Issue 3.4 # Nosokinetics News August 2006

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Pressure and Force or Space and Time

In May 2006, the NHS Confederation concluded that advances in technology and new ways of treating patients will continue to shorten length of stay, so fewer acute hospital beds will be needed. Later, listening to the rhetoric of a young management consultant using the latest three stage Harvard Business School concept – Authorisation, Information and Incentives – forcing 'THEM' to change, I began to despair.

Then I read a 1784 translation of Aesop's fable about the Crow and the Pitcher and I cheered up.

> 'Faced with the problem of getting water out of a pitcher, the crow saw some pebbles lying by. One by one he cast them into the pitcher; and thus, by degrees, raised the water up to the very brim, and satisfied his thirst'. The moral being:
>
> 'We cannot compass by force, we may by invention and industry.'

Changing human activity systems is not about pressure and force, it's a question of space and time. In the 1970's it took us three to four years to change a geriatric medical service with a waiting list of 68 to a 'just-in-time" no waiting list service, but only one day to close it down [1] (Millard, 1992). What incentive is that?

Then I remembered the warm welcome we received from everyone we met, at the ECCO 2004 conference in Beirut organised by Ibrahim Osman and prayed for peace.

Acute medical patients in orthopaedic wards, surgical operations cancelled; trolley waits; ambulance by passes, avoidable sickness and increased dependency. There has to be a better way: In this issue John Preater, a mathematician, Keele University, UK explains queuing theory, illustrating the relationship between bed allocation, bed occupancy and queues. We also report collaborative research by Gary Harrison and Andrea Shafer in Charleston, South Carolina, USA and Mark Mackay in Adelaide, Australia, which has developed a model that accounts for daily, weekly and seasonal variability general medical bed occupancy and use.

1. Millard, P. H. (1992). "Throughput in a department of geriatric medicine: a problem of time, space and behaviour." Health Trends **24**: 20-24.
2. Harrison, G. W., A. Shafer, M. Mackay. (2005). "Modelling variability in hospital bed occupancy." Health Care Management Science **8**(4): 325-34.

Congratulations to Christos Vasilakis - SPARC grant.

Building on experience gained from his year spent with Dr. Boris Sobolev and the team at the Department of Health Care and Epidemiology in Vancouver, we congratulate Dr Christos Vasilakis, Westminster University, for his successful grant application to the EPSRC Strategic Promotion of Ageing Research Capacity. **Developing capacity for evaluating proposed policies in the care for older patients through computer simulations,** 12 months, £38,838 Chris is collaborating with Dr Chooi Lee at Kingston Hospital.

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A Word on Queueing Networks

John Preater, Mathematics Department, Keele University

Editor's comment. Extracts from an email conversation between Roy Johnston and John Preater on queueing networks, or 'queues within queues', have appeared in recent editions of Nosokinetics News. This article comprises a brief account of these networks.

Imagine a post-office-like counter system: customers enter at random, wait in line for a free server, receive service and leave. Speaking roughly, the first half-century of the scientific study of queues was concerned with understanding such systems; the second half-century — bringing us up to the present day — has, additionally, glued these individual queues together to form a network in which customers departing from one queue may join another. This upward step of complexity is motivated by mathematical inquisitiveness together with applications in computer science and manufacturing systems, but it could equally have been prompted by patient flow through health care systems.

One may identify four kinds of queue, illustrated in Figure 1 [these diagrams are taken from a bibliography of queues in health and medicine covering years to 2000 which is available from myself j.preater@keele.ac.uk].

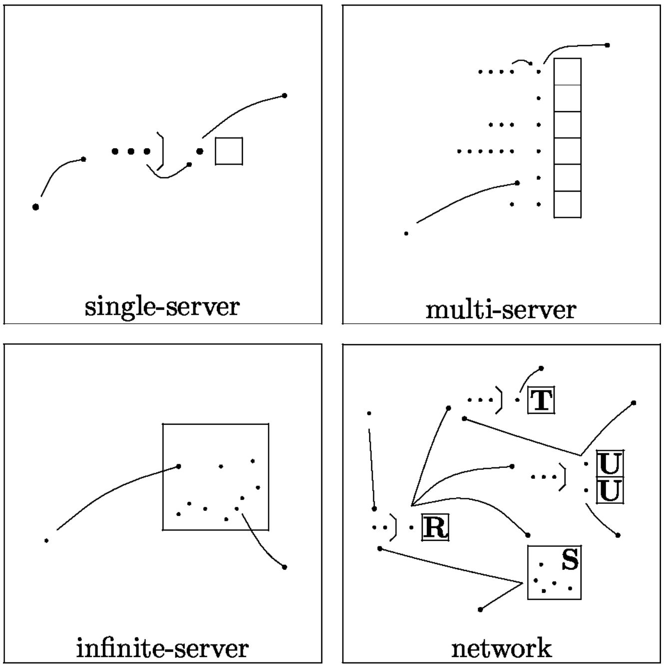


Fig 1. Types of queueing system

The simplest, single-server queue is a special case of the multi-server system already mooted. The infinite-server queue, where the length-of-stay of a customer is not dependent on the number of fellow customers, used quaintly to be proposed as a model for emergency bed provision. These are the building blocks of networks.

That depicted in the Figure comprises four *nodes:* R and T are single-server, U is 2-server and S is infinite-server. Customers - let us now say patients - enter the system by joining the queue at node R. When their service there is complete they join one of the queues at S, T or U, and from either leave the system or move to another node. Patients can therefore visit nodes more than once. The interpretation and arrangement of nodes is the prerogative of the modeller: for instance, R might represent a triage point, S a rest area, T a scanner and U a suite of treatment rooms.

For any system, the primary purpose of the network model is to understand how performance - measured by waiting times at nodes, lengths-of-stay in the system, congestion patterns, resource utilization, etc.- is affected by the architecture of the system and by the values of its parameters, such as external arrival rates, service rates and priority rules at nodes. Models may either be specific to an actual system or generic, promoting understanding. As usual, there is a tension between simplicity, graspability and clarity of analysis on the one hand and realism, relevance and plausibility on the other. There is often mileage in building more than one model for the same system.

The remainder of this article concerns a simple toy network model of Lilliput Hospital.

Lilliput Hospital Bed allocation, emptiness and trolley waits

Lilliput hospital patients arrive at rate λ at the infinite-server node A, representing acclimatization, administration and assessment. The hospital has n beds, and Lilliputians admitted when all beds are occupied are accommodated on small trolleys. Following an initial clinical decision a proportion p of patients require treatment at node B, which is modelled as a single-server, first-come-first-served queue; the other 1 - p are pronounced well and discharged.

Subsequent to treatment at B a patient moves to the infinite-server node C for recuperation and to await another clinical decision: this entails, with probability q, further treatment at B, or, with probability $1 - q$, discharge. Thus a patient may undergo several rounds of treatment. Mean lengths-of-stay at A and C are a and c, respectively, while the actual procedure at B has mean duration b.

At this point, poised to investigate how performance relates to the parameters a, b, c, p, q and n, the analyst asks, with bated breath, what are the statistical distributions of the lengths-of-stay at nodes A and C and the procedure durations at B? The answer comes back Exponential(-ish). Overjoyed the analyst proceeds to generate some results.

And here is a sample. First, for the system to be *stable,* i.e. for the mean occupancy to be finite, it is necessary that

$$\text{arrival rate} = \lambda < \lambda^* = (1 - q)/bp = \text{maximum arrival rate.}$$

Because of this it is convenient to choose as the final system parameter not λ itself, but rather

$$\text{proportion of capacity used} = x = \lambda/\lambda^*.$$

Various performance measures of interest to the hospital or the patient may then be calculated; for example:

$$\text{throughput} = \lambda = x\lambda^*,$$

$$\text{mean occupancy} = L = d + x/(1 - x),$$

$$\text{mean length-of-stay in hospital} = W = L/\lambda,$$

$$\text{probability of admission to a trolley} = p_{\text{trolley}} = 1 - \sum_{m=0}^{n-1} e^{-d}\frac{d^m}{m!}(1 - x^{n-m}),$$

where $d = \lambda(a + cp/(1 - q))$. The third formula is the apposite Little's law, which applies to most stable queueing systems.

For numerical illustration let us suppose that $n = 20$ beds, $a = 1$ day, $b = 0.2$ days, $c = 2$ days, $p = 0.8$ and $q = 0.3$. The above formulae then yield the results in Table 1 for different values of x; these evince the usual stark consequences of squeezing too close to capacity.

x	λ	L	W	p_{trolley}
0.2	0.88	3.1	3.6	0.000
0.4	1.75	6.4	3.7	0.000
0.6	2.63	10.1	3.9	0.011
0.8	3.50	15.5	4.4	0.200
0.85	3.72	17.9	4.8	0.329
0.9	3.94	21.9	5.6	0.505
0.95	4.16	32.7	7.9	0.731
0.99	4.33	113.2	26.1	0.943

We must now return to why the analyst was so relieved. The fact is that Exponential service times mean that the network is tractable mathematically. At the heart of this is the (surprising) fact that if a snapshot is taken of Lilliput Hospital then the numbers of patients at nodes A, B and C are statistically independent, having Poisson, Geometric and Poisson distributions, respectively. In other words, this is a *product-form* network, and by and large analysis of such can proceed apace without resort to simulation.

Over the last half-century the dividing line between product-form and non-product-form networks has been mapped with ever greater precision and completeness, and it gets very technical. Suffice it to say that the nice product-form would remain even if, for example, Lilliput hospital replaced B with a complex of treatment nodes among which patients moved along (up to a point) history-dependent pathways, if the service rate at a node depended on the number of patients there and if patients who could not be provided with a bed were diverted elsewhere.

But; slip in one node at which the service time has, say, a uniform distribution, or introduce dependence of one part of the system on another, or ... and the product-form is lost. This does not mean that analytical progress is impossible — it depends on the precise assumptions and what the analyst wishes to know — but things go less swimmingly.

If analytical approaches are not feasible then a simulation model is required. And this is fine. Extra system complexities can be appended with ease, performance statistics collected and a helpful user interface designed, perhaps incorporating an animation of patient flow through the system (such models are common in manufacturing). The price one pays is that conclusions are less crisp and a lot of interaction with the model may be required to acquire a reasonable understanding of system behaviour.

The best place to start to learn about queueing networks is probably selected chapters of general Operational Research texts *e.g., [1].* There are more technical treatments in [2], in the classic [3] and in [4]. Beyond this there are scores of other monographs and thousands of research articles in Operational Research and Applied Probability journals and elsewhere; these often concentrate on mathematical properties, but nevertheless have an eye to applications.

References

[1] Hillier, F. S. & Lieberman, G. J. *Introduction to Operations Research.* Pearson.
[2] Kleinrock, L. *Queueing Systems.* Wiley.
[3] Kelly, F. *Reversibility and Stochastic Networks.* Wiley.
[4] Chen, D & Yao, D. *Fundamentals of Queueing Networks: Performance, Asymptotics and Optimization.* Springer-Verlag.

PUBLISHED PAPERS

Lyratzopoulos, G., D. Havely, et al. (2005). Factors influencing emergency medical readmission risk in a UK district general hospital: A prospective study. BMC Emergency Medicine, BioMed Central. 5.

Examines factors associated with 20,209 readmissions to a Manchester hospital. Male sex, heart failure and chronic pulmonary diseases significantly associated. Shorter length of stay is associated with higher readmissions. Concludes that performance analysis should take deprivation into account.

Mackay, M. and M. Lee (2005). "Choice of Models for the Analysis and Forecasting of Hospital Beds." Health Care Management Science 8(3): 221-230.

The authors investigated model selection and assessment in relation to hospital bed compartment flow models. Training and test data related to the 1998 and 1999 calendar years. Increasing model complexity resulted in overfitting. Seasonal models were best. Results of single day census type models were similar, but inferior, to models generated from a full year of training data. The additional data make the models better able to capture the variation across the year in activity.

Breakthrough in Modelling Acute Medical Services

Harrison, G. W., A. Shafer, M. Mackay. (2005). "Modelling variability in hospital bed occupancy." <u>Health Care Management Science</u> 8(4): 325-34.

Step by step, Gary Harrison has been developing explanatory flow models of bed occupancy and use. First a dynamic two compartment model, with a what-if component, which explained why mixed exponential equation with two components fitted midnight bed occupancy data in thirteen UK departments of geriatric medicine (short stay one month; long stay two years). Then a three compartmental model based on a midnight bed state in a large UK psychiatric hospital (short stay three months, medium stay two years and long stay twenty-five years.

Verification of a mixed exponential fit to midnight beds states in acute medical services (acute care seven days, longer stay two months) led to further exploration of bed occupancy patterns in other services. Early criticism of these tools in acute services focused on the use of midnight bed states and the variable, daily, weekly, seasonal demand for admissions to acute hospital care. Now, in collaborative work with Mark Mackay from Adelaide, Gary has developed a model which follows the daily trajectories of acute patient care, thus creating a model of the average days bed use: i.e. Sunday, Monday, Tuesday, Wednesday etc admissions, revealing three stages:

First stage: new patients (7%) of all patients admitted are released on the first day,
Second stage: short stay leave within days; three in every hundred become longer stay, and
Third stage: longer stay leave within weeks.

Overall, upon admission the expected length of stay is 6.3 days, but for a patient who has been in the hospital 10 days the expected additional stay is 9.1 days. Moreover, though only 10.5% of the admitted patients are longer stay when they are discharged, they occupy 22.4% of the beds.

The model can simulate the resources needed as demand grows and shows the benefits to be gained by smoothing admission and discharge rates. It also explains the complex relationship between bed allocation, bed occupancy and emptiness. The model is both flexible and portable. The data used is already being collected. The work was done using Microsoft Excel and Visual Basic and sample spreadsheets are available from harrisong@cofc.edu

Darrab, A. A., J. Fan, et al. (2006). "How does fast track affect quality of care in the emergency department?" <u>European Journal of Emergency Medicine</u> 13(1): 32-35.

Fast tracking of non-urgent patients, between 13.00 and 19.00 hours, significantly shortened their length of stay without compromising urgent care. Used Canadian Triageand Acuity scale; data collection covered one week in August 2002 and 2003. Studies in other centres over longer periods are needed to confirm or refute this finding.

Kulinskraya, E., D. Kornbrot, et al. (2005). "Length of stay as a performance indicator: a robust statistical methodology." <u>IMA Journal of Management Mathematics</u> 16(4): 369-381.

NHS data. Compares standard general linear models with truncated maximum likelihood. Admission method, discharge destination, provider (hospital) type, specialty and NHS region all influence length of stay. Death occurs early and transfer occurs late. Since the new NHS case mix funding ignores transfers and destination at discharge, while encouraging shorter length of stay, trusts with higher mortality may be doing the best under the new system. Which is certainly not desirable from the patient's point of view.

MASHnews

Edition 3 - August 2006

REPORT BACK: - Westfocus Events - 31 May and 27 June 2006

Two recent workshops held by the Health Alliance (part of the Westfocus collaborative partnership in London) proved very successful. About forty to fifty people attended these workshops drawn from a wide range of backgrounds in health, social care, industry and research. MASHnet supported and was represented at both these events.

'Care Delivery Management' 31 May 06 Delegates at the WestFocus event gather for lunch in front of the MASHnet Banner.

The first workshop entitled 'Care Delivery Management' held on May 31st combined presentations from both healthcare managers and researchers. Houda Al-Sharifi (Director of Public Health, Richmond and Twickenham PCT) talked candidly about the practicalities of integrating modelling solutions in healthcare management and the need to put users first. Steve Gallivan (University College London) demonstrated the use of mathematical modelling in optimising the scheduling of admissions at a paediatric intensive care unit. Geraint Lewis and Maggie Iaonnou from Croydon PCT outlined the 'Virtual Wards' project where modelling is key in the identification of patients for targeted home based care; and Peter Millard (Editor of Nosokinetics) delivered a forceful rationale for modelling in the bed management of elderly care set against the background of the skewed priorities that so often accompany the political agendas in health service management. In addition, a range of poster presentations around the hall showed the potential of modelling and simulation in healthcare applications.

The second workshop 'Organisational Management' held on 27th June, focused more on modelling solutions in strategic areas. Steve Arnold (NW London Strategic Health Authority) explained a simulation using system dynamics which has been successfully used to understand and improve older people's services. Peter Lacey (Whole Systems Partnership) illustrated a wider range of areas where system dynamic solutions have been applied. Carolyn Manuel-Barkin (Matrix Research and Consultancy Ltd) discussed the key aspects of client collaboration essential to ensure successful projects and showed how her company's modelling tools can been applied and Martin Pitt (MASHnet Co-ordinator) delivered a final presentation about MASHnet and the challenges of healthcare modelling (see below).

Houda Al-Sharifi explains the challenges of integrating healthcare modelling solutions into real-world health management

In general the Westfocus events demonstrated the importance of bringing practitioners from differing backgrounds together. It is only a shame that this initiative cannot be sustained over a longer period to maintain an on-going active relationship between these groups.

MASHnet - Overcoming the Obstacles to Healthcare Modelling and Simulation

Based on presentations given by Ken Stein at the MASHnet Conferencein Cardiff (May 2nd 2006) and Martin Pitt at 'Organisation Care' event hosted by Westfocus (London 27th June 2006).

MASHnet is now one and a half years old and half way through its initial funding phase. Much of the network's impetus is to understand why the evident potential of modelling and simulation in healthcare has not been more obviously realised in practice. The mismatch between the evident research interest and potential on the one hand and the lack of successful implementations in healthcare modelling and simulation on the other, presents a frustrating scenario. Take for example the following excerpts from two recent reviews in the area.

- "Despite the increasing numbers of quality papers published in medical or health services research journals we were unable to reach any conclusion on the value of modelling in health care because the evidence of implementation was so scant." – *Fone et al 2003*
- "Despite the wealth of contributions, relatively few academic papers on health issues on Operational Research or Management Science journals address issues of outcome, implementation, or the use of the work reported." – *Bensley and Davies 2005*

Against this background MASHnet has brought together the key players in healthcare, research and industry to address the critical questions as to why modelling is not more widely applied in healthcare, and what actions are necessary to enable this potential to be more clearly realised.

At the MASHnet launch in September 2005 around 80 participants from a wide range of backgrounds attended. A key part of the day was the break-out sessions where in ten separate groups delegates were asked to answer a series of four basic questions from the point of view of each of the three communities (healthcare, research and industry). These outputs are summarized in the tables below (more detail about these outputs is given on the MASHnet website):

Question 1: WHY IS HEALTHCARE MODELLING IMPORTANT?

Health Services:	Academic Research	Industry
Improve effectiveness and efficiency- save resources, improve staff morale, deliver better care Greater understanding Act as a basis for shared understanding and dialogue Support evidence based decision making	A basis for publications, research projects, resources. A means to improve RAE grading Add value to the NHS – tangible outcomes from work	Basis for profit, Large consistent sector (good health is not likely to go out of fashion very soon) Help the NHS. Worthy objectives. Generation of Good will etc.

If there is any general message from this table is it one of opportunity. Specifically with the increasing emphasis on 'evidence based' medicine it seems meaningful to call for more 'evidence based' management. Modelling and simulation tools clearly have a central role in providing this.

Question 2: WHAT ARE THE MAIN OBSTACLES?

Health Services:	Academic Research	Industry
Lack of awareness and culture. Leading to lack of recognition of benefits. Capacity – time, expertise.	Funding, time. Opportunities for engagement with the health service Data issues	Ownership Lack of resources via trusts Complexity of the NHS and decision processes Applicability of tools - lack of a stable, generic user-base.

The central theme here seems to be a lack of common language and shared basis for understanding in tackling the issues. This argues strongly for more mechanisms by which the different communities can share ideas. The collaborative MASHnet/NHS confederation workshop for health service managers held in March 2006 emphasised this need. The gulf of perception between health service managers and research academics about what constituted the necessary time scales and resource requirements for proposed modelling projects was striking. It was also evident at this event that service managers typically struggled to precisely specify problems in terms that researchers found accessible, and likewise researchers struggled to address the real needs of the users in accessible terms. There is clearly much more to be done to improve the interface.

Question 3 : WHAT ACTIONS ARE NECESSARY?

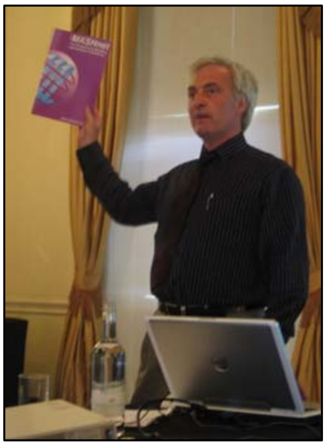
Health Services:	Academic Research	Industry
Champions and top level commitment Integrate into planning Training and Education	Feedback from users and working together Raise profile Persevere	Find champions Promote successful examples Build strategic relationships

The main message from these responses seems to be the need for the developing 'Top level commitment' in the health services in order to drive greater uptake. In particular the role of success stories and the pressing need to publicise them is highlighted as a key objective in order to encourage greater awareness of the benefits and the practicality of applying solutions.

Question 4 : WHAT ARE THE KEY ISSUES:

Health services:	Academic Research	Industry
Time, Innovation overload (too much change) Ownership and language.	RAE how to match this to useful applications Resources	Firefighting vs strategic development Sustainability

Here it is difficult to summarise the table in one theme but clearly the need for sustained collaboration is critical in developing the basis for a more successful transfer of research and commercial solutions into healthcare. One interesting aspect of this is the need to align incentives and cultures within each community. The academic drivers in the Research Assessment Exercise (RAE) for instance seem largely to be based on delivery of papers in academic journals and contain very scant incentives to develop working solutions for healthcare or even to publish more accessible articles to a wider audience.



Martin Pitt extols MASHnet during the recent Westfocus presentation June 27th

Big Ideas

In addition to the exercise described above, delegates at the MASHnet launch were asked to offer BIG IDEAS for ways of addressing the issues of improving the application of healthcare modelling. Around seventy submissions were made which fall into the following overlapping categories (more detail on the MASHnet website):

- **Promotion**:
  - Promulgate success stories
  - Target key decision makers
  - Keep it local
- **Education**:
- **Collaboration and communication**
  - **Resources**
  - **Recognition**

Conclusions

For the launch event and subsequent workshops organized by MASHnet, it is clear that there is an encouraging interest in the network and broad support for its objectives. MASHnet has made some initial strides to link to with other groups involved, but there is still considerable scope for extending collaboration with existing organisations and groups in the field of healthcare modelling and simulation.

Common themes around barriers and opportunities for modelling in healthcare clearly exist and have been revealed by the workshops. These need much more exploration and active work if significant progress is to be made in this area. In general there has been a broad validation of approaches suggested by MASHnet as encompassed in its objectives of linking the key communities central to the application of viable modelling and simulation solutions in health.

References

Fone D. et al (2003) Systematic Review of the use and value of computer simulation modelling in population health and healthcare delivery. *Journal of Public Health Medicine*. 25,4 pp.325-335

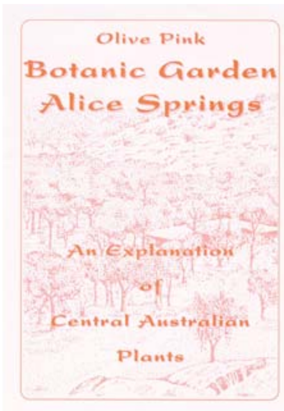
Davies R and Bensley D. (2005) Editorial in Meeting Health Challenges with OR – *Special issue of the Journal of the Operational Research Society*. 56,2. pp 123-125

For details of *MASHnet* : The UK Network for Modelling and Simulation in Healthcare – go to the website at: www.mashnet.org.uk

Nosokinetics News (continues)

Living with stress: Plants of the Central Australian Zone

‘You wouldn’t be alone if you tend to think in terms of the plants of the Central Australian arid zone as an unlucky group merely making the most of the tough environmental conditions in which they live. Take a look around you and you will see a complex and diverse flora which, with the help of a range of adaptations or specialized features, is living successfully with stress in the arid zone. These adaptations involve often subtle alterations in the outer form (morphology) or inner functioning (physiology) of a plant.



But however subtle, they give these plants an edge dealing with the daily stresses of the ‘Dead Heart’.

- An irregular and variable supply of water (annual budgets, political whim)
- High heat and radiation loads (seasonal factors, newspaper headlines)
- Soils low in vital nutrients (equipment by bedside and in hospital)
- Salt accumulation (bed-blocking)
- Grazing by indigenous and introduced herbivores (bed borrowing)

Faced with a selection of problems, some plants opt out and exist as dormant seeds or underground buds (the ‘Avoiders’) or adapt to meet the changing circumstances (The ‘Tolerators’).

1. An explanation of Central Australian Plants. Olive Pink Botanic Garden, Alice Springs

Forthcoming Conferences

OR 48 The Annual Conference of Operational Research Society, Bath, UK, 11-13 September 2006. Bath - a beautiful town with lots of interesting history and culture See http://www.orsoc.org.uk/ for more details.

RSS 2006 International conference of the Royal Statistical Society. Queen's University Belfast, 10-14th September 2006. contact p.gentry@rss.org.ukn

SimTecT 2006 Healthcare Simulation Conference 11-14 September 2006
Royal Brisbane & Women's Hospital Education Centre / Queensland Health Skills Development Centre. *Theme: "Simulation is for Patient Safety"* **http://www.simtecthealth.co/**

5th IMA QUANTITATIVE MODELLING IN THE MANAGEMENT OF HEALTH CARE
Goodenough College, Central London on 2nd - 4th April 2007
Conference website http://www.healthcareinformatics.org.uk/qmmhealth2007/
or the IMA website http://www.ima.org.uk/

The management of Health and Social Care constitutes an important area for the application of concepts and techniques from the disciplines of mathematics, operational research and statistics. Problems such as management of waiting lists and bed capacity, hospital redesign, workforce planning and scheduling, patient flow modelling, performance management, disease monitoring, and health care technology assessment have been tackled using quantitative techniques including statistical analysis, stochastic processes, queuing theory, mathematical programming, heuristics, discrete event simulation and system dynamics.

The aim of the conference is to bring together health care managers, clinicians, management consultants, and mathematicians, operational researchers, statisticians etc from across the world with a view to exploring recent developments and identifying fruitful avenues for further research.

Call for Papers-

We invite researchers in all relevant methodologies and problem domains to submit abstracts of 300-500 words to Lucy Nye at Lucy.Nye@ima.org.uk by 1 DECEMBER 2006. Authors of accepted abstracts will be notified by 1 January 2007. Authors should indicate whether they wish to make an oral or a poster presentation. We are also planning a special poster presentation session for PhD students to show their work in progress.

Selected papers presented at the conference (whether orally or as a poster) will be published in the Springer journal Health Care Management Science.

Dr. T.J. Chaussalet, Reader, Department of Information Systems, University of Westminster, 115 New Cavendish Street, London W1W 6UW. Email: chausst@wmin.ac.uk

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