ABMS & DES for Modelling an Emergency Department

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Abstract

Simulation is one of the preferred methods for health care modeling in operational research field. Particularly, discrete event simulation (DES) has been widely used for supporting operational decision making processes and for planning in different units of a health care systems. Most of the problems that have been tackled in health care with DES are staff scheduling, resource allocation, waiting time performance, patient flows, among others. Some aspects of human behavior have been incorporated in DES with some limitations. Human behavior is commonly modeled with agent based modelling and simulation (ABMS) particularly to represent interactions between agents and between the environment.

This paper attempts to show how DES and ABMS can be used to model operational aspects of the emergency department and human behavior aspects that affect the decision making process of doctors in the emergency departments.

1 Introduction

Among operations research methodologies, simulation is very popular for health care modelling. Particularly, discrete event simulation (DES) has enjoyed more popularity than other simulation methodologies such as agent based modelling and simulation (ABMS). According to Brailsdford [1] health care models can be classified in three groups. The first group includes model of the human body which are frequently used for assessing the effects of some clinical interventions, ABMS is often used in this group. The second one are operational or tactical models often used at single units in a health care system such as a clinic, an emergency department and an operating room. Generally, these model are used for modelling patient flows, reducing bottlenecks, capacity planning, resource allocation, among others. DES is commonly used in this group. Finally, the third group are strategic models in which patients are not modeled individually and which main objective is evaluating long-term effects of different strategies or policies.

DES allows modelling individual entities, which have characteristics that determine their flow inside the model. The entities engage some activities and need resources to complete the process. In DES the simulation executive is in charged of scheduling and sequencing the activities based on a three-phase simulation approach, that will be described later in this paper.

Similarly, ABMS also allows modelling individual entities called agents. Those agents have behaviors that are determined by rules that can be simple (reactive behavior) or more complex (proactive or deliberative behavior). The agents interact with each other and with the environment based on those rules. The features that distinguish ABMS from DES are the possibility of modelling heterogeneity of agents and the emerge behavior that arise from the interaction among the agents [2].

Some systems are characterized by having strong human behavior components and a large number of operation processes, resources and activities. An example system are the emergency departments, where patients arrive either by walk-in or by ambulance, ambulance patients' are registered and triaged on the way to the hospital whilst walk-in patients need to be registered and triaged directly at the emergency department. Afterwards each patient is assessed by a doctor who decides whether or not the patient needs tests or X-ray. If the patient does not need tests or x-ray the doctor treats him intermediately otherwise he waits until the patient comes back with the tests or x-ray results and give him a diagnosis.

The processes of this system are easily observable, which makes it fit very well in the type of problems that can be modeled with DES. However, it cannot be ignored the importance of doctors' and nurses' individual behavior because they affect directly the system performance. Currently in the UK, the national health system (NHS) has a structure based on performance measurements, specifically for the emergency departments, it is expected that 95% of the patients do not stay longer than four hours in it. This puts a lot of pressure, not only on the managers, but also on department's staff, since they need to consider the patient's condition as well as the time the patient has spent in the system, when making decisions. Therefore, modelling this type of human behavior in a DES model is a challenge.

The main aim of this study is to investigate how to use the strengths of both methodologies (DES & ABMS) for modelling the operational and human factors of emergency departments.

The paper begins by Section 2 with a literature review, of how simulation methodologies, specifically DES & ABMS, have been used in health care systems. It will then go on Section 3 to the description of methodology used to implement the simulation model, then Section 4 with all the details of the model and finally sections 5 and 6 with results, conclusions and further work.

2 Literature Review

A large and growing body of literature has investigated different aspects of health care using modelling and simulation. Accident and Emergency (A&E) department have enjoyed a great popularity in this area. Browsing the string '((“discrete event simulation” or “DES”) and (“emergency departments” or “A&E” or “ED”))' in topic search of the Web of Science produced 473 records from 2000 to 2015 when executed on November 2015. Figure 1 shows that the number of papers has increased in recent years. Surveys such as that conducted by Gunal and Pidd [3] show that the majority of the models focus in the solution of specific problems in individual area of health-care system instead of giving a general idea of the whole system. Second, it seems that health-care modellers do not reuse models produced by others but instead build their own each time, so they think that models are limiting opportunities to find out what others have already developed, needing every time to start from the beginning and to lag some way behind of this practice. Last conclusion is given for what specifics processes of care could be easy represent by DES such as staff schedules, adding or removing beds, increasing the number of nurses, and other clinicians.

Fone et al (2003) [4] report a widely list of papers have been published about modelling, simulation and

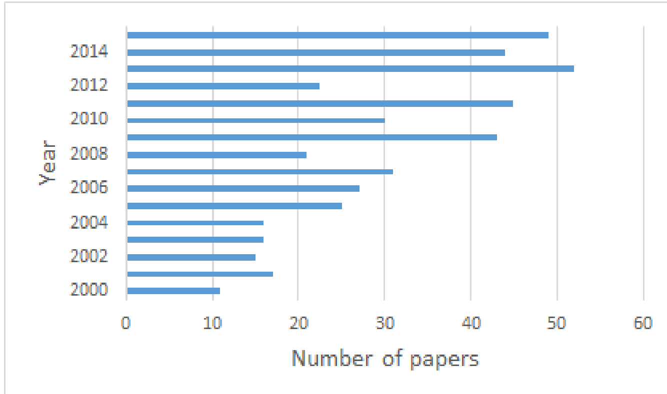

Figure 1: Number of papers of DES applications in emergency departments

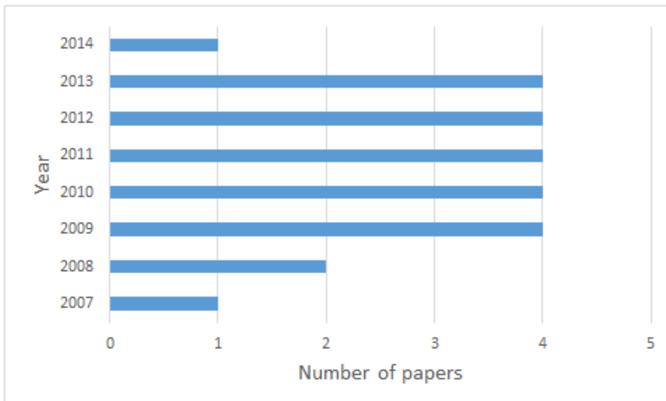

Figure 2: Number of papers of ABMS applications in emergency departments

other tools to model and represent the health care in its different areas such as hospital scheduling and organization, infection and communicable disease, costs of illness and economic evaluation, screening and miscellaneous.

Browsing the string '((“Agent* based modelling” or “Agent* based simulation” or “ABMS” or “ABM”) and (“emergency departments” or “A&E” or “ED”))' in topic search of the Web of Science produced 24 records from 2000 to 2015 when executed on November 2015. Figures 1 and 2 show the significant difference in how many researches have worked in one methodology than the other.

The use of ABMS in health care has been mainly for studying disease prevention and epidemiology problems, and there are very few applications at the strategy and policy, and tactical and operational level, especially for modelling Emergency Departments.

However, there is lack of work in using hybrid models (DES & AMBS), Stewart Robinson [5] makes emphasis that DES is not appropriate for modelling a complete operational system because it cannot help with detailed decisions about the layout of service operations where customers are present. Because this approach needs to model individuals and their interactions, he argues that DES is not particularly suited because the model needs to capture every single client movement, which means the simulation time has to be fixed in contrast of it that the simulation time is from event scheduling. Hence, he proposes the ABMS to approach for representing the customers and service staff as agents in order to model these interactions the overall system behavior emerges; using, what he thinks is the key to developing the agent intelligence the standard models of human decision-making in simulation, PECS (physical conditions, emotional state, cognitive capabilities and social status).

3 Methodology

In this research, DES was used to represent all the operational processes such as registration, triage, test and x-ray, whereas ABMS was used for modelling doctor's decision making processes.

The development process of the ABMS & DES model, as any simulation, is relatively standard, it will use the methodology proposed by Tako and Robinson [6] (see Figure 3), where they summarize some of the main steps. The first step is the problem formulation, the second step is the development of conceptual model, since we are going to have two different types of models, the conceptual model will be done in two main parts: the DES model development will be based in the conceptualization that Gunal and Pidd [7] have already done. For the ABMS model, we are going to use the framework called PECS [8] to represent some aspects of human behavior focusing in physics and emotional conditions. Next Section will explain the PECS framework in more detail.

The computer model was developed in Simul8 [9], what is a simulation software designed to simulate DES' models but it has a great powerful tool to manual programming called visual logic that makes possible to mix both methodologies and allows us to model human behavior from small scale.

Finally, the verification was made comparing our result with the results that Gunal and Pidd [7] had obtained and checking if the variables states, physical and emotional, of each doctor had an s-shaped as we modeled them.

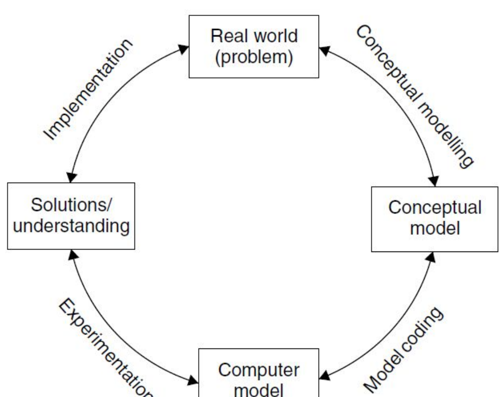

Figure 3: Simulation Studies: Key Stages and Processes.(Brooks, R.J. and Robinson, S., Simulation 2000, Palgrave Macmillan) [10]

4 The Model

Since the main goal of this research is to build an hybrid simulation model of discrete event simulation (DES) and agent based modelling and simulation (ABMS), all about conceptual model needs to be separated it in two different branches: the first branch is DES conceptual and basic computer model are based in one that Gunal and Pidd [7] have already done, even all the data are taken from them.

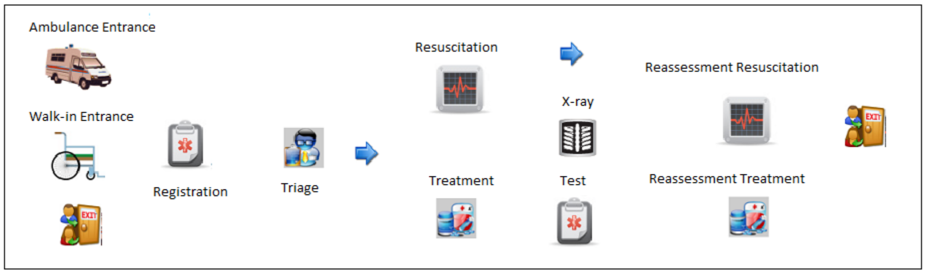

Figure 4: Discrete Event Simulation Model

The second branch is ABMS conceptual model and it is based in the framework PECS [8], as we mentioned before this is one standard models of human decision-making that has been used for modelling human behavior. PECS basis grounds on the assumption that integrating physical, emotional, cognitive and social attributes and their intensities, it can define the agent's personality. The architecture may be divided up into three different stages: sensor and perception, agent internal states and goals, and decision-making and agent behavior. The stages can be explain by Figure 5.

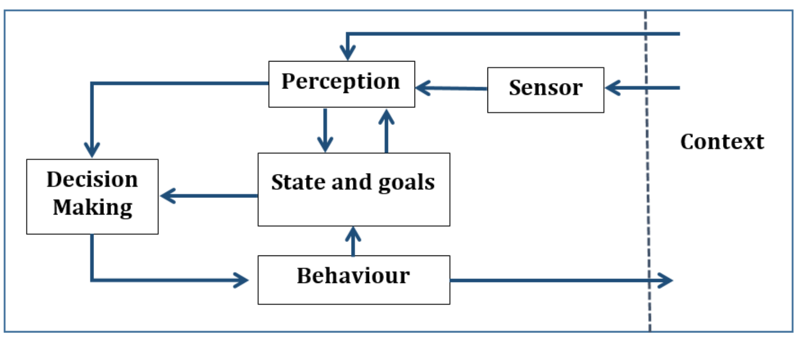

Figure 5: Description of an agent's behavior

To model the intensity of states variables in this paper, two main state variables are considered: physical state, that represents the doctor's energy (fatigue), and emotional state, that represents doctor's stress. To model those states variables, the logistic functions are used because they are commonly used for modelling several psychological processes such as the relation between physical stimuli and the sensations, neuronal signals, cognitive development and consumer behavior among others [11]. The logistic functions allow representing individual differences and personality. However the research on modelling emotion processes using those kinds of functions is scarce.

For example, Tong [11] investigated the nature of the relationships between emotions and appraisals and he founds that there are s-shaped relationships between emotions and behavior. These functions have a baseline that represents the minimum level of the emotion, 0, an asymptote that represents the maximum level of the emotion, 1, and a slope that represents the intensity of the relationships between behavior and emotions. The logistic function is defined by:

$$I(x) = \frac{M}{1 + e^{-\alpha(x-c)}}$$

where:

- M: is the asymptotic maximum value of $I(x)$.
- α: it is the growth rate (affects the steepness or with of the curve: this is as α increases, the curve approaches M faster).
- c: it is the value of x when the curve has its maximum growth (c also means the value of x at which the curve reaches the 50% of M).

Doctors were divided according to their experience:

- Low experience: We suppose them to get tired slower than the others but stressed fastest.
- Medium experience: We suppose them to be in a equilibrium point, where they get tired and stressed almost at the same rate, rate of getting tired greater than the low experience doctor but less than high experience and the opposite rate of getting stressed.
- High experience: We suppose them to get tired fastest than the others but stressed slowest.

Parameters selection was made by testing, values are shown in Table 1.

	Doctor		
Parameter	**Low_Exp**	**Med_Exp**	**High_Exp**
M	1	1	1
Energy - Alpha	0,03	0,04	0,05
Energy - C	300	300	300
Emotion- Alpha	0,08	0,05	0,04
Emotion- C	350	380	400

Table 1: Parameter's values

Every time the doctor ends an activity would check his internal state and could make basically two different decisions, if his stress level is greater than his fatigue level, as the stress is given by patient's maximum time in system, he would work faster trying to reduce that time, otherwise he would take a 5 minutes break. If only if those variables are up above of 0.5.

As it has been mentioned before DES executive is based on three-phase approach. Phase A is the time scan to know in what part of simulation it is happening, phase B is the start of those activity that are scheduled such as patients arrivals, the end of the activities that have already started, etc. Finally, phase C, conditional activity or cooperative activity, are those that are independent of simulation time but must wait until all the conditions are satisfied to start it, for example a doctor appointment needs, a cubicle, an available doctor and a patient if one of these condition hasn't been accomplished the activity cannot start. This process is explained by Figure 6. It is in this part of the process where doctors' decision are pretty important because they can decide whether to start or not the event that has been scheduled and they can make decisions about how much time to spend with each patient depending on their internal states (represented by stress and fatigue).

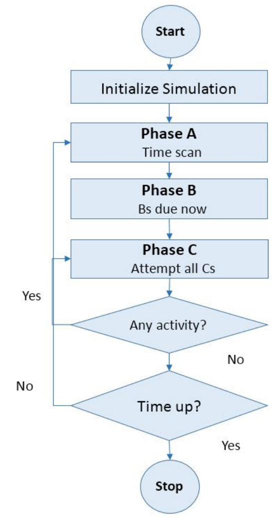

Figure 6: A three phases executive. [Pidd, 2005, p. 91]

5 Results

The last step of the methodology is the verification process. Since there are two models considered here, the verification process will be divided in two parts: first, the results of the DES model built in Simul8 without PECS implementation are compared with the DES model implemented by Gunal and Pidd [7]. Second, the results of DES model built in Simul8 using PECS implementation are compared with the model without PECS and by using a debugging process, the behavior of the doctors are analyzed to verify that the doctors' states trigger the expected behavior accordingly to each particular circumstance.

As the system being modeled is from an emergency department in the United Kingdom, where they have an strict policy that patient should not be in the system for more than four hours, the most important performance measurement is the patients' time in system.

The actual percentage of patients that leaves before 4 hours the emergency department that is being modeled here, is 96%. The results of the DES model built here are obtained after calculating the number of runs required to obtain a precision of 5% in the average and maximum time in the system of all patient. The number of runs required was 33. Table 2 shows the confidence interval of the percentage of patients that leaves the emergency department within 4 hours. It can be seen that the results of the model are close to the actual performance.

	-95%	Average	95%
% of patients that leave within 4 hours	96.992	97.159	97.325

Table 2: Confidence interval of patients that leaves before 4 hours

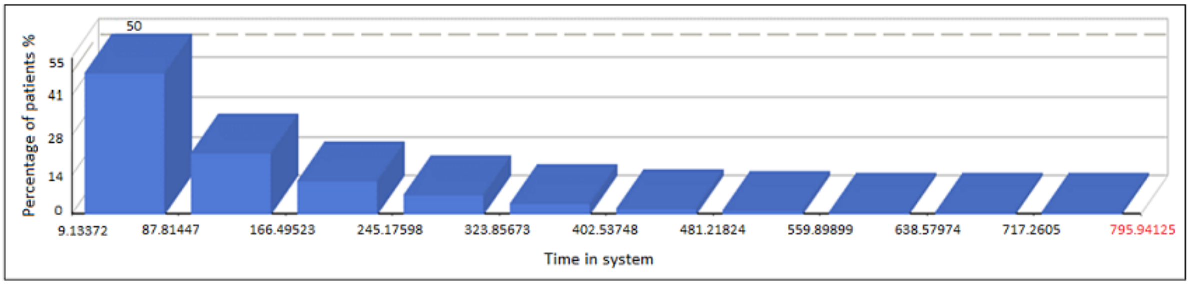

Figure 7: Time in system without PECS

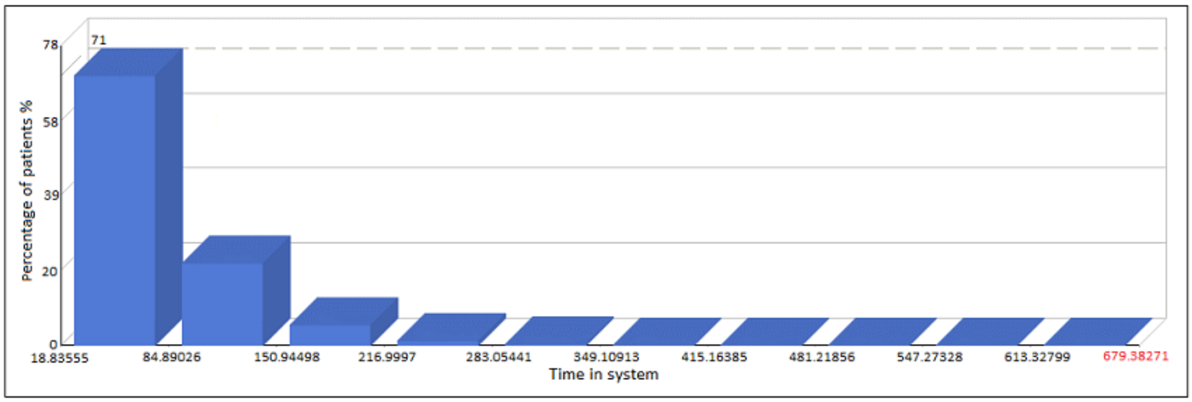

Figure 8: Time in system with PECS

Figures 7 and 8 represent the percentage of patient that stay certain time in the system.

	PECS			NO PECS		
	-95%	Average	95%	-95%	Average	95%
Average Time in System	72,29761	72,55588	72,81414	134,48608	135,75952	137,03296
Maximum Time in System	546,73301	618,13306	689,53312	1201,09015	1272,69871	1344,30728

Table 3: Comparison between PECS model and no PECS model

Table 3 shows how implementing some human behaves the model has significant changes in the results of average and maximum time in system, this is because the value of the parameters and the description of doctors' behave was empirical decided due to the objective was to make an example of how PECS can be implemented in a DES model to model the doctor's decision making closer than in a usual DES model.

6 Conclusions and Further Work

Reusing models was a great way to start this research because it allowed to go further due to the basis model was taken from Gunal and Pidd [7] so it wasn't necessary recollect data or invest time in the architecture of the model. Other model's feature is the generality of it what makes it more useful because many hospitals could use it just changing their data and adding their own behavior desires or implementing their targets.

Although it is not possible or at least not that easy to model complex behavior such as adaptation or learning but a simple reactive behavior including deliberative decision making can be included in a simple discrete event simulation model.

In further work, it is necessary to calibrate the parameters of PECS functions in order to obtain a much better representation of the actual performance. Also it might be interesting to asses how the other two aspects of the PECS framework (cognitive and social states) can affect the doctors' behavior. Additionally, it would be a challenge to consider the behavior of other people in the model such as nurses, patients and administrative staff.

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