eHealth Beyond the Horizon – Get IT There
S.K. Andersen et al. (Eds.)
IOS Press, 2008

Discrete event simulation as a tool in optimization of a professional complex adaptive system

NIELSEN, Anders Lassen [a1]; HILWIG, Helmer [b]; KISSOON, Niranjan [c]; TEELUCKSINGH, Surujpal [a]
Affiliations: [a] Dept. of medicine, The University of the West Indies, St Augustine, Trinidad; [b] Emergency Dept., Eric Williams Medical Science Complex, Mt Hope, Trinidad; [c] Dept. of Pediatrics, University of British Columbia, Vancouver, Canada.

Abstract. Similar urgent needs for improvement of health care systems exist in the developed and developing world. The culture and the organization of an emergency department in developing countries can best be described as a professional complex adaptive system, where each agent (employee) are ignorant of the behavior of the system as a whole; no one understands the entire system. Each agent's action is based on the state of the system at the moment (i.e. lack of medicine, unavailable laboratory investigation, lack of beds and lack of staff in certain functions). An important question is how one can improve the emergency service within the given constraints. The use of simulation signals is one new approach in studying issues amenable to improvement. Discrete event simulation was used to simulate part of the patient flow in an emergency department. A simple model was built using a prototyping approach. The simulation showed that a minor rotation among the nurses could reduce the mean number of visitors that had to be refereed to alternative flows within the hospital from 87 to 37 on a daily basis with a mean utilization of the staff between 95.8% (the nurses) and 87.4% (the doctors). We conclude that even faced with resource constraints and lack of accessible data discrete event simulation is a tool that can be used successfully to study the consequences of changes in very complex and self organizing professional complex adaptive systems.

Keywords: Discrete-event system simulation, patient flow, professional complex adaptive systems, emergency department, efficiency.

1. Introduction

Health care systems are struggling with financial limitations worldwide. The increasing demand for health care leads to the so called health care crisis [1]. The problems were highlighted by IOM [2] prompting health care systems to be more efficient [3].

The public healthcare system in Trinidad and Tobago is less than ideal. Daily headlines emphasize its' shortcomings including unacceptable long waits in the emergency departments (=ED). According to WHO 'malfunctioning health systems are

[1] Adress for correspondence: Anders.Nielsen@sta.uwi.edu

at the heart of the problem'. In addition 'countries with few resources struggle with creating infrastructures, inadequate financing, migrating doctors and nurses, and lack of basic information on health indicators' [3]. The question is how one can improve the service within the given constraints? Simulation technology is a new approach that could be used to evaluate and craft new solutions.

1.1. Why use modeling and simulation

Decision-making at first glance seems straightforward. Define the problem, diagnose its causes, design solutions, and decide how best to implement it [4]. This approach had been tried in the ED without success. So what happens when we cannot analyze us out of the problem? It leaves us with experimentation. It is the process of "doing first" trying something so that we can learn. But this approach is not reasonable in an ED [5].

When we are unable to experiment with the 'real world' could experiments in the 'virtual world' be the solution? Several papers all from the developed world indicate that simulation could be a tool [6-11]. Two elements are needed to apply simulation. The first is that a system has been identified for investigation (i.e. the ED) and the second element is that there is a problem relating to the system that needs to be corrected (i.e. waiting time and failure in treatment). The modeling activity creates an object (i.e. a model) that is used as a vehicle for experimentation – the simulation [12]. It is a discrete system because the state of the variables (i.e. patients) only changes at discrete points in time (i.e. contact with the health care staff)[13].

2. Objectives

The objectives of this paper are to evaluate the feasibility of using modeling and simulation as a management tool in an ED optimization effort in a developing country.

The goal is to identify bottlenecks from the data generated by the simulation and test possible improvements. The evaluation of the usefulness of the simulation can be broken down to: (1) evaluate the method, (2) assess the information required to build a usable model, and (3) to determine if the data collection was worthwhile [6].

3. Methods

3.1. Software

The model building and simulation software used was Arena v.10, Rockwell Software Inc.[5]. A terminating simulation over 24 hours with 500 replications was used.

3.2. The system under investigations

What kind of organization is the ED in a developing country? A holistic approach is to view it as one living organism – a complex adaptive system. As a collection of individual agents that acts in ways that are not always totally predictable, and whose actions are interconnected so that one agent's action changes the context for other agents [14]. No agent understands everything that is going on [15]. Each agent's action is based on the state of the system at the moment (i.e. lack of medicine, unavailable laboratory investigation). It is best viewed as a professional complex adaptive system [16]. Looking for solutions that recognizes this fact will be more sustainable [17;18].

3.3. The model building

The aim of the model was to mirror the day-to-day operation. A linear entry function and a first in / first out approach were adopted since the identifications of and subsequent removal of bottlenecks was seen as a mean to maximize efficiency. A prototyping approach to model building was adapted.

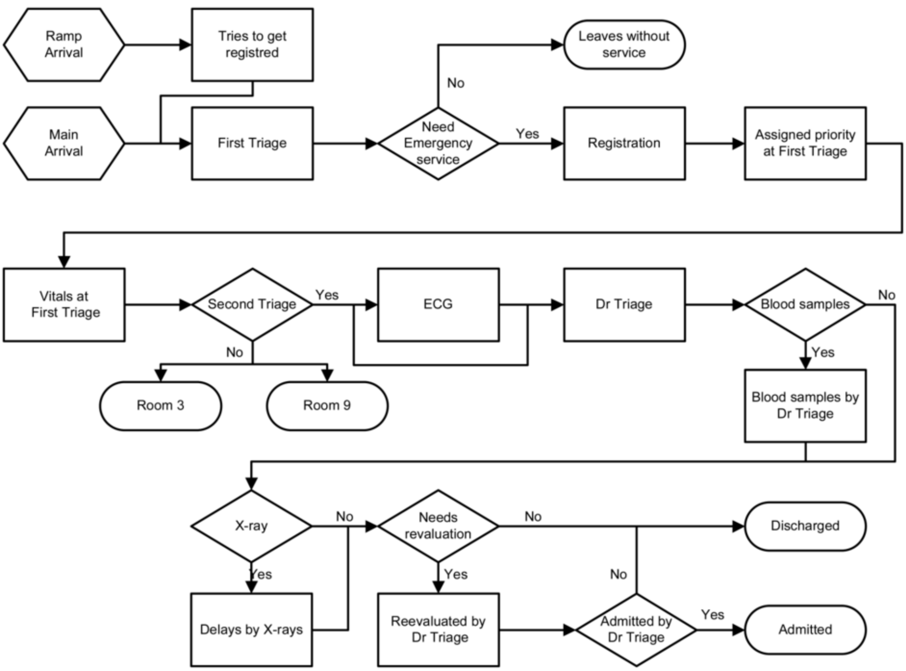

Figure 1 Emergency department flow model

The first step was interviews with senior staff to get a description of the perceived flow. Available data on admission frequencies was collected. A simple prototype model was build. Random observations of some activities were conducted to validate the model. The model was way off and raised the suspicion that far more flows existed. Hence the second step was to conduct more detailed observations. Thirty-two patients were observed (118 hours of observations). Clerical staff was used as observers to avoid interference with clinical decision and workload. Registration of individual staff performance was not done. Nine principal patient-flows were identified. An improved model was constructed. When the simulation was run it indicated a major bottleneck in the flow concerning the intake and triage. A total of 20 observed patients belonged to this flow. The remaining 12 patients were insufficient to identify the remaining eight flows type.

The third step was to build a more detailed model of the triage process (see figure 1). Based on the times observed a minimum, average and maximum time spent in each station was calculated and applied to a triangular delay type. Each station was assigned only one resource (a clerk, a triage nurse, an ECG nurse or a Doctor).

4. Results

Simulations of the existing flow with a mean of 174 (range 133-230) patients seeking emergency care resulting in accumulated average staff contact time of 36 (range 18-54) minutes. Only half of the patients were processed by the existing flow.

Simu-lation Flow	Fully processed N	Waiting time Hours	Utilization %			
			1st triage	Clerk	Dr	ECG
Existing	87 (62-115)	9.2 (2.4 -17)	99.5	73.9	44.3	6.9
Improved	147 (129-135)	5.0 (0.6-13)	95.8	88.7	87.4	89.7

Table 1 Results: Simulation of existing and improved flow

One bottleneck originating from the activity 'First Triage' was identified. The nurse taking 'ECG' was only active in 7% of her time. What would happen if she could assist in taking vital signs? She was therefore exchanged with the triage nurse as the resource doing 'vitals'. Now the simulation showed nearly a doubling of the numbers of patient processed. Total waiting time decreased and staff-utilization became more efficient.

5. Discussion

5.1. Evaluation of the method

We found like Vissers[11] that the degree of process thinking in the organization has consequences for the way the models are developed. The concept of processes is not widely shared in the observed organization. If one decides on a too detailed level, the model may be too complex for the organization to understand. If one on the other hand chooses a too high level of aggregation the information generated may not be very useful and health care practitioners may not accept the model's description of reality. A profound insight into the dynamics of the area being modeled is therefore important requirements for developing a successful model.

We found that a simulation can indicate where changes in staffing could lead to improvement by leveling the use of resources, as is the experience from the developed world [9]. We conclude as Coats [6] does: that even thou the model were not an accurate representation of patient flow the simulation was still useful. An entry function that more closely matched the patient arrival pattern would increase the value of the simulation as a decision tool for staff planning. We found as Hung et al [9] that one could effectively change the model and easily simulate its effects on patient flow.

The conclusion is that the model building and simulation process is valuable in that it can illuminate bottlenecks and help finding solutions to solve the problem. But it has to be emphasized that it was the whole process of identifying the flows that added most value for the organization, since several identified flows were not officially recognized.

5.2. Assess the information required to build a usable model

Harper et al.[7] argues that classification of patients should be included in a detailed model just, as detailed incorporation of recourses use should be included. However in the present case it was not practical to obtain such information. By having practitioners building the model it turned out that the initial guesses on time functions and distribution of each process were close to the ones actually observed. The prototyping approach made it feasible to quickly build meaningful models and incorporate updated knowledge as soon as it was available.

However the time consuming analysis of the activities in the organization is needed. No single expert fully grasp, and no set of documents fully captures, the subtle ways in which individual components are interwoven with one another. One has to look at the ongoing activity itself [19;20]. The employees' descriptions of their jobs correspond more or less to the formal procedure of the job manual. But when observed it is often discovered that the employees are not following those procedures at all. The employees rely on a rich variety of informal practice - not written in any manual - but crucial to getting the work done [21] but it is not necessarily efficient.

5.3. Determine if it was worthwhile to undertake the data collection needed to build a detailed model.

It was worthwhile to undertake the data collection needed to build the model. Nine performance indicators for ED[22] can be collected from the present model. That is five time definitions: Arrival-, MD contact-, decision to admit-, conversion- and discharge-time. Two time intervals: Door to doctor turnaround and discharged patients. Two defined elements of emergency: Numbers of ECGs and simple imaging procedures done. Our conclusion is that discrete event simulation can be applied to any ED. The collection of additional data and the development of more sophisticated models seem worthwhile [6].

5.4. Is it worthwhile in a developing country?

We believe so. It has been argued that the model of integrated patient pathways is a more comprehensive concept for healthcare institutions [23]. It will have to incorporate evidence-based medicine. Certainly that would require well-defined patient flow to be clinically adequate and simulation is one obvious tool to aid this development. It can be argued that potential tools have to synergistically combine people, organizational processes and technology to enable a holistic view. Simulation is one such tool.

Vissers [11] argue that modeling based health care management ought to become just as popular as evidence-based medicine. Young [24] argues that because healthcare systems around the world are undergoing redesign and refocusing on patients, there is a strategic role for modeling and simulation to play. The creation of strategic scenarios that work according to process philosophies - as used in manufacturing - could help to deliver high quality care to millions of people.

As a secondary effect of the process a picture of the real flow emerged not only the one described in the official diagrams as discussed previously but also critical aspect of the prevailing culture surfaced. We conclude that a successful application of simulation methodology in a Third World environment was achievable and that further potential exist.

Acknowledgements: This research would not have been possible without the valuable input, time and effort afforded by many dedicated staff from within the Eric Williams Science Complex. We acknowledge the help and guidance given by our colleagues, Madaniyo Mutabazi and Jason William at the department of Engineering at the University of the West Indies, St Augustine W.I. and Craig O'Neill from the University of British Columbia, Canada.

References

[1] Goldsmith JC. The new health-cost crisis. Harv Bus Rev 2001; 79(10):20-21.
[2] Kohn LT, Corrigan JM, Donaldson MS. To err is human: building a safer health system. Washington, D.C.: National Academy Press; 2000.
[3] WHO. World Report on Knowledge for Better Health - Strengthening Health Systems. 1-146. 2004. Geneva,Switzerland, World Health Organization. Report.
[4] Mintzberg H, Westley F. Decision Making: It's not What You Think. MIT Sloan Management Review 2001; 42(3):89-93.
[5] Kelton WD, Sadowski RP, Sturrock DT. Simulation with Arena. 4 ed. New York: McGraw-Hill; 2007.
[6] Coats TJ, Michalis S. Mathematical modelling of patient flow through an accident and emergency department. Emerg Med J 2001; 18(3):190-192.
[7] Harper PR. A Framework for Operational Modelling of Hospital Resources. Health Care Management Science 2002; 5(3):165-173.
[8] Huang X-M. Decision making support in reshaping hospital medical services. Health Care Management Science 1998; 1(2):165-173.
[9] Hung GR, Whitehouse SR, O'Neill C, Gray AP, Kissoon NM. Computer Modeling of Patient Flow in a Pediatric Emergency Department Using Discrete Event Simulation. Pediatric Emergency Care 2007; 23(1):5-10.
[10] Sinreich D, Jabali O. Staggered work shifts: A way to downsize and restructure an emergency department workforce yet maintain current operational performance. Health Care Management Science 2007; 10(3):293-308.
[11] Vissers JMH. Health care management modelling: a process perspective. Health Care Management Science 1998; 1(2):77-85.
[12] Birta LG, Arbez G. Modelling and Simulation - Exploring Dynamic System Behaviour. 1 ed. London: Springer-Verlag; 2007.
[13] Banks J, Carson II JS, Nelson BL, Nicol DM. Discrete-event system simulation. 4 ed. Pearson Education Inc; 2005.
[14] Plsek PE, Greenhalgh T. Complexity science: The challenge of complexity in health care. BMJ 2001; 323(7313):625-628.
[15] Cilliers P. Complexity & Postmodernism. New York: The Free press; 1998.
[16] Anderson RA. Managing health care organizations: Where professionalism meets complexity science. Health Care Manage Rev 2000; 25(1):83-92.
[17] Headrick LA. Learning to Improve Complex Systems of Care. Prepared for Counsil on graduate Medical Education and national Advisory Counsil on nurse Education and practice joint meeting Washington D C, 2000 [cited 2005 Dec. 25]; 75-88
[18] Nolan TW, Resar R, Haraden C, Griffin FA. Improving the Realiability of Health Care. Gordon AB, editor. 4, 1-17. 2004. Cambridge, Massachusetts, Institute for healthcare Improvement. Inovation series 2004. 21-7-2005. Report.
[19] Hirschhorn L. Campaigning for Change. Harv Bus Rev 2002; 80(7):98-104.
[20] Szulanski G, Winter S. Getting It Right the Second Time. Harv Bus Rev 2002; 80(1):62-69.
[21] Brown JS. Research that reinvents the corporation. Harvard Business Review on Knowledge Management. Boston: Harvard Business School Press; 1998. 153-159.
[22] Welch S, Augustine J, Camargo CA, Jr., Reese C. Emergency Department Performance Measures and Benchmarking Summit. Acad Emerg Med 2006; 13(10):1074-1080.
[23] Bali K R, Dwivedi A, Naguib R. Issues in Clinical knowledge Managemnt: - Revisiting Healthcare management. In: Bali R, editor. Clinical Knowledge Management - Oportunities and Challenges. Coventry UK: Knowledge management for Healthcare Group, Biocore, Coventry Univ.; 2005. 1-10.
[24] Young T. An Agenda for Healthcare and Information Simulation. Health Care Management Science 2005; 8(3):189-196.