# Designing improved healthcare processes using discrete event simulation

ABSTRACT
Over the past four years the vascular-surgery outpatient service at Good Hope Hospital has been re-engineered. Conventional 'suck-it-and-see' methods were replaced by evidence-based design of improved patient-centred care processes using a combination of casemix analysis and discrete event simulation (DES). A new software tool called the Care Pathway Simulator (CPS) was developed to meet the unique requirements of this novel approach in order to predict accurately the behaviour of the complex system resulting from the interaction of multiple patients following different care pathways and competing for shared resources. The CPS tool identified and quantified the problems within the existing processes that limited capacity (ie the bottlenecks); allowed us to test a range of proposed solutions using a virtual process model; and provided objective evidence to support implementation of the proposed solution. Just as importantly, the CPS tool allowed the relationship between performance and resource availability to be mapped and the point at which system failure is imminent to be seen — allowing time for predesigned escalation policies to be activated. The enhanced performance predicted by CPS was confirmed in practice.

Process-design tools based on discrete event simulation do appear to work in healthcare provided that the unique requirements of healthcare processes are taken into account and those who use these tools are appropriately trained and experienced.

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A new tool for analysing and redesigning processes in clinical services has been developed and tested in a service-improvement project at Good Hope Hospital. The application of advanced IT to clinical-process redesign using the evidence-based principles of a formal research methodology has enabled the staff of the vascular-surgery clinic to provide a better service for patients, a better working environment and better value for money for the taxpayer. **Mr Simon Dodds**, who created the necessary simulation tool, describes how the hitherto elusive result was accomplished.


Simon Dodds

Good Hope Hospital is a typical medium-sized district general hospital in the West Midlands, serving a mixed urban–rural population of around 400,000. In 2000, work was started to improve the quality of the patient and staff experience and to meet the increasing demand for the specialist outpatient vascular-surgery service within the ever-present constraint of existing resources. Following an initial team-wide 'strengths–weaknesses' assessment we audited existing activity, casemix and waiting times and used this as the basis for a redesign of the service. Initially, we used the conventional PDSA (plan-do-study-act) method but found that this had limitations: it was not possible to predict the effect of a proposed change before implementation and it was not possible to compare a range of proposed options objectively. We realised that this widely used method of service improvement was little better than trial and error, so we adopted a research-style approach that would provide objective evidence of benefit to support any proposals. We needed to identify the 'least-effort, maximum-benefit' changes, as we had no resources to invest other than our own free time and our desire to improve the experience for our patients and ourselves.

## Process improvement by design

Formal process analysis and design has been used for many years in manufacturing industries as a component of continuous quality improvement (CQI) programmes and to reduce production costs and increase competitiveness. There is a whole branch of management science called operational research (OR) that covers the theory and practice of process optimisation, and one proven technique used in OR is the use of process simulation tools to assist the design of improved production lines.

Interestingly, healthcare seems to have largely resisted the application of these methods.[1, 2] One reason may be that a production line requires that the 'widgets' are uniform and passive and pass through 'work-centres' in an orderly and predictable way. Patients, however, are not so obliging: they are distinctly varied, somewhat unpredictable, do not like sitting in queues waiting to be processed and are far from passive! This fundamental difference suggests that industrial process-design tools may have limited direct applicability to patient-centred healthcare services. A second reason may be that, like all sophisticated tools, the users need to be appropriately trained, experienced and competent to use them: you need the right craftsman and the right tools to get the job done properly! Provided these requirements are met, however, there seems to be no logical reason why these methods should not be applied to healthcare process design.

## Creating the process model for the vascular-surgery outpatient clinic

There are three components of a healthcare process model:

- the work list of patients, which represents the demand;
- the pathway or sequence of actions required to 'process' each patient; and
- the resources required to perform each action, which represents the capacity.

With this information it is possible to simulate an outpatient clinic and to predict how it would perform over a range of conditions. To apply this methodology to our problem we needed to define the three components. So the first task was to audit the existing outpatient service in terms of activity and waiting times, to provide a baseline from which subsequent changes could be measured and to conduct a detailed casemix audit to identify broadly the types of patient presented to the clinic. From this audit a minimum set of patient pathways was identified and each one formally defined by following individual patients and recording what happened to them.

From an individual patient's perspective, the journey is a sequence of predictable events separated in time, and these events mark when specific resources (eg staff or equipment) are required for the journey to continue without delay. The interval between linked events is either a period of activity or of waiting, and these intervals are variable: the timing of the events showed marked variation from one patient to another. From the perspective of a specific resource, such as a member of staff, the experience is also a sequence of discrete events that mark times when patients use the resource separated by periods of inactivity (figure 1); again the intervals demonstrated considerable variation.

Thus, for the purposes of a process model, the patient pathway is mapped in terms of the resources that are required, in what order and for how long. This can be obtained using conventional pathway mapping techniques that are already widely used in healthcare.

The overall performance of the whole system is the result of the interaction of multiple, variable patient pathways competing for the available resources and explains why it is difficult to predict consciously the future performance and resilience of the system even if the work list, pathways and resources are known. Normally, we are forced to extrapolate from past performance and to use simple statistical tools to monitor current activity to identify developing problems. In order to create accurate predictions of future clinic performance we needed a process simulation tool and the appropriate technique appeared to be a well-described one called discrete event simulation (DES). Our essential requirements of the DES tool were:

- capable and affordable;
- easy to learn and use;
- the ability to define pathways from the patient perspective;
- the ability to incorporate wide variation between patients;
- the ability to modify demand, pathways, and resource allocations independently; and
- the ability to format outputs as appropriate measures of system performance.

Unfortunately, none of the available commercial tools met our essential requirements; in particular affordability and the ability to define the pathways from the patient perspective easily without needing advanced programming or statistical analysis skills. So we opted to create the necessary simulation tool — the Care Pathway Simulator (CPS) — and were able to consider this option only because one member of the team had a formal training in computer science and previous experience of developing advanced computer simulation techniques.

Analysis of the audit database showed that, in terms of their resource requirements, there were four broad classes of patient attending our clinic. This meant that the pathway mapping process only had to be done for a small number of patients to define the sequence of resource requirements and the mean and variance of the essential intervals. The least complex pathway only took around 15 minutes and used only two resources while the most complex took over 90 minutes and used all the resources in the clinic. The process maps were converted to process flowcharts using the graphical interface

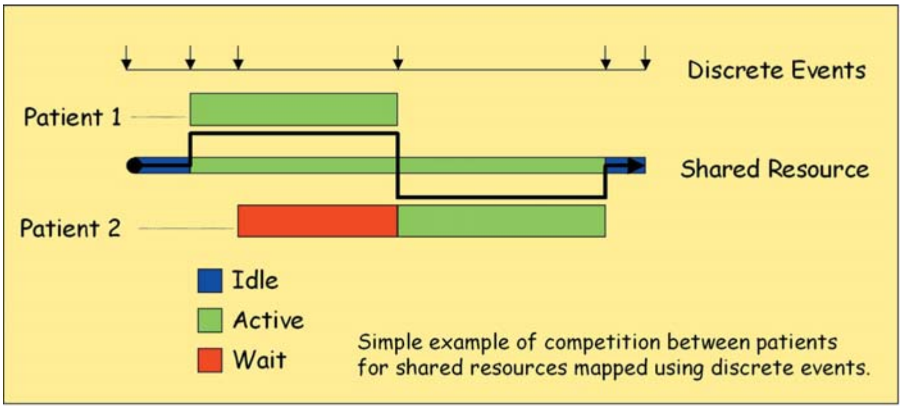


**Figure 1 Interaction between two patients competing for a shared resource is represented by a sequence of discrete events for both the patients and the resource.**

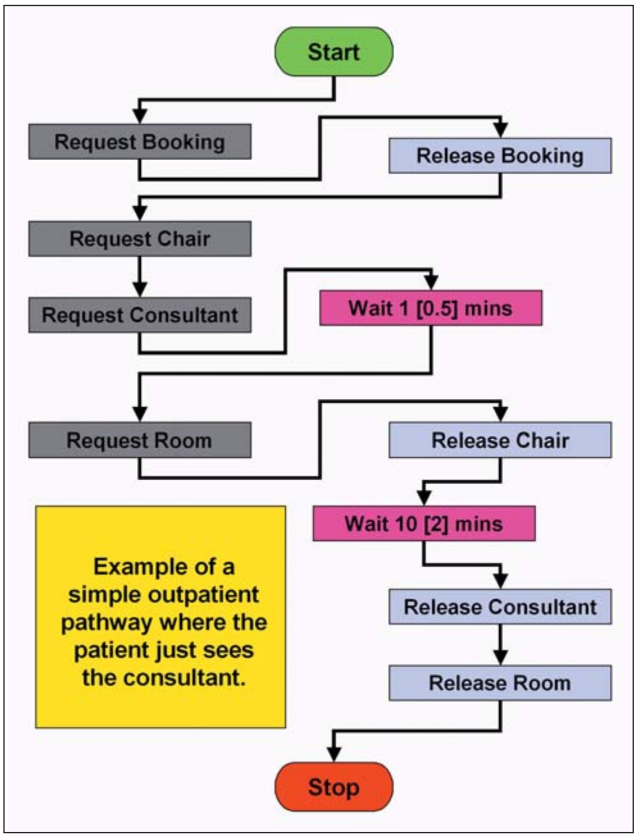


**Figure 2 Example of the least complex patient pathway for the vascular outpatient clinic mapped in terms of resource requirements. The wait actions define the mean and variance of the necessary time intervals between events that are measured by direct observation.**

(figure 2) of the CPS tool along with a definition of the types of resource that were needed and the amount of each available. The final model was validated by comparing the CPS's prediction of clinic finishing time with the actual finishing time for a number of real clinics. The results showed wide variation but good agreement. This confirmed our impression that the booking schedule was a major determinant of whether or not a particular clinic overran its scheduled time; if a basic first-come-first-served booking method was used, the clinic finishing times and patient waiting times showed high variation and inefficient use of resources because of the inherent variation between patient categories.

Having validated the model there were two questions that we needed to answer:

- what is the maximum capacity of the clinic, given the resources available?; and
- what is the booking schedule that achieves this maximum?.

## Designing improved performance

The CPS tool was next used to simulate a range of hypothetical outpatient booking schedules, and the best were identified using objective criteria that included total patient waiting time, resource activity, clinic finishing time, and number of patients seen. This approach of running a series of virtual experiments provided a useful insight into the behaviour of the whole system from all aspects. The interactive design of the CPS tool avoids the need for sophisticated optimisation algorithms and allows the operator to find a solution that has the required performance and resilience to cope with the known demand and casemix variation quickly.

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The final output was a booking schedule that predicted a 40% increase in maximum clinic capacity in terms of the number of patients that could be seen. Although surprising, it was the result of the pathways of individual patients interweaving in an elegant and efficient 'dance' with the available resources. The new schedule was implemented very simply as a paper-based diary and the clinic clerk just had to match the assigned patient category with the next free slot in the schedule of that category to get the starting time and then make bookings in the patient administration system for the required resources (ie doctor, nurse, and technologist) as directed by the schedule.

The new system was piloted in November 2004 and the subsequent audit showed that the clinic behaved just as predicted. Even when booked to maximum capacity the clinic was busy but not frantic and still finished on time. The informal feedback from the staff was that it just ran better and the days of late finishes, missed lunch breaks and frustrated patients appeared to be over.

The increased maximum capacity created by the optimised scheduling template meant that the clinic had enough resilience to absorb the inevitable unpredictable variation in demand, such as urgent appointments.

We achieved a win-win-win outcome by evidence-based design using a rigorous application of advanced information technology. It just shows what can be achieved when you focus on your strengths! ■

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### *References*

1. Bagust A, Place M, Posnett JW. Dynamics of bed use in accommodating emergency admissions: stochastic simulation model. *BMJ* 1999; 319: 155–8.
2. Young T, Brailsford S, Connell C, Davies R, Harper P, Klein JH. Using industrial processes to improve patient care. *BMJ* 2004; 328: 162–4.

HITEA 2005 Healthcare IT Effectiveness Awards

The Care Pathway Simulator, created by Mr Dodds and piloted by his vascular-surgery outpatient clinic team at Good Hope Hospital, won first place overall for the use of IT in the Health Service, as well as first place in the category for innovative use of technology, at this year's Healthcare IT Effectiveness Awards.