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# A GENERALISED SIMULATION SYSTEM TO SUPPORT STRATEGIC RESOURCE PLANNING IN HEALTHCARE

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## ABSTRACT

Healthcare services within the western economies are currently undergoing many fundamental changes. Growing demand within a context of economic constraint are creating a need for efficiency savings and tighter control of limited resources. Healthcare managers are invariably faced with organisations which are highly complex and interactive in nature. Increasingly they require the tools which will enable them to accurately assess and quantify the impact of possible changes. This paper describes a generalised simulation system aimed to address some of these needs. This has been developed in liaison with health authorities in West Yorkshire, UK. where a new hospital is currently planned. The simulation system is designed as a 'shell' to support the development and use of a wide range of models rather than representing a bespoke solution to a specific issue. Developed in the Windows environment it utilises a Visual Basic graphical user interface linked to WITNESS simulation software. Key features are its ease of use, visual interaction and its flexibility, making it an accessible tool for direct use by healthcare managers. A sample case study is summarised which illustrates the use of the system to conduct 'what-if' type experiments. The results are validated against real healthcare data and the potentials of the system are evaluated within the strategic management process.

## 1 INTRODUCTION

The Health Service in the United Kingdom has over the last decade undergone major changes in its organisation and delivery. This experience has to a large degree been mirrored in most major western nations. Increasingly large amounts of resource are being directed to support a service which is strained sometimes to its limit under growing demands. Changes in technology and medical practice generally have led to shifting patterns of care which are often difficult to predict. In addition demographic shifts (e.g. an increasingly ageing population) also impact on healthcare demand. In this context therefore there is a growing need to tightly manage healthcare resources. Bed usage in hospitals, for example, is a specific area where capacity management techniques can be implemented more widely to even out monthly variations and other fluctuations in demand (Yates 1982). In addition, strategic changes, often instigated by central government, have been pursued by health authorities and need careful management if they are to succeed. One prominent example of this is the current attempt in the UK to move resources from secondary to community based care. Future initiatives may have an even more radical impact on the shape of hospital based services (see Vetter 1995). Such strategic shifts of direction have enormous implications for the provision and use of resources at the different levels of the health service.

The management of healthcare particularly at the strategic level has realised the need to more precisely control the use of expensive resources. Bed numbers within hospitals, for example, are becoming much more tightly controlled and the old tolerances for surplus capacity are increasingly questioned as the trend towards smaller more efficiently run hospitals is pursued. The fact that the issues surrounding the provision of resources in healthcare services are often politically charged emphasises the need for objective methods and tools to inform the debate and provide a better foundation for decision making.

## 2 THE PRISM PROJECT

The PRISM Project (Planning Resources using Interactive Simulation Modelling) was established as part of a four year Engineering Doctorate research program (funded by the Engineering and Physical Research Council). It is based at Manchester University UK and is sponsored by Lanner Group plc (who market and develop the WITNESS simulation software). In

November 1995 approaches were made to Calderdale and Kirklees Health Authority, West Yorkshire, UK and the PRISM Project was initiated as a collaborative work programme which aimed to investigate the use of interactive simulation in strategic healthcare management.

One specific issue identified at the start of the project was the need to model hospital bed use in order to assess future need. Plans were already at an advanced stage for the development of a new hospital within the area controlled by the authority. Concerns had been raised about the planned level of bed provision and quantitative assessments of bed usage were required to properly gauge the size of the planned hospital in the context of projected changes in healthcare delivery. Limitations of linear statistical models typically used by health economists and consultants had been highlighted. Such models, for example, often rely on aggregate data and fail to adequately capture the fluctuations and variability in healthcare demand. Such factors pointed to a role for dynamic simulation to gauge the impacts of planned and expected changes. The PRISM work aimed to develop a simulation system which could demonstrate support for these identified management needs.

## 3 DESIGN ISSUES

From an early stage in the PRISM Project it became apparent that the scope and diversity of strategic healthcare concerns vastly outweighed the capacity of any one simulation model to offer a universal solution. It was apparent that the level of complexity and interaction both *within* and *between* the specific institutions of the healthcare (e.g. within hospital organisation and between hospitals and community care institutions) presented a particular challenge to any attempts to model and quantify the effects of likely changes. Often changes within one institution impact profoundly on the operations of another. Faced with these issues it is not surprising that most attempts to use simulation within healthcare to date have concentrated on relatively tightly constrained environments of operational care (e.g. the organisation of Accident and Emergency Departments) or have needed to vastly simplify the modelled domain in order to produce usable results. In general such studies have been directed at specific issues of concern within identified institutions of care (see, for example, OR Soc. 1995).

The approach of the PRISM project has been to look at the feasibility of establishing a more general framework or ‘shell’ which could support a range of models and variables in contrast to bespoke solutions. Initial discussions with managers and other healthcare professionals led to the formulation of a set of criteria to inform the design of such a system which included the following requirements:-

***ease of use*** - the system should be sufficiently accessible for healthcare managers to understand the simulation models and to easily enter inputs to control and experiment with ‘what-if’ scenarios.

***transparency*** - visual elements and animated displays should be available to allow observers to easily visualise the key elements of the simulation and provide a direct means for observers to gain confidence in the capacities of the model. This is particularly important given the political context of healthcare management.

***interactivity*** - it should be possible for end-users of the system to view and control the key variables and to browse and control simulation outputs directly. Ideally changes should be possible during a simulation run to enable the impact of any changes to be observed.

***flexibility and versatility*** - the system needs to be able to support a wide range of models across a variety of healthcare scenarios and at many different levels of detail (or granularity). Ideally models will offer a range of variable inputs to support investigation of interactive effects.

***validation*** - models need to be fully validated against real healthcare data and experience in order for system users and others to have confidence in the outputs. Clear methods and criteria for validation need to be outlined.

These specification needs resulted in a design architecture for the PRISM simulation system as depicted in Figure 1 below. This consists of the following linked elements:-

- A simulation engine supported by a modelling methodology used to develop a range of models.
- A generalised user interface, used to display and control key parameters of a simulation model.
- Data files used to store the menu and control data needed to populate the interface linked with the appropriate simulation model files.

The software chosen to develop this system was WITNESS (Version 8 - marketed by Lanner Group Ltd. UK.) linked to an interface programmed in Microsoft Visual Basic (Version 4). The wide range of OLE (object linking and embedding) functionality supported by the recent versions of WITNESS make it an ideal system for the PRISM design. Visual Basic was chosen for developing the interface due to its good support for mouse based graphics, rapid development times, and its OLE data linking features.

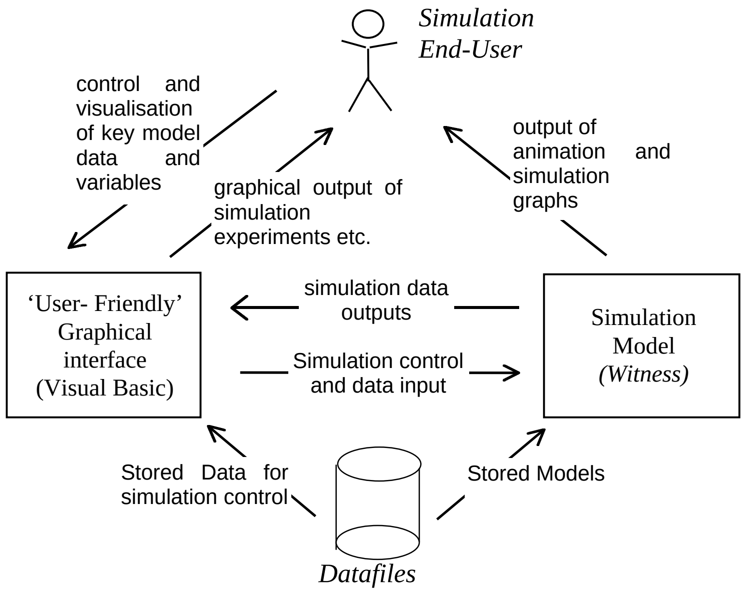


Figure 1. Design Architecture for Simulations and Interface

At all stages during development of the PRISM system the principle of generic design were adhered to in order to ensure the wide range of application desired for the final system. Any specifics relating to the design of the healthcare models themselves, the data used to populate those models, as well as the menu controls and parameters used to control the simulation experiments were restricted to the individual data files loaded into the system rather than forming a 'hardwired' part of the interface or simulation system itself. The PRISM system is thus designed as a *generic application* into which specific healthcare models and controls are loaded rather than representing one particular simulation model. Case study examples of simulation models have been used throughout the development of the system to test and evaluate successive versions of the prototype.

### 3.1 The PRISM interface

Figure 2 below shows an example screen from the PRISM interface. This comprises a set of graphical browsing tools controlled via a standard menu based screen. All menu elements and control items within the interface (with the exception of the general 'File' and Help' menus) are a product of a data file loaded for a specific experimental simulation. These controls enable users to interactively control key parameters of a model during simulation experimental runs using mouse and keyboard commands . Outputs from the simulation can also be viewed via graphical browsers. In addition control routines for file and data management are included to support data transfer to the WITNESS software (via OLE functions) and for datasets to be saved to disk. A small control panel window is provided to allow the users to switch between the WITNESS simulation and the interface menu screen during experimental runs.

### 3.2 Simulation Modelling

A central element in the design of the PRISM system was the modelling methodology used as a basis for the development of healthcare simulations. Although a full treatment of this subject would not be appropriate here, a number of considerations are important when adopting a modelling paradigm. Two central criteria to emerge from the work described here, for example, are that the modelling system should be *accessible* (important to enable the process of knowledge elicitation and capture) and secondly that there should be a specified method to translate the elements of the modelling language into the simulation system itself.

Much has been written on the issues of healthcare modelling (e.g. Davies 1985, Cohen and Molteno 1993, Millard and McClean 1994). In the context of building simulations it is likely that the many alternative modelling systems available will be appropriate to different problem domains. This is certainly an interesting area for further research (see Lehaney and Paul 1996). A related issue arising from this is the potential to use modelling software linked directly to simulation systems, again an interesting research area. Although such software already exists which supports

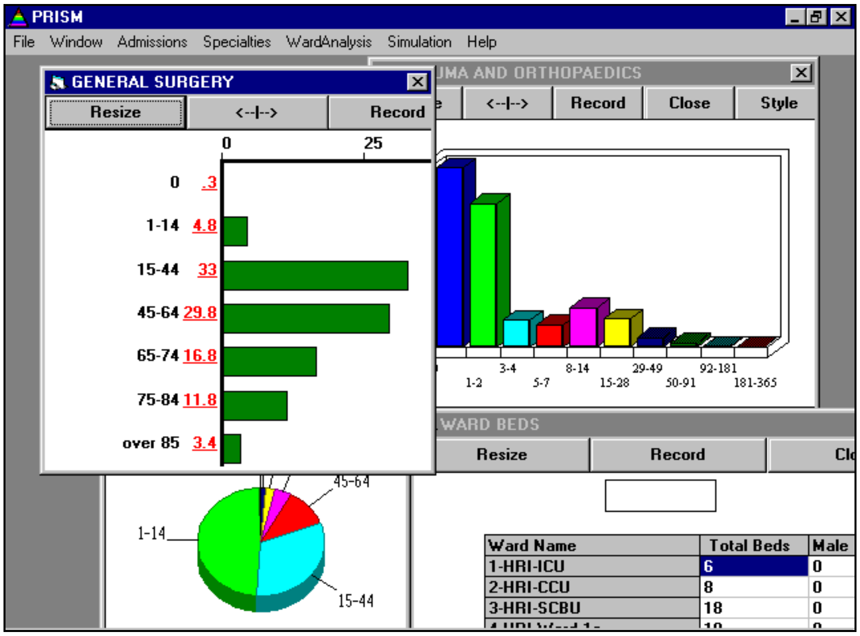


Figure 2. PRISM Interface Showing a Number of Graphical Controls

linkage to the WITNESS system (e.g. software based on IDEF3 modelling paradigm) it was decided in the PRISM Project to directly program models in WITNESS from paper based diagrams and specifications.

Within the PRISM Project a modelling paradigm based on State Transition Networks (STN) has been adopted. This was considered appropriate since it satisfied the criteria as mentioned above and also offered a patient-centred perspective of care which was considered useful by managers. Certainly the modelling diagrams used were quickly understood by those experienced in managing and delivering services. Indeed STNs would often resemble the diagrams they would draw themselves to describe the processes under their control. Figure 3 below shows a relatively simple example of an STN used in an early case study. This models the flow of patients in an elderly care specialty across four phases of treatment.

The main elements of the modelling framework consists of *patient states* (rectangles), *events* leading to state transitions (triangles) and *conditional branching elements* (circles) which determine flow based on the attributes of a given patient.

Each of these elements needs to be separately

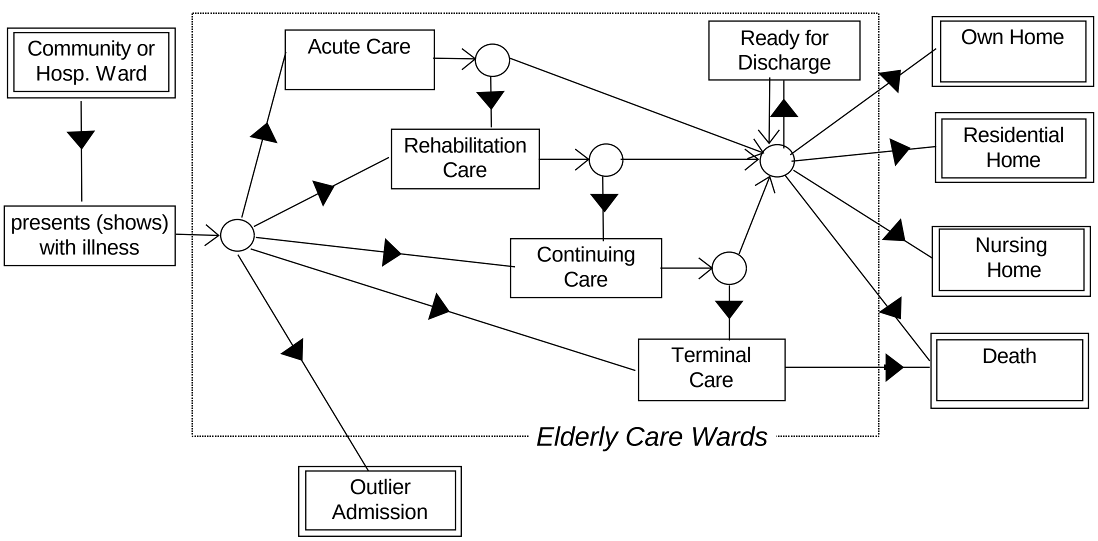


Figure 3. State Transition Network for Four Phase Model of Elderly Care

specified to enable the translation from the model to the simulation. A methodology has been developed for this purpose.

Although the use of STNs has been adopted in the modelling work described here, on-going research is investigating the different modelling systems that may be appropriate within the healthcare domain. This aims to analyse which techniques may most usefully be applied to different situations. The development of software modelling tools integrated within the PRISM simulation system itself holds the potential for significant enhancement of the overall system in the longer term.

## 4 A SAMPLE CASE STUDY

Central to the PRISM project has been the need to develop case study examples and to demonstrate useful applications in strategic healthcare management. Indeed the involvement of the Health Authorities has been contingent on the development of simulations useful to the management process. These conditions have assisted the development of the PRISM system as a whole. Case study simulation models have enabled the simulation framework to be tested at every stage and evaluated against management objectives for potential usefulness. The case study example summarised below illustrates one of a number of simulation experiments that have been conducted as part of the development of the PRISM simulation prototype.

### 4.1 A General Hospital Simulation

A simplified high level hospital model was developed in WITNESS to simulate the flow of patients through the different specialty streams and wards of existing hospitals in Halifax, UK. This simulation uses an array of demographic and healthcare data to generate representative daily case loads of patients. The treatment pathway of each simulated patient is then modelled through the different specialties of care and across a series of treatment phases (acute, rehabilitation etc.). These pathways are a function of each simulated patient's attributes as well as the on-going conditions of the hospital system (e.g. level of bed occupancy).

### 4.2 Model Inputs

In order to specify the model, a range of variables are transferred to the simulation via the PRISM interface. The graphical controls of the interface enable end-users of the system to browse and change many of the key parameters of the model. Variable categories accessible in this way are summarised below:-

- Demographic controls - including variation of sex, and age profiles by specialty for the underlying treatment population.
- Demand fluctuations - including standard variability as well as monthly and daily trend data
- Admissions - total admissions by specialty as well as ratio of admissions type (e.g. elective versus emergency admissions).
- Hospital Ward Configuration - number of beds, ward inventory, allocation of ward beds by sex and by specialty.
- Length of Stay - distribution across each of the different diagnostic groupings
- Day Case percentages - for each specialty and admissions type.
- Simulation controls - Settings for length of simulation run and other elements of run-time operation.
- Output controls - selection of graphical outputs from the simulation, and specification of data file outputs

In all over fifty graphical browsers are offered via the PRISM interface menus to control over a thousand separate variables which are transferred to the WITNESS simulation. The scope for experimentation is therefore very extensive. A baseline default setting is established for each of these variables, set according to the real healthcare data supplied by Calderdale Healthcare Trust. This dataset is given by the initial file which is loaded into the interface and hence vastly simplifies the process of experimentation.

### 4.3 Model Outputs

Outputs from the simulation are in general controlled via the PRISM interface. The animated display of the WITNESS model supports a range of output graphs which can be monitored during the simulation run. In addition a number of data file outputs can be chosen to record various aspects of output. These include data which records the admissions profile, periodic 'snap shot' records of ward states, treatment pathways for individual patients and the discharge record. The data from these files can then be read via the PRISM interface on completion of each experimental run or alternatively imported into other applications (e.g. spreadsheets) for further analysis.

### 4.4 Model Validation

Early validation trials have revealed, that despite the simplification entailed in such a high level model of hospital activity, bed occupancy graphs are remarkably faithful to the actual record when the simulation is run with actual health trust data. Figure 4 below shows a typical sample output from the simulation compared with real data supplied by the healthcare trust. Validation of the model is currently planned against data taken from another hospital in West Yorkshire to increase confidence in the simulation output. In addition more qualitative validation techniques are being pursued. These include evaluation by operational managers to confirm that the flow of patients broadly matches their experience of care and comparison of sample treatment pathways for simulated patients against the anticipated experience of real patients with similar attributes.

**BED OCCUPANCY DATA (No of Beds)**

| | Calderdale Healthtrust Data | | | | PRISM simulation output | | | | *%diff* |
|---|---|---|---|---|---|---|---|---|---|
| | MEAN | MIN | MAX | RANGE | MEAN | MIN | MAX | RANGE | *MEAN* |
| **Jan** | 647 | 607 | 685 | 78 | 625 | 597 | 690 | 93 | *3.40%* |
| **Feb** | 668 | 606 | 680 | 74 | 659 | 581 | 686 | 105 | *1.35%* |
| **Mar** | 636 | 587 | 685 | 98 | 620 | 548 | 665 | 117 | *2.52%* |
| **Apr** | 630 | 572 | 676 | 104 | 650 | 599 | 692 | 93 | *3.17%* |
| **May** | 618 | 575 | 667 | 92 | 620 | 584 | 668 | 84 | *0.32%* |
| **Jun** | 609 | 551 | 656 | 105 | 607 | 559 | 629 | 70 | *0.33%* |
| **Jul** | 621 | 562 | 657 | 95 | 607 | 561 | 641 | 80 | *2.25%* |
| **Aug** | 608 | 566 | 648 | 82 | 600 | 564 | 648 | 84 | *1.32%* |
| **Sep** | 595 | 563 | 641 | 78 | 587 | 547 | 625 | 78 | *1.34%* |
| **Oct** | 587 | 544 | 635 | 91 | 600 | 540 | 637 | 97 | *2.21%* |
| **Nov** | 568 | 529 | 600 | 71 | 563 | 538 | 595 | 57 | *0.88%* |
| **Dec** | 555 | 477 | 595 | 118 | 557 | 469 | 588 | 119 | *0.36%* |
| ***Mean*** | ***601*** | ***542*** | ***640*** | ***98*** | ***591*** | ***533*** | ***639*** | ***106*** | *1.66%* |

Figure 4. Sample Table of Simulation Results Compared with Real Data

### 4.5 Simulation Experiments

Early experiments with the general hospital model have focused on issues of resource and particularly the level of bed use under varying conditions. Key questions concerned the impact of flexibility of bed provision, the affects of predicted changes in healthcare performance, and changes due to demographic factors (e.g. shifts in age profile of the underlying population.). In many cases projections are available for the likely levels of such changes. These can be input into the simulation to assess the impact on hospital activity. Figure 5 below shows the simulation output of bed occupancy for each month of a simulated year of activity based on a set of projected performance data for the year 2000.

Currently a series of simulation experiments are planned using the PRISM framework to investigate the impact of flexibility of allocation on hospital bed usage. Although previous studies (e.g. Dumas 1984) have shown simulation to be a useful tool in the optimisation of bed allocation between different specialties, further work is needed to assess the affects of centralised bed management rather than the current system of allocation by specialty. Another factor is UK Government directives which aim to restrict the use of mixed sex wards which will reduce flexibility of bed allocation.

## 5 CONCLUSIONS

At this stage in the PRISM project a number of important objectives have been achieved. The main elements of the generalised system for supporting healthcare simulation have been developed although many enhancements are planned. Early case studies have demonstrated the potentials of the system against a range of ‘what-if’ scenarios and the models have been validated against real health data.

The PRISM simulation system has been designed for direct use by managers within the healthcare professions. The graphical user interface transfers control of many key simulation variables to end-users and enables them to specify models and view simulation outputs. The facility to store sets of such variables as files holds the potential for cross-comparison between different scenarios of care. Although not definitive the outputs from such ‘what-if’ experiments are potentially very useful inputs into the strategic management process,

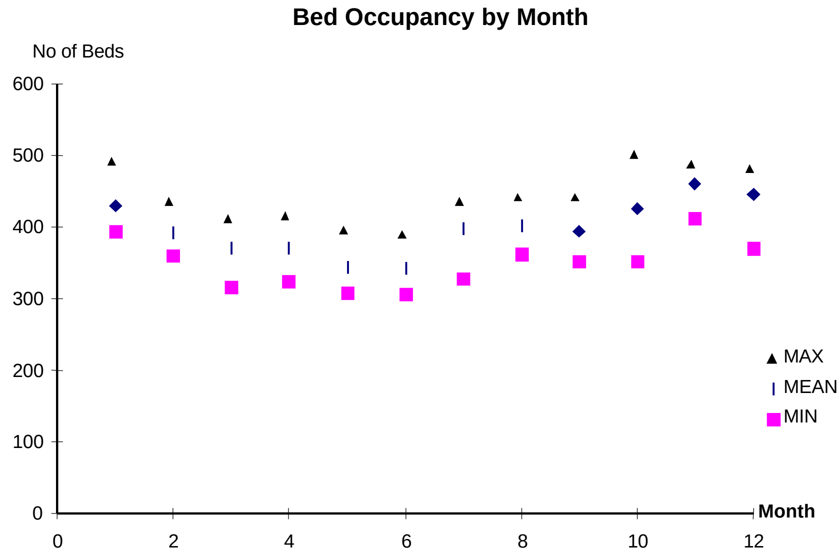


Figure 5. Output Graph of Simulation with Projected Health Data

especially in a context where quantified and objective measures of effect are often in short supply.

Early evaluation of the PRISM system has revealed that the graphical interface makes it especially suited to sensitivity analysis. Key variables within a simulation model can be adjusted interactively and the effects of changes can be directly observed from the simulation. This offers strategic managers a facility to determine the likely effects and magnitudes of any changes which are planned or envisaged. This is seen to have a valuable role in the education and communication of objectives within the management process as a whole.

The generic design rationale of the PRISM system has established a framework which supports the development of a wide range of interactive simulation models. Future work aims to explore a number of areas within strategic healthcare management which may be accessible to this approach. Of particular interest are changes in the delivery and organisation of rehabilitation and intensive care, increased flexibility of resource use, management of waiting lists, emergency contingency planning, and the growing trend towards community care away from institutionalised services. At all stages close liaison with healthcare professionals is essential to ensure that simulation tools address the real needs of the those who actually provide and manage the services of care.

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