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Using an Agent-Based Simulation for predicting the effects of patients derivation policies in Emergency Departments

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Abstract

The increasing demand of urgent care, overcrowding of hospital emergency departments (ED) and limited economic resources are phenomena shared by health systems around the world. It is estimated that up to 50% of patients that are attended in ED have non complex conditions that could be resolved in ambulatory care services. The derivation of less complex cases from the ED to other health care devices seems an essential measure to allocate properly the demand of care service between the different care units. This paper presents the results of an experiment carried out with the objective of analyzing the effects on, the number of patients attended and the level of activity of ED (patients’ Length of Stay, the number of patients attended and the level of activity of ED Staff) of different derivation policies. The experiment has been done with data of the Hospital of Sabadell (a big hospital, one of the most important in Catalonia, Spain), making use of an Agent-Based model and simulation formed entirely of the rules governing the behaviour of the individual agents which populate the ED, and due to the great amount of data that should be computed, using High Performance Computing.

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1. Introduction

Hospital emergency departments (EDs) are a primary healthcare unit, usually the main entrance to the hospital and a key component of the whole healthcare system. The increasing demand of urgent care, the overcrowding of ED and limited economic resources are phenomena shared by health systems around the world [1-5], giving place to the delay in the first attention of patients who attend ED.

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Between 70 and 80% of patients visit the ED on their own initiative [3,4,6,7], and it is estimated that up to 50% of patients that are attended in ED have non complex conditions that could be solved in ambulatory care services [7]. In addition several Spanish authors have established that a variable percentage of these patients for up to 80% visit the ED inappropriately.

The derivation of less complex cases from the ED to other health care devices seems an essential measure to allocate properly the demand of care service between the different care units. Such derivation should be decided once the triage process is completed, the ED process in which nurses or physicians identify the priority level of patients. This has been borne out by the results of studies conducted in Spanish hospitals of large size like Hospital Clinic of Barcelona or Hospital Mutua de Terrassa [5].

Salmeron et al. [5] try to identify ways for achieving safety and efficacy of discharging from a hospital emergency department with referral to another point of care based on the application of an Algorithmic Aid to Triage (AAT) by nurses without physician evaluation of the patient. They carried out the study with data of the ED of the Hospital Clinic of Barcelona, considering a total of 102,063 visits, and concluding that the referral done by nurses accredited using the AAT is safe and effective. Gomez et al. [8] conclude that structured emergency department triage scales can be used to develop patient referral strategies from the ED to primary care, and specifically that non urgent patients that attend ED may be discharged. In fact in Spain several hospitals redirect to more appropriate levels of care (without being visited) those patients that go to the ED with minor illnesses [9].

There are no standard models to describe complex systems like ED, but simulation becomes an important tool for their modeling. Simulation modeling approach started to be used for solving healthcare problems in the US and UK more than three decades ago. In 1979 computer simulation was applied to hospital systems for improving the scheduling of staff members [10], and in Saunders et al. [11] the aim was to quantify the impact that the amount of staff members and beds had on patient throughput time. Especially over the last decade there have been fruitful efforts in developing simulation-optimization models for solving healthcare management problems [12, 13].

Discrete event simulation (DES), system dynamics (SD) and agent-based modeling and simulation (ABMS) are the main three approaches used in simulation of healthcare systems. Healthcare systems are based on human actions and interactions, and the ability of ABMS to represent this makes it an appealing approach, while DES is not well suited to model them [14]. The potential of the use of agent-based modeling and simulations techniques in emergency departments modeling is clearly illustrated and shown in Kanagarajah et al. [15], Günl [16] and Stainsby et al. [17].

In 2008 Hutzschenreuter et al. [18] present an agent-based simulation and evaluation tool for patient admission scheduling, with the aim of achieving an efficient use of the hospital resources through the combination of different profiles of resource use. The work carried out by Jones et al [19] is a specific example of simulation applied to Hospital Emergency Departments. Authors present an agent based simulation tool, developed with NetLogo, and designed to evaluate the impact of various physician staffing configurations on patient waiting times. Brenner et al. [20] use simulation, conducted in the emergency department at the University of Kentucky Chandler Hospital, for identifying bottlenecks and investigate the optimal numbers of human and equipment resources (eg, nurses, physicians, and radiology technology). In the case of Holmes and Dahl [21] simulation is used for evaluating the influence of a 45% increase in patient volume on the ED of Akershus University Hospital

This paper presents the results of an experiment carried out by the “High Performance Computing for Efficient Applications and Simulation” Research Group of the University Autonoma of Barcelona (UAB), with the participation of the ED Staff Team of the Hospital of Sabadell (one of the most important Hospitals in Spain, that gives care service to an influence area of 500,000 people, and attends 160,000 patients/year in the ED). Its general objective is to analyze the effects over the ED of different derivation policies, using for that an ABM model and simulation designed and developed by the Research Group, with the purpose of aiding the
administrators and heads of the ED to allow additional knowledge in the purpose of choosing the policy that let to achieve the best quality of service of the service with the available human and technical resources.

Then, in an attempt to extend the previous studies, specifically the carried out by Salmeron et al. [5], the model and simulator have been used for evaluating the effects over the ED performance (patient’s Length of Stay, number of patients attended, and level of activity of ED Staff) of derivation to ambulatory and primary care services of those patients who go to emergency service without requiring an urgent attention. High Performance Computing (HPC) have been used due to the specific features of the model (a great number and variety of agents), the amount of data to be computed and finally the number of executions of the simulator needed in the experiment.

The remainder of this paper is organized as follows; section 2 describes the methodology and the details of the model and simulation. The features of the experiment and the analysis of results are presented in section 3 and 4 respectively. Finally section 5 closes this paper with discussion and conclusions.

2. Methodology

The objective of the experiment is to provide impact values of the patients’ derivation alternatives, using for that and Agent-Based Model and Simulator previously designed and developed by the Research Group. The methodology applied in the design and development of the tool is divided in five phases: 1) System analysis; 2) Model design; 3) Simulator implementation; 4) Simulator verification and validation; 5) and finally Simulator execution and results analysis.

2.1. System analysis

The information was obtained from two different hospitals. The first one was the above mentioned Hospital of Sabadell, a large center, and the second a medium size hospital, the Hospital of Mataro, that provides care service to a geographical area with a population of 250,000 people, attending an average of 110,000 patients per year in its ED. Such information was collected with the following tools:

- Focus groups with the directors of the ED, the coordinators of the main areas of the ED, and different kinds of the ED staff (admission personal, triage nurses, sanitary nurses and doctors).
- Observation of the different ED zones of both Hospitals, with the purpose of analyzing and taking notes about how the different processes take place.
- Data given by the Information System Department of the Hospitals (ISDH), concerning to the activity carried out by the ED.

As result of this phase the key information of the system was identified (different kinds of agents, the interactions that take place, the different areas, etc).

2.2. Model design

This consists of the formal definition of the model, including the environment, the different kinds of agents, and their behavior. The ED model has been designed using the Agent-Based Modeling and Simulation approach, in which the system behavior emerges as a result of agent’s actions and interactions. Such a model describes the complex dynamics found in an ED, representing each individual and system as an individual agent. Two distinct kinds of agents have been identified, active (the persons involved in the ED such as patients and the different kinds of ED staff) and passive (reactive systems, such as the information technology (IT) infrastructure or labs that perform tests). State machines are used to represent the actions of each kind of agents. This takes into account all the variables that are required to represent the different states in which such agent may be throughout the course of time in ED. The change in these variables, invoked by an input received
from an external source, is modeled as a transition between states. In order to control the interactions that take place between agents, the communication between individuals (modeled as the Inputs that agents receive and the Outputs they produce, both implicitly and explicitly) and the physical environment in which these individuals interact are modeled. Figure 1 shows a general image of all the elements that includes the model.

The communication model represents three basic types of communication: 1) 1-to-1, between two individuals (as happens between admission staff and patient, during the admission process); 2) 1-to-n, representing an individual addressing to a group (like a doctor giving information to patient and nurses during the diagnostic process); 3) and 1-to-location, when an individual speaks to all occupants of a specific area (for instance when any staff member uses the speaker system to address a message to all the people who are in a specific waiting room). The environment includes: Admissions Zone (where patients have to address just when they arrive to the ED, and Admission Staff register their arrival); Triage Box (where a “triage nurse” receives the patient, takes his/her vital signals and obtains some additional information in order to identify the priority level); Waiting Rooms (where patients and their companions wait for being triaged, and once they have past the triage process, until be called to enter the treatment zone); diagnostic and treatment zone (where Doctors, nurses and other ED Staff carry out the diagnostic and treatment process with patients).

2.3. Simulator implementation

The simulation of the model has been implemented using the agent-based simulation environment NetLogo [22], a high level platform that lets modelers give instructions to hundreds or thousands of independent agents, all operating concurrently, making possible to explore connection between the micro-level behavior of individuals and the macro-level patterns that emerge from the interaction of many individuals.
The current version of the simulator includes the four primary areas: admissions, triage, 3 waiting rooms (one for patients before triage, the second for patients after triage process who are waiting for treatment, and the third in the treatment area, in which patients wait while have no interaction with physicians or nurses), and the diagnosis and treatment area. The kind of active agents represented in this simulation are patients (P), admission staff (AS), triage nurses (TN), clinical nurses (CN) and doctors (D). TN carries out the triage process, phase in which the priority level of patients is identified, and CN acts in the Diagnostic and Treatment process. In the specific case of the ED Staff (AS, TN, CN and D), two distinct levels of experience have been considered (low, labeled as junior, and high, labeled as senior).

Depending on physical condition and symptoms, through the triage process patients are classified in 5 different levels of acuity and priority (from 1, the maximum level, to 5, the minimum) following the Spanish Triage Model, the acuity scale used in the Spanish Emergency Services. The diagnosis and treatment process will be different depending on the priority level. In addition, in accordance with the organization model used in large Spanish EDs, the treatment zone is divided into two different areas: one for treatment of patients with a level 4 or 5, and the other one for the attention of patients with a level 1, 2 or 3.

In the simulation implemented patients arrive at the ED by their own means, and wait to be attended in the admission zone. The simulation reads the input information from a text file within the data given by the hospital within the number and typology of patients arriving at any time within a 24-hour cycle. Once the admission process has been carried out, the patient waits in a first waiting room (WR) until he/she is called by a triage nurse, who takes his/her vital signs and obtains some additional information in order to identify the priority level with which patient will be attended. After the triage process, the patient goes to a different WR and waits there until a doctor is free and calls him to start the process of diagnosis and treatment. Once this process has been completed, the patient leaves the ED. In the current version of the simulation patients of all the kinds (1 to 5) are taken into account until the triage process. But only the part of the diagnostic and treatment zone in which patients with a priority level 4 or 5 are attended is considered.

The diagnostic and treatment process for such patients is divided into three phases:

- Initial evaluation: a phase that takes 20 minutes on average, during which patient and physician remain in a treatment booth interacting;
- Additional testing: during the first 10 minutes the patient and the clinical nurse interact in the treatment booth, while the test is carried out. After that, the patient leaves the booth and waits in the WR until the results are received. The total duration of this phase will depend on the Lab’s workload. Once the results of the test have arrived, physician decide whether patient may be send to home or has to receive a treatment.
- Application of medication or treatment: patient is called to enter a treatment booth, and during the first five minutes the clinical nurse applies the treatment to the patient. Once the treatment has been applied, the patient leaves the booth and will be waiting in the WR until the treatment has taken its effects, which on average takes 45 minutes.

Considering the information given for the Hospital of Sabadell, 20% of patients attended in this zone are discharged after the initial evaluation, the other 80% require additional testing. Only the 20% of the total will remain for medication. The simulator takes into account all theses specifications. Figure 2 shows a screenshot of the simulator. The layout of the different parts of the ED implemented is shown in the central framework. The user can set both the number of each one of the different types of the ED staff (AS, TN, CN and D), and their level of experience (junior or senior), through the configuration console which is on the left-hand side of the interface.
2.4. Simulator verification and validation

Taking the definitions of Sargent [23], model verification is the task of ensuring that the model behaves as intended, while model validation is the process of determining whether the simulation model is a useful or reasonable representation of the real system. Following the recommendations of Sargent, the model and simulator verification and validation have been carried out performing the face validity on the conceptual model and exploring the simulation model’s behavior. In the specific case of the validation, it only has been developed partially because the current version of the simulation is not the final one. In both cases the process has been carried out with the participation of the team from the Hospital of Sabadell ED, and it leads us to conclude that both model and simulation represent an ED correctly. The techniques applied have been:

- Animation: the model’s operational behavior has been displayed graphically. The movements of the different parts of the ED are shown graphically during the simulation run.

![Fig. 2. Screenshot of Netlogo with the features of the Simulator](image)

- Degenerate Tests: the logic of the proposed model has been examined through a varied set of experiments, observing overall operations in the simulation ED and tracking different types of patients. All these experiments needed a great amount of computation, reason why they have been carried out using HPC.
- Face validity: the Hospital of Sabadell ED Staff has been heavily involved in all the process, verifying that the model behaves like the real system.

The details of the verification and validation process done are presented in Taboada et al [24].

2.5. Simulator execution and results analysis

Introduction in the simulator of the configuration and input data given by the ISDH, and then execution of the simulation for the different scenarios considered in the experiment, in order to obtain the output data required for completing such experiment.

3. The experiment

In an attempt to extend the previous studies, specifically the carried out by Salmeron et al. [5], the objective of the experiment is to provide impact values of the alternatives policies of patients’ derivation. With that purpose the model and simulator have been used for evaluating the effects over the ED performance of
derivation to ambulatory and primary care services of those patients who go to emergency service without requiring an urgent attention. High Performance Computing (HPC) have been used due to the specific features of the model (a great number and variety of agents), the amount of data to be computed and finally the number of executions of the simulator needed in the experiment.

The Performance of the ED has been measured through three indicators: 1) the number of patients of each acuity level (in this case only 4 and 5; the patients treated in the ED zone considered in the experiment) that complete the treatment during the period of time considered in the experiment (1 day of activity); 2) Patients’ Length of Stay (calculated separately for patients of 4 level and 5 level of acuity); 3) and finally the occupation level of each one of the physicians, calculated as the percentage of time that such physician is attending or interacting with a patient, in relation with the total time available for attending patients.

The simulation has been executed several times for the equivalent to one day of activity, considering the arrival information of February 2012 (daily average of 397 patients, the 43.22% of them with a 4 level of acuity, and the 25.35% with a 5 level), and the mix of ED Staff informed by the Hospital of Sabadell (2 AS with senior profile, 2 TN with junior profile, 1 CN with senior profile and 3 D, 1 senior and 2 junior).

Concerning to the derivation percentage of patients with a level 5 of acuity, six different scenarios have been considered: 0%, 20%, 40%, 60%, 80% and 100%. A 0% means that all the patients with a level 5 of acuity are attended in the diagnostic and treatment zone, while a 100% means all the patients with a level 5 of acuity leave the ED after the triage process. In addition, six different scenarios of patient arrival have been taken into account: the original one (0%) and five more calculated applying an increase of the original data of 20%, 40%, 60%, 80% and 100%. Combining both, derivation and arrival of patients, a total of 36 different scenarios have been considered. For each one of them twenty simulations have been executed, each one with a different seed. Then, a total of 720 executions have been done, what means about 60 hours of computation that have required the use of HPC. The data taken for each scenario is the average of the results obtained in such twenty executions.

4. Analysis of results

This section is dedicated to the analysis of results. First part focuses on the scenario concerning to the original data, and after the analysis takes into account data from all the scenarios.

Table 1 summarizes the results obtained for the original patients’ arrival in the six different scenarios of derivation, including information about the number of patients that complete the treatment and patients’ Length of Stay. For each one of the % of derivation, the table includes a column identified as “value” with the value of each variable (in the case of LoS expressed in hours) and another with the variation (identified as “var.”), calculated as difference with the data of the original column, and expressed in percentage (positive values mean an increase and negative values a decrease). With a 0% of derivation, only 136 patients complete the process during the execution (51 of kind 5 and 85 of kind 4), in front of 174 (60 of kind 5 and 114 of kind 4) when the derivation is 100%. This represents an increase of the 27.94% in the patients attended (34.12% in the case of patients 4, and 17.65% for patients 5).

Focusing on LoS, with a 0% of derivation patients remain in the ED in average 4.17 hours (4.12 hours in the case of patients of kind 5 and 4.36 for patients of kind 4), in front of an average 3.73 hours (3.18 in patients of kind 5 and 3.90 in patients of kind 4) when the derivation is 100%, what represents a reduction of the 14% considering all patients (6% in the case of patients 4, and 23 % for patients 5). In conclusion both the number of patients treated and the LoS improve with the increase of the % of derivation.

Analyzing the occupation level of each one of the physicians, calculated as the percentage of time that such physician is attending or interacting with a patient, in relation with the total time available for attending
Table 1. Number of patients that complete the ED process and their LoS (expressed in hours) for different percentage of derivation (from 0% to 100%) in the case of the original data of patients’ arrival

<table>
<thead>
<tr>
<th></th>
<th>0%</th>
<th>20%</th>
<th>40%</th>
<th>60%</th>
<th>80%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>value</td>
<td>var.</td>
<td>value</td>
<td>var.</td>
<td>value</td>
<td>var.</td>
</tr>
<tr>
<td>Number of Patients</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All patients</td>
<td>136</td>
<td>143</td>
<td>5%</td>
<td>146</td>
<td>156</td>
<td>15%</td>
</tr>
<tr>
<td>Patients 4</td>
<td>85</td>
<td>90</td>
<td>6%</td>
<td>92</td>
<td>101</td>
<td>8%</td>
</tr>
<tr>
<td>Patients 5</td>
<td>51</td>
<td>53</td>
<td>4%</td>
<td>54</td>
<td>55</td>
<td>8%</td>
</tr>
<tr>
<td>LoS (in hours)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All patients</td>
<td>4.17</td>
<td>3.98</td>
<td>-5%</td>
<td>3.96</td>
<td>3.84</td>
<td>-12%</td>
</tr>
<tr>
<td>Patients 4</td>
<td>4.36</td>
<td>4.30</td>
<td>-1%</td>
<td>4.08</td>
<td>4.00</td>
<td>-4%</td>
</tr>
<tr>
<td>Patients 5</td>
<td>4.12</td>
<td>3.67</td>
<td>-11%</td>
<td>3.55</td>
<td>3.41</td>
<td>-17%</td>
</tr>
</tbody>
</table>

patients, such occupation level is lower as the percentage of derivation increases (66.01% with a 0% of derivation, 53.13% with a 40% and a 44.71% with a 100% of derivation). Taking this information into account, a new execution was carried out, now reducing the number of doctors to 2, both with junior profile, and considering a 100% derivation. With this new mix of Staff, the occupation level increases to 63.96% and the LoS of patients with a IV level of acuity is 4.21 hours, what means an increase of 18 minutes. In conclusion a very similar performance is achieved reducing the number of physicians but discharging the 100% of patients with a 5 acuity level.

Now results obtained for all the scenarios will be analyzed. Such results are summarized in figures 3 and 4. In general, as it has been concluded before, whatever the scenario of patients’ arrival, both the number of patients treated and the LoS improve with the increase of the % of derivation. But it seems to have a roof of 200 patients for the number and mix of ED Staff considered (2 AS with senior profile, 2 TN with junior profile, 1 CN with senior profile and 3 D, 1 senior and 2 junior), which means that seems no possible to attend more than 200 patients per day, whatever the patients’ arrival. If the objective is to treat a bigger amount, discharge could be a measure to consider but not sufficient, and would have to think in involving more staff and/or improving their experience.

Fig. 3. Number of patients that complete the ED process for the different scenarios of derivation and increase of the patients’ arrival
Concerning to the patients’ LoS, usually used for measuring the quality of service of ED, derivation policies let its improving, but again with the number and mix of ED Staff considered, it seems to have a floor or minimum value of 3.73 hours. For improving this level it will be necessary to involve more staff and/or improve their experience.

5. Discussion and conclusions

The results obtained show that the derivation of patients that don’t require an urgent attention allows to increase the number of patients attended in the ED, and also reduce the Length of Stay of patients that remain in the ED. Even more, in some cases the number of physicians required in the zone in which are attended patients with level of priority IV or V is lower, what make possible to move some of them to other parts of the ED. In addition the results show that potential benefits of derivation policies have a limit in scenarios of bigger patient’s arrival, reason why the derivation has to be combined with other complementary actions like involving staff with a higher level of experience and/or increasing the amount of staff.

Although the experiment has been carried out for a concrete hospital, the generality of both model and simulator makes possible that may be applied in different hospital emergency departments, after a previous adjustment of the configuration parameters achieved through a two-steps process which is carried out through parametric simulation. The first step consists in carry out a tuning process between the simulator and the real system, and let to obtain the value of parameters that produce the best similarity level between them. The second step which is called predictive validation consists of testing its predictive power. After completing the whole process the simulator will be ready to be used as DSS in such real system (hospital).

The experiment presented in this paper is a clear example of the benefits of using simulation as the core component of a decision support system that aids healthcare managers to make the best informed decisions possible (patient admission scheduling, to manage physician staff and resource optimization amongst other situations), and making better use of resources, achieving a more efficient and improved patient care cycle. This in turn allows better management of dynamic patient flow, either as a result of specific circumstances (pandemics, disasters, etc) or seasonal fluctuation of the demand of healthcare service.

Furthermore, using High Performance Computing, the simulator could be used to execute a large number of simulations, each one of them concerning to different scenarios, in order to obtain a large amount of information about the real system, which in some cases would not be available without simulation. Applying data mining techniques on such data could allow to extract interesting patterns maybe unknown before, as well as other conclusions useful for the decision making process.

One final and remarkable conclusion is that HPC is essential both in the execution of the experiment, the use of parametric simulation in the two-steps adjustment process mentioned above, and obtaining a great amount of data concerning to the real system for the improvement of the decision making process.
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