Support managing population aging stress of emergency departments in a computational way

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Abstract
Old people usually have more complex health problems and use healthcare services more frequently than young people. It is obvious that the increasing old people both in number and proportion will challenge the emergency departments (ED). This paper firstly presents a way to quantitatively predict and explain this challenge by using simulation techniques. Then, we outline the capability of simulation for decision support to overcome this challenge. Specifically, we use simulation to predict and explain the impact of population aging over an ED. In which, a precise ED simulator which has been validated for a public hospital ED will be used to predict the behavior of an ED under population aging in the next 15 years. Our prediction shows that the stress of population aging to EDs can no longer be ignored and ED upgrade must be carefully planned. Based on this prediction, the cost and benefits of several upgrade proposals are evaluated.

Keywords: Population aging, Agent-Based Model, Emergency Department

1 Introduction

Hospital emergency departments provide a crucial public service. It is critically important to the health of the population. Older patients often present to EDs with more complex clinical conditions and normally require more diagnosing and consultation service than younger patients. With one in nine persons in the world aged 60 years or over, projected to increase to one in five by 2050, population aging is a phenomenon that can no longer be ignored [15]. All countries in Europe are experiencing an aging of their populations, a trend that is projected to continue until at least the middle of the 21 century. This is mostly because of a combination of low fertility and longer life expectancy [12]. For example, the Catalonia in Spain is facing new challenges with an in-depth population aging process compared with other European countries. Currently, 17% and 4.4% of the population are over 65 and 80 years old, respectively. In 2050, over 30% and 12% of the population will be over 65 and 80 years old, respectively. As a consequence, an increasing number of people with chronic conditions will increase very

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intensively [6]. This process is often regarded as a major cause of upward stress on health care costs [11]. Several studies have investigated the increased presence of elderly patients in ED [12, 16, 5]. To the best of our knowledge, there is no work on quantitively predicting the influence of aging on EDs and overcoming the stress by using simulation. The objective of this paper is to evaluate overcrowding problem in ED arising from the population change. Our method enables ED managers to quantify the effects of system redesign prior to the implementation and to examine how the redesign can be best applied to their particular hospital.

The rest of the paper is structured as follows: §2 gives a literature review on related work. The care service requirement of elderly patients will be analyzed in §3 based on real data from a public hospital. Then, by using an ED simulator, the §4 will predict the behavior of an ED in the future based on population pyramid prediction. In terms of the impact of population aging on ED, the §5 will demonstrate the use of simulation techniques on decision support for policy makers. At last, §6 draws the conclusions.

2 Related work

Worldwide, impacts of population aging are steadily attracting researchers' attention. For example, by using current trends and estimates in conjunction with future population growth and climate change scenarios, G. Toloo et al. [14] studied the effects of increasingly warmer temperatures on the burden of already overcrowded hospital EDs. S. Vilpert et al. [16] investigated the trend in ED visits by patients aged 85 years and over between 2005 and 2010, and to compare their service use to that of patients aged 65–84 years during this period and to investigate the evolution of these comparisons over time. Their results highlight the growing importance of elderly patients in EDs, and indicated that the ED managers should be aware of these oncoming challenges so that they can adapt their training curricula and working procedures accordingly.

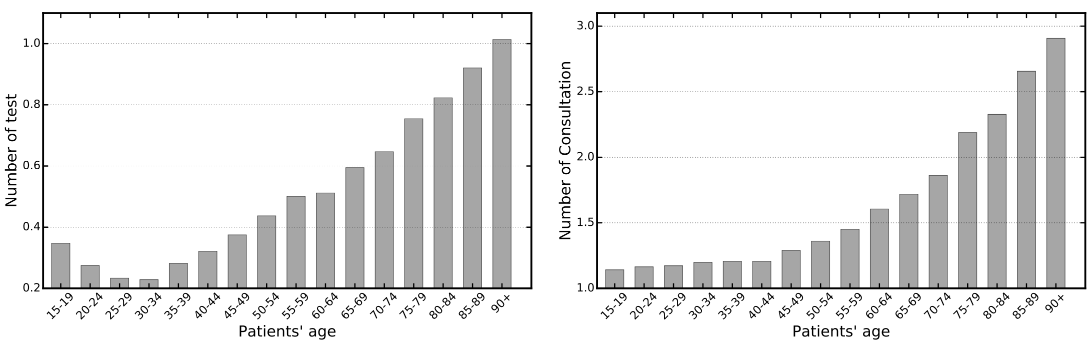
By comparing data collected in 1990 and 2004, George et al. [4] found that the stress on emergency care is associated with a disproportionate increase in the number of elderly patients and with an increased tendency to investigate them. They concluded that, increasing life expectancy and a declining birthrate have caused the population to age, the needs of older people are crucial in planning emergency healthcare in developed countries. Ref. [10] studied how the aging of the U.S. population would affect the demand for ED services and hospitalizations in the coming decades. They found that demographic change will not cause the number of ED visits to increase, but visits will get longer and there will be more hospitalizations. Authors indicated that, ED capacity will have to increase by 10 %, even without an increase in the number of visits and, hospital admissions from the ED will increase 23 percent faster than population growth, which will require hospitals to expand capacity faster than required by raw population growth alone. In order to assess micro-simulation for testing policy options under demographic aging, Davis et al. [2] applied a novel micro-simulation approach both to create a synthesized data set from a number of sources and to present quantifiable scenarios. The authors concluded that there is potential for micro-simulation to assist in the synthesis of data and to help quantify scenario options for policy development.

In summary, most of the work on analyzing the impact of population aging in literature are qualitative analysis or prediction with linear extrapolation or intuition. Since ED is a complex system, extrapolation based on data-driven models may meet the singularity point in nonlinear response and result in unacceptable error in prediction. We believe that a precise ED simulator can more accurately predict the ED's behavior in the coming decades with population aging. Moreover, as a typical complex system, tackling the problem of efficiently managing ED has became a great challenges to both managers in ED and policy makers in the governments.

A good understanding of the reasons why EDs are overcrowding with population aging and the potential opportunities for intervention is essential for policymakers to planing informed strategies to meet the health care needs of an aging population.

3 Problem statement from real data

In this section, we state the stress of population aging to an ED by throughly analyzing 12-month real operation data in 2014 with a total number of 137,757 visits, from the ED at the Hospital Taulì de Sabadell in Spain. The ED is in a university tertiary level hospital in Spain that provides care service to a catchment area of 500,000 people. Here, the number of medical tests and consultations are analyzed to indicate patients' service requirements. In this analysis, we classified patients by their age with an intervals of 5 years. Then we calculate the average tests and consultations of patients in each age interval. Results are shown in Figure 1.

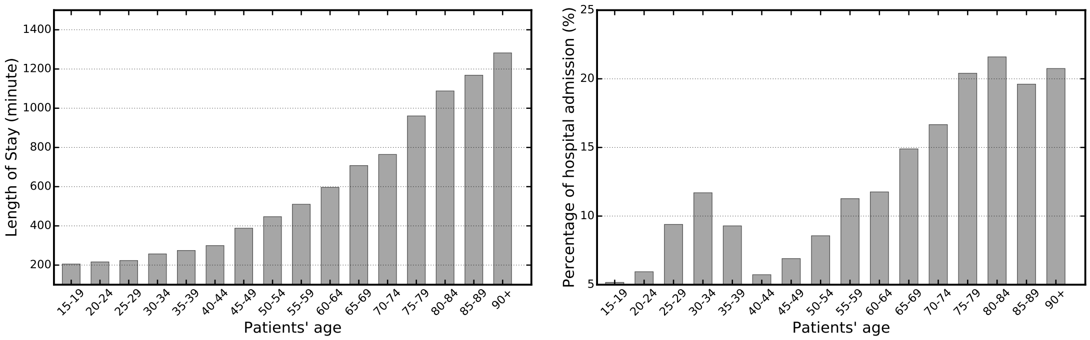


(a) Average medical-tests versus age. (b) Average consultations versus age.

Figure 1: Histogram of patients' service requirements versus their age.

The Figure 1a shows the average number of medical test (includes medical imaging and laboratory test) versus patients' age. It is obvious that elderly patients need more tests than younger patients to diagnose their complex issues. Furthermore, for those patients with complex issues, they usually also need more doctor consultations.The Figure 1b shows the average consultations due to patients' age. It is clear that elderly patients need more consultations as well. If we consider an ED as a multi-class queuing systems with probabilistic routing, the more service a patient needs, the longer time a patient will spend in ED. The long time is not only due to more time on service, but also more time on waiting in the queue. Therefore, it is reasonable to infer that elderly patients would stay longer in EDs than younger patients. The Figure 2a details the distribution of patients' average length of stay (LoS) versus their age. It clearly validates our inference.

There are four possible destinations when a patient finish the treatment: admission to hospital, going back home, being transferred to another hospital or death. If a patient is admitted to hospital and there is no bed available in the hospital, they have to stay in ED, keep occupying services in ED. That is, patients admitted to hospital often occupy ED beds (also referred as "access block" or boarding) due to the unavailability of beds in hospital. Thus, we also analyzed the difference of hospital admission probability to patients' age in Figure 2b. It is obvious that elderly patients are more likely to be admitted to hospital. If the hospital cannot expand capacity faster than the requirement increasing from aging growth alone, the ED will be even more overcrowding. In terms of ED, the process of hospital admission will have to become more efficient as well.



(a) Patients' average length-of-stay versus age. (b) Hospital admission frequency versus age.

Figure 2: Patients' length of stay in ED and hospital admission analysis.

Based on the analysis of patients' care service requirement in Figure 1, LoS in Figure 2a and hospital admission rate in Figure 2b (results in more patients occupy the ED). Thus, it is reasonable to infer that the ED system will be more overcrowding with the increasing proportion of elderly patients. Although this inference is straightforward and clear, how much overcrowding the ED will suffer is more informative for policymakers. The §4 will quantify the overcrowding of the ED at Hospital Taulì de Sabadell based upon population pyramid prediction issued by the Spanish National Statistics Institute.

4 Impact of population aging to the ED

4.1 The target ED

The ED in this case study is the Hospital Taulì de Sabadell, a public hospital in Catalonia. The scale of triage used in the ED is very similar to the worldwide Canadian Emergency Department Triage and Acuity Scale [1]. The scale consists of 5 acuity levels (AL), with 1 being the most critical (resuscitation), and 5 being the least critical (non-urgent). There are two treatment areas (labeled as urgent and non-urgent area in this study), which operate independently to provide a diagnosis & treatment service. The urgent area is for patients with AL 1, 2, and 3 and consists of small rooms containing essential medical equipment and supplies that can be used for patient's treatment, called careboxes. Patients in the urgent area tend to stay in their carebox. When a doctor assigns a medical image test which requires moving the patient, they are assisted by auxiliary staff. The non-urgent area is a dedicated stream of resources to process patients of AL 4 and 5 more quickly. It consists of attention boxes in which doctors and nurses interact with patients, and a large waiting room in which all patients will remain while not having interaction with the ED staff. The doctors and nurses are specified for different areas, but medical image test-room and laboratory testing services are shared by the two areas.

4.2 The simulator

Simulation is any activities where an actual or proposed system is replaced by a functioning model that approximates the same cause and effect relationship of the "real" system. It is most appropriately used when for reasons of cost, ethics or feasibility real-world trials and experiments cannot be conducted [13]. In this article, we use an agent-based ED simulator [7, 8] to generate evidence and support for the policy making and explanation. The simulator is based on the modeling of individual behavior and allows for a more disaggregated approach to scenario building. This is useful in the health area where it is often necessary to mimic the heterogeneity of the population and the complexity of relationships [3]. The simulator has been carefully calibrated and validated with four-year's historical operation data from the Hospital Taulì de Sabadell [9]. The simulator was designed as highly customizable. A simulation user can customize patients' characteristics (e.g., age distribution, acuity level, number of arrival, time of arrival) and ED's resources (e.g., physical and human resources). Then the simulator can predict the ED's behavior under the user's customization. The costs and benefits of their proposed changes can be evaluated by using these quantitative prediction.

4.3 Patient arrival prediction

According to the historical operation records, we also found that elder patients come with higher severity as well, i.e., they are usually triaged as urgent patients (CATS 1,2,3). We analyzed the relationship between patient's age and acuity level. Figure 3 shows the distribution of patients' severity versus patients' age. It is clear that younger patients are less likely to be triaged as urgent than elder patients (over 65 years). That is to say, if the number of elder patients increases and number of younger patients decreases, more patients will be triaged as urgent and the urgent area will become more overcrowding.

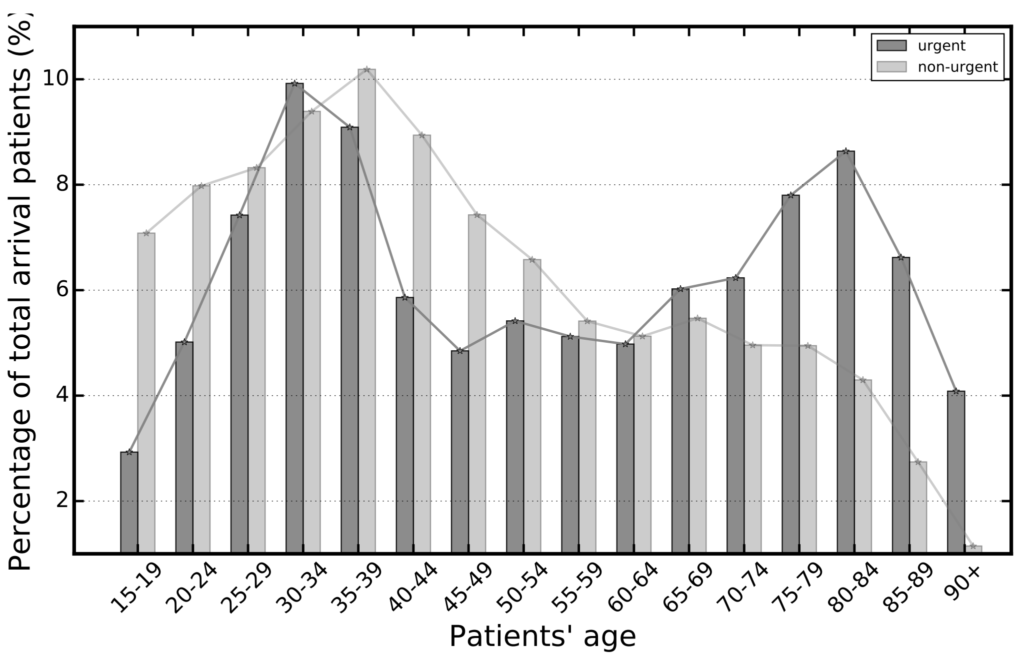


Figure 3: The distribution of patients' severity due to their age.

Here, we describe a model to predict the number of patient arrival and their age distribution in the next 15 years. Table 1 lists symbols that will be used in this model. This model was based on the population pyramid prediction of Spain and patient arrival pattern in the ED of Hospital Taulì de Sabadell in 2014. The population pyramid data are obtained from the National Institute of Statistics.

Table 1: Symbols used in this model.

Symbol	Description
$\overline{N_{ED}^{age}}$	The number of patients attend to the ED in *age* intervals (5 years) in 2014.
N_{ref}	The total population in the catchment area of the hospital.
D_{age}^{year}	The distribution of various *age* intervals (%) in the target catchment area in *year* (i.e., population pyramid of *year*).
P_{ED}^{age}	The frequency (the number of visit) of a person (due to *age*) who goes to ED.
P_{rate}^{year}	The ratio of population in *year* to the reference year (2014).

The frequency of a person who goes to ED depends on lots of factors, here we assume that the frequency only depends on age and do not change over year. That is to say, a fix frequency will be used to predict the number of patients attend to ED in each *age* intervals. So, the number of patient attend to an ED in a *age* interval in *year* can be predicted by:

$$N_{ED}^{age}(year) = P_{ED}^{age} \cdot N_{ref} \cdot P_{rate}^{year} \cdot D_{age}^{year} \tag{1}$$

Regarding that

$$P_{ED}^{age} = \frac{\overline{N_{ED}^{age}}}{N_{ref} \cdot D_{age}^{ref}} \tag{2}$$

Replace P_{ED}^{age} in Equation 1 with Equation 2, we get:

$$N_{ED}^{age}(year) = \frac{D_{age}^{year}}{D_{age}^{ref}} \cdot \overline{N_{ED}^{age}} \cdot P_{rate}^{year} \tag{3}$$

With Equation 3 and demography prediction and patient arrival data in 2014, it is possible to predict the number of patients at each *age* interval in the future. We made a 15-year patient arrival prediction from 2015 to 2030. The patients' age distribution is illustrated in Figure 4. It is clear to see from Figure 4 that, the elder patient will increase and younger patient will decrease significantly in the next 15 years.

4.4 ED behavior prediction

The §4.3 described the prediction of patients' aging distribution in the coming 15 years. Synthesize it with analysis in §3, it is clear that the ED will have stress to deal with more elderly patients. This section will give the quantitive prediction of ED behavior in the next 15 years. Specifically, with the patients arrival prediction shown in Figure 4 as input, we simulate to predict the ED behavior year by year. Here we will use patients' LoS and door-to-doctor time (the time difference between arrival time and the first medical screening exam) as key performance indicators to describe the behavior of ED. The simulation results are visualized in Figure 5.

As shown in Figure 5, patients will meet longer door-to-doctor time and longer LoS issues in the future. The urgent patients will meet serious delaying problem (about 4× door-to-doctor time to 2014). Note that, this situation is solely caused by the change of patient arrival (shown in Figure 4), other limitations such as, ambulance service (will delay patients' discharge, analyzed in [8]) and hospital bed availability are not considered. If these connection services do not expand accordingly, it is reasonable to say that the overcrowding will be even worse.

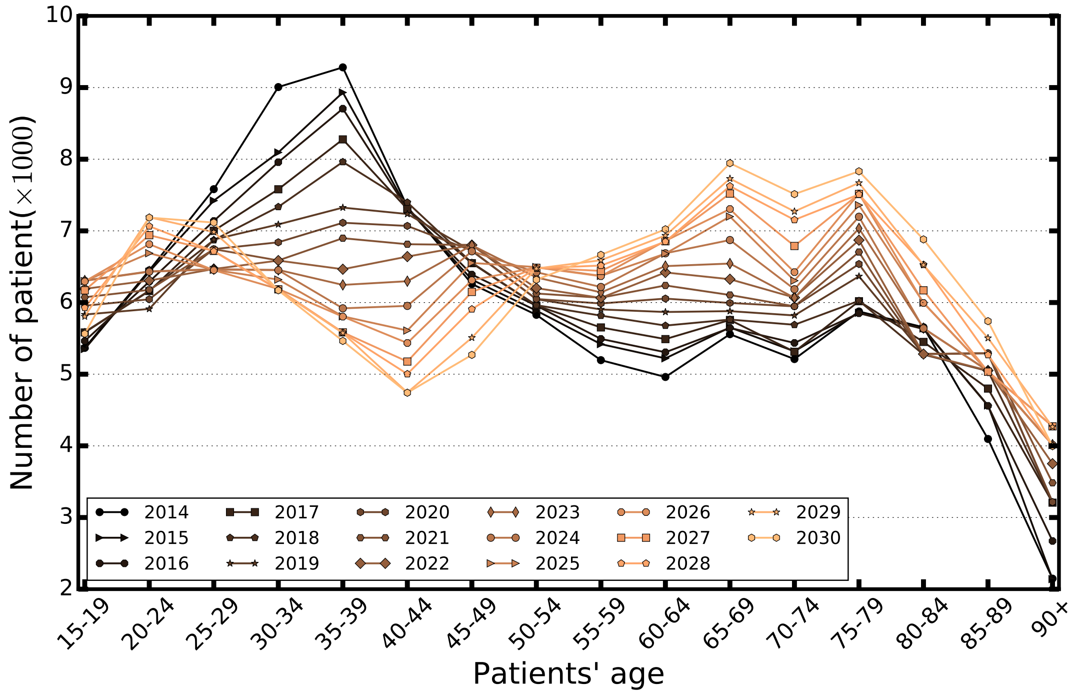
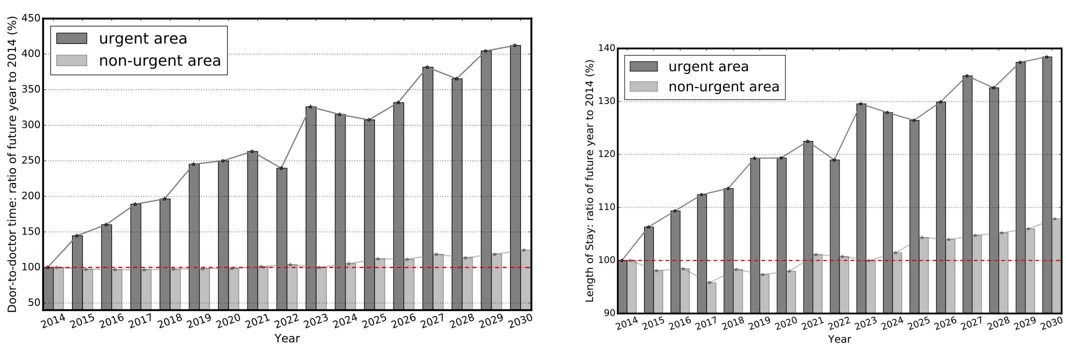


Figure 4: Patients' age distribution for the next 15 years.



(a) Door-to-doctor time.

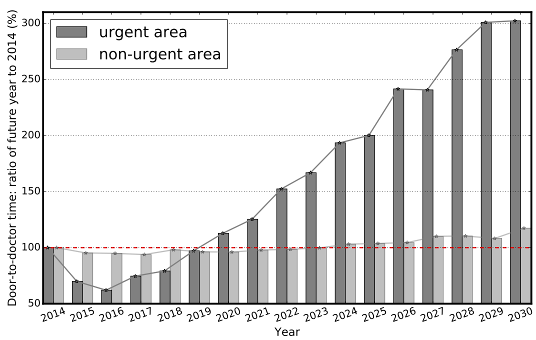
(b) Length of stay.

Figure 5: Changes of door-to-doctor time and patients' length of stay, as a ratio to 2014.

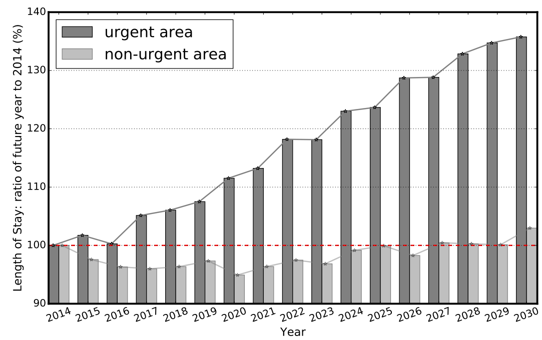
5 Potential solution demonstration

The §4 quantified the behavior of ED in the next 15 years with the influence of population aging. It is clear that the quality of services will become worse and worse due to population aging. To keep pace, EDs must expand their capacity to overcome the overcrowding issue. This case study demonstrates the potential use of simulation on decision support. Specifically, similar as §4, the simulator will be used to predict the ED behavior under proposed changes to the ED. Different with the use of simulator in §4 that only changed patients' character, we will change both the patients character (the same as §4 according to the patient arrival prediction in §4.3) and ED resource in this section.

With the stress caused by population aging, there are many potential solutions depends on practical constraints (e.g., budget, place, time). In this section, we will only demonstrate two potential solutions in order to show the capability of an ED simulator on evaluating decisions for policymakers. Specifically, due to the fact that the door-to-doctor time will increase significantly for urgent patients. That is, there will be more and more patients wait in the waiting room for a free bed (i.e., enter the urgent treatment area). Therefore, one of the straightforward solution is to expand the urgent area. Leaving aside the constraints, we thus try to add 10 more careboxes to the urgent area and simulate to see if it works. The same indicators as §4 are used to quantify ED's behavior. Simulation results are shown in Figure 6.



(a) Door-to-doctor time.

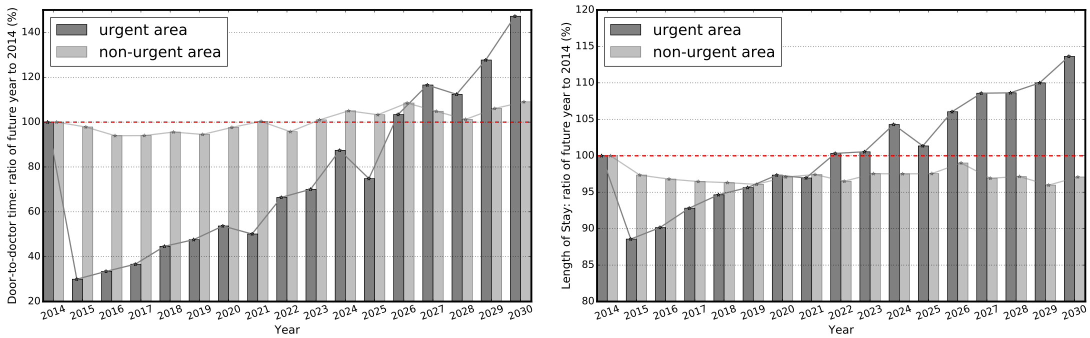


(b) Length of stay.

Figure 6: Changes of door-to-doctor time and patients' length of stay, as a ratio to 2014 after adding 10 careboxes to the urgent area.

Changes of ED's key performance indicators after adding 10 additional careboxes are shown in the Figure 6. Compared with Figure 5, there are significant improvement on door-to-doctor time in the urgent area while very limited improvement on LoS. This is because the additional careboxes in the urgent area makes staff over-occupied. Specifically, although a patient can get a free carebox and see a doctor earlier (Figure 5a versus Figure 6a) after adding 10 careboxes, the patient will suffer longer waiting time in their carebox. This phenomena has been carefully analyzed in our previous publication [7]. In summary, simply adding 10 careboxes cannot overcome the impact of population aging in the coming decades. Based upon these information as well as ED resource occupancy information extracted from the simulation, we proposed another solution, i.e., adding 10 careboxes, 2 nurses and 1 doctor to the urgent area. Then the ED's performance is quantified again with simulation and the average LoS and door-to-doctor time are shown in Figure 7.

It is obvious to see from Figure 7 that adding 10 careboxes, 2 nurses and 1 doctor to the urgent area is effective in the first several years. The door-to-doctor time can be guaranteed to be no worse than current until 2026. The LoS in the urgent area can be kept the same as current before 2023. In terms of the non-urgent area, as shown in Figure 3, since elderly patients are more likely to be admitted to the urgent area, and the fact that the number of young patients will decrease year by year (shown in Figure 4), it is reasonable that the non-urgent area will become less occupied in the future. Note that as described in the §4.1, these two areas are dependent because they share the same test services. Thus, indicator value of the non-urgent area in Figure 6 and Figure 7 are different although there is no change to this area.



(a) Door-to-doctor time. (b) Length of stay.

Figure 7: Changes of door-to-doctor time and patients' length of stay, as a ratio to 2014 after adding 10 careboxes, 2 nurses and 1 doctor to the urgent area.

In summary, an ED simulator is a useful tool for quantifying the cost and benefit of changes (patient arrival or resource) to an ED. The quantitive prediction can be used as reference for making decision. Moreover, different with blackbox prediction, simulation can also provide detailed information to explain why the prediction is made, why it performs like this and which factors influence performance most. It is important to note that, the proposed solutions may not be the final decision since, in this example, lots of constraints are not considered, e.g., adding 10 carebox may become impossible due to the space limitation.

6 Conclusion and future work

The elder people is an ever increasing proportion in population especially in developed countries. Elderly people need more health care because they are more prone to get diverse diseases. Since ED is a main entrance to healthcare service system, it is evident that the population aging will challenge ED.

In this article, we firstly stated the stress of population aging by analyzing the relationship of patients' care service requirements and patients' age. The results show that elderly patients normally attend an ED with more complex issues (mostly are triaged as urgent according to CATS), they usually need more care service than young patients, and they are more likely to be admitted to hospital. Then, consider an ED in Spain as case study, we used an ED simulator to quantitively predict the impact of population aging in the next 15 years. Although our study is specific to this ED and ignores constraints of ED upgrading, we believe that the method of using simulation to support decision making is effective. Our projections also suggest that hospitalizations from the ED will increase dramatically in the coming years. To keep pace, hospitals have to improve their service capability, or optimize the movement of admitted ED patients to inpatient units. Furthermore, optimizing changes to the ED system under practical constraints to overcome the stress from population aging is a crucial future work direction.

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