Simulation for emergency care process reengineering in hospitals

Sung J. Shim
Stillman School of Business, Seton Hall University, South Orange, New Jersey, USA, and

Arun Kumar
School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Melbourne, Australia

Abstract
Purpose – Using computer simulation, this paper seeks to model the emergency care process in a hospital and evaluate the effects of some proposed changes to improve patient wait times in the process.
Design/methodology/approach – The paper is based upon a case study conducted at the hospital and uses historical data provided by the hospital to simulate the emergency care process.
Findings – The simulation results demonstrate that the changes proposed can shorten patient wait times in the emergency care process. The proposed changes involve adding another payment station and a new short-stay ward in the process. Based upon the results, the paper supports the implementation of the changes proposed.
Research limitations/implications – A couple of limitations are recognized in this paper. First, the simulation does not consider varying the capacity of resources and locations involved in the emergency care process. Second, the simulation does not consider patients by clinical disciplines in which they are treated.
Practical implications – The simulation results show that computer simulation can be an effective decision support tool in modelling the emergency care process and evaluating the effects of changes in the process. The results would be helpful to those who are considering reengineering and improving emergency care or other similar processes in hospitals.
Originality/value – Based upon a case study using real-world data, this paper extends the line of studies on computer simulation in healthcare by considering not only patient wait times in the emergency care process but also some ways to improve patient wait times and their effects on the process.

Keywords Business process re-engineering, Simulation, Health services, Hospitals, Modelling

Paper type Research paper

Introduction
Organizations reengineer their business processes to contain costs, improve efficiency, and stay competitive in the marketplace. With escalating healthcare costs, hospitals also seek ways to contain costs and provide quality healthcare services. Hospitals have traditionally emphasized breakthroughs in healthcare procedures and technology to stay competitive. As competition among hospitals continues to intensify, however, patients may perceive little difference in healthcare procedures and technology used by different hospitals. Consequently, hospitals come to understand that process reengineering could be a better solution to achieve competitive advantage. Just as many businesses successfully
reduce costs and gain competitive advantage by reengineering their business processes, hospitals can reengineer the way certain healthcare processes are carried out to achieve efficiency and cost containment. Computer simulation, which has proven successful in improving various business processes, can also be an effective tool in searching for more efficient processes in hospitals.

This paper describes a case study undertaken at Tan Tock Seng Hospital in Singapore (referred to as “the Hospital” hereafter for brevity). The Hospital management considers implementing some changes to improve patient wait times in the emergency care process. Using computer simulation, the study models the emergency care process and assesses patient wait times in the process. Then, it evaluates the effects of the changes considered by the Hospital management on patient wait times in the process. Given the paucity of studies on the methods and techniques for emergency care process reengineering in hospitals, the results of the study will prove helpful to those considering reengineering and improving emergency care or other similar processes in hospitals.

**Computer simulation in healthcare**

Computer simulation involves modelling processes. These models enable analysts to study how a system reacts to conditions that are not easily or safely applied in a real-world situation and how the working of an entire system can be altered by changing individual parts of the system (Proctor, 1996). The real power of simulation is fully realized when it is used to study complex systems (Kelton et al., 1998). Healthcare is a dynamic system with complex interactions among various components and processes. Furthermore, healthcare management operates in an environment of aggressive pricing, tough competition, demanding patients, and rapidly changing guidelines. To meet these challenges, healthcare management must respond quickly to identify critical system processes, recognize all relevant resources, access real-time information, and analyze “what if” cases (Stepanovich and Uhrig, 1999).

While there are many applications of computer simulation to healthcare management and operations, we may classify these into two groups:

1. applications to healthcare systems at various levels of communities, regions, or the nation; and
2. applications to specific operations, processes or services in healthcare institutions.

The first group includes applications intended to study the provisions of mental health, public health, health reform, or healthcare workforce, often with policy implications. For example, Anderson et al. (2002), Jacobson and Sewell (2002), Levy et al. (2002), Rauner (2002) and Zaric (2002) illustrate the use of simulation for various health policy analyses. The second group, which is relevant to the case study of this paper, includes applications intended to improve facility design, staffing, and scheduling and to reduce patient wait times and operating costs (Anderson, 2002).

It is worth noting that many applications of computer simulation to specific healthcare processes assess patient wait times. Everett (2002) describes a simulation model that provides a means for a central bureau to schedule the flow of elective surgery patients to appropriate hospitals in Australia to reduce wait times. van Merode et al. (2002) use simulation to determine the optimal production and inventory policies for each combination of patient type and cytostatic drug type to minimize patient wait times.
times and costs. Further, Blake et al. (1996) describe a simulation model of the emergency room to investigate issues contributing to patient wait times, and indicate that patient wait time is affected by the availability of staff physicians and the amount of time physicians are required to spend engaged in the education of medical residents. Lane et al. (2000) also describe a simulation model to understand patient wait times in an accident and emergency department, and find that while some delays to patients are unavoidable, reductions can be achieved by selective augmentation of resources within, and relating to, the accident and emergency department. A common objective of these simulation models is to reduce patient wait times in the emergency department or other settings. The case study described in this paper attempts to extend this line of studies by considering not only patient wait times but also some ways to improve patient wait times in the emergency care process.

Methods
The Hospital is the second largest in Singapore with 1,400 beds and it provides healthcare services in 17 clinical disciplines. The Accident and Emergency (A&E) Department of the Hospital treats about 390 patients on a daily average, which counts for about 28 percent of all emergency patients treated in the public hospitals in Singapore.

Modelling the emergency care process
Any patient coming to the A&E Department first stops over the screening station, at which the patient is determined on which part of the A&E Department he or she should be routed to next. After the screening, the patient registers at the registration station, and then, based upon the screening result, a nurse triages the patient at the triage station. The patient then waits to see a doctor, who determines and provides the appropriate treatment for the patient. When the patient is discharged after the treatment, the patient arranges payment at the payment station before leaving the A&E Department.

The A&E Department classifies emergency patients into four classes including PAC 1, PAC 2, PAC 3, or PAC 4, based upon the patient’s acuity class (PAC). PAC 4 patients are those who should go to clinics instead of the A&E Department owing to their minor symptoms or diseases. In contrast, PAC 1 patients are seriously ill or injured, for example, in car accidents or stroke/heart attack, and they need life-saving treatments. Data from the Hospital show that many PAC 1 patients are treated in the specialty areas of cardiovascular and respiratory medicine as they have difficulty in breathing. The diseases or injuries of PAC 2 and PAC 3 patients are generally related to activities in workplace. The top three specialty areas where PAC 2 and PAC 3 patients are treated include general medicine (e.g. food poisoning), general surgery (e.g. bleeding injury requiring minor operation), and orthopedics (e.g. broken bones).

PAC 1 patients are most urgent and so they are immediately treated, followed by PAC 2, PAC 3, and PAC 4 patients in this order. PAC 4 patients are treated last after PAC 1, PAC 2, and PAC 3 patients are treated. Table I shows the profile of patients treated in the A&E Department from July 2005 to January 2006. Most emergency patients are either PAC 2 or PAC 3 patients, and PAC 3 patients are generally a little more frequent than PAC 2 patients. PAC 1 patients usually account for less than 10 percent of all emergency patients.

PAC 1 patients do not experience long wait times. In fact, all PAC 1 patients should be treated immediately, and hence, there should be no wait time for them. The median wait
times recommended by the Singaporean Ministry of Health are 20 minutes for PAC 2 patients and 30 minutes for PAC 3 patients (Ministry of Health, 2003). However, the median wait times experienced in the A&E Department of the Hospital are 0.79 hours (or 47 minutes) for PAC 2 patients and 1.03 hours (or 61 minutes) for PAC 3 patients, as shown in Table I. Prolonged wait times make patients frustrated and dissatisfied, as reported in previous studies, e.g. Kyriacou et al. (1999). Also, prolonged wait times prevent doctors and nurses from doing their best work and leave them disillusioned and angry (Waldrop, 2009). Ultimately, patients may be diverted away from the Hospital.

The Hospital management is aware of these problems and wants to explore some direct ways to improve patient wait times in the emergency care process, while still considering making more resources and space available in the A&E Department in the long term.

Figure 1, which was constructed in SIMUL8, shows the simulation model for the current emergency care process. The simulation model consists of four basic components:

1. Input (entrance);
2. Queues (waits);
3. Work stations (screening, registration, triage, consultation, and payment stations); and
4. Exits (discharged or hospitalized).

At each work station is a queue of patients waiting to be serviced. Patients are entities that the simulation model processes, and work stations are locations where entities are routed for processing. Also, each work station is attended and serviced by healthcare providers. Healthcare providers are resources that the simulation model uses for servicing entities. Healthcare providers in the A&E Department include doctors (who are further classified into senior doctors and medical officers, based upon their qualifications and experiences) and nurses (who are further classified into senior staff nurses, staff nurses, assistant nurses, nurse officers, and healthcare assistants). The path networks in the simulation model are from the entrance to the exits.

The changes that the Hospital management considers in order to improve patient wait times in the emergency care process include:

- adding another payment station; and
- adding a new short-stay ward.

<table>
<thead>
<tr>
<th>PAC 1</th>
<th>PAC 2</th>
<th>PAC 3</th>
<th>PAC 4</th>
<th>Total (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average daily number of patients (a)</td>
<td>31</td>
<td>166</td>
<td>188</td>
<td>3</td>
</tr>
<tr>
<td>(a)/(c) (%)</td>
<td>8</td>
<td>43</td>
<td>48</td>
<td>1</td>
</tr>
<tr>
<td>Average of monthly medians of patient waiting times</td>
<td>0.00</td>
<td>0.79</td>
<td>1.03</td>
<td>0.73</td>
</tr>
<tr>
<td>Average daily number of patients being hospitalized (b)</td>
<td>23</td>
<td>79</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>(b)/(c) (%)</td>
<td>18</td>
<td>62</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>(b)/(a) (%)</td>
<td>74</td>
<td>47</td>
<td>14</td>
<td>0</td>
</tr>
</tbody>
</table>

Table I. Profile of patients
Figure 1.
Simulation model before the changes
Figure 2, which was also constructed in SIMUL8, shows the simulation model for the emergency care process with these two changes (circled in Figure 2).

A payment station is already located at the end of the emergency care process. Starting with registration and ending with payment is common in any emergency care or similar healthcare processes. There are two types of patients based upon their payments, i.e. those who pay only the standard fee (currently $70) for standard services and those who pay more than the standard fee for services in addition to standard services. The payment station currently handles both types of patients, but it takes more time to arrange payments for patients who pay more than the standard fee than to arrange payments for patients who pay only the standard fee. Therefore, the Hospital management considers setting up another payment station between the registration and triage stations. With two payment stations in the process, all PAC 2, PAC 3, and PAC 4 patients first arrange the standard payment at the new payment station located between the registration and triage stations, and then, only those patients who have to pay more than the standard fee stop over the second payment station to arrange additional payments while the other patients bypass the second payment station. In contrast, PAC 1 patients do not go to the triage station, and they pay at the second payment station as they pay more than the standard fee. The Hospital management expects that the new payment station can improve patient wait times not only at the existing payment station but also at other work stations in the process.

There are some PAC 2, PAC 3, or PAC 4 patients whose medical conditions are still unstable and undetermined for the next step of treatments even after the consultation by doctors. Then, these patients are routed to the observation room for further observation and monitoring by doctors and nurses. They stay in the observation room until their medical conditions become stable and can be determined for the next step of treatments. Some patients stay in the observation room for a few hours, while some patients stay there for several days. Given the limited capacity of the observation room, the longer patients stay in the observation room, the longer the wait times are for other patients to get into the observation room. Thus, the Hospital management considers setting up a new short-stay ward (called as emergency diagnosis and therapy center in Figure 2) only for patients who need to be further observed and monitored for less than a day, while keeping the observation room for patients who need to be further observed and monitored for longer than a day. The Hospital management expects that the new short-stay ward can also improve patient wait times in the process.

Data

For the simulation in this study, we used historical data provided by the Hospital. The data entry in the A&E Department is computerized. The computer system keeps both healthcare data used mainly by healthcare providers and non-healthcare data used mainly by the operation quality management. The Hospital also uses radiofrequency identification technology, which increases the accuracy of data on patients, particularly on their movements from one work station to another in the emergency care process. Patients in the A&E Department go through many steps from screening, registration, payment, triage, and consultation with possible additional paths to laboratory and X-ray, to the point of observation before discharge. We were provided with computerized data for various factors associated with the emergency care process, such as:
Simulation model after the changes

Entrance

Queue for screening

Screening booth

Queue for registration

Registration

Queue for triage

Triage

Queue for payment

Payment

Pac 1

Resuscitation or consultation Rm

Resuscitation or consultation Rm

EDTC

EDTC

Pac 2

Consultation Rm

Consultation Rm

Pac 3 and 4

Upgraded p3 and p4

Upgraded p3 and p4

Queue for counter payment

Counter payment

Medication and discharge

1 683

Bed request

Bed actualised

176

Bed request

Bed actualised

176

Emergency care process reengineering

Figure 2: Simulation model after the changes
When data needed in the simulation model were not readily available, we used the best estimates provided by the Hospital staff familiar with the emergency care process. We used SPSS software for statistical analysis of data and obtained various parameters such as mean and median values of patient wait times, number of patients in the different acuity classes, inter-arrival times of patients, service times at work stations, probability distributions, and so on.

Running and validating the simulation model
The simulation model was run for 100 independent replications, with each replication using an additional warm-up period. The warm-up period is set for the simulation run to eliminate any bias at the early stages of the process (Law and Kelton, 2000). The run length and number of independent replications of the simulation are determined based upon the tests of normality and independence proposed by Law and Kelton (2000). The simulation results presented in the following section are based upon the average results of the 100 independent replications.

Validation is the process of determining whether the simulation model is a useful or reasonable representation of the real system (Pritsker et al., 1997). Absolute validation is usually impossible because the simulation is at best an approximation of the real system, and the most definitive method is to compare the output data from the simulation with the actual data from the existing system using formal statistical analyses such as confidence intervals (Son, 1993). In validating the simulation model of this study, we calculated the confidence intervals of the simulation outputs at 95 percent ($\alpha = 0.05$) confidence level and compared them to the actual values provided by the Hospital. We also verified the architecture of the simulation model with staff in the A&E Department before the simulation runs and showed the simulation results to the staff after the simulation runs to ensure that the simulation results are reliable.

Results and discussion
We ran the simulation model in two different scenarios: “before” and “after” the changes in the emergency care process. Both the scenarios are built on a common foundation or base model in which all variables are held constant. Table II shows the average numbers of

<table>
<thead>
<tr>
<th>PAC</th>
<th>Before the changes</th>
<th>After the changes</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average (a)</td>
<td>Low 95% range</td>
<td>High 95% range</td>
</tr>
<tr>
<td>PAC 1 patients</td>
<td>149</td>
<td>144</td>
<td>154</td>
</tr>
<tr>
<td>PAC 2 patients</td>
<td>778</td>
<td>769</td>
<td>786</td>
</tr>
<tr>
<td>PAC 3 and PAC 4 patients</td>
<td>934</td>
<td>926</td>
<td>943</td>
</tr>
</tbody>
</table>

Table II.
Number of patients in the simulation model

BPMJ 16,5 802
patients processed in each simulation run. The simulation runs in both the scenarios use almost the same numbers of patients in total as well as by PACs.

Table III shows the simulation results on patient wait times at each work station in the emergency care process before and after the changes. Before the changes, patients experience the longest wait time at the registration station (3.29 minutes), followed by the triage station (2.29 minutes), the payment station (1.12 minutes), and the screening station (0.15 minutes). The actual average patient wait times at the registration and triage stations were 3.60 and 2.50 minutes, respectively, which are within the 95 percent confidence intervals of the simulated estimates. The new payment station and the short-stay ward help shorten patient wait times most at the triage station by 2.20 minutes and then at the payment station by 0.64 minutes, while the changes have little effect on patient wait times at the screening and registration stations. Throughout the emergency care process from the screening station to the payment station, the changes shorten patient wait times by 2.81 minutes, i.e. about 41 percent of the wait times experienced before the changes.

Table IV shows the simulation results on patient wait times in the emergency care process before and after the changes, by PACs. Before the changes, PAC 3 and PAC 4 patients experience the longest total wait times (64.55 minutes), followed by PAC 2 patients (63.88 minutes) and PAC 1 patients (0.27 minutes). The changes shorten the wait time of PAC 2 patients by 7.80 minutes and the wait time of PAC 1 patients by 0.27 minutes. It is notable that there is no wait time for PAC 1 patients in the process after the changes. However, the changes lengthen the wait times of PAC 3 and PAC 4 patients by 6.01 minutes. It is worth noting that the changes help significantly shorten the wait times of PAC 1 and PAC 2 patients who need more immediate treatment than PAC 3.
and PAC 4 patients. In fact, 74 percent of PAC 1 patients and 47 percent of PAC 2 patients get hospitalized, whereas only 14 percent of PAC 3 patients and few PAC 4 patients get hospitalized (Table I). On average, patients stay in the emergency care process for 133.93 minutes before the changes and for 123.33 minutes after the changes.

Table V shows the 95 percent confidence intervals of the simulated estimates against the actual values of patient wait times by PACs. All confidence intervals include the actual values. Thus, the simulation model seems to be capable of reproducing patient wait times in the emergency care process in the Hospital.

A couple of limitations are recognized in this case study. First, the simulation does not consider varying the capacity of resources (healthcare providers including doctors and nurses) and locations (work stations from the screening station to the payment station) involved in the emergency care process. The varying capacity of resources and locations may have significant effects on not only patient wait times in the process but also flexibility and quality of the process. Utilizing more resources and locations, however, may incur increased costs. Second, the simulation does not consider patients by clinical disciplines in which they are treated. Data from the Hospital suggest that PAC 2 and PAC 3 patients experience long wait times when they are treated in the disciplines of general medicine, general surgery day, or orthopedic, and that many PAC 1 patients are treated in the disciplines of cardiovascular and respiratory medicine. Patients treated in different disciplines may experience different wait times in the process. These limitations are certainly not exhaustive, but important ones. Obviously, these limitations, in turn, suggest several possibilities for future study.

**Conclusion**

The Hospital management considers some changes in the emergency care process in order to improve patient wait times in the process. Using computer simulation, this study models the emergency care process and evaluates the effects of some changes on patient wait times in the process. The simulation results are validated with the actual values. More specifically, the simulation estimates on patient wait times by PACs are compared against the actual values obtained from the Hospital. The 95 percent confidence intervals of the simulation outputs include the actual values, indicating that the simulation model is capable of reproducing the emergency care process in the Hospital with respect to patient wait times. The simulation results demonstrate that the new payment station and the short-stay ward can shorten patient wait times in the emergency care process, and show that computer simulation can be an effective decision support tool in modelling the emergency care process and evaluating the effects of changes in the process. Based upon the simulation results, we support the implementation of the changes to improve patient wait times in the emergency care process in the Hospital.

<table>
<thead>
<tr>
<th>Table V.</th>
<th>PAC</th>
<th>95% confidence interval</th>
<th>Actual value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient wait times (in minutes) – simulation results versus actual values</td>
<td>PAC 1 patients</td>
<td>(0.18, 0.37)</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>PAC 2 patients</td>
<td>(60.24, 67.52)</td>
<td>61.51</td>
</tr>
<tr>
<td></td>
<td>PAC 3 and PAC 4 patients</td>
<td>(63.81, 65.29)</td>
<td>65.01</td>
</tr>
</tbody>
</table>
References

Corresponding author
Sung J. Shim can be contacted at: sung.shim@shu.edu

To purchase reprints of this article please e-mail: reprints@emeraldinsight.com
Or visit our web site for further details: www.emeraldinsight.com/reprints