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AN APPROACH TO HOSPITAL PLANNING AND DESIGN USING DISCRETE EVENT SIMULATION

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ABSTRACT

Recent reports have established the need for change in the US health system. Building projects can play an important role in enabling change to support organizational objectives. The current major investment in hospital construction in the US provides an opportunity to improve health service. Planning and design of hospitals generally uses benchmarks and experience without rigorous analysis of processes, resources and facility requirements. This paper considers an improved approach to planning and design of hospitals by using Discrete Event Simulation (DES) to enable improvement in the quality and productivity of health services and an improved workplace environment for staff.

1 INTRODUCTION

The subject of this paper is the use of Discrete-Event Simulation (DES) as a decision making tool in the planning and design of hospital buildings. The basis of the paper is a review of the literature on the major issues of the US health care system and the role that building projects can play in enabling organizational change. A review of current hospital planning and design and use of DES provides the basis for describing an improved process for design of health services and facilities using DES.

2 BACKGROUND

2.1 Crossing the Quality Chasm

The Institute of Medicine (2001) documents the problems of the quality of the US health system and the need for improvement to be based on evidence-based clinical practice, best use of staff, buildings and equipment.

The conclusions were summarized by Corrigan 2001 as:

"The American health care delivery system is in need of fundamental change. The current care systems cannot do the job. Trying harder will not work. Changing systems of care will."

2.2 Cost of Health Care

The quality problem is compounded by the current high cost of delivering health care and hospital buildings. OECD 2004 showed that the US had the highest proportion of GDP allocated to health care of 14.9% compared to the average of 8.9% for all OECD countries. The recent forecast by the Bureau of Census (2006) estimates 2006 costs at $2.1 trillion per annum or 16% of GDP and rising to $4.1 trillion per annum or 20% of GDP by 2016. The Bureau of Census (2006) forecast for expenditure on structures and equipment shows current costs of $92 billion and forecast to reach $190 billion in 2016.

2.3 Current Design Practice

Current design of hospitals is largely based on custom and practice and benchmarks. Current best practice is outlined as follows:

- The clinical managers develop a descriptive model of care and functional brief
- Experienced hospital planners and architects consult with the managers who will be responsible for the proposed health service. The consultation may consider the patient's journey in receiving health services.
- Databases for planning and design are used to develop the design. These standards can be mandated in regulations and appointing design teams.
- The design may be tested with prototypes before documentation for construction.

2.4 Building Projects and Organizational Change

Better Choices Better Health, 2003, considered the current and future health care needs for a state public health system serving over 1.5 million people. The report recommended extensive change to the health system and noted that capital development is a driver of change.

The Office of Government Commerce 2004, reviewed best workplace projects that integrate business, organizational and physical changes and emerging best practice. While the report is based on experience in government offices the principles are relevant to health workplaces.

Relevant points are

- The physical workplace can significantly impact effectiveness and efficiency. The extent to which physical layout, appearance, comfort and functionality affect work is now widely recognized.
- The workplace can be a resource in change and improvement to achieve the organization's objectives.
- Successful organizational change requires consideration of people, process and place.

2.5 The Role of the Physical Environment

The Center for Health Design 2006 considered the urgent need to address the problems in healthcare workplaces that result in staff injuries, medical errors and waste.

Key steps to be considered in designing workplaces to support these improvements are

- Design the buildings to effectively address operational and systems problems impacting staff effectiveness and productivity.
- Promoting cultural change as part of the design process to ensure effectiveness and acceptance of innovation.
- Effective consultation with healthcare teams.
- Provide space for carers to effectively contribute to the care.
- Design spaces and equipment to enable safe work practices – particularly lifting of patients, infection control and low noise stress.
- Consider workflow in the provision and layout of spaces to minimize walking.

2.6 Nurse Environment Innovation Summit

The rationale for the Nursing Work Environment Innovation Summit 2007 was:

"Because traditional nursing unit design and layout, combined with the episodic introduction of disparate technologies, have introduced tremendous inefficiencies and waste into nurses' work environment, which greatly reduces the amount of direct patient care time that nurses can provide.

Because returning direct patient care time to nurses in current and planned nursing units has the opportunity to positively affect professional nursing practice, the role of the nurse, and the safety and quality of patient care delivery.

2.7 Systems Engineering Approaches

Reid et al 2005 outlined the systems engineering tools appropriate for addressing the issues in the health system. These systems engineering tools have transformed the quality and productivity performance of other large complex systems including manufacturing, transport and telecommunications.

Three tools are particularly relevant to this paper:

1 Discrete Event Simulation.

2 The Baldrige National Quality Program created in 1987 to improve U.S. industrial competitiveness and encourage the pursuit of quality in all sectors of the economy.

3 Toyota Production System which focuses on respect for people, satisfying customers requirements, eliminating waste, smooth production, minimizing waiting, movement and rework. This approach has resulted in improved quality, reduced costs and improved customer satisfaction. The approach is being introduced to health care (Jones et al 2006) through process mapping as a tool in improving functioning of departments of the health care system. Improvements reported include improved quality, safety, service delivery, throughput and staff satisfaction. For example in Flinders Medical Centre South Australia reduced emergency waiting times by 25% by improving the flow of work and a pathology laboratory reducing the floor area by 40% and up to 90% reduction in production times.

3 CURRENT USE OF DISCRETE EVENT SIMULATION IN HEALTH

3.1 A Recent Survey of Current Use in Health Care

Jacobson et al 2006 surveys the use of discrete-event simulation to understand the operations of health care facilities over the last thirty years.

Key findings include:

- *"A significant amount of research has been conducted in the area of patient flow and asset allocation.*
- *The multiple performance measures associated with health care systems make discrete-event simulation particularly well suited to tackle problems in these domains.*
- *A large number of discrete event simulation studies reported in the literature have the common theme that they attempt to understand the relationship that may exist between various inputs into a health care delivery system (e.g., patient scheduling and admission rules, patient routing and flow schemes, facility and staff resources) and various output performance measures from the system (e.g., patient throughput, patient waiting times, physician utilization, staff and facility utilization)."*

- *"Discrete event simulation offers perhaps the most powerful and intuitive tool for the analysis and improvement of complex health care systems."*

3.2 Examples of Use of DES as a Design Tool

3.2.1 Building Planning and Design

O'Hara et al 2004, provide examples of using discrete-event simulation as a tool in the design of an ambulatory care surgery.

A simulation model was used to establish the optimum relationship between the throughput, staffing, number of operating rooms, recovery beds and the waiting room.

The approach combined the expertise and experience of health care planners, architects, simulation modelers, nurses, doctors and patients. It enabled the options to be tested by harnessing the knowledge of these stakeholders and rigorously evaluating design options. Bottlenecks in the process and space were identified in the study and design solutions developed to avoid them in the built facility.

The primary value of use of DES was better assessment of health care processes and productivity opportunities, improvement of staffing and space utilization.

3.2.2 "Three Wins – Service Redesign Through Flow Modeling"

Dodds 2006, describes the successful use of work flow modeling in the redesign of a vascular health service.

Vascular diseases are an example of a chronic, non-life threatening disease that are considered to be the biggest challenge to 21st century medicine. The service is typical of many health services where quality and productivity depends on coordination of services for the varied needs of patients. Detailed assessment requires specialist staff using sophisticated non-invasive tests and often requires a consultation with a consultant vascular surgeon. Successful treatment requires close cooperation between primary and secondary care and can include surgery.

The new service was prompted by increased demand and new regulatory standards for care. It was not uncommon for people to wait four months for an outpatient appointment, six months for ultrasound and 12 months for an operation. The demands on the service required a radical and innovative solution to provide the required services. The challenge was to improve service quality without increasing the staff, equipment and facilities used.

Use of DES was essential for the success of the project. The benefits resulting are improved quality of care to patients, staff motivation and performance of the organization. Throughput was increased by 40% with constant resources and the time to deliver health care was substantially reduced. In 2005 Dodds received awards for the "*Best use of IT in the Health Service* and *"Best innovative use of Technology"* for this project.

4 OVERVIEW OF THE PROPOSED APPROACH

The preceding sections of this paper have considered the need for change in delivery of health services and the opportunity that building projects provide in consider health care processes, staffing, equipment and buildings.

The following sections outline an approach to hospital planning and design utilizing DES to improve current methods by rigorous analysis of patient, clinical, staff, equipment and facility requirements; and building layout.

5 PROBLEM FORMULATION

The problem is to plan and design a major hospital building to:

- Enable the delivery of patient care which is safe, appropriate, timely, evidence based, patient focused, efficient and economical.
- Make best use of staff, equipment and facilities.
- Provide a physical environment which promotes safety, effectiveness and amenity for patients, staff and visitors.

6 SETTING OBJECTIVES

The objective is to plan and design a major hospital building to:

- Provide the health service forecast for the design date.
- Enable the delivery of evidence based best practices health care.
- Optimize the staffing, equipment, processes technology and facility to deliver the health services.
- Provide an improved environment for patients, staff and carers.

7 OVERALL PROJECT PLAN

The following outline of the Baldrige National Quality Program for the Health Sector 2007 provides a framework for a comprehensive management context for the project.

1. Leadership in creating a vision and leading the clinicians, staff and patients.
2. Strategic planning defining the future role of the organization in the short, medium and long term.

3. Focus on patients, other customers and markets as the primary basis for considering the process and operational rules.
4. Measurement, analysis and knowledge management by using evidence based clinical practice and rigorous analysis of staffing, equipment and facility requirements.
5. Workforce focus in providing adequate resources to provide the required health service, through appropriate involvement, considering the workplace safety and needs.
6. Process management in terms of clinical and operational practices to deliver the results.
7. Results to be measured against the safety, appropriateness, timely, evidence based, patient focused, efficient and economical.

The disciplines involved in the project are

- Senior executives and hospital Board,
- Doctors, Nurses and Allied Health professionals,
- Facilitators able to translate health knowledge for simulation engineers and architects and
- Simulation Engineers to create models of health care processes and resources.

The project team needs to establish a strong working relationship recognizing the different paradigms in their disciplines. Engineers are generally used to creating models of reality to enable planning, design and construction projects. Health professionals are generally focused on the reality of particular patients and diseases.

Consultation and verification with the clinicians responsible for the service is essential throughout all parts of the study. TConsultation, process mapping and simulation provide a transparent way of communicating how the service is to be delivered.

The process for planning and design using DES integrated with current practice is shown in Figure 1. The three phases are outlined as follows:

- Planning phase develops the brief describing the requirements of the hospital to provide for the forecast demand for the health services in terms of spaces, equipment, operational requirements, policies and staffing.
- Master plan which defines the spaces required and preferred layout of the departments.
- Schematic design defines the layout of the rooms, spaces and equipment. This design provides the basis for a limit of cost budget, program and contract documentation.

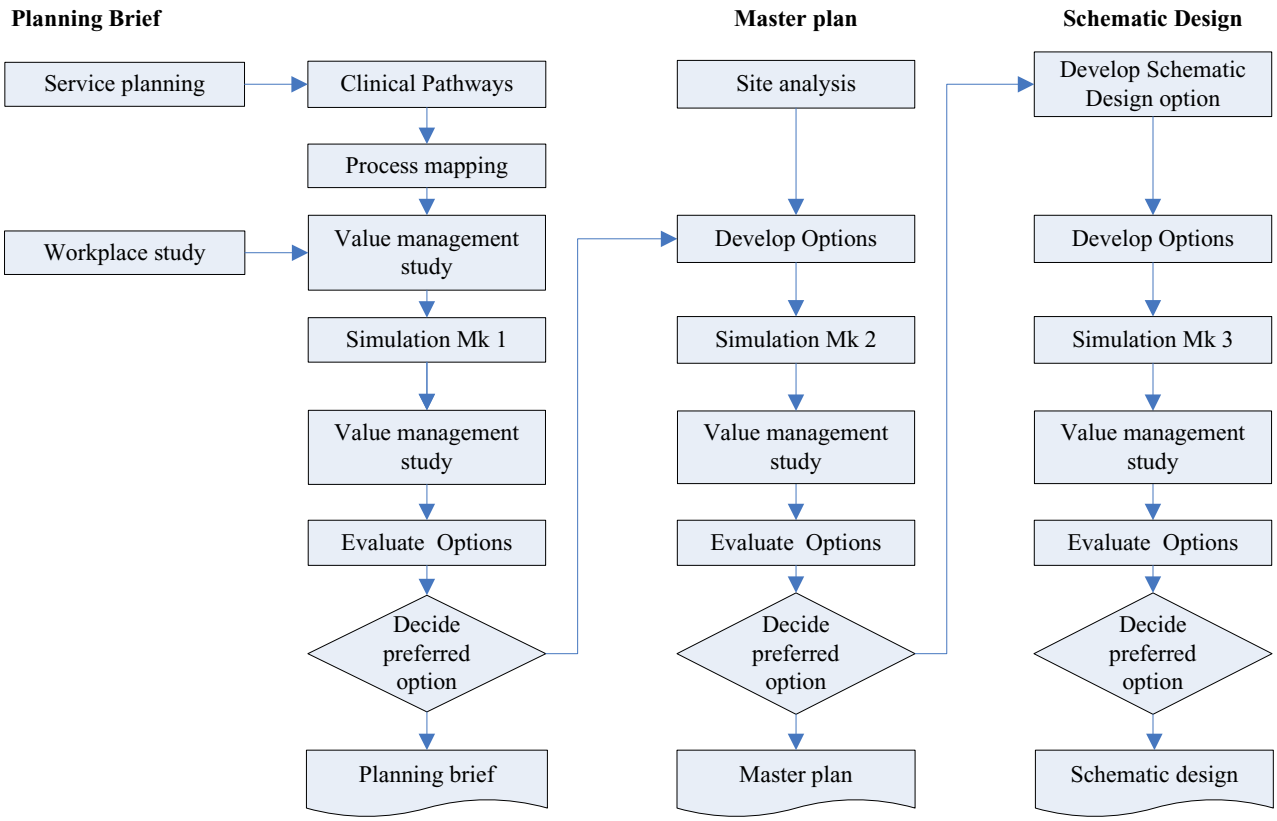

Figure 1: Planning and Design Process

8 PLANNING PHASE

8.1 Activities Prior to Simulation

The Planning Phase commences with Service Planning to estimate the health services demand using a population forecast for the design period and data of prevalence of disease in the community. The health care services are defined by Diagnosis-Related Groups (DRG), a system which classifies hospital cases into approximately 500 groups. They have been used since 1983 to determine how much Medicare pays the hospital, since patients within each category are similar clinically and are expected to use the same level of hospital resources. The demand would be expressed as number of patients per year and the time distribution for the service demand.

Clinical pathways describe the treatment required for a DRG. Use of evidence based clinical pathways provides a basis for the diagnosis and treatment to be based on the best current clinical knowledge.

Process maps are prepared for the activities involved in the clinical pathway, related staff activities and supply chain for drugs, medical and other supplies. Basing the process on the patient journey ensures the simulation and the design is patient centered.

Figure 2 shows a process map based on an clinical pathway for Acute Coronary Syndrome (ACS) on the day of presentation to the health service. The process map commences when the patient first engages with the health service in this case via the paramedic identifying a suspected ACS. The process mapping includes bring together the doctors, nurses, information and supplies necessary for the diagnostic and treatment activities described in the clinical pathway. These activities include X-ray, blood testing, observation and documentation leading to the Physician reviewing the information and deciding the treatment options. A key feature is the patient waiting for the resources to be assembled before an activity can proceed. During this period the patient care is also required to provide relieve pain, counsel the patient and carers, feed, wash and monitor the patient's condition.

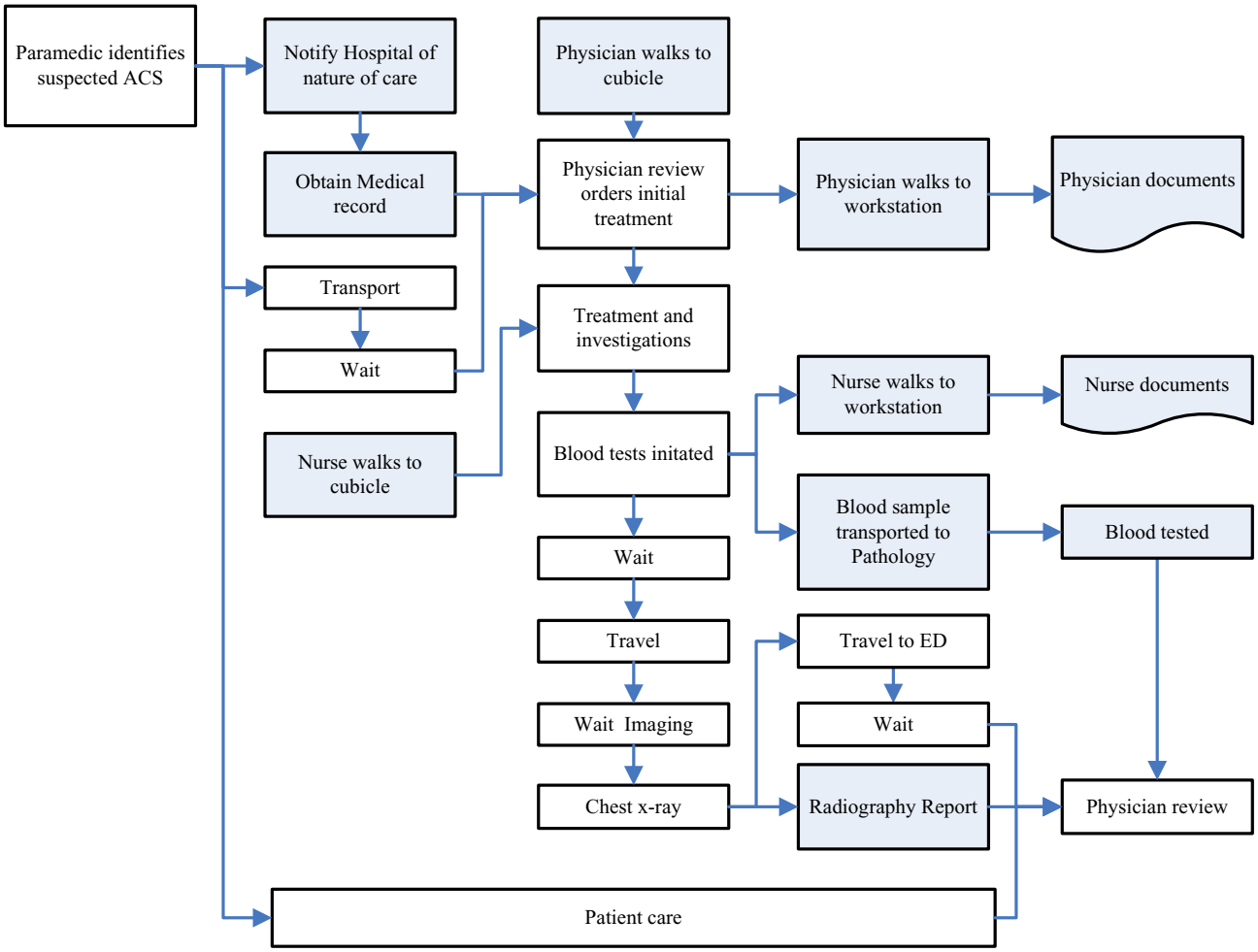

Figure 2: Process Map for the Clinical Pathway for the presentation of Acute Coronary Syndrome

A workplace study provides the basis for planning the facility requirements to achieve the organizations objectives for collaborative teams, appropriate patient and staff amenity. This study complements the process mapping and DES in considering the people factors.

A value management study (VMS) considers the process mapping and workplace study information to provide the required utility and amenity at least cost. VMS is a recognized method of developing and evaluating ideas to improve products and services. The study of the process would seek to reduce the number of activities in the process, reduce waiting, reduce patient movement, smooth patient flow and optimise staff, facility and equipment utilization.

8.2 Simulation During Planning Phase

Simulation Mk 1 considers the process as mapped; operating policies; staff, equipment and facility requirements to estimate the time taken for clinical activity, resource utilization, waiting time, supplies required and cost.

Data sources for the model include hospital records, observation, interviews with clinicians and studies. Elective and emergency patient arrivals can be estimated based on similar hospitals and scheduling practices.

Staff availability can be modeled considering shift practices, meal and rest breaks, training and administration requirements. Allowances can also be made for travel time for staff based on knowledge of typical time spent traveling. Variability in patient arrival and activity times for carry out diagnosis and treatment can be modeled based on the statistical distribution.

If the resource is not available the patient waits until the resource becomes available based on the operational procedures adopted.

The model measure the waiting time prior to commencing treatment; time to complete diagnosis and treatment; time spent waiting for resources; cost of treatment and waiting; staff and equipment utilization.

Once the model is coded, validated and verified initial runs can identify critical resources (i.e. medical specialists) and medical equipment (i.e. imaging equipment). Further runs can consider the models of care options, operating policies and patient scheduling and prioritizing options.

The simulation will enable consideration of options for scheduling patients, process, roles, and numbers of rooms, layout and use of technology. Simulation would enable rigorous analysis of options to integrate outpatient and inpatient facilities and options to provide diagnostic services with the health delivery function or in a centralized department.

Simulation enables analysis of the whole hospital system. Figure 3 provides a high level view of the components involved in delivering health care services in a major acute hospital. Modeling can provide means of rationally considering the various components of the hospital. Models of care, staff and facility requirements can be analyzed and the optimum means of delivering the required health services developed. The planning modeling considers the clinical pathways which would be bundled into departments. The simulation can analyze the options of providing health services through General Practitioners, Community Services, Ambulatory care or Inpatient services.

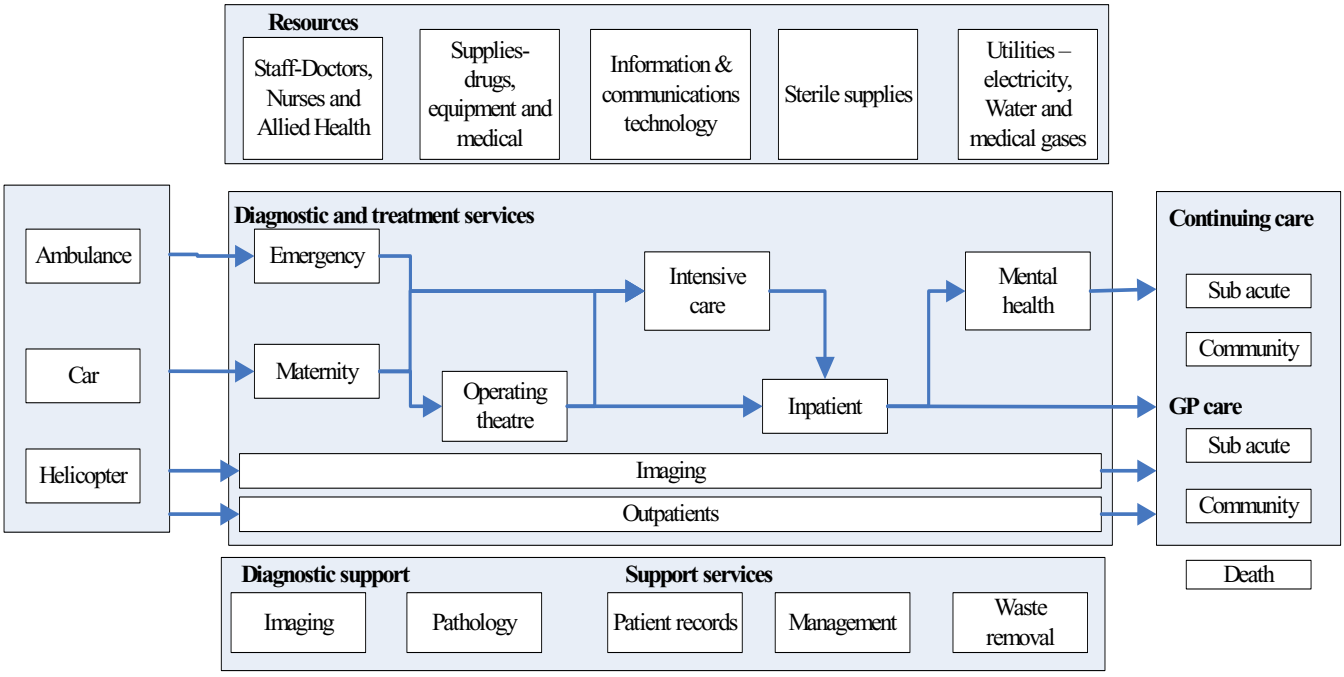

Figure 3: A high level systems view of a hospital

The cost of delivering the health care can be estimated on an activity based costing basis. Evaluation of the options leads to a preferred option to be developed in the Master Planning Phase.

Throughout the Planning and Design Phases the results developed can be reviewed against current practice and benchmark information. Where the simulation indicates changed requirements the differences need to be carefully considered in developing the design.

The output from the Planning Phase is a Planning brief which defines:

- Estimates of facility requirements such as number of inpatient beds, operating theatres and emergency cubicles.
- Major equipment requirements – number of imaging machines.
- Staffing requirements for doctors, nurses, allied health professionals and clinical support staff.
- Operational policies on booking elective patients and prioritizing health services.

9 MASTER PLANNING PHASE

Master planning commences with site analysis and developing physical planning options and is complete with a preferred master plan locating all departments in the proposed facility.

Site analysis considers existing conditions on the site including the topography, statutory requirements, transport systems, utilities and building conditions.

Development of options commences with the preparation of a Space Budget based on the Planning Brief. Preliminary layouts of the building are prepared based on the Space Budget and Site analysis. A number of options are usually developed to consider difference assumptions such as different building height, access or siting options.

Simulation Mk2 is based on the Planning Model but adds the travel distances between the departments as proposed in the master planning options. The analysis considers the same metrics as the Planning Phase to enable evaluation and development of the options.

Value engineering will consider where the options and seek means of improving the delivery of health services. For instance master planning usually provides an opportunity for sharing reception areas rather than provision on a departmental basis. Simulation will enable analysis of the demands to estimate the space requirements for such shared use.

The master plan architectural and engineering designs can be developed based on the results of the simulation. This provides the basis for preparing a preliminary capital and operating cost estimate, program and the business case for the health service.

10 SCHEMATIC DESIGN PHASE

Schematic design involves preparation of preliminary architectural and engineering design to define the building and systems to be used in the hospital. The detailed information developed in the Planning Brief and the Master Plan provide the basis for architects to prepare the layout of the rooms and other spaces which make up the departments.

Preparation of an architectural layout of the rooms and equipment will provide the basis for refining the simulation and considering further "what ifs." The level of detail can be developed to consider the staff bases, work spaces, location and size of storage of supplies and equipment. The nurse work environment could be modeled in detail to minimize movement and provide the basis for collaboration and communications.

Further value engineering can seek opportunities to reduce wasted time and resources based on the schematic design proposals.

The Schematic Design Phase will result in architectural and engineering designs which are based on rigorous analysis through simulation of the service demand, processes, staffing, equipment, technology and building layout. Models of care can be further tested and refined in the Schematic Design Phase. This enables the cost estimate, program and business care to be finalized to a limit of cost budget and commitment to proceed with contract documentation and construction.

Animation based on the design proposals (Figure 4) provides an important means of communicating and verifying the proposals. The proposals can also be tested by benchmarking, training simulation studies and prototyping.

11 CONCLUSIONS

Health care needs to change to improve quality, productivity and job satisfaction. Major hospital building projects provide an ideal opportunity to implement change through the planning and design phases. Discrete event simulation can be used to analyze processes, resources and facility requirements to deliver best clinical practice. This will require a team approach by doctors, nurses, allied health professionals and administrators, architects and simulation engineers.

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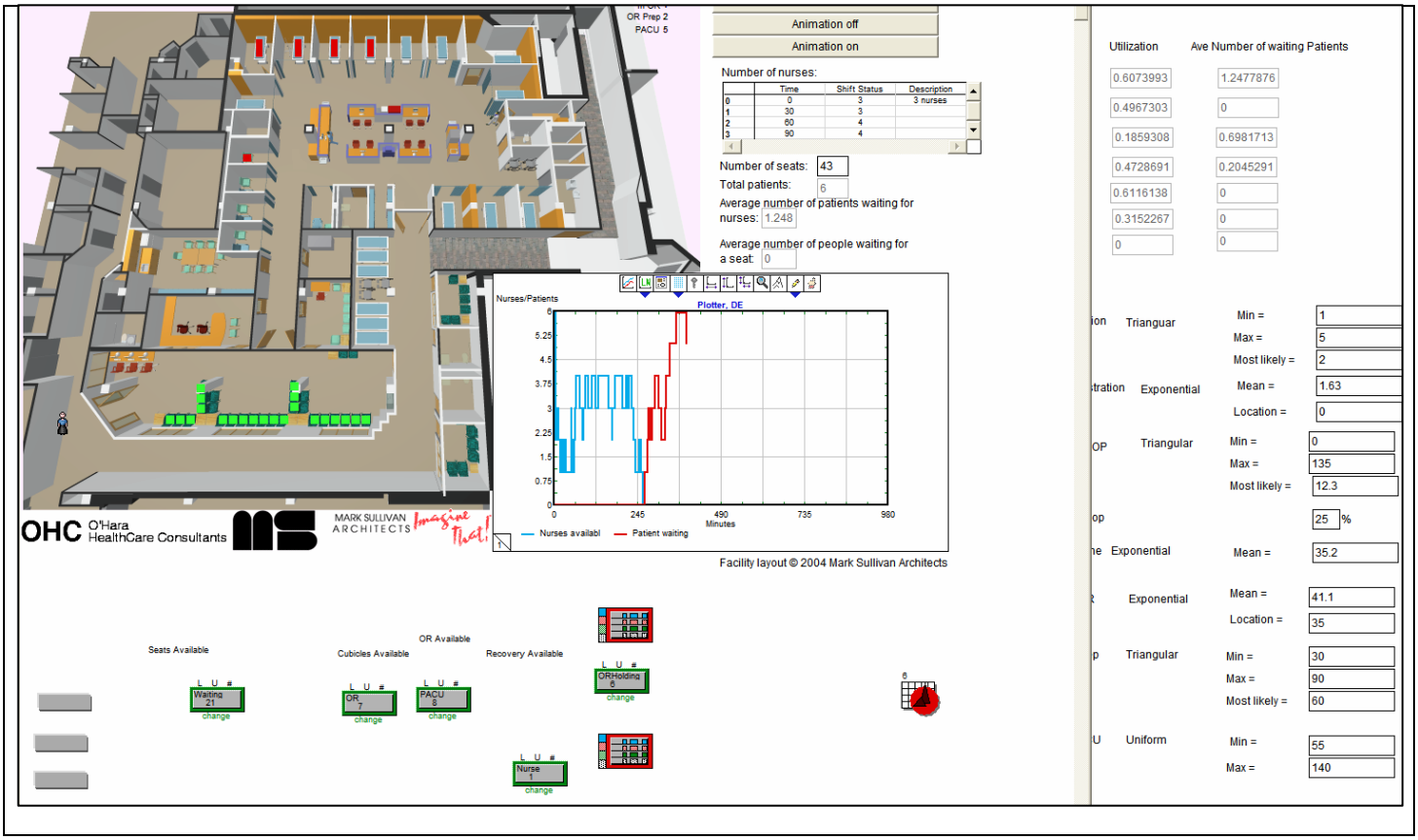

Figure 4: Animated simulation of health services based on schematic design

REFERENCES

Baldrige National Quality Program 2007 *Health Care Criteria for Performance Excellence* http://www.quality.nist.gov/PDF_files/2007_HealthCare_Criteria.pdf

Better Choices Better Health, Final Report of the South Australian Generational Health Review, South Australian Government http://www.dh.sa.gov.au/generational-health-review/

Bureau of Census, 2006, *National Health Expenditure Projections 2006-2016* http://www.cms.hhs.gov/NationalHealthExpendData/downloads/proj2006.pdf

Corrigan Janet M., 2001 Crossing *the Quality Chasm Institute of Medicine,* Committee on the Quality of Health Care in America http://www.mhsip.org/mhstat-pres/janetcorrigan.pdf

http://www.simondodds.com/downloads/Dodds_BJHCIM_June2005.pdf

Dodds, Simon, 2006, *Three Win: Service Redesign Through Flow Modeling*, Kingsham Press. http://www.simondodds.com/downloads/Award_Report_HC2005.pdf

Institute of Medicine *Crossing the Quality Chasm: A New Health System for the 21st Century* (2001) http://books.nap.edu/openbook.php?record_id=10027&page=1

Jacobson, Sheldon H., Hall, Shane N. and Swisher James R 2006, *Chapter 8 Discrete-Event Simulation of Health Care Systems Patient Flow: Reducing Delay in Healthcare Delivery* Spring US http://www.springerlink.com/content/q55m67703wk0qu3m/

Jones, Daniel and Mitchell, Alan 2006, *Lean thinking for the NHS,* Lean Enterprise Academy UK, http://www.leanuk.org/articles/lean_thinking_for_the_nhs_leaflet.pdf

Nurse Work Environment Innovation Summit, 2007 Robert Wood Johnston Foundation

http://rwjproject.com/default.aspx

OECD Health Data, 2006, *How Does the United States Compare* Organization for Economic Co-operation and Development http://www.oecd.org/dataoecd/29/52/36960035.pdf

Office of Government Commerce, 2004, *Working without walls: An insight into the transforming government workplace,* United Kingdom Office of Government Commerce http://www.ogc.gov.uk/documents/cp0039_working_without_walls.pdf

O'Hara, Susan, 2004 Sullivan, Mark, Bell, Henry, *Using Simulation to Improve the Patient Pre-admission Testing Design Process,* Proceedings of the 36th Winter Simulation Conference, Washington, D.C. http://www.wintersim.org/abstracts04/CS.htm

Reid Proctor P., Compton, W. Dale, Grossman, Jerome H. and Fanjiang Gary, Editors, 2005 *Building a Better Delivery System: A New Engineering/Health Care Partnership,* Committee on Engineering and the Health Care System, National Academy of Engineering, Institute of Medicine http://www.nap.edu/catalog/11378.html

Robert Wood Johnston Foundation *Nurse Work Environment Innovation Conference,* Oakland California. http://rwjproject.com/default.aspx

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