependency between the patients' age and the priorities assigned (Figure 2), and between the patients' age and the resource consumption (the results for the ECG and CT Scan utilization are shown in Figure 3): aged patients have more complex cases and they also consume more resources.

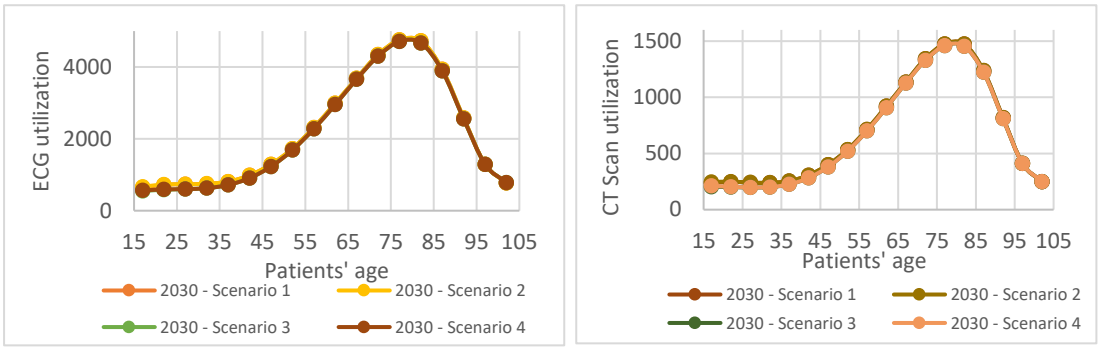

Figure 3: ECG (left) and CT Scan (right) utilizations obtained for 2030, according patients' age.

Based on this, the projection of the future ED patients shows an increase in the ED visits as well as an increase in the resources consumed. This is also supported by the increase in the senior population in Navarra. Figure 4 shows the global values for each category studied and compares the current data (green bars) with the projected data for 2030 (blue bars). A general increase for all categories evaluated is verified.

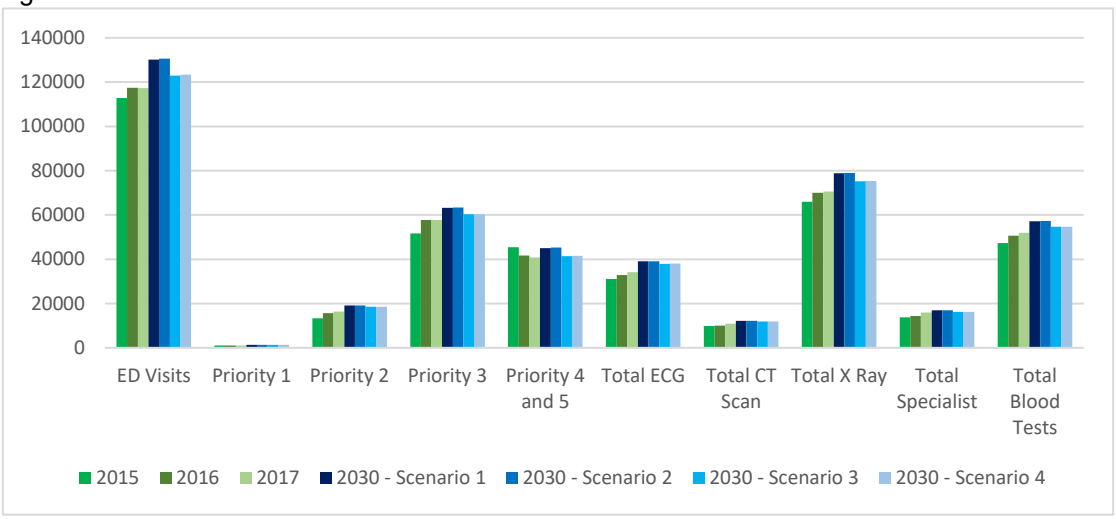

Figure 4: Comparison between the current and future figures for ED visits.

Finally, the evaluation of the ED at CHN uses a simulation model that use as inputs the patients' characteristics and the number of physicians in each shift. The current demand is attended with 5 physicians in each shift. However, the results of this simulation model with the ED patients for 2030 with 5 physicians in each shift, show an increase in the waiting time and an increase in the scheduled usage for the physicians. Thus, to meet similar values in the performance of the ED with the visits of 2030 to the ones found for the current situation, it is necessary to implement 5 physicians in one shift and 6 in the other shift.

VI. Conclusions:

More complex and severe cases in ED are expected in the near future due to the demographic changes, where ED visits by the elderly are expected (Roskos & Wilber, 2006) and the results of this study also show that. ED visits have been increasing worldwide which contributes to the ED overcrowding and inefficiency of this department. Population aging has a direct effect on this increase

because aged patients have a higher impact on ED: they present more urgent cases and they consume more ED resources.

The aim of this study is to forecast the future ED demand and resource capacity to meet future ED visits in the CHN context. The results show that the patients' age and gender influence the priority assigned in the triage and the resources consumed in the ED visit at CHN. The population projection performed expects an increase of the senior population in the Navarra region, which means that a general increase in the aged patients in this department is also expected. As these patients have a higher contribution in terms of the ED overcrowding and require more medical attention, an increase of the resource consumption in a near future is expected as well as the increase in the ED visits with higher urgency. Future patients' characteristics and needs are used to study the effects of the performance of the ED by a simulation models that simulate the ED and the results show that it is necessary to increase the level of staff (one physician in a work shift) to meet future ED demand. This is expected since an increase in the ED demand with a more complex need of care is motivated by the senior population increase.

This study associates demographic characteristics of the patients with clinical needs in the ED. This is a useful approach to forecast the needs of the future ED patients. The model developed to project the future population can be used and adapted to project the future population of any other place, for any other time period. With the analysis of the current patients' needs in a certain ED and the population projection of the same place, the needs of the future ED demand can be achieved.

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