Computer Simulation in Health Care Service: the Emergency Department of CUH

F. Fruggiero\textsuperscript{1}, A. Lambiase\textsuperscript{1}, S. Vitale\textsuperscript{1} and D. Fallon\textsuperscript{2}

Department of Mechanical Engineering
University of Salerno
Fisciano (SA), via Ponte Don Melillo 1, 84084, ITALY

AND

Department of Manufacturing, Biomedical & Facilities Engineering
Cork Institute of Technology (CIT)
Bishopstown, Cork – IRELAND

Abstract

In the health care service is important to minimize staff idle time and patient waiting time maintaining a high utilization rate of medical facilities. Some hospitals have insufficient resources. Many hospitals have inefficient ways to use them. In order to respond to the growing number of incoming patients, hospital departments, including emergency rooms, have to re-evaluate their current facilities, procedures and practices from an operations management perspective. Computer simulation is recognized as a powerful tool, for medical management, to improve productivity while increasing service level to patients.

This paper presents some observations arising from the development of a case study in the public health care system. An optimal layout design and process configuration in the Emergency Department (ED) of the Cork University Hospital (CUH) – Ireland was developed and tested. Through a discrete event simulation model of the ED, bottlenecks were analysed and a new system configuration was proposed. An optimising procedure based on Simulated Annealing (SA) methodology, group technology approach and axiomatic design procedures was employed into layout analysis. The performance of the implemented model was evaluated in terms of mean patient’s waiting time, resource (static and staff) utilization, service level to patients and managerial costs.

KEYWORDS: Health care, Emergency Department (ED), Discrete Event Simulation, Simulated Annealing (SA)

1. INTRODUCTION

Health care management is a serious and impeding problem all over the world. Expenditures are reaching costs and levels that put managers and economists to quest the importance of using powerful methodologies to manage the health system. Engineers, out of the operations (only a medical staff can face with them), can manage the health care system. The implementation of a discrete event simulation model is recognized as a powerful tool whatever it is performing and predicting a study on systems capabilities and flexibility. A constrained optimisation approach have to be performed [Jelinek, et al., 1999; Kyriacou, et al., 1999].

Health Care is a “calling” not a product. Into Emergency Department (ED) facilities a calling can have different priorities in relation to revealed disease level. Traditionally, incoming ED patients are prioritised according to a manchester procedure [MackWay, et al., 2005]. Each priority and its related queue have to be treated following detailed procedures (i.e., a set of treatments from an entry state to whatever output: death or cure status). According to national statistics, the Health-care industry is a vital element of the economy accounting for 7.1% of the Ireland Gross Domestic Product-GDP (8.4% of Italian one). With the aging of the population level (life expectancy in Ireland stood at 78.3 years) and the rising of costs, the situation of health costs has seen the public

\textsuperscript{1} Alfredo Lambiase, Fabio Fruggiero, Saverio Vitale, - University of Salerno, Dpt. Mechanical Engineering- Italy. Tel. +39 089 963473, Fax: +39 089 964037; Email: ffruggiero@unisa.it; lambiale@unisa.it; svitale@hotmail.it

\textsuperscript{2} Daithi Fallon - Department of Manufacturing, Biomedical & Facilities Engineering, Cork Institute of Technology (CIT) –IRELAND; Email: d.fallon@cit.ie
share increase nearly the 75%. Ireland and Italy have almost the same level in terms of health spending per capita, with $2500. This amount is dwarfed in comparison with medical services offered to patients. The average of 3 care hospital beds per 1,000 population means there is the high possibility for Italian and Irish patients to request resource that are still busy. Simulation can be used to test system’s behaviour and to study different configurations anticipating the potential performance of a system. [Fetter, et al., 1965; Austin, et al., 1995]. A tool, which integrates process simulation modelling and optimal scheduling procedure and layout consideration, has given benefits in the optimisation of a real ED (Fig 1). The environment of this approach is the Cork University Hospital-CUH, the main hospital site of Cork - IRELAND.

![Fig. 1: The proposed framework in ED of CUH](image)

2. The Emergency Department (ED) of CUH

The care of patients and quality of services is the main objective of the health system. ED performance concerns with resource amount and allocation, process standardization, patient’s classification and prioritisation, patient’s waiting and throughput time, queuing disciplines. ED employees were interviewed to get the overall picture of functions and problems. Numerical data of historical patient arrival were analysed. In ED “rules” the patient highest priority is assigned to critical arrival (care type = 1-2-3). A resuscitation room should always be available for priority 1 patient’s arrival. The patient’s condition is assessed by a triage nurse (an experienced nurse), who determines the priority level of the scheduling policy basing on patient’s vital signs as well as symptoms. Patients with a non-life threatening condition (care type = 4 and 5) go through standard queue procedures and, eventually, waiting room stay. Cubicles in Major and Minor area are equipped for treatments.

The ED of CUH has 12 primary treatment rooms for major patients (65% of arrival). Patients can arrive to the facility by ambulance (26%) or by car (74%). Different paths and entrances are associated to the way the patient’s coming. There is a direct correlation between ambulance arrival and high pain level (i.e., level ≤ 3 ⇒ 99% ambulance arrival). Static (i.e., treatment areas) and running resources (i.e., hospital’s staff) and patients are the entities into system. The ED has two
observations wards. A registration desk (with 2 hospital’s clerk during the day, one otherwise), a waiting room, a triage room (with a nurse manager), 4 beds for minor treatments (the 33% of arrivals are categorized as minor), 4 resuscitation rooms (1.5% of incoming patients need its facilities) and separate stations for the unit secretary, nurses, nurses aides and physicians complete the layout. An area for paediatric cure is assigned to child treatments (13% of arrivals). The nurse staff (13 units) assumes recumbent patients to be prevailing (porters are delegated for transport tasks). Each shift is staffed with 2 porters and 6 practical nurses. Moreover, 4-5 physicians in training (i.e., SHO), 2 registrars and 1 technician are on the emergency duty. Specialists can give a consultative support. The specialist can order tests. There are, in detail, two types of test ordered within the ED: lab and X-Ray (includes CAT). X-Ray technicians are eventually committed. Analyses revealed that the recumbent patients (64%) dominate the ambulatory patients in the patient population. According to the output of the simulation model, the number of bed care unit is able to cover only the 48% of the cumulative daily demand distribution. The flow charts, into ED paths, can be different in relation to the disease level. It has recognized 50 different paths in relation to the same number of danger list (limb problems represents the 38% of diseases). The arrival rate can be fixed in a patient every 11 minutes. Particular trends have been evaluated: growth of arrival during the bank holidays (an increment of 15%) was noticed. Daily and monthly trends have been implemented into the discrete event simulation model. The main flow chart evolves according to fixed rule. After a registration task and a triage visit, the patient waits for treatment and for an available resource (according to its level). When a patient is called to bed, he/she is seen by a nurse and/or by a doctor (mainly SHO) and receives adequate treatments. The SHO is super-visioned by the registrar doctor. Patients coming through ED are treated in different units. After treatments, they are discharged (26%) or left ED for other hospital/clinics (23%), or admitted to one of the units (39%). Death (0.2%) and other cases occasionally occur (4% decide to escape from hospital because of long waiting time for first visit).

2.1. The Facility Layout Design across a Simulated Annealing approach

The layout of ED in CUH was investigated in order to improve system’s performance. Increase of unit care and improvement in patient’s waiting time for treatment are the close consequences of a new layout assessment. Flows, distances and zoning constraints were taken into consideration. A heuristic strategy, with robust design considerations, was implemented. The Quadratic Assignment Problem (QAP) [Koopman, et al., 1957] represents the implemented mathematical formulation for the location of a set of treatments room. An Axiomatic Design procedure (mapping Functional Requirement \(\{FRs\}\) and Design Parameters \(\{DPs\}\) across the definition of a suitable Design Matrix \(\{DM\}\) helped to define the problem in the correct way [Suh 2001]. Cubicles, minors and majors, paediatric treatment room, X-Ray and plaster room, intensive care units were switched, in location, considering flow paths and zoning constraints. A tabu list forbade the assignment to a particular location (e.g., the location of resuscitation close to ambulance’s entrance). Mathematically the problem is the allocation of a set of facilities to a set of locations. A fitness function related to distance, flow and user’s defined penalty value lead the assignment process (Eq. 1).

$$\min_{\Phi \in S_n} \sum_{i,j=1}^{n} f_{ij} d_{\Phi(i)\Phi(j)} + \sum_{i=1}^{n} b_{\Phi(i)}$$

Where \(S_n\) is the set of permutations \(\Phi: N \rightarrow N\); \(f_{ij}\) represents the flow from facility \(i\) to facility \(j\); \(d_{kl}\) is the distance between location \(k\) and location \(l\); \(b_k\) is the cost (i.e., a function of assignment relevance according to expert analysis) of placing facility \(i\) in location \(k\).

A Simulated Annealing (SA) procedure [Metropolis, et al., 1953; Kirkpatrick, et al., 1983] was implemented. Starting from an initial state, a perturbation to a new state in the neighbourhood is performed. Each state is associated to a particular energy level in the objective function. The
solution is accepted if $\Delta E < 0$. If $\Delta E > 0$ the transformation is accepted with probability $p(\Delta E) = \exp(-\Delta E/(k_bT))$ where $T$ represents the control parameter and $k_b$ the Boltzmann’s constant. This mechanism is able to guarantee the acceptance of small changes with a little growth of the objective function (Eq.1). The output of such an approach is the definition of emergency close areas. Which are the areas of the ED that can be shifted to reduce Length of Stay (LOS), to overcome bottlenecks and to increase efficiency? Paediatric area and its waiting hall can be displaced into layout if there is the necessity to have more cubicles for major area.

2.2. The discrete event simulation approach
A simulation model is able to depict the flow of patients, the resources’ utilization evaluating the “way” and “time” the patients are treated. The ED can be modelled as a “complex” Job Shop environment. The type of simulation employed was “discrete event simulation”. A visual interface helped to present the model and to discuss the behaviour with medical staff. A realistic way of patient waiting for treatment was portrayed. Flow charts, for different level of disease, have been implemented. Each of the admitted patients has a Length of Wait (LOW) according to snarl of ED. Different LOWs and dispatching rules were modelled for every triage level. The data pertaining to patients, and their triage level, were obtained from the order entry system of the hospital information system. An appropriate distribution, that most closely represents the empirical arrival distribution, was chosen to depict the arrival rate during the day. A Poisson function modelled the daily patient’s arrival. The pick of arrival is near the 9a.m. Differentiations into months and categories were done (the day hours are at least three times busier than the night hours). Different rules were applied into simulation in order to discriminate which patient is admitted firstly into the treatment area. The treatments are managed across FIFO rule. Each category has its own queue list. Running resources are submitted to a calling procedure. The first resource available, according to rota and competencies, was put in action. Moreover, the scheduling procedure interacts with running resource availability. Treatment’s time was evaluated across simple fuzzy rules [Zadeh 1965]. It is decided to use simple triangular membership functions according to hospital staff suggestions. The intent is to assign the processing time according to modal values. The simulation was able to depict the recumbent patients that need bed during their stay, the space utilization, the number of beds transportations and the demand of different specialties. The system was investigated in terms of efficiency and costs, resource (static and running) utilization rate, service level to patients (i.e., waiting time). Resource efficiency (i.e., how well resources are used- $Re$), utilization rate (i.e., how much the potential capacity is used- $Ur$) were investigated.

\[ Re = \frac{\text{OUT}}{R_i} \quad 2 \quad Ur = \frac{T_i}{T_f} \]

Where OUT is the number of patients that are treated by the resource $R_i$; $T_f$ is resource’s theoretical maximum capacity (24h) and $T_i$ is resource real occupancy time. $Re$ gives information on ED efficiency (how many patients are treated and how many patients receive treatment compared with how many patients are waiting for treatment); $Ur$ depicts the saturation rate of a resource.

State charts are able to update and visualize, dynamically, the performance of resources. Rota joins with the simulation model. SHO staff and major cubicles availability are responsible for unsuited LOS. It is going to provide how is possible to review efficiently the scheduling of treatments and the number and efficiency of resources. It has been decided to re-evaluate the scheduling policy according to predictable trends in patient’s arrival. The result implies a need for reallocation physician staff according to pick of arrival. Employees have been assigned from the night to day shift. Has been tested solution with extra work hour and with the introduction of a new professional nurse. The mayor treatment area can be considered the bottleneck of the system. The triage level 3 has been tailed in over the 55% of arrival. A better triage policy could help to assign to bottleneck
(i.e., mayor treatment area) only patients who really needs mayor treatments. A senior doctor, with great experience, could support triage examinations. After ten simulations, the gamma distribution was found to fit best the empirical LOS (which probability density function has 344.28 min of mean and 13.07 min of variance). Changes in the staffing structure could increase the utilization rate of medical facilities. Nurses and SHOs can set into standby mode to face the day picks and night shift. They can be called if needed. The shift’s change, the increment of resources of the same type, a balancing policy, a re-scheduling of tasks (i.e., treatments), a better layout assessment trying to overcome bottlenecks, have been tested in order to explain a full optimised solution.

2.3 An optimal ED assessment
According with statistical data analysis, results of the facility layout design and output of the simulation model improvements are going to prospect. To avoid prolonged LOS more cubicles for treatments are needed for major patients. Investigating the optimal assignment of specific departments, the monthly total distance travelled by patients, due to connection between areas, has been investigated.

The procedure began searching for improvements by swapping pairs of assignments according with Eq.1. A close relation between resuscitation area and ambulance entrance need to be preserved. The implemented SA approach pointed out the possibility to translate paediatric area to another location. The output joins with rise in mayor’s cubicles (from 12 to 16 units). Improvements in space usage can help to increase the satisfaction level in medical facilities and cut of LOS (to mean LOS 237.6 min).

![Patient Mean throughput time](image)

**Fig. 2:** A discrete event simulation model in ED of CUH; a. Patient’s mean throughput time into the ED; b. Performance and improvements (form initial configuration) in different configurations.

The utilization rate of running resources is mostly remarkable unbalanced. A new scheduling could be adopted in SHO rota who represents the most saturated resource (over 80%). A chase approach has been adopted levelling number of SHOs to the arrival picks. The daily Gantt needs to be modified. There are hours of the day (i.e., 8am-9am and 2pm-3pm and 9pm-10pm) when two SHOs
are needed. Occasionally one-hour overtime could take up extra patient arrival. Moreover, the high LOS for patient into plaster and suture room suggested the introduction of a new professional figure, e.g. a professional nurse, able to treat those patients. A little growth in cost, comparable to 0.7% of global hospital balance, will be the fee to pay for new configuration. These considerations have shown considerable advantages in ED performances (Fig. 2).

3. Conclusions and future trends
The implementation of a discrete event simulation model of ED has given the possibility to test alternative layouts and resources configuration. Patients waiting time and resources utilization has been portrayed. A care graphic expression showed running ED behaviour. The flexibility of the system to epidemic conditions was tested. Improvement into scheduling activity has been realized. A cost-benefit analysis, in different configurations, was tested. Patient’s situation in LOW and LOS was improved. Managerial and patient points of view were merged in order to find the best suitable configuration. Constraints ranged the considerations about the facility layout assessment. The approach and study have yielded results that could save the hospital considerable time as well as are helping to characterize tremendous costs and inefficiencies. Actually, a dynamic scheduling of physicians and hospital workers are implementing. An integration of balancing theories between inter and intra resources assessment, an automatic-real time scheduling approach, a changeable planning of activities is going to perform.

4. References