Tenth International Conference on Computer Modeling and Simulation

Using Discrete Event Simulation (DES) to Manage Theatre Operations in Healthcare: An Audit-based Case Study

Alexander Komashie
Brunel University, School of Engineering and Design, London, UB8 3PH, UK
Alexander.Komashie@brunel.ac.uk

Ali Mousavi
Brunel University, School of Engineering and Design, London, UB8 3PH, UK
Ali.Mousavi@brunel.ac.uk

Justin Gore
North West London Hospitals NHS Trust (R&D), London, HA1 3UJ, UK
Justin.Gore@nwlh.nhs.uk

Abstract

This paper discusses the application of Discrete Event Simulation (DES) in modelling the complex relationship between patient types, case-mix and operating theatre allocation in a large National Health Service (NHS) Trust in London. The simulation model that was constructed described the main features of nine theatres, focusing on operational processes and patient throughput times. The model was used to test three scenarios of case-mix and to demonstrate the potential of using simulation modelling as a cost effective method for understanding the issues of healthcare operations management and the role of simulation techniques in problem solving. The results indicated that removing all day cases will reduce patient throughput by 23.3% and the utilization of the orthopaedic theatre in particular by 6.5%. This represents a case example of how DES can be used by healthcare managers to inform decision making.

1. Introduction

The application of Discrete Event Simulation (DES) modelling techniques for studying healthcare systems is a relatively new but rapidly growing field of research and service improvement. The value of the application of industrial techniques for improving healthcare systems is extensively debated [12]. However, DES in particular has seen an increase in application covering almost all areas of healthcare in the past decade [13]. DES has been used in Emergency Departments (ED) for modelling operations and for the analysis of patient flows and throughput time [11], [3], [5], [7], and [6]. Others have used DES to forecast future capacity requirements and expansion of new or existing ED facilities [8], [9]. To utilize the flexibility of DES, researchers have integrated simulation with other techniques like Integer Linear Programming (ILP), Six Sigma etc for specific applications [4], [10]. This has led to better management of operations where the pressures for operational efficiency under ever increasing system constraints as in healthcare prevail.

This paper discusses an application of DES for auditing and managing theatre operations within an NHS hospital in London, UK. The Trust is committed to providing the highest level of service that resources allow, and medical staff and managers have various views on how the current level of service could be maximized. Due to the complexity of theatre operations, it is normally difficult to justify such views or approaches to problem solving exclusively in anecdotal terms. Therefore, an evidence based approach is required for quantifying the potential impact on patient care and minimising the need and cost of testing out different initiatives for improvement on the real system.

The aim of this project was to use DES in a hospital setting to predict and understand the impact of various case-mix scenarios on patient throughput and utilization of theatres. The methodology employed is outlined in section 2, while section 3 highlights the description of the theatre operations which was used to build the model. The schedules for the theatres are given in section 4 and section 5 explains the patient pathways on which the model's logic was based. Section 6 summarises the load distribution for the theatres and describes the methods of patient classification used. In section 7, the technical approach to the modelling process is presented. Model validation is presented in section 8. Section 9 deals with experimental results and finally discussions and conclusions are presented in section 10.

This paper is not an assessment of performance at the hospital, but a case example of using DES to inform decision making in healthcare.

978-0-7695-3114-4/08 $25.00 © 2008 IEEE
DOI 10.1109/UKSIM.2008.112

2. Methodology

The structure of the simulation model that was developed is based on patient flow through nine theatres. It was necessary to commence with an accurate description of the operations of the theatres to provide a current picture of activity that would be used in the model. This was achieved by conducting a service audit, involving routine activity data analysis and discussions with managers. Throughput was assessed, various activities and waiting areas defined, and different routes (pathways) that patients may take during a visit identified. DES was then applied, as described in the proceeding sections.

3. Operation of the theatres

Most of the nine theatres at the Trust site were dedicated:

- ✓ Theatre 1 – Ear, Nose and Throat (ENT)
- ✓ Theatre 2 – Urology
- ✓ Theatre 3 – General Surgery
- ✓ Theatre 4 – Elective Orthopaedic
- ✓ Theatre 5 – Colorectal
- ✓ Theatre 6 – Gynaecology
- ✓ Theatre 7 – Monday: Other Unit; Tuesday: Community Dental etc
- ✓ Theatre 8 – Vascular
- ✓ Theatre 9 – Orthopaedic Trauma

The theatres are served by one transfer control area and one recovery unit. Each theatre however has a dedicated anaesthetics room.

4. Theatre schedules

The theatres are scheduled to operate in one of the following modes:

- ✓ Morning list (8:30 to 12:30)
- ✓ Afternoon list (1:30pm to 5:30pm)
- ✓ All day list (8:30 to 5pm)
- ✓ Private ops (Theatre 7 on Wednesdays.)
- ✓ Reserved for another unit (Theatre 7 on Mondays.)
- ✓ Comm. Dental ops (Theatre 7 on Tuesdays.)
- ✓ Idle

The current model only considers NHS patients; hence theatre 7 is modelled as not being available on Mondays, Tuesdays and Wednesdays. Regular operations of the theatres take place from Monday to Friday 8:30 to 17:30 even though emergency cases are treated outside these hours.

The simulation model was constructed to reproduce the various paths that patients can take in the theatres. This was done in consultation with staff of the department who have expert knowledge of its operations and through analysis of theatre activity data. The three important elements of this model are the patients, theatres (resources) and the process paths.

5. Patient pathways

There are four main streams of patients that flow through the theatres. These are identified by the NHS Standard Codes termed Intended Management. These are reduced to three in this study because one category constitutes less than 1% of total cases. More appropriate classifications of patients termed 'short stay' and 'inpatients' are presented below.

6. Theatre load distribution and patient categories

The theatre load distribution was analysed from the theatre data in order to decide how to distribute entities (patients) into various theatres. This analysis showed that theatre 1 processes the highest value of 25.94% of patients whilst theatre 7 has the least load of 1.20% of total cases.

Four main categories of patients are distinguished based on their intended management codes. These are:

a. Day care
b. Short stay
c. Inpatients
d. Emergency (have highest priority)

For the purposes of this project, another form of patient classification was introduced based on the duration of operation. This produced the patient classes named Minor, Major or Major +, Intermediate, Complex Major. The detail of this classification is excluded from the volume of this paper.

7. Technical approach

This simulation work was accomplished using the Arena simulation software from Rockwell Automation. The model comprises all activities between when a patient leaves the ward to theatres and when he or she returns to the ward after recovery. It however does not include the details of any activities that take place within the wards.

This section briefly describes the various parts of the department that have been included in the model.

7.1 Transfer control room

This is the first point of call for all patients except day cases. Activities that take place here include:

- ✓ Patient waiting to be seen by staff
- ✓ Staff checking patient is fit for operation
- ✓ Patient waiting to be picked up by anaesthetist

The time spent in this area may vary from about 10min to 25min. The model input therefore was chosen to be a Triangular distribution of parameters 10, 15, 25.

7.2 Anaesthetics room

From transfer control, patients are sent to the anaesthetics room of the corresponding theatre. Activities that take place here depend on the kind of anaesthetics required and include:

- ✓ Connecting patient to monitors
- ✓ Anaesthetizing patient
- ✓ Transferring patient into theatre
- ✓ And usually at least one anaesthetist to maintain anaesthesia during operation

The time it takes to do all these depends on the type of anaesthesia required for the operation. By analyzing the theatre activity data on duration of this process, a histogram was obtained and the distribution that best described the histogram was a normal distribution with a mean of 20.1 minutes and a standard deviation of 12.3 minutes.

7.3 Theatres

The theatre process normally involves:

- ✓ Setting up
- ✓ Actual operation
- ✓ Clean-up
- ✓ Preparing for next operation

Patients are normally sent for towards the end of an existing operation. As a result, the next patient will normally be in the anaesthetics room whilst the theatre is being set up after the last operation.

In this model, the duration of the theatre process was identified from the theatre data and analysed. The analysis was carried out based on the patient classifications. Thus for example, for minor patients, the data revealed a triangular distribution with parameters 0, 10.5 and 29.5.

7.4 Recovery room

This area marks the end of the theatre process as described in this modelling project. From this area, patients go either to the ward, short stay area or day care unit. The following are the procedures that are normally carried out:

- ✓ Airways management
- ✓ Patient retention (selected patients only)
- ✓ Wait for ward nurse and porter

Patients spend about 30 to 108minutes in this area. The model was therefore based on a Triangular distribution with parameters 30, 90, 108.

7.5 Model output

The performance measures of interest in the system are displayed during the simulation run. These are also written to data files at the end of the simulation run for further analysis.

The evidence presented in this paper is based mainly on activity data (July-Nov 2005) provided by the Information Department of the hospital. However, not all data or data interpretation (e.g. appropriate coding), were available and therefore we had to sometimes rely on opinions of the clinicians/managers (e.g. classifying operations into ‘minor’, ‘intermediate’, ‘major’). This work was not designed to produce final models of performance for implementation, but provide guidance to clinicians and managers on decision making. Data items used as input to the model include the following: Physical system layout, Resources (Theatres) data and Entities (patients) data. The following subsection explains the modelling of the arrival processes.

7.6 Arrival patterns and schedule

From the theatre data, the daily arrival pattern was obtained (figure 1). It would be observed that although arrival patterns for the days of the week look somewhat similar, specific values on different days vary quite significantly. For this reason it was considered more accurate to model the arrivals on a schedule which has not been described in this paper, rather than use statistical distributions.

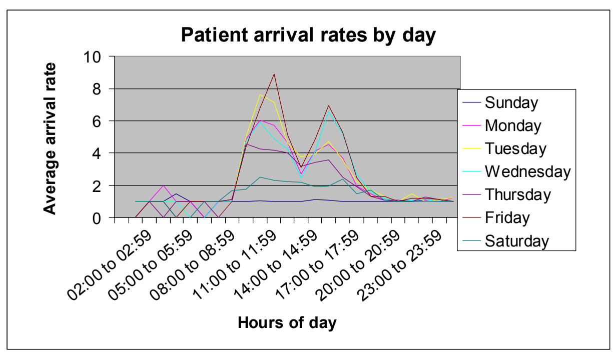

Figure 1. Daily patient arrival patterns

8. Model validation

In order to validate the model, its output was compared with some of the actual theatre activity data. This comparison shows that the model represents the real system considerably well. The validation was based on values of total throughput and throughput of individual theatres as shown in fig. 2 below.

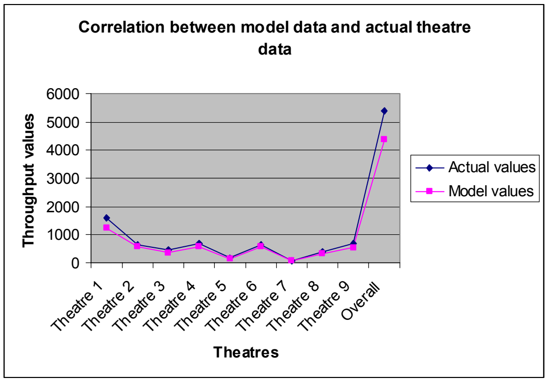

Figure 2. Plot of correlation between model and actual throughput values

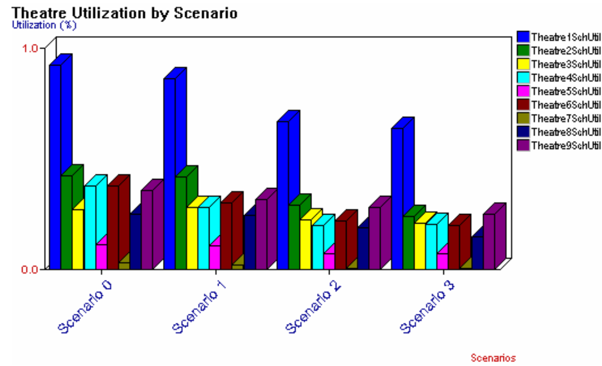

Figure 3. Theatre utilisation by scenario

9. Experimental results

The experiments carried out on the model were aimed at the key performance measures of the system. The next section discusses run conditions for the model and then the results for the experiments conducted are presented in the following section.

9.1 Model run conditions

The theatre department operates mainly by the schedule presented in section 4. However, there is always an emergency list available at all times. The model was therefore developed to run 24 hours a day, 7 days a week but with the theatres scheduled mainly within the regular times. After a number of tests, it was concluded to run the model for 152 days and 10 replications.

9.2 Scenarios and results

In all the charts and tables used in this section, scenarios 0 through 3 are defined below.

- ✓ SCENARIO 0 – System as it is now (As Is Scenario)
- ✓ SCENARIO 1 – Assuming no day cases through theatres
- ✓ SCENARIO 2 – Assuming no day cases and only 20% of short stay cases
- ✓ SCENARIO 3 – Assuming no day cases and no short stay patients

9.2.1 Utilizations. Fig. 3 shows the chart of the theatre utilizations as they varied over the various scenarios. It will be observed that theatre 1 has the highest utilization for all the scenarios. This is entirely consistent with the discussion under theatre load distribution above where theatre 1 was observed to have the highest load amongst all the theatres. Table 1 shows the comparison of the utilizations between scenarios 0 and 1 for all theatres.

Table 1. Comparison of utilisation for scenario 0 and 1

Theatre	Scenario 0 (%)	Scenario 1 (%)	% Change
Theatre 1	92	86	-6.5
Theatre 2	43	42	-2.3
Theatre 3	27	28	+3.7
Theatre 4	38	28	-26.3
Theatre 5	11	11	0
Theatre 6	38	30	-21.1
Theatre 7	3	2	-33.3
Theatre 8	25	24	-4
Theatre 9	36	32	-11.1

9.2.2 Analysis of utilization results. Figure 4 shows the Box-and-Whisker plots of the scheduled utilizations for theatre 1 over the different scenarios. According to Govaerts et al. [1], Box-and-Whisker plots give a graphic view as accurate as possible of a population that does not necessarily have a normal distribution. In this case there is no assumption of normality that may flaw analysis if the data were not normally distributed. The parameters for the plots in fig. 4 have been omitted from the volume of this paper. The extreme minimum value is zero (0) for all scenarios since utilization cannot be less than zero. The other parameters vary according to the scenarios.

Boyer et al. [2] used Box-and-Whisker plots with notches in the boxes that represent the 95% CI of the median. They concluded that when the notches between boxes do not overlap, the medians may be considered significantly different. By similar argument and observation of the plots from the various scenarios as shown, we conclude that there may not be a significant difference between scenario 0 (current operation level of the theatres) and scenario 1 (no day cases at site under investigation). On the other hand, it can be seen that the utilizations of the other two scenarios 2 and 3 are significantly different from that of scenario 0. This means that removing all day cases from the present site plus 80% of short stay patients (scenario 2) or removing all of both day cases and short stay patients (scenario 3) will cause a significant reduction in the utilization of the theatres. Note that in this analysis, results of theatre 1 have been used but a similar procedure could be carried out for each of the theatres.

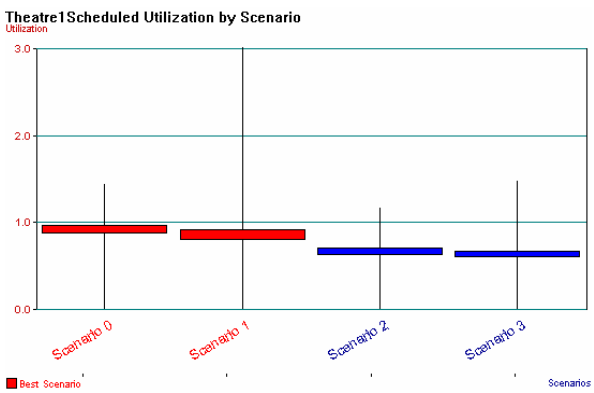

Figure 4. Box and Whisker plot for theatre 1 utilization by scenario

9.2.3 Patient throughputs. It is found that by removing all day cases from the present site (scenario 1), the total throughput of patients reduces by 23.3%. The corresponding reduction in theatre utilization for this scenario is given in table 1. Theatre 1 is seen to have its utilization reduced by 6.5% to 86% which is still considerably high. The worst case of 33.3% reduction occurred in theatre 7, which already takes only a minimal load as mentioned in section 4.

9.2.4 Analysis of throughput results. By conducting similar analysis to that presented under 'analysis of utilization results', it is observed that there are significant differences between the results of the various scenarios. These results are discussed in the next section.

10. Discussion and conclusions

In the final analysis, it can be said that the general impact of all the scenarios tested has been a reduction in both theatre utilization and patient throughput. This impact is seen to be greatest when both day cases and short stay patients are taken out of the site under investigation (scenario 3).

Utilization is an indicator of how well available resources are used. Throughput on the other hand refers to the amount of work that has been through the system in a period of time. In any given system, it is desirable to maintain these two performance measures at a reasonably high level so as to economically justify the existence of the system and to be able to survive in an increasingly competitive environment. In this project, service managers were interested in finding the best scenario of case-mix without unduly affecting the level of utilization and throughput. DES was used as an evidence-based approach in this endeavour. The validated model still remains a platform for further investigation if necessary. Since this is a systems approach to problem solving, and further data can be inputted, managers can make decisions while taking into account other aspects of the system e.g. patient outcomes.

The impact of not having day cases (scenario 1), on theatre 1 for example, was a reduction of 6.5% in its utilization from 92% to 86%. This is not very significant in view of the fact that it remains at a considerably high utilization. On the other hand, this also caused a reduction in the utilization of the other theatres. This does not seem a very high impact, however, probably because it has been found that there are not many day cases that go through the theatres. It turns out that almost all the theatres have considerably less day care patients than short stay or inpatients.

It is evident that none of the scenarios tested improves utilization or patient throughput beyond the original values of scenario 0. Implementing any option may have to depend on the reason for which the decision needs to be made which is outside the scope of this model. The argument presented in this paper, however, is that it is important to understand (in measurable terms) the likely impact of all alternative decisions (scenarios) so that managers can make informed predictions and decisions. Other methods, such as spreadsheet data analysis etc, are unable to capture the dynamics of the system as effectively as DES. This model clearly shows, in quantifiable terms, the degree of impact each scenario may have on the chosen performance measures (theatre utilization and patient throughput). In this regard, scenario 1 (no day cases) may be a preferred option since it has the least impact on the performance measures. Finally, having validated the model, it is possible to experiment with further combinations of case-mix as may be necessary.

It should be noted that this model did not take into account other variables such as the interest a consultant may have in undertaking a minor case or a major case. This is because the model did not focus on manpower or working patterns at this phase. These issues may be important if scenario 1 means there will be only major cases to deal with. From the data available, it seems that there are a certain amount of minor cases amongst short stay patients, inpatients and even emergency patients.

Some lessons learnt from this project include the notion that DES can be used to model and predict the operations of operating theatres in healthcare, as long as a picture of current activity is developed as accurately and thoroughly as possible and used as the basis of the model. It was also learnt that, though the impact of patient case-mix may seem obvious, DES is a better option for problem solving and understanding since it is able to *quantify* the impact of the scenario, taking into account the dynamics of system behaviour. This suggests that DES is a useful and reliable tool enabling service managers and clinicians to make decisions with greater confidence.

Acknowledgments

We would like to thank Miss Sophie Renton, Consultant General Surgeon, for her invaluable input and all the managers and clinicians who provided direction throughout the audit project.

References

[1] P. J. Govaerts, T. Somers, F. E. Offeciers, "Box and whisker plots for graphic presentation of audiometric results of conductive hearing loss treatment", *Otolaryngology Head Neck Surgery,* vol. 118(6) pp. 892-895, 1998.

[2] J. N. Boyer, P. Sterling, R. D. Jones, "Maximizing information from a water quality monitoring network through visualization techniques", *Estuarine, Coastal and Shelf Science* vol. 50, pp. 39-48, 2000.

[3] E. R. Blasak, W. D. Starks, S. W. Armel, and C. M. Hayduk, "The use of simulation to evaluate hospital operations between the emergency department and a medical telemetry unit", *In Proc. 2003 Winter Simulation Conference,* S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice (eds), pp. 1887-1893, 2003.

[4] M. A. Centeno, R. Giachetti, R. Linn, and M. A. Ismail, "A simulation-ILP based tool for scheduling ER staff", *In Proc. 2003 Winter Simulation Conference,* S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice (eds), pp. 1930-1938, 2003.

[5] S. Samaha, S. W. Armel, and W. D. Starks, "The use of simulation to reduce the length of stay in an emergency department", *In Proc. 2003 Winter Simulation Conference*, S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice (eds), pp. 1907-1911, 2003.

[6] S. Takakuwa, and H. Shiozaki, "Functional analysis for operating emergency department of a general hospital", *In Proc. 2004 Winter Simulation Conference,* R. G. Ingalls, M. D. Rossetti, J. S. Smith, and B. A. Peters (eds), pp. 2003-2011, 2004.

[7] S. Mahapatra, C. P. Koelling, L. Patvivatsiri, B. Fraticelli, D. Eitel, and L. Grove, "Pairing emergency severity index5-level triage data with computer aided system design to improve emergency department access and throughput", *In Proc. 2003 Winter Simulation Conference*, S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice (eds), pp. 1917-1925, 2003.

[8] F. F. Baesler, E. H. Jahnsen, and M. Da Costa, "The use of simulation and design of experiments for estimating maximum capacity in an emergency room", *In Proc. 2003 Winter Simulation Conference,* S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice (eds), pp. 1903-1906, 2003.

[9] A. Wiinamaki, and R. Dronzek, "Using simulation in the architectural concept phase of an emergency department design", *In Proc. 2003 Winter Simulation Conference,* S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice (eds), pp. 1912-1916, 2003.

[10] J. M. Miller, and M. D. Ferrin, "Simulating six sigma improvement ideas for a hospital emergency department", *In Proc. 2003 Winter Simulation Conference*, S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice (eds), pp. 1926-1929, 2003.

[11] A. Komashie, and A. Mousavi, "Modelling emergency departments using discrete event simulation techniques", *In Proc. 2005 Winter Simulation Conference,* Kuhl, M. E., Steinger, N. M., Armstrong, F. B., and Joines, J. A., (eds.), pp. 2681-2685, 2005.

[12] T. Young, S. Brailsford, C. Connell, R. Davies, P. Harper, and J. H. Klein, "Using industrial processes to improve patient care", *BMJ* Vol. 328, pp.162-164, 2004

[13] S. C. Brailsford, "Tutorial: Advances and challenges in healthcare simulation modeling", *In Proc. 2007 Winter Simulation Conference,* S. G. Henderson, B. Biller, M.-H. Hsieh, J. Shortle, J. D. Tew, and R. R. Barton, (eds.), pp. 1436-1448, 2007.