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MANAGEMENT OF EMERGENCY DEPARTMENTS USING COMPLEX SYSTEMS MODELLING

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ABSTRACT

Managing Emergency Department (ED) in the light of unpredictable patient demand, limited resources and the need to meet national targets is a major challenge. Launched by the UK's Department of Health since 2000, the National Health Service (NHS) is now facing a 4-hour maximum time target to meet, where failures will trigger considerable financial penalties. However, the target is often missed especially with an increasing demand year on year, and it's widely accepted that process management is one of the key reasons. In this work, a state-of-the-art approach using Agent-based Modelling (ABM) is introduced to provide a *decision support system* for the ED to obtain information ahead of time in order to optimise the management of human and material resources. By modelling each patient, member of staff and other related resources as agents, this model has the nature of flexibility and capability of providing any detail. With the benefit of modularised design, this platform can also be easily customised for any ED.

KEYWORDS

Emergency Department; management; modelling; prediction; decision support

1. INTRODUCTION

Managing Emergency Department (ED) has been a challenge for a long time [Derlet 2000]. Since the 4-hour time target was introduced by the UK's Department of Health in 2000, many EDs have struggled to meet it. According to the survey carried out by the British Medical Association, seven main reasons were listed for not reaching the target [BMA survey]: 1) Not enough in-patient beds; 2) Delayed discharges; 3) Delay in accessing specialist opinion; 4) Not enough nurses; 5) Not enough middle grade doctors; 6) Department too small; 7) Delay in accessing diagnostic services. Thus ED experiences a lack of human/physical resources, and also has bottlenecks in resource management. Over the next few years, the National Health Service (NHS) in the UK will continue experiencing budget pressure, which makes it difficult to improve the ED services by increasing the amount of staff and physical resources. Therefore, improving the efficiency of NHS systems, especially the ED, becomes necessary in order to provide a comprehensive and high quality care with limited funds, and to improve efficiency filling the gap between demand and funding [NHS five year forward view]. There is a predicted growth in attendance of 5-7% year on year [Health Building Note 15-01]. However, recent reports in the press have indicated a near 10% rise in attendance at ED. As shown in Fig. 1, the failure to meet the 4-hour target is likely to be amplified in coming years without an improved resources management strategy.

To help manage ED, simulation has been proposed as a possible solution [McGuire 1994]. Studies have been carried out using different methodologies, such as traditional Discrete Event Simulation (DES) [Connelly and Bair 2004], Agent-based Modelling(ABM) [Wang 2009 and Cabrera et.al. 2012] etc. So far, there is no successful system capable of simulating the whole emergency department with deep-level details. This paper proposes an ABM based approach that models the complete emergency department based on historical data and interaction rules, and provides a rich set of real-time and predictive information of the status of the department. Agent-based modeling is used in many areas for the analysis and management of complex systems, especially those involving humans. It is radically different to the discrete event approach adapted to hospitals from the world of factories.

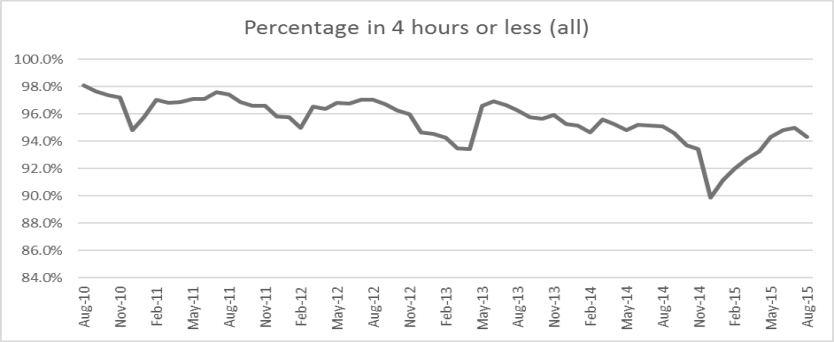

Figure 1. The number of patients seen within 4 hours over the past 5 years at all NHS EDs

2. THE EMERGENCY DEPARTMENT MANAGEMENT EMERGENCY

The growing demand on emergency services and the target regime that it has to satisfy has lead to significant problems for hospitals, both financial and reputational. Hospitals are fined for missing their ED targets, for example, this could amount to £500k a quarter. Hospitals are also increasingly judged through publicly available league tables.

Given this situation, a decision support system driven by an Agent-based Model (ABM) can help the managers in ED to improve their control through prediction of resources and patients. The system provides the benefits of overview of future potential bottlenecks within the department.

2.1 The Hospital Context

Table 1. Number of patients seen within 4 hours and penalties (05/04/2015 to 28/06/2015)

	Attendees to Department of ED	**Attendees seen > 4 hours**	**Percentage of attendees seen < 4 hours**	**Penalty Charges**
Total number of patients over 140 EDs	3,702,458	329,060	91.1%	£39,487,200
CMFT ED	37,220	3,542	90.5%	£425,040

The agent-based model was designed and developed in collaboration with the ED of Central Manchester Foundation Trust (CMFT) that is one of the busiest EDs in the UK. Data from the CMFT shows there were 5,628 attendees visiting the ED in the last week of July 2015. An average of 86% of attendees were seen to transfer or be discharged within 4 hours that is lower than the current target required by the NHS of 95%. ED staff are constantly under a high pressure due to the high demands and inevitably the quality of care provided is affected.

In order to urge EDs to improve their performance, a financial penalty of £120 per breach under the 95% target is enforced on a monthly basis. In the period of June 2015, ED of CMFT had 12,005 major patients, in which 7.68% (916) of those were not seen within 4 hours triggering a penalty charge of £109,920. A comparison is given in the Table 1 to show the how the 4-hour target was met and penalty charges across the country. The figures in the table indicate a large number of hospitals in the UK are struggling to meet the target, and the CMFT ED needs extra effort.

Under these circumstances, an ABM based decision support tool was developed to help CMFT ED to improve their management by simulating the operation of the whole department. The CMFT ED has three major emergency zones: *red* for patients delivered by ambulance who require rescue; *amber* for urgent medical treatment; *green* for stable patients. As a detailed simulation technology, the agent-based modelling is able to simulate each individual member of staff, patient, and other resources, e.g. room, cubicle etc. in

each zone. Based on the knowledge of how patients flow within the department and the historical data, this model is capable of reproducing the accurate picture of the department.

2.2 The Model

The implementation is based on the Flexible Large-scale Agent Modelling Environment (FLAME) [www.flame.ac.uk, Coakley *et.al.* 2006 & 2012]. FLAME is a generic agent-based modelling system which can be used to develop applications on majority of computing systems ranging from laptops to HPC super computers. FLAME based ABM has been successfully used in many fields, such as economy and biology [Holcombe *et.al.* 2013, Bai *et.al.* 2014 and Gavin *et.al.* 2015].

ABMs represent complex systems as a collection of autonomous entities – *agents* – and set of rules of how these *agents* interact and behave. Among the agents in this model are patients, doctors, nurses, nurse practitioners, consultants, receptionists, porters. Each agent has integrated into it a dynamic data set that identifies it, its attributes and location, etc. There can be many different examples of each of these agent types. Each agent type can behave in a number of ways depending on what they are, what their attributes are, who they are interacting with and what options are open to them.

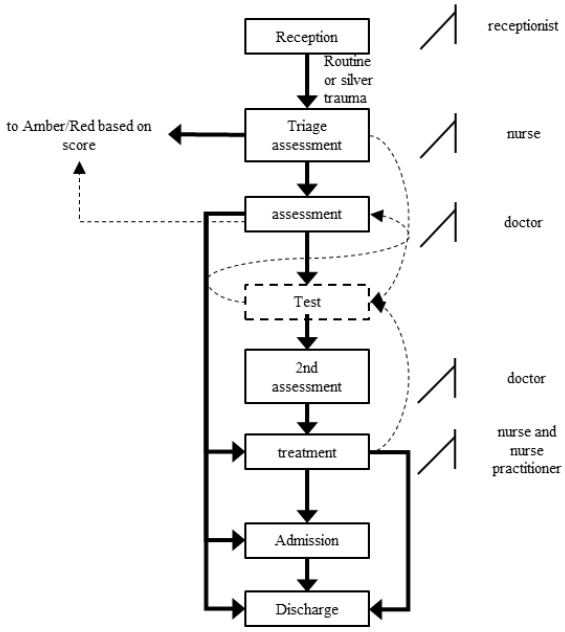

Figure 2. Patient flow in green zone of the CMFT ED department

Thus within CMFT, for example, on arrival in the green zone reception (self-admitting patients) the receptionist agent will collect information from the patient and when this happens the patient agent will be given an *id* and a basic set of details which are then 'attached' to it in the model as attributes. The patient then waits in the waiting area unless they are identified as an emergency. The next stage will be triage and for this a nurse, when available, will examine the patient and record the basic aspects of triage. This information is again attached to the patient but will also be broadcast for other staff to read when appropriate – e.g. when making decisions about who a doctor should see next or during further treatment. The patient flow in green zone is presented in Figure 2. The patient agents go through the flow and interact with staff agents at each process. Depending on the availability of staff and other resources, the performance of green zone is therefore simulated and the model naturally generates outcome based on randomness.

An example of model output is shown in Fig. 3. In this figure, the profile of patient arriving at and discharged from green zone is displayed, where the numbers were counted hourly. As a comparison, the usage of resources, such as reception, triage and cubicles within green zone, are presented. Starting a simulation from 8:30 in the morning, it can be observed that there are more patients present in the daytime. With the patient number increasing, more resources are used for patient registration, triaging, diagnosis and treatments. The model outputs correctly reflect the status of daily running of the department.

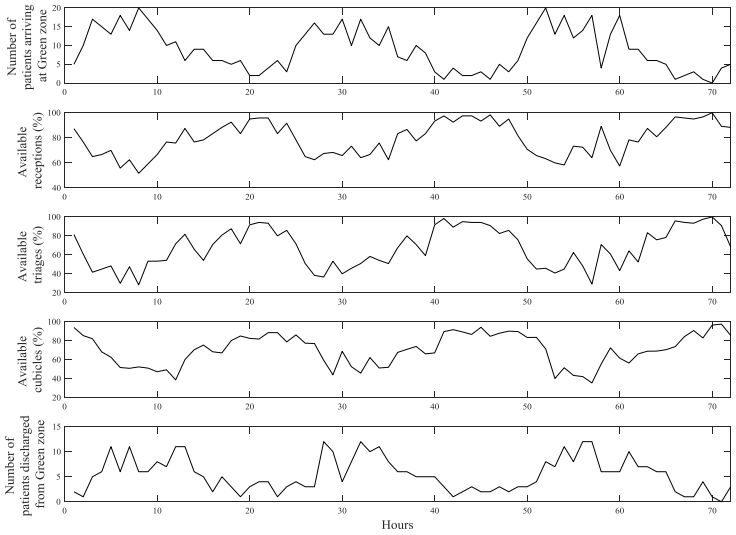

Figure 3. Patient flow in green zone *vs.* usage of resources

2.3 The Decision Support System

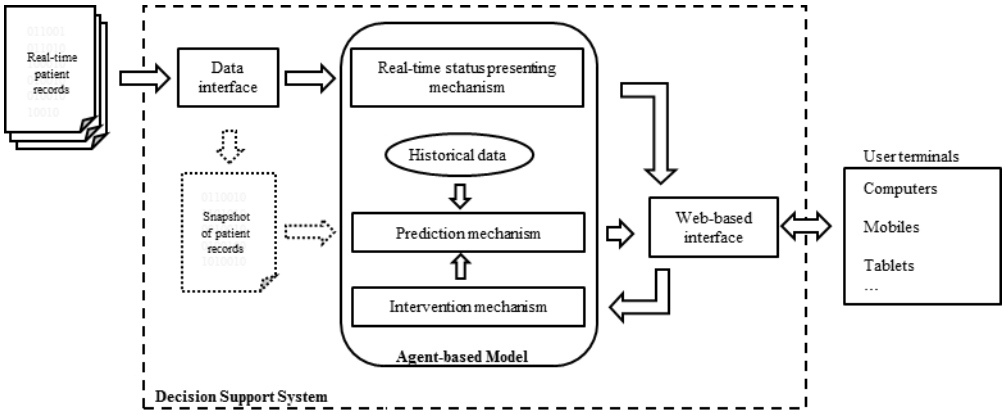

Figure 4. Diagram of ABM-based decision support system

The system model is based upon the detailed set of agent types which have been developed based on both observations at the hospital but also from the use of historical data going back 3 years. The decision support system is composed of a web-based interface and the ABM model running at the back-end. The architecture of proposed system is displayed in Fig. 4. The system could connect with the real-time patient record database for presenting the current status of the whole department. Upon user's request, when a prediction is needed, a snapshot could be generated, and from where a *faster than real time* predictive simulation would be run based on historical data. The predictive results would be provided to user for looking ahead of time. If an intervention is necessary, user would be able to apply the intervention to the model, and re-run the simulation to test its effectiveness.

3. CONCLUSION AND FUTURE WORK

As a state-of-the-art approach, the Agent-based Model captures the complexities of process of patient flow in ED department, and provides the opportunity to monitor the situation and to predict what is likely to happen in the next 4, 12, 24, 48, ... hours. This gives managers and clinicians a foresight view to understand where the blockages are and optimise their management accordingly. Future work will be carried out to collect more information and data from CMFT ED for the purpose of further model testing and validation, which will improve the realism and accuracy of this system. Real-time patient records and staff measurement data will be connected to the model to enable the model to present on-going status of the department and to predict from any chosen scenario.

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