

PERFORMANCE ASSESSMENT OF HOSPITALS BY USING SIMULATION

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ABSTRACT

It is common to use discrete event simulation (DES) to model healthcare systems for different objectives such as performance improvement, resource planning and facility design. Within this, accident and emergency rooms and outpatient clinics are the most commonly studied. However, despite this success with simulation at an operational level, there are no reported uses of discrete event simulation for the development and improvement of health policy. We describe the early stages of the development of such a policy-oriented model, aimed at improving performance assessment in the UK National Health Service. As part of the model building, we also discuss simulation software for health care modeling.

1 INTRODUCTION

Health care expenditure has increased massively in the last decade and this trend is likely to continue. Total expenditure on health care in the US in 2004 is estimated at \$1.6 trillion (Pier-skalla, 2004), having risen at annual compound rate of 10% in the past decade. In the UK, expenditure on its publicly-funded National Health Service (NHS) is budgeted to rise to over £90 billion by 2007/8. Though technological innovations such as genomics may transform some elements of service delivery, we need to understand their implications for other parts of the patients' pathways through hospitals, so that the benefits can be realised. That is the logistics of health care, if badly managed, may make it impossible to achieve the benefits promised by scientific advances no matter how much money is spent. This is true in the private health sector and also in the public health sector. In the latter case, tax payers and politicians alike wish to see high quality public services, whilst spending as little as possible.

In the UK, most health care is provided through the publicly-funded NHS in which all services, except some drugs, are provided free at the point of need. It is probably impossible to meet all conceivable demands for health care and so all systems of provision, public or private, include some form of rationing – by price or availability. In the UK, the rationing is most evident in waiting lists treatment and their reduction has been a major aim of health policy since the Labour Government was elected in 1997. To this end, the NHS has a performance assessment framework that attempts to measure aspects of the quality of health provision in England. The performance of Acute Hospitals, as one of the major players in the system, has been star-rated in recent years. Excellent performance wins 3-stars and poor performance leads to no stars – the latter are labeled as failing and the Chief Executive is likely to lose her job. This performance assessment framework has brought improvements in performance together with some suspicions that more could be done if the performance measurement systems were better defined. One way to do this is to develop a simulation model, that represents

the entire operations of an acute hospital in sufficient detail for experimentation with different performance assessment regimes.

Since the intended model represents whole-hospital systems, it should cover different levels of detail to be of use in assessing performance measurement at a hospital level. The resulting model is intended to be sufficiently complex to meet these requirements and to offer ease of use.

2 SIMULATION IN HEALTH CARE

Discrete event simulation has been widely used in attempts to improve the delivery of health care (see Fetter and Thompson (1965) for an early example).

2.1 Literature Surveys

There have been periodic reviews of simulation applications in health care. Examples include Davies (1985), Lehaney and Hlupic (1995), Jun et al (1999) and Fone et al (2003). From these a consistent pattern of successful application emerges, albeit with a focus on specific operational issues such as the management of accident and emergency rooms and of outpatient clinics. Jun et al (op cit) surveys an approximately 30 year period, from the early 1960s applications of simulation in healthcare, to the late 1990s. They review 117 journal articles and classify them according to their objectives. Their main interest is the impact of patient and resource scheduling on patient and work flows, followed by the allocation of resources such as beds, rooms and staff. They also searched for studies of more complex, integrated and multi-facility systems and concluded that there seems to be a lack of such work reported in the literature. They suggest that the major reasons for this shortage are first, the level of complexity and of course the data needs and, secondly, the resource requirements including the time and money needed to conduct such research. They suggest that the main dilemma in such work is deciding on the appropriate level of detail. Increased detail leads to more realistic representation, which should increase the confidence of stakeholders. However, increased detail requires extensive, validated data and this may be expensive and time-consuming to collect – if indeed it can be collected at all. They further suggest that Soft System Methodologies (SSM) might be used to determine the right level of detail for such complex systems and a similar point is made by Lehaney and Paul (op cit).

Fone et al (2003), is a systematic review of the literature related to the use of simulation modeling in health care and covers almost the same period, 1980-1999, as Jun et al (op cit). This review aimed to assess the quality of published studies and to consider their influence on policy, rather than on operations. They divided the published work into 5 categories: hospital scheduling and organization, infection and communicable disease, costs of illness and economic evaluation, screening and, finally, miscellaneous. As with Jun et al (op cit), Fone et al (op cit) reports that most of the reported simulation studies focus on very specific aspects of hospitals such as Accident & Emergency rooms, operating theatres, outpatient and inpatient wards. Within these, works aiming to improve scheduling and screening seem to be the most popular areas of research and they opine that the quality of the papers has increased over the survey period. However, few papers provide enough detail of model implementation.

2.2 Accident & Emergency and Outpatient Clinics

It is clear, then, that there are many studies of specific departments of hospitals, of which the most common seem to be Accident and Emergency Departments (A&E), followed by outpatient clinics, operational theaters, laboratories and screening facilities such as MRI. It is interesting to speculate why there are so many simulation models of A&E., such as Miller et al

(2004), Sinreich and Marmor (2004) and Shiozaki (2004). One obvious reason is that they are the public face of the hospital for many members of the public and problems with waiting time quickly become public knowledge. A second likely reason, though, is that these departments are relatively self-contained and are required to cope with highly variable and exogenous demand for their services. This does not mean that successful A&E simulations are easy to develop, which is an issue discussed in Carter and Blake (2004), which mentions problems in tracking doctors and in data collection. The same authors discuss some of the issues to be faced when attempting more generic simulation models that might be applied, by suitable parameterization, to different A&E departments.

Studies of outpatient clinics are also popular, which may not be surprising since they have some characteristics that are similar to A&E, even though objectives may differ. In these applications, the focus tends to be on scheduling and capacity planning, as in Levy (1989). Lehaney et al (1998) describes a simulation study of an outpatient department and argues that the use of a graphical interface and visual elements are critical for gaining client's confidence and attention. Kuljis et al (2001) presents a generic outpatient clinics model, CLINSIM, that was built for UK Department of Health. It simulates how operating policy can influence patient waiting times. Like Lehaney et al (op cit) this also emphasizes the importance of information visualization and iconic animation. The model has been used 20 clinics in the UK, apparently with some success. Hashimoto and Bell (1996) is another example of a simulation of an outpatient clinic, in this case focusing on staffing and patient scheduling.

Also at clinic level, Swisher et al (2001) model a network of family practice clinics in the US. They first built one clinic model as a template and used it, suitably parameterized, for other clinics. This work is one of the examples of modeling of independent healthcare facilities replying on a common scheduling and information centre.

2.3 Hospital Level

Though there are many reports of successful simulation studies of A&E departments in individual clinics, this is not true of simulation studies of whole hospitals, which include many clinics, wards and types of treatment. This is probably because hospitals are very complex systems in which there are many components that interact to produce the performance of the hospital. This may be why other approaches, most notably system dynamics have been used in studying hospitals at a holistic level. Brailsford and Hilton (2001) compare the use of discrete event simulation and system dynamics in health care. However, it must be noted that system dynamics models are not well-suited to detailed modeling and cope rather badly with stochastic variation, which is an important issue in the demand for health care. Brailsford et al (2004) reports on a study of the use of system dynamics to model emergency and on-demand healthcare in Nottingham, UK, which includes a representation of patient flows through different departments in a hospital.

One of the very few hospital level discrete event simulation studies is reported in Moreno et al (2000). This is a simulation of a Spanish hospital intended to predict future hospital behaviour such as waiting times and queue lengths. The idea was to help hospital managers to consider the deployment of resources and the model is, to some degree, linked to the hospital's information system. There are three sub-systems in the overall model; human resources, hospital management and the dynamic model of the hospital. Patient flow resides at the core of the model, which includes a diagrammatic representation of five major types of patient flow: medical, surgical consulting, medical hospitalization, surgical hospitalization and emergency. The model covers not only outpatients and emergency departments but also central services (labs, radiology, hematology, cardiology), wards (medical and surgical), operation theatre, intensive care unit and post anesthetic care unit.

3 SIMULATION MODELLING

No simulation model is valid for all purposes and so the intended use of the model is a crucial ingredient of any decision about what to include and exclude from the model. The main objective of our research is to develop better understanding of performance measurement in acute hospitals so as to help improve their performance. A known problem with performance measurement is that it can lead to unintended consequences, which include sub-optimization that is, local managers may focus on their own limited and short term goals (Smith, 1995). Therefore for understanding the performance of large complex systems, such as acute hospitals, it makes sense to propose a whole-system model. However, it seems reasonable to ask whether this needs to be a simulation? Would it not be much better to use approximate models, such as those provided by queuing theory? However, taking an analytical approach based on queuing theory is simply too complex if the model is to be sufficiently close to reality to be used in policy making and management. Thus, the scientific core of this work is the development of a whole-system simulation model of a set of generic acute hospitals that, by appropriate parameterization, can be tailored for use in particular acute hospitals.

The model will be a generic discrete event simulation model to represent the stochastic demand and resource deployment in a typical district general hospital (DGH). Though the model will be generic, we intend to make it fit particular DGHs by using data available from those hospitals. The model will be based around patient flows through the processes of the hospital and their interaction with resources. This will involve expert judgments.

The broad-brush operation of the model is shown in Figure 1. Two types of demand will be modeled:

1. Exogenous: which will include elective and emergency admissions organized in a specific number of omnibus diagnostic categories.
2. Endogenous: that generated by other hospital processes such as A & E, outpatient and inpatient treatments.

A typical DGH sees between 50 and 100 A & E patients each day and between 200 and 250 out-patients. It operates between 700 and 800 beds across its specialties and typical lengths of stay for inpatients are between 2 and 8 days. Thus there is considerable opportunity for complexity within the simple flows shown in figure 1. To model endogenous (internally generated) demand will require semi-aggregate data to allow the estimation of state change probabilities for patients in each omnibus diagnostic category as they move through a hospital – that is, on a macroscopic level. Exogenous demand can be modeled as individual patients – that is, on a microscopic level. Hence the model, DGHSim, will be a mesoscopic simulator – some elements will be modelled in detail (e.g. the continuing flows of patients through A & E), whereas the semi-aggregate state changes of others (e.g. elective admissions each day) can be modeled from probability distributions.

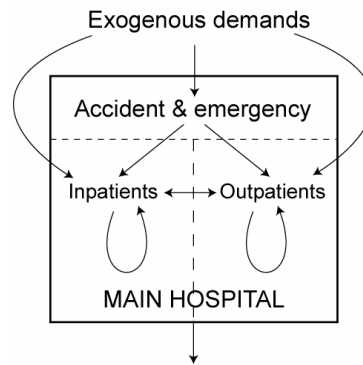


Figure 1: Outline Patient Flows

Two model-building approaches seem possible as discussed in Pidd (2004). First, to model patient flows for each omnibus diagnostic category and then to follow their progress through the hospital, all within a single, unified model. Secondly, to model each service center separately such as wards, A&E, clinics, laboratories and then to merge them in a suitable environment. We believe that the latter approach is better to tackle the complex nature of the system than the first approach and will be more appropriate given the varying level of detail across the sub-models.

4 SELECTING SIMULATION SOFTWARE FOR MODELLING HEALTH SYSTEM LOGISTICS

Using Commercial Off the Shelf (COTS) simulation software is an option to model DGHs. However the complexity of DGHs and varying levels of detail in the problem definition makes software selection more difficult. The software to be used must be able to cope with both of these modelling process issues, as well as other conventional user and modeller requirements. There are periodic surveys, of which the most comprehensive is that conducted biennially by (Swain 2003) for *OR/MS Today*, which summarises the features available in simulation packages, with the no specific application area in mind.

Hlupic (2000) surveys academic and industrial simulation software users. It reveals that Simul8™ and Witness™ are the two most common used by academics and Witness™ is the most widely used among participant industrial users. After manufacturing, health is the second application area of simulation in academics. The survey also reveals that most of the important features of software are ease of use, ease of communicating with other programming tools and applications for building a user interfaces. Eldabi and Paul (2001) evaluates three simulation packages for modelling manufacturing systems design with multiple levels of detail and concludes that none of the packages evaluated are well-suited to variable detail modelling. They suggest a methodology for classifying entities with regard to the level of detail of manufacturing system design framework.

In the following section, we examine the use of simulation VIMS for health system logistics. First, selected literature is surveyed to investigate the software packages (VIMS) used to model health systems. Secondly, we briefly summarise our experiences with selected software for modelling an A&E department.

4.1 A Literature Based Survey

There may be various reasons why a modeller selects a simulation software package to model a problem area. Selection may be based on advice from colleagues, likely costs, personal experience, reading related articles etc. In addition, there are formal approaches to simulation software evaluation and selection, such as that provided in Nikoukaran et al (1998), which

presents a hierarchical framework for criteria organized into seven main groups with several subgroups.

Papers in the literature reporting the use of a simulation model are listed in two tables in the Appendix. Table 5 deals with selected papers from a range of journals and Table 6 with selected papers from Winter Simulation Conference (WSC) proceedings. Journal papers cover the period 1999-2005 and includes those with explicit reports of simulation software use. The set of WSC papers consists of health related papers of the period 1997-2004, excluding software tutorials. In total, 20 journal and 20 WSC papers are reviewed and the results are given in Table 1 and Table 2.

The survey reveals that Simul8™ is used in 7 out of 20 selected projects reported in journals. Five of the studies are done with custom made software rather than using COTS simulation software. In the 20 WSC papers, Arena™ is used in half of the studies and 3 used custom made software. MedModel™ is used in 5 cases overall.

Table 1: Software used in selected journal papers.

Name	# of used
Simul8	7
Custom software	5
MedModel	2
Arena	1
eM-Plant	1
Excel	1
MicroSaint	1
Modsim	1
XCell+	1

Table 2: Software used in selected WSC papers.

Name	# of used
Arena	10
Custom software	3
MedModel	3
Witness	2
Extend	1
ProModel	1

We aimed to include only most recent studies and therefore some papers coincide with the papers reviewed by Jun et al (1999) and Fone et al (2003) literature surveys. A more extensive study can be done by including papers in these surveys.

4.2 Experiences Using Simulation Software

To check the features of some available packages, we modeled a notional A&E Department of an imaginary hospital using the four packages listed in Table 3.

Table 3: Simulation Software Used.

VIMS Software Name	Version
<i>Micro Saint Sharp</i> ™	2.0
<i>MedModel</i> ™	6.0
<i>Simul8</i> ™	4.0
<i>Witness</i> ™	2002

The A&E process simulated combines and simplifies the features of the A&E departments described in the reference articles. It starts with patient arrivals either by ambulance or directly. Triage and registration is done on the way for ambulance patients, whereas direct arrivals are triaged by a nurse after registration by a clerk. The key node is the doctor's initial examination, since test and treatment needs are decided at this point. Depending on a patient's illness or injury severity, diagnostic tests are ordered, or if this is thought unnecessary the patient is forwarded to nurse treatment. Laboratories and screening facilities are included in the models in a minimum level of detail. Doctor re-evaluation is done after tests and if surgery is

required, patient is forwarded to an operating theatre. At the end of all processes, patients are either “admitted to hospital” or “discharged”. Human resources are “Doctors”, “Nurses”, “Clerks” and they work 8-hour shifts.

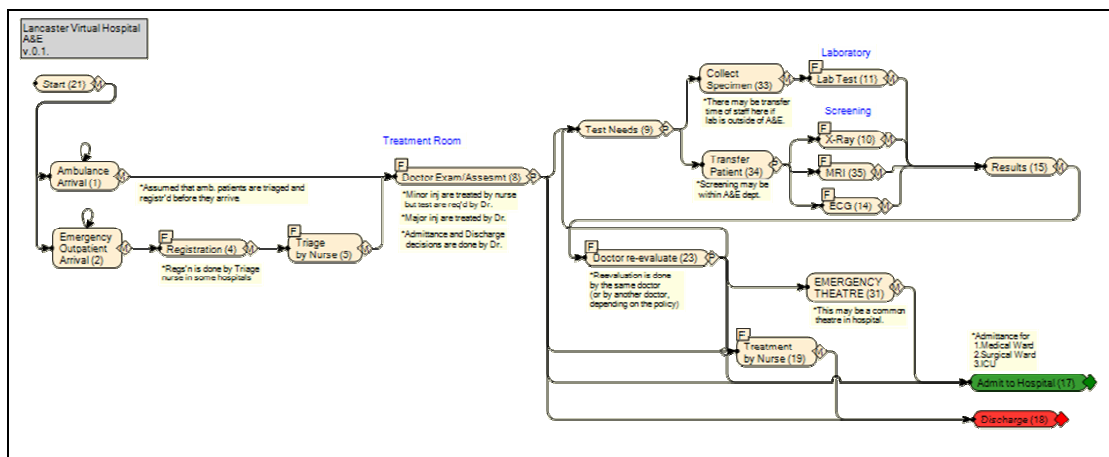


Figure 2: General Flow Chart of assumed A&E Department. (This chart is drawn using Micro Saint Sharp™ 2.0)

Using any of these selected VIMS software; it is easy to model such a system. But even though they are much like the same, there still exist weaknesses and advantageous features. Table 4 shows the comparison of our modelling experience. Main categories are Modeling, Programming, Entity and Resource.

Table 4: Comparison of selected simulation software.

	Micro Saint Sharp™ v2	MedModel™ v4	Simul8™ v4	Witness™ 2002
Modeling				
Object types	Task, sub-networks, groups (Queues are attached to Tasks.)	Locations, Entities, Path Networks, Resources,	Work centers, work entry&exit points, storage (queues), conveyers, resources.	Machines, buffers, labor, conveyor etc... (There are more items in Designer Elements palette)
Animation-2D	Iconize, after the network is built	Iconize, as the model is built	Iconize, as the model is built	Iconize, as the model is built
Diagrammatic Process Flow	Yes, Easy to create	Yes, With icons.	Yes, With icons.	Yes, Process view can be seen
Warm-up Period	No, It must be coded explicitly	Yes, It can be specified	Yes, It can be specified	Yes, It can be specified
Simulation Speed	Very fast, adjustable	Very fast, adjustable	Very fast, adjustable	Very fast, adjustable
Data Collection	Via snapshots, charts, printOut function	Automatically (As time series or basic)	Automatically	Automatically
Run length	It must be coded explicitly (e.g.if clock==1440 then Model.Halt(;))	Yes, It can be specified	Yes, Can be set as "Results collection period"	Yes, "Stop time at..." box.
Queue Management	Queues are attached to Tasks, different disciplines can be selected.	Queues are attached to "Locations". Different disciplines can be given (FIFO, LIFO, order by att.)	Que capacity, shelf life can be specified.	Buffers are manageable objects
Arrivals	No, Can be defined only by coding. (from "Timing tab" of generator-loop task)	Yes, Can be defined by "Arrival Cycle Editor"	Yes, Different arrival distributions for different time slots can be given.	Yes, Different arrival rates can be entered by input text files.
Programming				
Language	C#	Logic Elements	Visual Logic	Actions and rules (BASIC)
Need	Yes, Must write code to gain full advantage (e.g. Shift patterns, arrival patterns)	Yes, Resource use, parameters to statistical distributions, variable, graphic changes must be coded. (e.g. USE DR ,20 for E(20))	Yes, Basic things can be done without coding. (e.g.No need to code for shift&arrival patterns)	Yes, Build in functions can be used to do things.
Communication with Windows Applications	It can read/write from/to Excel, web service, ADO source and text.	Arrays can be imported from Excel. Data plots can be imported to Excel.	It can read Excel files, dynamically linked.	It can link Excel spreadsheets, read and write data to/from.
Global variables	Yes, Data types: Integer, floating, Boolean, Entity, arbitrary, string, object, hashtable.	Yes, Data types: Integer, real	Yes, Data types: Number, Text, Time, Spreadsheet (can copy/paste to/from Excel)	Yes, As Designer Elements Data types: Integer, real, name, string.
Arrays	Yes, All data types can be defined as arrays.	Yes, Integer, real types. Can be exported or imported to/from Excel	Yes, As defined in Spreadsheet variable type.	Yes, All data types can be defined as arrays.
Entity				
Name	Entities are "Patients" and "Tests"	Entity	Work Item	Parts
Attributes	Yes, Data types: String, number, boolean, object, array, entity	Yes, Data types: Integer, real	Yes, Data types: Text and number	Yes, Data types: Integer, real, name, string
Types	One entity type	One entity type exists, but different names can be given to create different types of entities.	As many entity type as you want	As many entity type as you want
After processing an entity	The same entity leaves the task	A different type of entity can leave	A different type of entity can leave (e.g. a test request may leave after doctor treatment of a patient)	A different type of entity can leave
Resource				
Ease of usage	Resources are "Doctors", "Nurses", "Clerks".	Resources are "Doctors", "Nurses", "Clerks".	Resources are "Doctors", "Nurses", "Clerks".	Resources are "Doctors", "Nurses", "Clerks".
Ease of usage	Coding needed (e.g. "numberofDoctors--;")	No coding needed, (done via GUI, points must be specified where resources will be used)	No coding needed, (done via GUI)	No coding needed, (just typing the name of resource)
Shift assignment	No shortcut for shifts. Coding is needed.	Yes, Easy to define shifts by "Shift Editor"	Yes, Easy to define shifts by "Shift Patterns" editor.	Yes, Easy to define.
"Process efficiency" and "Downtime" entry	No, It must be coded explicitly	Yes, Downtimes can be set.	Yes, Detailed efficiency for the processes can be specified. (e.g. breakdowns & recoveries)	Yes, Downtimes, setup times can be set.

5 CONCLUSION

Performance measurement exists in virtually all organizations, in both the public and private sectors and in the UK, as the biggest public organization, the NHS has a performance measurement framework. On the other hand, it has been known for many years that badly designed performance regimes lead to game playing by those whose performance is being measured – that is, targets affect behavior in ways other than those intended.

It seems sensible to assume that availability of systems' models, preferable with some generic features, would enable the development of better performance metrics and measurement systems. DGHSim should provide the basis of a scientifically-based, analytical approach with benefits for local managers in district general hospitals, those responsible for NHS performance assessment, and the wider research community. DGHSim is being developed at the level of the individual hospital and hence it is here that its initial benefits will first be realised in the sites selected for our research. The model will be designed to help local hospital managers identify the cause of problems and explore how they may best be resolved. A key task for our research is to assess how the value of models for local use need to be specifically tailored.

DGHSim is also being developed to improve the bases of performance assessment frameworks by allowing policy staff to:

- Assess the potential systemic impacts of proposed changes to the performance assessment regime, particularly with regard to waiting times;
- Evaluate whether the currently regulatory regime is satisfactory;
- Suggest alternative approaches that would lead to improvement from the perspective of patients;
- Improve regulation of performance by enabling checks on gaming analysis from analyses based on audited data.

Experience with the selected VIMS packages revealed that each has minor pluses and minuses, but otherwise they are very similar. In all cases, the modelling simple processes is easy to do whereas, as the complexity increases, limitations appear. An alternative to use VIMS software is to write custom software with simulation libraries but the drawbacks for this approach are evident; development time, customization etc. At the time of writing, conceptual modeling is underway and we expect to give more technical account in the future.

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APPENDIX

Table 5: Selected Journal Papers

No	Reference	Software Used	Place of Modelling	Purpose of Study
1	Ledlow G.R., Bradshaw D.M., Perry M.J. (1999), Animated Simulation: a Valuable Decision Support Tool for Practice Improvement. <i>Journal of Healthcare Management</i> 44-2.	MedModel	Clinic	Design
2	Eldabi T., Paul R.J., Taylor S.J.E. (1999) Computer Simulation in Healthcare Decision Making. <i>Computers & Industrial Engineering</i> 37, 235-238	Simul8	Clinic	Breast cancer treatment trial
3	Lehanev B, Clarke SA, Paul RJ (1999) A case of an intervention in an outpatients department. <i>J Ops Res Soc</i> , 50, 877-891	Simul8	Dermatology Out-patient Clinic	Waiting times
4	Kim SC, I Horowitz, K.K. Young, TA. Buckley (1999) Analysis of capacity management of the intensive care unit in a hospital. <i>European Journal of Operational Research</i> 115, 36-46.	XCELL+	ICU	Capacity utilization
5	Bagust A., M. Place and J.W Posnett (1999) Dynamics of bed use in accommodating emergency admissions: stochastic simulation model. <i>BMJ</i> 1999;319;155-158.	Excel	A&E	Waiting times
6	Moreno L., R.M. Aguilar, C.A. Martin, J.D. Pineiro, J.I. Estevez, J.F. Sigut, J.L. Sanchez. (2000) Patient-centered simulation to aid decision-making in hospital management. <i>Simulation</i> . 74, 5, 290-304.	MODSIM Modula2 based language	Hospital	General
7	Kuljis J., Paul RJ., Chen CM. (2001) Visualization and Simulation: Two sides of the same coin? <i>Simulation</i> 77 (3-4) 141-152	Custom Software CLINSIM	Generic Clinic	General
8	Pulat PS, Kasap S, Splinter GL (2001). Simulation study of an ideal primary care delivery system. <i>Simulation</i> 76 (2): 78-86	Arena	Hospital	Bed capacity planning
9	Swisher J.R., Jacobson S.H., Jun J.B, Balci O. (2001). Modelling and Analyzing a Physician Clinic Environment Using Discrete-event (visual) Simulation. <i>Computers & Operations Research</i> 28, 105-125	Custom Software with Visual Simulation Environment	Clinics	General
10	Groothuis S., van Merode G.G., Hasman A. (2001) Simulation as decision tool for capacity planning. <i>Computer Methods and Programs in Biomedicine</i> 66, 139-151.	MedModel	Cardiac Dept.	Capacity planning
11	Harper PR, AK Shahani (2002) Modelling for the planning and management of bed capacities in hospitals. <i>Jnl Ops Res.Soc.</i> 53, 11-18.	Custom Software TOCHSIM	Hospital	Bed capacity
12	Couchman A., Jones D.I., Griffiths K.D. (2002) Predicting the future performance of a clinical biochemistry laboratory by computer simulation. <i>Simulation Modelling Practice and Theory</i> 10, 473-495	Simul8	Biochemistry Laboratory	Capacity planning
13	Harper P.R., H.M. Gamlin (2003) Reduced outpatient waiting times with improved appointment scheduling: a simulation modelling approach. <i>OR Spectrum</i> , 25: 207-222.	Simul8	ENT Clinic	Appointment Scheduling
14	Syi Sua, Chung-Liang Shihb (2003), Modeling an emergency medical services system using computer simulation. <i>International Journal of Medical Informatics</i> 72, 57-72	eM-Plant	A&E	Emergency response policy
15	Baldwin L. P.,T. Eldabi, R.J. Paul (2004) Simulation in healthcare management: a soft approach (MAPIU). <i>Simulation Modelling Practice and Theory</i> , 12 541-557.	Simul8	Clinic	Liver transplantation
16	Griffiths JD, N Price-Lloyd, M Smithies, JE Williams (2005) Modelling the requirement for supplementary nurses in an inten-	Simul8	ICU	Nurse scheduling and number of nurses

	sive care unit. <i>Jnl Ops Res Soc.</i> , 56, 126–133.			required.
17	Ashton R., L Hague, M Brandreth, D Worthington, S Cropper (2005) A simulation-based study of a NHS Walk-in Centre. <i>Jnl Ops Res Soc.</i> , 56, 153–161.	Micro Saint	Walk in Centre	Design and plan of operations of a Walk in centre
18	Rauner MS, SC Brailsford, S Flessa (2005) Use of discrete-event simulation to evaluate strategies for the prevention of mother-to-child transmission of HIV in developing countries. <i>Jnl Ops Res Soc.</i> , 56, 222–233	Custom Software with patient-oriented simulation technique (POST)	Disease Prevention	HIV prevention
19	Van der Meer RB, LA Rymaszewski, H Findlay, J Curran (2005) Using OR to support the development of an integrated musculo-skeletal service. <i>Jnl Ops Res Soc.</i> , 56, 162–172	Simul8	Musculo-skeletal service in a hospital	Waiting times
20	Harper PR, S Phillips, JE Gallagher (2005) Geographical simulation modelling for the regional planning of oral and maxillofacial surgery across London. <i>Jnl Ops Res Soc.</i> , 56, 134–143.	Custom Software with TOCHSIM library	London area	Oral and maxillofacial surgery planning & scheduling

Table 6: Selected Winter Simulation Conference Papers.

No	Reference	Software Used	Place of Modelling	Purpose of Study
1	Swisher J.R., B. Jun, S.H. Jacobson, O.Balci (1997). Simulation of the Qestion Physician Network. Proceedings of the 1997 Winter Simulation Conference.	Custom Software Visual Simulation Environment	Clinic	General
2	Pitt M. (1997). A Generalised Simulation System to Support Strategic Resource Planning in Healthcare. Proceedings of the 1997 Winter Simulation Conference.	Witness + VB interface	Hospital	Bed size planning (PRISM project is funded by EPSRC)
3	Barnes C.D., J.L.Quason, C.Benson, D.McGuiness. (1997). Success stories in simulation in health care. Proceedings of the 1997 Winter Simulation Conference.	Witness	Outpatient clinic	pre-op procedures, space utilization and outpatient studies
4	Johnson W.C. (1998). Birth of a new maternity process. Proceedings of the 1998 Winter Simulation Conference.	MedModel	Maternity ward	Capacity planning
5	Rossetti M.D., Trzcinski G.F., Syverud S.A. (1999). Emergency Department simulation and determination of optimal attending physician staffing schedules. Proceedings of the 1999 Winter Simulation Conference.	Arena	A&E	Staffing, scheduling.
6	Lowery J.C., J.A. Davies. (1999). Determination of operating room requirements using simulation. Proceedings of the 1999 Winter Simulation Conference.	MedModel	Operational Theatre	Size, scheduling.
7	Cahill W., Render M. (1999). Dynamic simulation modelling of ICU bed availability. Proceedings of the 1999 Winter Simulation Conference.	Arena	ICU	Bed size planning
8	Weng M.L., A.A. Houshmand. (1999). Healthcare simulation: A case study at a local clinic. Proceedings of the 1999 Winter Simulation Conference.	Arena	Clinic	A new performance measure, cash flow.
9	Alvarez A.M., Centeno M.A. (1999). Enhancing simulation models for emergency rooms using VBA. Proceedings of the 1999 Winter Simulation Conference.	Arena	A&E	General
10	Ramis F.J., Palma J.L., Estrada V.F., Coscolla G. (2002). A simulator to improve patient's service in a network of clinic laboratories. Proceedings of the 2002 Winter Simulation Conference.	Arena + Excel	Laboratory	Standardize the service processes, the assignment of personnel and to guide investment decisions
11	Eleazer M., Gronhaug R., Haugene K. (2003). Proposals to reduce over-crowding, lengthy stays and improve patient care: Study of the geriatric department in Norway's largest hospital. Proceedings of the 2003 Winter Simulation Conference.	ProModel	Geriatric Department	Bed size, LOS.
12	Blasak R.E., Armel W.S., Starks D.W., Hayduk M.C. (2003). The use of simulation to evaluate hospital operations between the emergency department and a medical telemetry unit. Proceedings of the 2003 Winter Simulation Conference.	Arena	A&E	Waiting time
13	Wong C., Geiger G., Derman Y.D., Busby C.R., Carter M.W. (2003). Redesigning the medication ordering, dispensing and administration process in an acute care academic health sciences centre. Proceedings of the 2003 Winter Simulation Conference.	MedModel	Hospital	Medication ordering, dispensing
14	Baesler F.F., H.E. Jahnsen, M. DaCosta (2003) The use of simulation and design of experiments for estimating maximum capacity in an emergency room. Proceedings of the 2003 Winter Simulation Conference.	Arena	A&E	Bed and staff capacity
15	Miller M.J., Ferrin D.M., Szymanski J.M. (2003) Simulating six sigma improvement ideas for hospital emergency department. Proceedings of the 2003 Winter Simulation Conference.	Extend + Visio + Access	A&E	Process improvements
16	Centeno M.A., Giachetti R., Linn R., Ismail A.M. (2003) A simulation – ILP based tool for scheduling ER staff. Proceedings of the 2003 Winter Simulation Conference.	Arena	A&E	Number of staff required, scheduling

17	Guo M., Wagner M., West C. (2004) Outpatient clinic scheduling – a simulation approach. Proceedings of the 2004 Winter Simulation Conference.	Arena	Outpatient Clinic	Appointment scheduling
18	Miller M.J., Ferrin D.M., Messer M.G. (2004) Fixing the emergency department: A transformational journey with EDSim. Proceedings of the 2004 Winter Simulation Conference.	Custom Software EDSim	A&E	General
19	Takakuwa S., Shiozaki H. (2004) Functional analysis for operating emergency department of a general hospital. Proceedings of the 2004 Winter Simulation Conference.	Arena	A&E	Waiting times, patient flows
20	Sinreich D., Marmor Y.N. (2004) A simple and intuitive simulation tool for analyzing emergency department operations. Proceedings of the 2004 Winter Simulation Conference.	Custom Software	A&E	General *A generic A&E modelling study.