Proceedings of the 2005 Winter Simulation Conference
M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, eds.

SIMULATION MODELLING FOR PERFORMANCE MEASUREMENT IN HEALTHCARE

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ABSTRACT

Discrete event simulation is widely used to model healthcare systems with a view to their improvement. Most applications focus on discrete aspects of healthcare, such as accident and emergency rooms or outpatient clinics. 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 development of such a policy-oriented model, aimed at improving performance assessment in the UK National Health Service.

1 INTRODUCTION

Heathcare expenditure has increased massively in the last decade and this trend is likely to continue. Total expenditure on heathcare in the US in 2004 is estimated at $1.6 trillion (Pierskalla, 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 though hospitals, so that the benefits can be realised. That is the logistics of heathcare, 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, whist spending as little as possible.

In the UK, most heathcare 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 heathcare 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 starrated 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.

2 PERFORMANCE IMPROVEMENT AND MEASUREMENT IN THE NHS

The NHS is the largest organization in Europe and performs well in international comparisons of the efficiency of health as measured by the World Health Organization (About the NHS, 2005). Like many public bodies it undergoes periodic reorganization and its current structure in England is shown in Figure 1. Most public heathcare is delivered through NHS Trusts, of which the 5 main types are shown in Figure 1. Primary Care Trusts (PCTs) are the major interface between the NHS and the public. PCTs are regional organizations and provide and manage a range of health services. As their name suggests, they are primarily responsible for primary care, through general practitioners (GPs) and dentists, in addition they purchase hospital services for their populations. The services they buy are mainly provided by NHS Hospital Trusts (for acute care) and Mental Health Trusts (for psychiatric care). All of these services (except many pharmaceuticals) are free at the point of need for everyone living in the UK, funded by taxation. GPs operate clinics for their patients and refer patients to hospitals or community services, should specialist treatment and support be needed. This care is paid for by the PCT, the revenue accruing to the NHS Trust that provides the services. Both purchaser and provider Trusts are expected to balance their books and are expected to meet quality standards prescribed in the performance assessment framework.

Waiting time targets are a major element of the current NHS performance assessment framework in England and play an important role in determining the star rating of NHS Trusts. The targets, which have changed and become more stringent through time, have included waiting times for emergency treatment, planned inpatients, outpatients and readmissions. NHS Trusts are allowed some leeway in achieving these targets: for example, in 2002/3 no more than 8 patients should wait more than 12 hours for emergency admission. If that target is breached, a Trust would be labeled as 'underachieving' (9 to 50 breaches) or 'significantly underachieving (up to 50 breaches).

These targets for outpatients and for inpatients (or day-case admissions) have been made more demanding and will continue to be so. The most recent target specifies that, by 2008 no-one waits more than 18 weeks from GP referral to hospital treatment for acute hospital care. Average waits in 2008 are expected to be around nine weeks from GP referral to treatment, with waits for an outpatient consultation not normally exceeding six weeks (Department of Health, 2004). However there is no published analysis showing how this target, and others, will be achieved. If, for example, hospitals lack the resources or information and know-how to operate with such short waiting times, there will be high costs from them being in a state of permanent crisis, or having significant extra capacity that is under-utilized, or possibly both. In particular, this targeting seems to ignore possible interaction with other performance indicators.

Though it seems that the target regime has been effective in reducing waiting times for heathcare in England, there is no substantive analysis of whether proposed future targets are feasible. There is also no way to be sure that NHS Trusts are not making some, unmeasured services worse by diverting resources into service aspects that are measured. Thus, the time is ripe for attempting some holistic, dynamic modeling of the operations of hospitals with a view to assessing their capacity and to gain some understanding of the real, possibly hidden, effects of the performance assessment framework.

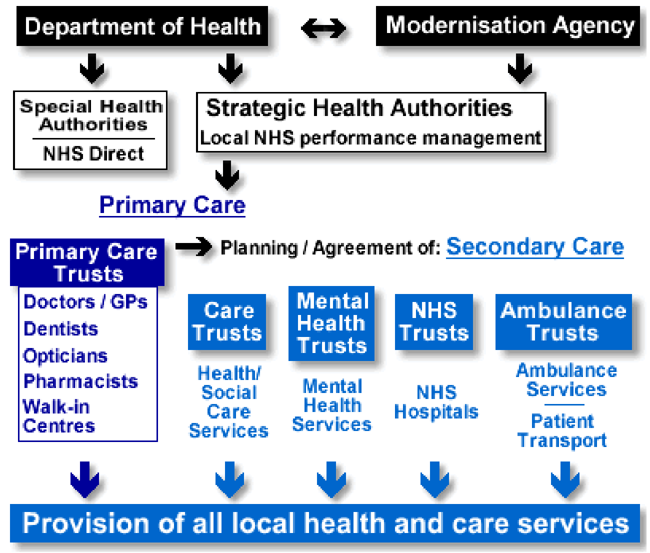

Figure 1: The new structure of NHS in England

3 SIMULATION IN HEATHCARE

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

3.1 Literature Surveys

There have been periodic reviews of simulation applications in heathcare. 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 (1996).

Fone et al. (2003), is a systematic review of the literature related to the use of simulation modeling in heathcare 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.

3.2 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 Takakuwa 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 et al. (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.

3.3 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 heathcare. 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 heathcare. 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.

4 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 2. 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 2. 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.

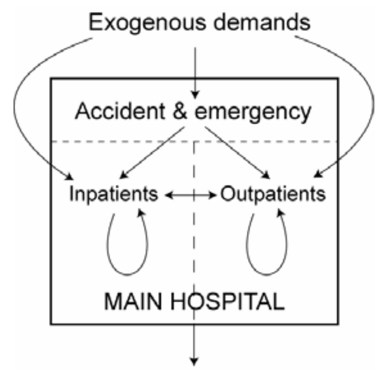

Figure 2: Outline Patient Flows

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.

At the time of writing, conceptual modeling is underway and we expect to give a more technical account at the conference.

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.

ACKNOWLEDGMENTS

This research is funded by the Engineering and Physical Sciences Research Council (EPSRC) in the UK under grant EP/C010752/1. Research collaborators are Gwyn Bevan and Alec Morton (London School of Economics), Peter C. Smith (University of York), Morecambe Bay Hospitals Trust, Royal Orthopaedic Hospitals Trust and the Department of Health.

REFERENCES

About the NHS. 2005. About the NHS – How the NHS works [online]. Available via <http://www.nhs.uk/England/AboutTheNhs/Default.cmsx> [accessed March 14, 2005].

Brailsford S.C. and N.A. Hilton. 2001. A comparison of discrete event simulation and system dynamics for modeling healthcare systems. In: Riley J (ed.) *Proceedings from ORAHS 2000*, Glasgow, Scotland, 18-39.

Brailsford S.C., V.A. Lattimer, P. Tarnaras, J.C. Turnbull. 2004. Emergency and on-demand heathcare: modelling a large complex system. *Journal of Operational Research Society*, 55: 34-42.

Carter M.W. and J.T. Blake. 2004. Using simulation in an acute-care hospital: Easier said than done. In: Bradeau M.L., F. Sainfort, W.P. Pierskalla (eds.) *Operations Research and Heathcare*. Kluwer. Boston.

Davies R. 1985. An assessment of models of a health system. *Journal of Operational Research Society*. 1985; 36(8): 679–686.

Department of Health. 2004. National Standards, Local Action. Health and Social Care Standards and Planning Framework 2005/6-2007/8. Department of Health, London.

Fetter R.B. and Thompson J.D. 1965. The simulation of hospital systems. *Operations Research*. 13: 689-711.

Fone D., S. Hollinghurst, M. Temple, A. Round, N. Lester, A. Weightman, R. Roberts, E. Coyle, G. Bevan, S. Palmer. 2003. Systematic Review of the use and value of computer simulation modelling in population health and heathcare delivery. *Journal of Public Health Medicine*. 25 (4): 325-35.

Hashimoto F. and S. Bell. 1996. Improving outpatient clinic staffing and scheduling with computer simulation. *Journal General Internal Medicine* 11: 182-184.

Jun J.B., S.H. Jacobson, J.R. Swisher. 1999. Applications of discrete event simulation in heathcare clinics: a survey *Journal of Operational Research Society* 50: 109-23.

Kuljis J., R.J. Paul, C.M. Chen. 2001. Visualization and Simulation: Two sides of the same coin? *Simulation* 77(3-4): 141-152.

Lehaney B. and V. Hlupic. 1995. Simulation modelling for resource allocation and planning in the health sector. *Journal Royal Society of Health*. 115(6): 382–385.

Lehaney B. and R. Paul. 1996. The use of soft systems methodology in the development of a simulation of outpatient services at Watford General Hospital. *Journal of Operational Research Society*. 47: 864-870.

Lehaney B., S. Clarke, H. Kogetsidis. 1998. Simulating hospital patient flows. *Journal Royal Society of Health*. 118(4): 213-216.

Levy J.L., B.A. Watford, V.T. Owen. 1989. Simulation analysis of an outpatient services facility. *Journal of Health Systems*. 1: 35-49.

Miller M.J., D.M. Ferrin, M.G. Messer. 2004. Fixing the Emergency Department: A Transformational Journey With EDSIM. *Proceedings of the 2004 Winter Simulation Conference*, R .G. In-galls, M. D. Rossetti, J. S. Smith, and B. A. Peters (eds.), 1988-1993.

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. *Simulation*. 74(5): 290-304.

Pierskalla W.P. 2004. Heathcare delivery. Plenary address to the INFORMS annual meeting, Denver CO, October 2004.

Pidd M. 2004. *Computer simulation in management science* (5th edition). John Wiley & Sons, Chichester.

Sinreich D. and Y.N. Marmor. 2004. A Simple and Intuitive Simulation Tool for Analyzing Emergency Department Operations. *Proceedings of the 2004 Winter Simulation Conference*, R .G. Ingalls, M. D. Rossetti, J. S. Smith, and B. A. Peters (eds.), 1994-2002.

Smith P.C. 1995. On the unintended consequences of publishing performance data in the public sector. *International Journal of Public Administration*, 18(2&3): 277-310.

Swisher J.R., S.H. Jacobson, J.B. Jun, O. Balci. 2001. Modelling and Analyzing a Physician Clinic Environment Using Discrete-event (visual) Simulation. *Computers & Operations Research*. 28: 105-125.

Takakuwa S. and H. Shiozaki. 2004. Functional Analysis for Operating Emergency Department of a General Hospital. *Proceedings of the 2004 Winter Simulation Conference*, R .G. Ingalls, M. D. Rossetti, J. S. Smith, and B. A. Peters (eds.), 2003-2011.

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