# AN INVESTIGATION OF EMERGENCY DEPARTMENT OVERCROWDING USING DATA MINING AND SIMULATION:
A PATIENT TREATMENT TYPE PERSPECTIVE

**Andrzej Ceglowski**

B Sc (Chemistry) University of Natal, Durban, S.A.

M Bus Sys (Res) Monash University, Melbourne, Australia

A thesis submitted in fulfilment of the requirements
for the degree of

**Doctor of Philosophy**

Department of Accounting and Finance

Faculty of Business and Economics

Monash University, Caulfield, Australia

September 2006

# Table of Contents

# List of Tables

# List of Figures

# Abstract

In ongoing efforts to limit the proportion of budgets allocated to healthcare, governments have closed hospitals, reduced bed numbers, and minimised staffing levels. These efficiency drives in Australia and elsewhere have led to the healthcare system being more sensitive to shocks and disruptions because there is little excess capacity to absorb extra demand. Among other impacts, this has resulted in hospital emergency departments (EDs) having to balance patient throughput with patient queues. This balance is often difficult to achieve and EDs become overwhelmed, resulting in long patient waits, overcrowded treatment areas and excessive stress for ED staff.

Much research has been done in an effort to limit the frequency and severity of these "overcrowding" incidents. Projects have been driven by preconceived ideas about activities in EDs and often employ parametric methods to identify correlated factors. As such they are limited by the extent of analysts' knowledge or observations. While these approaches have added to knowledge about ED operations, the problem of patient overcrowding persists.

This research questioned whether patient treatment could be implicated in ED overcrowding. Process-based thinking was used in order to derive a simplified model of emergency department operations. This "process-focussed" model of ED operations directed thinking towards the identification of homogenous clusters of treatment with similar activities, so each treatment cluster could be considered to have matching inputs, outputs and resource consumption.

Scientific Method was selected as an appropriate methodology for the research. Techniques from the dissociated methods of Data Mining and Management Science were combined within the hypothesis / experimentation framework of Scientific Method. Undirected clustering techniques from Data Mining were used to identify definitive treatment clusters. Discrete event simulation techniques from Management Science were used to drive the study towards the overcrowding problem

The treatment clusters were verified and validated through a number of studies. Process perspectives were employed together with the treatment clusters to simulate patient flows through the ED at an aggregated level. The clusters were combined with patient urgency and disposition to create "patient treatment types" that were tracked through the ED. Analysis of the simulated ED indicated that simultaneous occupation of the ED by certain patient types made the ED unable to accept any new patients for treatment.

This thesis contributes to the understanding of ED overcrowding by confirming that exit block is the most likely direct cause of ED overcrowding, and by suggesting that the mix of patients types in, and arriving at, the ED are the most likely precursors of ED overcrowding. It concludes that there will always be a finite chance that a mix of patient types will occur who require admittance to hospital or have long ED treatment times, and consequently, are likely to block the ED. This suggests that it will never be possible to completely eliminate ED overcrowding. Rather, acceptable levels of risk of overcrowding need to be determined. The capacity of EDs and of hospitals to admit ED patients may then be determined based on how risk adverse the hospital is to ED overcrowding.

# Acknowledgements

This work was conducted with the support of Australian Research Council Linkage Grant #LP0214141. Thanks to Frankston Hospital and Dr. Jeff Wasserthiel, Director of Emergency Medicine at the hospital, for their support of this study.

Thanks to Dr. Leonid Churilov for his insight, time and patience in discussing the work, for his encouragement to follow new avenues of research, for the loan of innumerable valuable reference texts, and for his good humour throughout the process.

Thanks to the referees for their time in reviewing this thesis, and for their comments and suggestions.

# Declaration

In accordance with Monash University Doctorate Regulation 17 / Doctor of Philosophy and Master of Philosophy regulations the following declarations are made:

I certify that this Thesis does not incorporate, without acknowledgement, any material previously submitted for a degree or diploma in any university and that, to the best of my knowledge and belief, it does not contain any material previously published or written by another person where due reference is not made in the text.

A list of papers resulting from the thesis and published in peer reviewed conference proceedings and journals are included below, along with invited and non-reviewed publications. The ideas, development and writing of all papers that resulted from the thesis were the principle responsibility of me, the candidate, working under the supervision of Dr. Leonid Churilov and with the expert advice of Dr. Jeff Wasserthiel, the Director of Emergency Medicine at Frankston Hospital. The inclusion of Drs. Churilov and Wasserthiel as co-authors reflects that the works arose from active collaboration between the authors.

### Peer-reviewed Journals

1. Ceglowski, A., L. Churilov, et al. (2006). *Combining data mining and discrete event simulation for a value-added view of a hospital emergency department* Journal of the Operational Research Society **Special Issue**
2. Ceglowski, A., L. Churilov, et al. (2005). *Don't panic - Prepare: Towards crisis-aware models of emergency department operations* Clinical and Investigative Medicine **28**(5): 320-322.

### Peer-reviewed Conference Proceedings

1. Ceglowski, A; Churilov, L; Wasserthiel, J (2005) *Facilitating Decision Support in Hospital Emergency Departments: a Process-Oriented Perspective* 13th European Conference on Information Systems, Regensburg
2. Ceglowski, A; Churilov, L (2005) *Knowledge Discovery through Mining Emergency Department Data* Hawaii International Conference On System Sciences (HICSS 38), Kona
3. Ceglowski, A; Churilov, L; Wasserthiel, J (2004) *Towards Flexible and Configurable Emergency Department Information Systems* Australasian Conference on Information Systems, Brisbane
4. Ceglowski, A; Churilov, L (2004) *Process Mining Informed Industrial Engineering In Hospital Emergency Departments* The Fifth Asia-Pacific Industrial Engineering and Management Systems Conference (APIEMS), Brisbane
5. Ceglowski, A; Churilov, L, Wasserthiel, J (2004) *Data driven process modelling for a hospital emergency department* The First International Workshop on Computer Supported Activity Coordination (CSAC) at The 6th International Conference on Enterprise Information Systems (ICEIS), Porto

### Invited Talks & Non-Refereed Conference Presentations

1. Ceglowski, A; Churilov, L; Wasserthiel, J (2005) *(Back to the future) Towards data rich, socially responsible OR:A case of process modelling in Hospital Emergency Departments* IFORS Triennial 2005 Conference, Honolulu (Australian National Paper)
2. Ceglowski, A; Churilov, L; Wasserthiel, J (2004) *Process Focused Patient Clustering for Hospital Emergency Departments (a cross campus perspective)* 15th Australian Casemix Conference, Sydney

-------------------------------------------------

A. Ceglowski

Department of Accounting and Finance

Faculty of Business and Economics, Monash University

20 September 2006

# Chapter 1: Introduction

This introductory chapter will set the scene for the research. It will provide background to the problems faced by emergency departments (EDs) in general and exemplified by Frankston Hospital's ED, a partner in this research. It will describe the workings of EDs and general problems faced by them. This will lead to introduction of the research problem and justification for doing the research.

The chapter will not deal with similar problems at an international level because health care systems vary from country to country. Nonetheless, the problems indicated in this chapter for Australian EDs are similar to those faced by EDs around the world (This is discussed in Chapter 2). Instead the chapter will move from a broad overview of ED performance at a national level through that at state level and then consider performance at Frankston ED.

The first section contrasts the ED management problem to typical production or service environments. This is followed by an overview of ED patients and data. Subsequent sections provide a context for the problem by looking at ED performance. This paves the way for statement of the research problem in Section 1.4 and justification for the research in following sections. The thesis scope and key assumptions are stated before the flow of the thesis is outlined in Section 1.7 and contributions listed in Section 1.8.

The form and function of the ED should be well understood by the end of the chapter, and the nature and complexity of operational issues adequately framed to facilitate a review of previous research and formulation of research objectives in the next chapter. This will lead to considerations of methodology in Chapter 3 and then to description of the data analysis and experimentation in Chapters 4 to 6.

## 1.1 Background to EDs

An ED is a hospital department that specialises in providing emergency medical care for patients who are delivered by ambulance, referred by their doctor or choose to seek treatment in an ED. Public hospital EDs provide urgent care to patients with life threatening or serious health problems and also provide care to patients with less serious conditions. However, patients with urgent medical needs always take priority.

EDs must be available for patients seeking care, regardless of time of day and number of patients (Duckett, et al., 1997). This 'always open' and 'ready for any eventuality' nature of EDs make resource management extremely complex and uncertain (D Richardson, et al., 2003; Stuart, 2003).

Urban hospital EDs typically draw patients from surrounding residential and industrial areas. The demographic mix of patients is usually wide and can vary, particularly in the instances of itinerant groups such as holiday resorts or sports stadiums. Patients may be of any age or either sex, have a full spectrum of ailments and injuries from life-threatening to minor, and range from lucid to incommunicado (Coleridge, et al., 1993; Liaw, et al., 2001).

Patients are typically discharged home once treatment in the ED is completed or admitted for further bed-based care. In the former case almost all patients leave the ED quickly and largely unaided. However, patients who are to be admitted to hospital continue to consume resources in the ED by occupying a treatment bed while they await transfer to an appropriate ward. Hospital admittance may be hampered by a variety of factors, such as a lack of communication between hospital wards and the ED, a dearth of porters or a shortage of ward beds at the time (Department of Health, 2003; D C Lane, et al., 2000). Delays in the ED may impact the recovery of the patient (Liaw et al., 2001).

In an analogous manufacturing situation, assembled, perishable products fill the end of the assembly line because of inability to move them to storage or despatch them. No more products can be assembled until the end of the assembly line is cleared. Both raw materials and assembled products require constant monitoring. Suites of feasible solutions are available for problems of this nature (Konz, et al., 2000)). These solutions are driven by a thorough understanding of all activities involved in the manufacturing process.

If the ED is likened to a manufacturing plant then the plant would manufacture a huge range of products (analogous to patient treatments) in a wide variety of specifications or combinations (patient severity and needs) – and deliver near perfect customer satisfaction (patient recovery). ED "manufacturing" (of healthier patients) is a more difficult problem than that posed in manufacturing or service environments because the product range is extensive (every patient is unique) and defective quality impacts on lives, not merely costs and profit.

The pivotal role of EDs (EDs) in the community makes them highly visible, newsworthy and politically sensitive. Incidents ranging from 'less than satisfactory' to 'life threatening' are quite likely to be reported in news media and rapidly promoted to level of political comment. Disruptions such as patients waiting 'too long' for treatment or admittance to hospital are the most frequent causes of news reports, but there may also be graver incidents such as treatment quality issues (Figures 1-1 and 1-2 provide excerpts from such media reports in the years preceding this study).

**Our sick health system**

June 1996: Confidential documents show large numbers of patients are being forced to wait up to two days in the Royal Melbourne Hospital's ED for a bed. In the first three weeks of June 79 people were left on trolleys at the hospital for longer than 12 hours - some waiting up to 48 hours - because the hospital had no beds.

April 1998: The official opening of the $70 million Northern Hospital is marred by the leaking of documents showing more than 100 emergency patients endured long waits on trolleys in its first weeks of operation. The North Western Health Network report said the 225- bed Epping hospital well exceeded its quarterly target for patients waiting longer than 12 hours. The report blamed the ED delays on the failure to replace staff from the old Preston and Northcote Community Hospital, unexpectedly high patient demand and difficulties in recruiting medical officers.

June 1998: A memo released by the State Opposition says privatisation of cleaning at The Alfred Hospital has left the hospital's ED with a substandard service. The memo says meetings with the cleaning contractor failed to fix problems including dirty toilets and grease and dirt being left on surfaces.

Figure 1-1: Excerpts from an article in by Darren Gray in The Age newspaper (Melbourne) 18th July 1998 that listed a chronology of incidents at Melbourne hospitals. This shows the range of potential impacts from ED incidents – on individuals, staff and operations.

**System on critical list.**

EVERY day an average of 10 Victorians spend more than 24 hours on ED trolleys in public hospitals. Figures from the state's major hospitals show almost 4000 people waited more than 12 hours for a bed between July and September last year. Documents obtained by a Herald Sun INSIGHT investigation show in August alone, 273 patients spent more than a day on trolleys. The Monash Medical Centre had 181 patients who waited more than 12 hours, but they did not reveal how many of those spent longer than a day on a trolley.

Medical experts have warned the state's public health system is on the brink of collapse. The stark warning comes just days after the dramatic breakdown of health funding talks between the federal and state governments. Premier Jeff Kennett stormed out of last week's Medicare crunch meeting, claiming the Federal Government's offer of an extra $1.1 billion over five years would leave 125,000 patients a year without treatment.

According to the most recent figures, 260 emergency patients had to be transferred to another hospital in one month because no beds could be found at the first one they were taken to. Eighty six, or almost 40 per cent, of those were emergency heart patients needing coronary care beds.

The Office of the Coordinator of Emergency and Critical Care finds beds for emergency patients, and when none are available in the public system, beds are bought in the private system. One of the office's coordinators, Dr Johannes Wenzel, said no patient had missed out on an emergency bed in the past four years. But Dr Wenzel, who is also the director of emergency at Monash, revealed the government had paid for 444 public patients to be treated in private hospitals since 1994. Last year, $800,000 of taxpayer-funded private beds were bought to treat 140 patients.

Victorian Health Minister Rob Knowles said it was wrong to say the public hospital system was in crisis but he said it would be unless better federal funds were offered. "Public hospitals are meeting the needs but can only do so because we have run down their cash reserves and driven up productivity," Mr Knowles said.

Figure 1-2: Politically oriented article by Helen Carter and Michelle Coffey in the Herald-Sun newspaper of 27th March 1998

Having “set the scene” in very general terms, the following section will introduce how EDs work, the performance of ED across Australia and within the state of Victoria. It will end with an analysis of performance at the ED that was a partner in the research. This will allow for general statement of the research problem in Section 1.4.

## 1.2 Description of ED function and operations

The Australian College of Emergency Medicine (ACEM) gives a definition of a Department of Emergency Medicine applicable in Australasia and internationally recognisable[1] as: “The pyramidal structure for the medical staff within a hospital who are responsible for the provision of medical care plus management teaching and research in emergency medicine.”(Australian College for Emergency Medicine, 2001)

The ACEM definition of EDs adds a definition of emergency medicine as “a field of practice based on the knowledge of skills required for the prevention, diagnosis and management of acute and urgent aspects of illness and injury affecting patients of all age groups with a full spectrum of undifferentiated physical and behavioural disorders. It further encompasses an understanding of the development of pre-hospital and in-hospital emergency medical systems and the skills necessary for this development.” (Ibid)

ACEM goes on to prescribe that the ED must be part of a recognised hospital and be licensed or recognised by the appropriate authority. EDs must be purpose designed and include a dedicated area with the capacity for advanced life support including mechanical ventilation designed and used for the reception and stabilisation of critically ill patients (ibid). There must be a registered nurse on duty in the department at all hours with a senior nurse responsible for the organisation of nursing services. The ED must have a 24 hour per day on-call access to a senior doctor (who is an emergency physician) for clinical support whose primary commitment is the ED.

### 1.2.1 ED patient flow

Hospital ED (ED) operations may be viewed as a series of value-adding functions (Figure 1-3). These functions describe the flow of patients through the ED from arrival to departure. Patient arrival and departure modes are excluded from this model as they lie beyond the walls of the ED.

Triage is the assessment of each patient’s medical condition by a qualified medical practitioner (most commonly an experienced nurse) and assignment to an 'urgency' or

[1] The complete ACEM Standard Terminology is provided as Appendix 1-A.

'triage' category. There are five triage categories defined by the Australian College of Emergency Medicine ranging from patients who require resuscitation (triage category 1) to patients whose medical needs are not urgent (triage category 5). For each of these categories, the Australian College of Emergency Medicine has identified the maximum time patients should wait until they are seen by a nurse or a doctor for treatment (Figure 1-4).

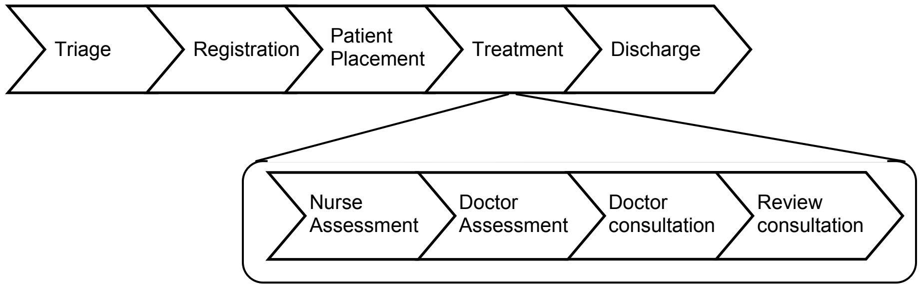



Figure 1-3: Core ED value adding functions (Djorhan, et al., 2003)

After assigning each patient to a triage category, the next task of the triage nurse is to gather information regarding the patient's medical history and generate instructions for the nurse who treats the patient once they have been shown to a cubicle[2].

Registration follows triage, in general. Registration is the documentation and recording of patients' personal details and to check whether the patient has an existing medical record at the hospital. Registration may be deferred if the patient urgently requires medical attention.

Patient placement is the direction of the patient to a treatment site (usually an ED bed in a cubicle). Patients may have to wait for a cubicle to become available. Once the patient is in the cubicle they receive initial treatment from a nurse based on the initial procedural order generated by the triage nurse. There may be a further wait until a doctor is available to attend the patient.

Treatment is the next step in patient flow. Treatment begins with nurse assessment of the patient and carrying out the triage nurses initial instructions. Doctor assessment usually follows. Doctors consult a (computer) list of patients that have not yet been seen in order to select the next patient to assess. Doctors may prioritise patients within urgency categories, or select to assess one patient over another owing to that doctor's

[2] This process description comes from direct consultation with staff and observation of activities at Frankston ED. This was performed as part of a separate research project (Djohan, 2002).

experience. The primary task of the doctor assessment is to gather as much information as possible before initiating treatment. Information may come from interviewing the patient, examining them, looking at their medical record, or from the nurse's observations.

**Triage category 1:** need for resuscitation - patients seen immediately. People in this group are critically ill and require immediate attention. Most arrive at the ED by ambulance. This group includes people whose heart may have stopped beating, whose blood pressure may have dropped to dangerously low levels, who may be barely breathing or have stopped breathing, who may have suffered a critical injury or who may have had an overdose of intravenous drugs and be unresponsive.

**Triage category 2:** emergency - patients seen within 10 minutes. People in this group will probably be suffering a critical illness or very severe pain. For example, the group includes people with serious chest pain likely to be related to a heart attack, people with difficulty breathing and people with severe fractures.

**Triage category 3:** urgent - patients seen within 30 minutes. People in this group include patients suffering from severe illnesses, people with head injuries but who are conscious, and people with major bleeding from cuts, major fractures, persistent vomiting or dehydration.

**Triage category 4:** semi-urgent - patients seen within 60 minutes. People in this group usually have less severe symptoms or injuries, although the condition may be potentially serious. Examples include people with mild bleeding, a foreign body in the eye, a head injury (but where the patient never lost consciousness), a sprained ankle, possible bone fractures, abdominal pain, migraine or earache.

**Triage category 5:** non-urgent - patients seen within 120 minutes. People in this group usually have minor illnesses or symptoms that may have been present for more than a week, like rashes or minor aches and pains. The group includes people with stable chronic conditions who are experiencing minor symptoms.

Figure 1-4: Triage categories (Australasian School of Medicine, 1994)

A decision is made regarding appropriate action once the doctor assessment is complete. The decision generally involves a choice between observation, a medical procedure, additional tests or request of a second opinion. All junior doctors at Frankston ED ask for second opinions before finalising patient treatment.

Discharge is initiated once the doctor has made a decision about the patient's condition. The doctor creates a discharge summary and all patient documentation is checked before the patient exits the ED.

### 1.2.2 ED layout and design

An ED is comprised of a number of functional areas (Australian College for Emergency Medicine, 1998; The Department of Human Services, 2004):

- An **entrance/reception** that is paved and covered to facilitate discharge of patients from vehicles. The reception should allow for patient registration. A separate area is required for patient triage. The waiting area needs to provide seating and space for prospective patients and their support, as well as providing a children's play area. Staff need to be able to observe and control access to treatment areas, pedestrian and ambulance entrances and public waiting areas.

- A **resuscitation area** that is used for the treatment of critically ill or injured patients. This area is highly equipped with monitoring, imaging and resuscitation equipment and needs to be large enough to permit easy access by staff to all parts of the patient.
- **Acute treatment and associated consultation rooms** used for the management of patients with acute illnesses. Each acute treatment area needs a minimum of a standard mobile bed, storage space for necessary equipment and space for monitoring equipment. Acute treatment areas need to be at least nine metres squared in area and separated from its neighbours by at least 2.4 metres. Consultation areas are used for the examination and treatment of ambulant patients.
- **Staff amenities** such as an enclosed central staff station that is permits view of the patients and can be used to provide security and privacy for staff and information.
- Administration offices.

In addition to these core functional areas, EDs need access to laboratories, a pharmacy or medication area, medical imaging (X-ray, CT scanning, Ultrasound and Nuclear Medicine) and pathology services. Of course, EDs must have clear signage, controlled access, connecting corridors and sufficient toilets for patients and staff. Some EDs also provide for teaching and research. EDs may also have specially designed areas for specific roles such as management of paediatric, major trauma or psychiatric patients.

EDs are high volume users of telecommunications and information technology. There need to be adequate telephone facilities and space for computer terminals to support clinical management. Many EDs have dedicated purpose-built information systems that assist with clinical management, patient tracking and departmental administration.

### 1.2.3 ED Problems

A number of problems are common to EDs throughout the world. This section provides definitions of terms most commonly used in referring to ED problems in Australia (Fatovich, et al., 2003):

- **ED Overcrowding** is the situation where ED function is impeded primarily because the number of patients waiting to be seen, undergoing assessment and treatment, or waiting for departure exceeds the physical or staffing capacity of the

ED (that is, demand exceeds supply). This hampers doctors and nurses in the provision of high quality care. Objectively, this is reached when the ED exceeds 100% occupancy, or earlier if there are inadequate staff or other resources.

- **Entry Block** indicates that entry to the ED is effectively "blocked" because of overwhelming numbers of patients attending the ED in a short space of time (entry overload). It is overwhelming because it exceeds the physical and medical processing capacity of the ED. This results in impaired access to emergency care.
- Ambulances may be redirected away from an ED experiencing entry block to an alternative facility (**ambulance bypass**). Frequently ambulance bypass at one ED will trigger a chain of entry block events in neighbouring EDs (Fatovich et al., 2003).
- **Access Block** refers to the situation where patients in the ED requiring inpatient care are unable to gain access to appropriate hospital beds within a reasonable time frame.
- **Exit Block** is an alternative term to access block that refers to a lack of inpatient beds (within the hospital) thus limiting outflow from the ED.

All of the above terms refer to different levels of ED blockage. If the ED is overcrowded then all excess capacity is already being used, so the ED is prone to blockage. It's typical that exit block or access block will trigger overcrowding as ED staff try to handle new patient arrivals without sufficient departures to balance the arrivals. ED overcrowding may be viewed as an initial phase of entry block. If the departure / arrival imbalance persists then ambulances will be diverted.

### 1.2.4 Funding of EDs

There are three levels of Government in Australia - Commonwealth (also known as "Australian" or "Federal") Government, State and Local. Each level of government has responsibility for some aspect of healthcare, but local government involvement is generally to support healthcare facilities at a municipal level.

The states are largely responsible for the direct funding and operation of public hospitals, psychiatry institutions, and non-medical community and public health services. The largest single area of health expenditure by state and territory governments is public hospitals. In 2003-04, state and territory governments spent $9,664 million or 54.5% of their total health expenditure in meeting the operating costs of public hospitals. In addition, a large part of these governments' $1,215 million capital expenditure and $1,090 million capital consumption related to public hospitals (Department of Health and Ageing, 2004b).

The states have insufficient revenue raising capacity to fund their outlays while the Commonwealth government raises more than it needs so the Commonwealth makes up the States' shortfall (Barraclough, et al., 2002). This means that the Commonwealth government has significant influence on state health policy. The Commonwealth government and the State governments gather performance statistics in order to ensure that the public interest is being served and as a reference to use when determining eligibility of hospitals for funding. Samples of these performance statistics are presented in the next section to provide a backdrop for the research problem that follows.

## 1.3 ED attendance and performance

### 1.3.1 National attendance and performance statistics[3]

EDs are a primary route for admission into Australian hospitals. They are also becoming the primary source of care (there was an 11% increase in presentations to ED's between 1998 and 2004 (Department of Health and Ageing, 2005)). Higher numbers of patients in the ED system lead to access block, overcrowding, and entry block and other issues that have the potential to affect the ability of the ED to save lives. This section will briefly review and comment on some of the data and statistics available on Australian ED operations.

#### 1.3.1.1 Patients attending EDs

EDs got busier between 1998 and 2004 (Figure 1-5). In 2003–04, about 4.1 million Australians presented to EDs for treatment (2002-03: 3.8 million), 11 per cent more than in 1998-99. 32 per cent (or 1.3 million) patients were triaged as urgent and about 1.9 million (or 47 per cent) were considered semi–urgent. Around 40 per cent of urgent and 15 per cent of semi–urgent patients were later admitted to hospital (Department of Health and Ageing, 2005).

Males accounted for 52.5% of ED occasions of service in 2003-04. There were more occasions of service for males than females in all age groups from 0 to 75 years and there were more occasions of service for females than males for persons aged over 75

[3] The figures in this section are culled from a range of government publications. The data specifications for these are listed in Appendix 1-B

years. The most common age groups reported for non-admitted patient ED care were 15–24 years (15.3%), followed by 25–34 years (14.9%) and 0-4 years (12.8%).

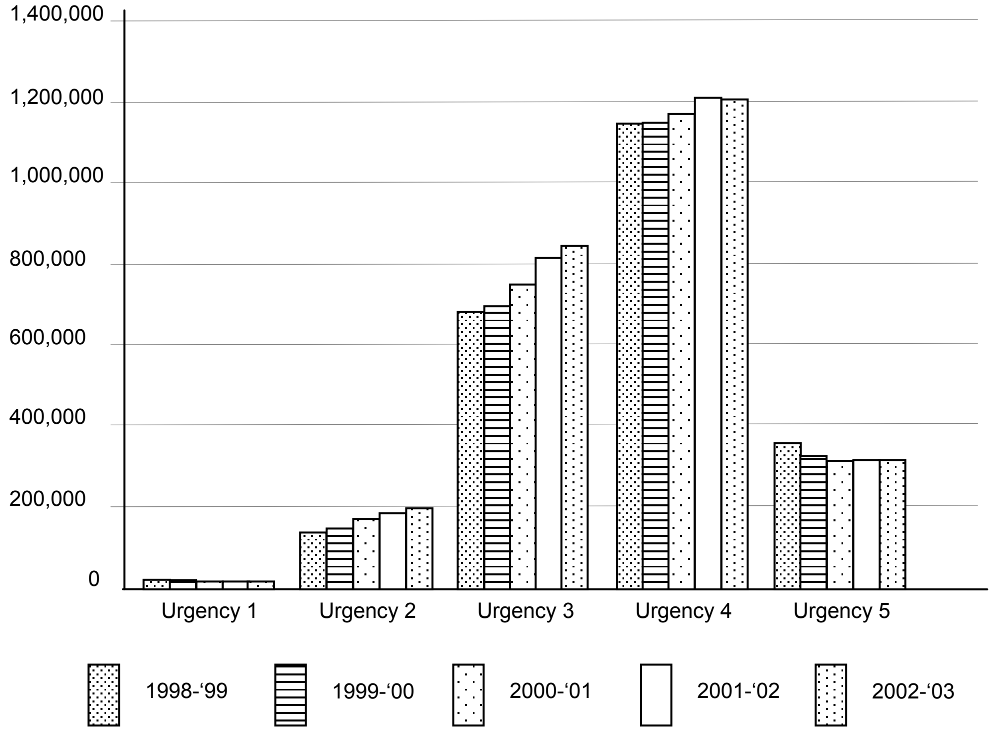



Figure 1-5: ED attendances in Australia from 1998-99 to 2002-03 (Department of Health and Ageing, 2003)

#### 1.3.1.2 Wait time before treatment commences

Nationally, almost 70 per cent of people were seen within the times recommended by their triage categories (cf. Figure 1.5) and 50 per cent of all patients were seen within 25 minutes (Table 1-1).

Table 1-1: Percentage people seen at EDs within the recommended time (Department of Health and Ageing, 2003; Department of Health and Ageing, 2004b)

| State | 1998-99 | 2002-03 | 2003-04 |
|---|---|---|---|
| Western Australia | 74% | 68% | 70% |
| Victoria | 78% | 73% | 80% |
| Tasmania | 78% | 64% | 64% |
| Queensland | 71% | 60% | 61% |
| South Australia | 68% | 53% | 55% |
| Northern Territory | 60% | 58% | 64% |
| New South Wales | 71% | 65% | 66% |
| Australian Capital Territory | 76% | 73% | 65% |
| National average | 71% | 65% | 69% |

Performance across Australia varied for different triage categories (Department of Health and Ageing, 2003):

- In 2003-04, 99 per cent of patients across Australia in need of resuscitation were seen immediately. The fact that the figure is slightly lower than 100 per cent probably reflects difficulties in recording data accurately in an emergency situation and not what actually happens when a person is at imminent risk of dying. Over 61% of Resuscitation patients were male, and over 22% of patients were aged 75 years and over. The most common arrival mode for Resuscitation patients was Ambulance (84.8%). 72.6% of Resuscitation patients were admitted to the same hospital (which includes admission within the ED). The most common time of day for the arrival of a Resuscitation patient was between 6pm and 8pm (11.1%) and the number of arrivals for these patients was lowest between 4am and 6am.
- Critical illness or severe pain patients (triage category 2) had a 77% chance of being seen within 10 minutes in 2003-04. This has not changed significantly since 1998-99. 50 per cent of category 2 patients are seen within five minutes, but 10 per cent have to wait longer than 23 minutes to be treated. The level of performance is not consistent across the country. South Australia, Tasmania and the Northern Territory all performed below the national average, while Victoria performed better than average.
- The national average for urgent or semi-urgent (triage categories 3 and 4) in 2003-04 was 65 per cent seen within 30 minutes or 1 hour, respectively. This is down on the rates reported for 1998-99. For urgent patients, the rate ranges from 49 per cent in South Australia to 83 per cent in Victoria, while for semi-urgent patients the rate varies from 54 per cent in South Australia to 75 per cent in Victoria.
- 87 per cent of non-urgent patients (triage category 5) presenting to EDs were seen within 120 minutes. The proportion seen within the benchmark time varied between 77 per cent in the Australian Capital Territory to 92 per cent in Western Australia and Tasmania.

#### 1.3.1.3 Hospital admittance from EDs

Around a quarter of people attending EDs are subsequently admitted to hospital. Admission is not necessarily related to urgency. For example, patients with chest pain need to be seen quickly, but after observation a doctor may conclude that the problem is not related to a heart attack and send the patients home. Patients may have medical conditions that are semi-urgent but nevertheless serious, and subsequently require hospitalisation. Nineteen per cent of semi-urgent patients in 2001-02 were subsequently admitted to hospital. A small proportion of non-urgent cases are also admitted.

There are not any national statistics on patients waiting for an excessive time to be admitted to a hospital ward from the ED. These data should be available from 2006. New South Wales and Victoria do collect and publish these data, but use different definitions for excessive time.

New South Wales considers that patients have waited excessive time if they are not admitted eight hours after active treatment starts. In 2003-04, 68 per cent of patients in New South Wales public hospitals were admitted within eight hours of the commencement of active treatment (New South Wales Department of Health, 2003). This proportion has declined steadily since 1998-99, when 82 per cent of patients were admitted within eight hours. Waits of longer than eight hours are 22 percent more likely at large metropolitan hospitals in New South Wales than hospitals in a rural area.

In Victoria, patients who stay in EDs for more than 12 hours from the time they arrive to the time they are admitted are considered to have had an 'extended wait' (this was shortened to eight hours from 1st July 2005). In 2002-03, 86 per cent of emergency patients were admitted within 12 hours of arriving at the ED (Victorian Department of Human Services, 2000; Victorian Department of Human Services, 2001; Victorian Department of Human Services, 2003; Victorian Department of Human Services, 2004). This level of performance has been fairly constant since 1999-00.

### 1.3.2 Performance of EDs in Victoria, Australia

In 2003-04 Victoria performed better than the national average in all triage categories in treating ED patients within desirable times (Figure 1-6) (Metropolitan Health and Aged Care Services Division, 2005a).

- In 2000- 2001 EDs went on hospital bypass 6.2 per cent of the time. From January to June 2005 EDs went on hospital bypass 1.2 per cent of the time, unchanged from the same period in 2004 (Figure 1-7)
- In 2004- 2005, 797,894 people presented to Victorian EDs, an increase of 27,385 or 3.6 per cent over the previous year.
- From January to June 2005, there were 402,069 people presenting to EDs, an increase of 20,908 or 5.5 per cent over the same period in 2004 (Figure 1-8).
- In 2004– 2005, 24,451 more people presenting to EDs needed to be admitted to a bed than in the previous year, an increase of 13 per cent (Figure 1-8).

- Of the patients admitted to a bed in 2004–05, 177,062 (85 per cent) were admitted within 12 hours.  This is an increase of 19,926 or 13 per cent compared with 2003–2004 (Figure 1-9).
- From January to June 2005, 92,821 patients, or 88 per cent, were admitted to a bed within 12 hours. This proportion is unchanged from the same period in 2004.

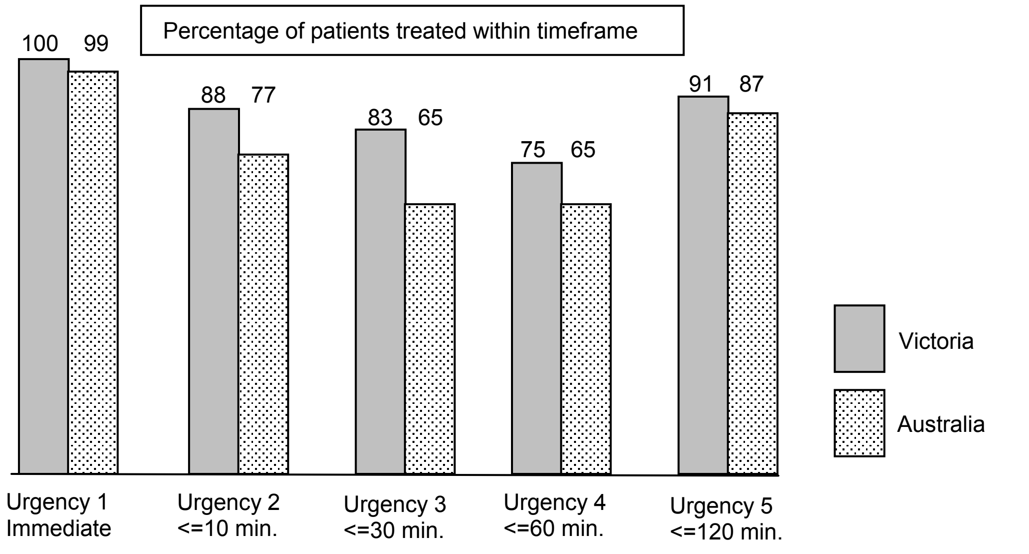



Figure 1-6: Performance of Victorian EDs in 2003-04 relative to the Australian average (Metropolitan Health and Aged Care Services Division, 2005a)

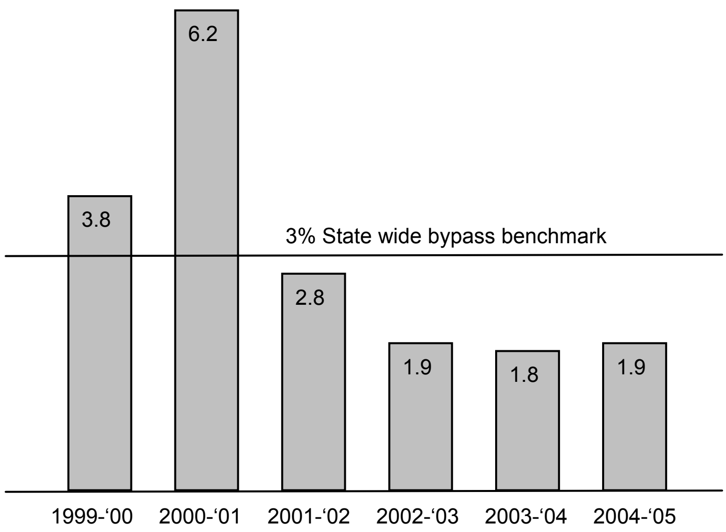



Figure 1-7: Percentage of time Victorian EDs went on Bypass

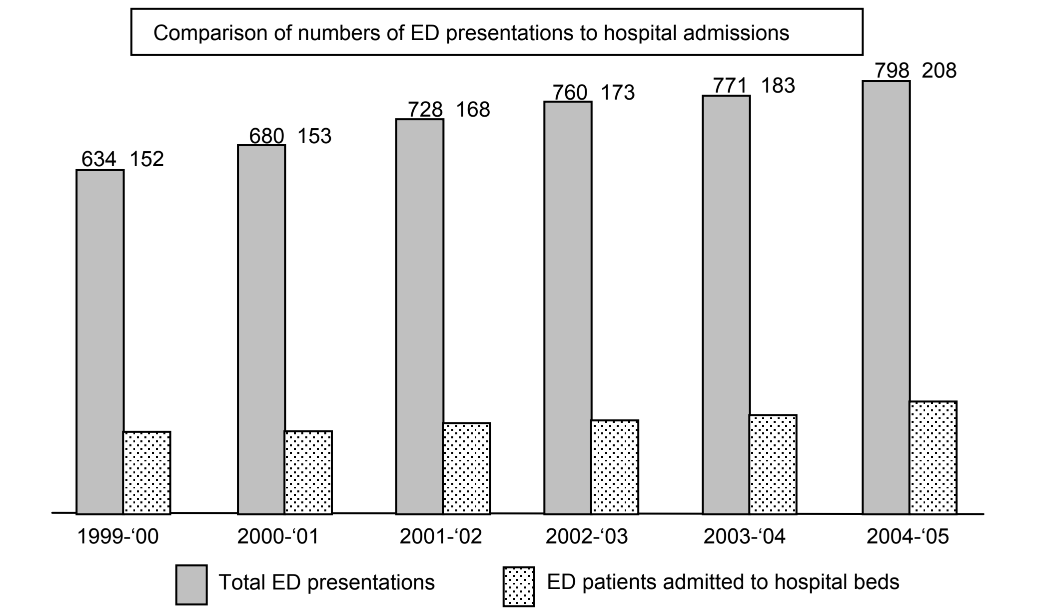



Figure 1-8: Number of patients admitted to hospital beds from EDs

Strategies to improve performance in time to admission to a bed include extending ED care co-ordinators and fast-track services across all major metropolitan and regional hospitals, and further expanding new models of care such as short-stay observation units and day treatment centres (Metropolitan Health and Aged Care Services Division, 2005b). The state at Frankston ED is discussed in the next section as a prelude to introducing the research problem addressed in this thesis.

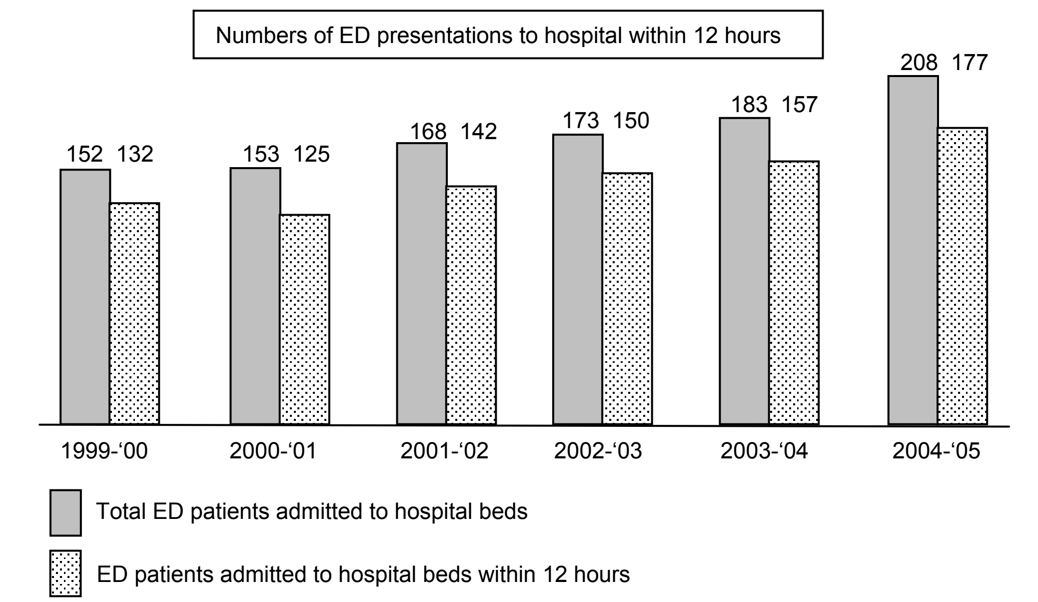



Figure 1-9 Number of patients admitted to hospital beds from EDs within 12 hours

### 1.3.3 The state at Frankston ED

Although the official statistics for the ED in 2001- 2002 were excellent, and an improvement in some areas over the figures reported for 2000- 2001 (Table 1-2), the suggestion that the ED ran at or near capacity for large portions of the day was anecdotally supported through discussions with members of staff and through visits to the ED when it was seen to be entering bypass situations.

Table 1-2: ED statistics for Frankston hospital

| | 2000- 2001 | 2001- 2002 |
|---|---|---|
| Percentage of Category 1 patients receiving immediate attention | 100 | 100 |
| Percentage of Category 2 patients receiving attention within 10 minutes | 68 | 82 |
| Percentage of Category 3 patients receiving attention within 30 minutes | 57 | 56 |
| Percentage patients staying in ED over 12 hours waiting for a hospital bed | 23 | 20 |
| Ambulance bypass (total minutes) | 402 | 186 |

It was no simple task to extract a clear picture of the number of patients in the ED from historic patient data in order to determine the extent of the problem at this ED. The principle reason for this difficulty was the degree of granularity that was required in order for the analysis to have any meaning.

Theoretically it should have been possible to count the number of patients in the ED at each hour merely by manually counting the number of patients there at midnight on 1st January and then adding new arrivals and subtracting departures. Unfortunately this strategy quickly fell prey to missing and erroneous data in the entry and departure times. Knowledge provided by this first model was applied in the building of an improved version in which patients counts were reconciled at midnight every day. Once again this model fell short of providing a seemingly accurate picture of the number of patients in the ED at any given time.

These analyses had provided some indication that there were more patients in the ED for many hours of the day than there were ED beds, but the information was not considered accurate enough to be of value. Some overcrowding could be inferred from intermediate results so the research was pursued on this basis. This inability to produce accurate figures about the number of patients in the ED at any time of the day from the data was considered yet another symptom of the lack of understanding of ED overcrowding.

A new tool (HillMaker[4]) became available later in the research project that

[4] HillMaker is an open source healthcare modelling project from Mark Isken, Associate Professor, Dept. of Decision and Information Sciences, School of Business

confirmed the frequency of ED overcrowding. HillMaker is a software program specifically targeted at analyses of this nature. The research dataset was duly placed into an appropriate format and analysed using HillMaker.

Figure 1-10 gives the HillMaker graph for ED occupancy (derived from Bed Time) in 2 hour slices by day of week. One of the first things to notice is a typical ‘camel hump’ of occupancy by day as arrivals gradually increase through the morning and peak in early evening (cf. Figure 1-1). On average the ED occupancy was around 26 beds, which indicated that the ED (with 33 beds) was big enough and there was no need to increase the number of beds.

The maximum occupancy was regularly over 40 patients in the ED[5] (the top, bold line in Figure 1-10). The ED with 33 beds was simultaneously treating more patients than could be placed into beds. The 75$^{th}$ percentile showed that such overcrowding was not as rare as implied by the performance figures of Sections 1.3.1 and 1.3.2, and Table 1-2.

It’s possible with HillMaker to break occupancy down by urgency, disposal or other categorical field in the data. One could immediately see the impact that hospital admissions can have on the ED by looking at the subgroup of patients who are awaiting admittance to a hospital ward (Figure 1-11).

---

Administration, Oakland University, isken@oakland.edu;
http://www.sba.oakland.edu/faculty/isken/

[5] This ED, like most these days, has instituted a “Short Stay Unit” specifically for patients awaiting admittance. Such units are a mechanism whereby EDs can temporarily admit patients and so relieve pressure on hospital inpatient beds. Figures 1-11 and 1-12 show the situation for patients in the ED before transfer to the Short Stay Unit.

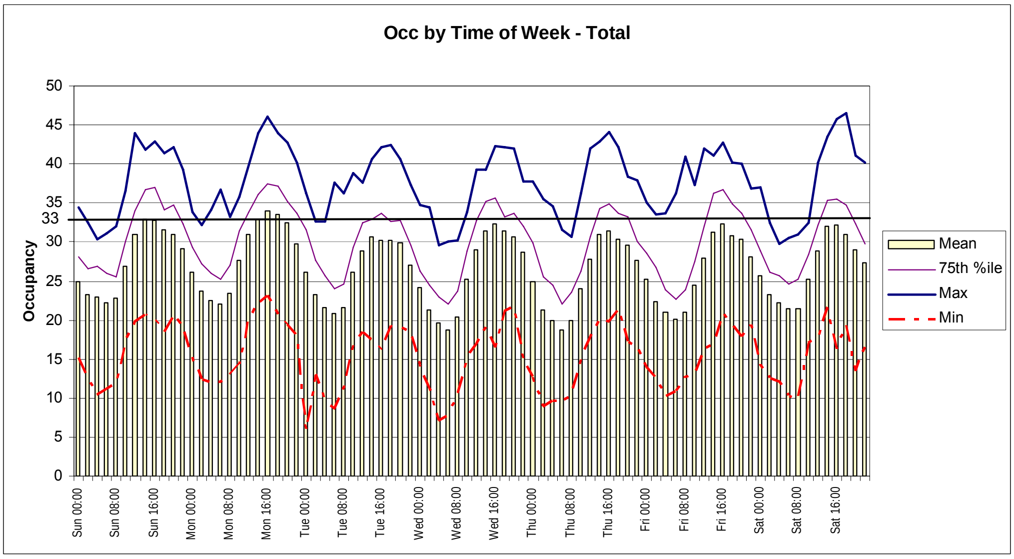



Figure 1-10: Occupancy in the ED (between being shown to a bed and physically departing the ED)

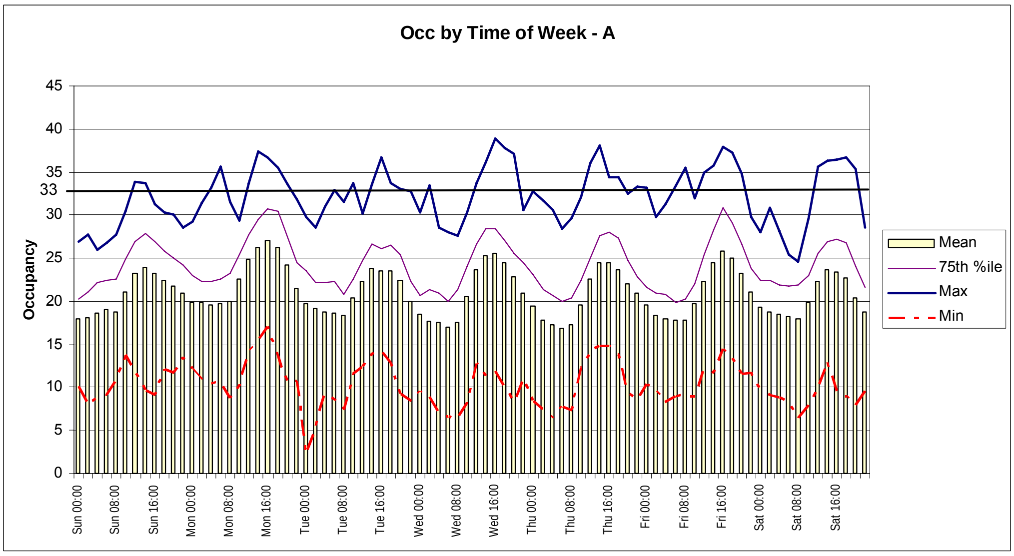



Figure 1-11: Patients awaiting admittance to a hospital ward

It's obvious that the bulk of patients in the ED at any given time were awaiting hospital admittance. Since the decision to admit is usually made very early during ED treatment, and while some patients do need to be stabilised in the ED before they can be moved, in the vast majority of cases the ED was 'forced' into treating these patients because of delays in getting them admitted to hospital. More patients could be in the ED awaiting hospital admittance than beds in the ED - whence the press reports of pain, suffering and neglect in hospital corridors that were reproduced in Section 1.1.

### 1.3.4 Summary of ED performance statistics

This section followed on from the extended definition of EDs and problems they face by sketching an outline of ED performance. It showed that ED performance has improved against performance standards, but failed to reduce ambulance bypass. This is related to the changes in ED usage – many of the changes to operational practice merely provide capacity to maintain the performance status quo against a background of increasing demand. The section concluded by identifying persistent overcrowding at Frankston ED.

The attendance statistics demonstrate EDs have a wide range of presentations, but the use of averages hide the true variety of people, times of day and treatment times that EDs suffer. The statistics are silent on overcrowding, preferring instead to work with more concrete measures such as access to treatment or hospital admittance. In this is an inherent assumption that overcrowding will be moot if access is sufficiently fast.

In ignoring overcrowding the performance statistics avoid having to define overcrowding or blockage in numerical terms and stating at what stage of overcrowding blockage should be considered imminent (although Drew B Richardson, 2004 attempts to provide a definition for this). This leads to the research problem stated in the next section.

## 1.4 The research problem

EDs are complex environments. Factors such as patient well-being, economic sustainability, disaster contingency, stress and risk all play a part in influencing the state of EDs. Unfortunately, the complexity of the ED environment means that issues such as ED blockage are complex and ill-defined problems. By this it is meant that it is not possible to isolate a single aspect of ED blockage as the problem area for research (excess patient demand, for instance) without taking into account other aspects such as resource constraints and patient mix. The research problem must be viewed against this setting of complexity.

---

The problem addressed in this research is:

What are the mechanisms internal to the ED of overcrowding and blockage?

---

Existing ED data is examined in this thesis using a range of techniques from Data Mining and Management Science. The research is a combination of exploratory and explanatory work. Existing data were explored for new knowledge. This knowledge was used to build explanatory models that could synthesise data. Evaluation of the synthetic data led to insights regarding ED blockage.

A conclusion reached in the thesis is that ED blockage is an inevitable consequence of the complexity of the ED environment. While excess resources may reduce the incidence of blockage there remains a chance that certain combinations of patients (most often implicated in long ED stays) will be in the ED simultaneously. This “confluence of patients” causes all treatment sites in the ED to be occupied and prevents treatment of new patients until patients leave the ED.

## 1.5 Justification for the research

Apart from the weight of public opinion, the politically sensitive nature of EDs and the contribution that EDs make to the health of the population, there are a number of other reasons why it is imperative to understand the nature of ED overcrowding. These can be placed into two general classes. The first is the changing nature of the health care system. The second relates to population and social dynamics.

Some of the incidents described in the news articles in Figures 1-2 and 1-3 arose because of the changing nature of the health care system. EDs have experienced an increase in demand related (among other things) to changes in the way general practitioners work (a focus on office hours and diminished house calls) and the cost to patients of visits to general practitioners (general practitioner costs are, in the most part, no longer completely covered under the Commonwealth Medicare Health Insurance system). In addition, EDs have become one of the primary routes for admission to hospital for surgery since ED patients bypass the (long) queues of patients who await elective surgery through the conventional specialist referral route.

While such changes have already taken place and have already had an impact upon EDs, they continue to evolve and so affect demand for ED services. In addition, elements such as the progression of health technologies are changing the way patients are treated and EDs operate. A thorough understanding is required of the mechanism of ED overcrowding and its effect on operations if they are to be sufficiently dynamic to adapt to this changed and shifting environment.

Population ageing, changes in where people live (increasingly on the periphery of metropolitan areas) and changing attitudes to health care delivery (patients want to be treated more like customers) fall into the general class of reasons relating to population and social change. In their “Metropolitan Health Strategy” (2003) the Victorian

Government indicates that future plans must cater for these general issues, as well as specific challenges such as the greater prevalence of chronic health conditions such as diabetes and cancer. EDs need to be in a position to support such strategic planning. Better understanding of the mechanism of ED overcrowding and its effect on operations may help with planning for projected population and social changes.

In addition to these external pressures there is pressure within EDs to ensure that staff working conditions remain reasonable – that staff be protected from unnecessary or excessive pressure to work rapidly yet accurately; that staff are able to ensure the quality of their work; and that hospitals can entice staff to work in EDs.

This chapter has provided a brief justification for research that improves understanding of ED operations to assist with improved decision making in and around EDs. In summary it may be said that the key motivators for this research are:

- Public opinion of ED service;
- The politically sensitive nature of that public opinion;
- The contribution that EDs make towards a healthy population;
- Changes (both current and future) in healthcare systems;
- Changing population demographics and attitudes;
- ED staff pressures.

### 1.5.1 Stakeholders and their interests in the problem

Stakeholders in the ED environment may be grouped into three classes, as summarised in Figure 1-12. The stakeholders in the ED environment constitute entities that have a potential interest in the research in this thesis. Of course the extent of their interest is limited by their awareness of the research.

Patients, ED staff and ambulance services are the stakeholders who are most directly affected by conditions in the ED. All people are potential ED patients because accidents can happen to anyone. Thus the list of prospective patients expands to include all society. This is one of the reasons that EDs are so newsworthy. It’s self-evident that ED staff will be interested, both out of concern for the well being of their patients and out of consideration of their own working conditions. Ambulance services have similar interests to ED staff since the state of EDs directly affects their operation since ambulance services immediately feel the effects of blockage.

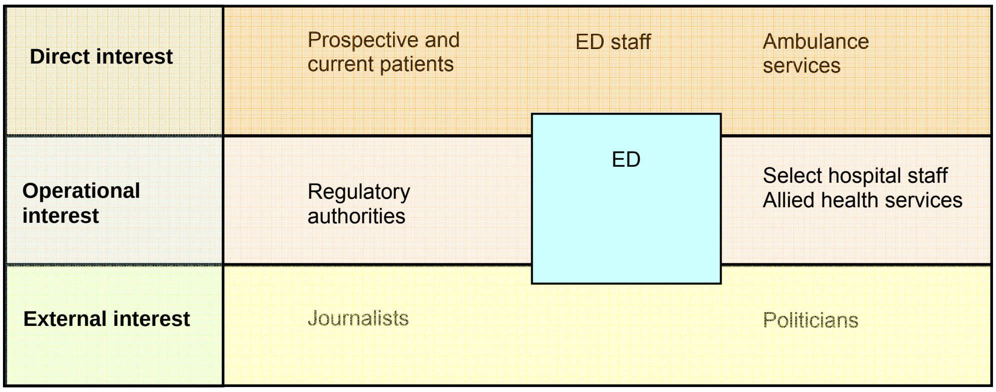



Figure 1-12: Stakeholders in the ED environment

Although hospital staff and regulatory bodies are less directly affected by the state of the ED, both have qualified interest in ED operations. Hospitals generally provide services for EDs such as laboratory and imaging investigations, surgical operations and beds to admit ED patients. Changes to ED operations that affect demand for any of these services have an impact on the resources available for hospital ward and day-patients. Hospital administrators and regulatory bodies have similar interests in smooth operation of EDs. They wish to see the most efficient and effective use of funds with the least adverse publicity and disruption of allied health services such as outpatient services and aged care.

Examples were given at the start of this chapter of newspaper articles reporting on the state of EDs. These are indicative of reports from other media such as radio, television and internet sites. The wide popular interest in EDs makes stories a popular choice for journalists when the opportunity presents itself. Similarly, politicians are sensitive to the opinions of their electorate and criticism of their peers with respect to affairs relating to ED operations.

This brief overview of stakeholders who are concerned with EDs gives rise to discussion in the next section of how actions taken in the ED might affect stakeholders in the healthcare system.

### 1.5.2 ED actions effect on other elements of the healthcare system

The concern of certain stakeholders with adverse publicity relating to ED activities was mentioned in Section 1.5.1. This section will not expand on this point, but rather address more direct impacts of ED activities.

EDs interact directly with ambulance services and hospitals. They also receive patients who are referred by general practitioners, and refer patients in turn to health services such as mental health institutions, aged care facilities and other initiatives aimed at distributing ED demand throughout the health system.

- Ambulance services deliver patients to EDs. Most often these patients are in need of urgent care. EDs endeavour to facilitate reception of ambulance patients by keeping beds available for them. These beds are usually sites used for resuscitation of patients who will be moved to alternative sites as soon as their condition has stabilised. It is possible that general demand is such that all available ED beds are occupied, forcing ambulances to deliver new patients to alternative EDs. Often this bypass situation triggers a chain reaction through EDs in the region and they may all move into bypass, forcing ambulances to circulate until an ED is once again able to receive patients. Obviously this means that the ambulances will be unavailable to respond to new patients, so the linkage between ED actions and prospective ED patients is quite direct.

- EDs use hospital-based services for laboratory tests and imaging. The volume of patients in the ED who require these services directly impacts on these services because ED requests are usually prioritised. Services plan for predictable ED demand but it is possible that the volume of requests may fluctuate owing to the mix of patients in the ED. In addition, significant changes in the way the ED uses allied hospital services can affect the projected need for these services.

- ED patients can impact on operating theatre schedules, since ED patients often require urgent attention. Unfortunately, the incidence of ED patients requiring surgery is unpredictable and they usually arrive at theatres unscheduled. This forces adjustment to theatre schedules that has a knock-on effect on the surgeons, their staff and patients.

- A large percentage of ED patients are later admitted to hospital. While the proportion of ED patients that are admitted to hospital wards does not vary enormously so can be anticipated, the mix of patients cannot. The hospital may have beds available to admit patients, but not the particular patients in the ED at the time. For example the hospital may have beds in a paediatric and orthopaedic wards but the ED may request beds in an isolation ward. The close coupling of ED and hospital operations has been extensively reported and will be further discussed in Chapter 2.

- Patients are referred by their doctors to EDs. These patients are part of normal ED operations. They are affected by ED actions much the same way as all prospective patients. However, if the ED changes operations significantly (it introduces specialised facilities such as a head trauma centre), then general practitioners may change their referral activities.

- Patients also return to the ED in accord with prior instructions regarding further treatment (to have a plaster cast removed, for instance). If the ED changes its policy regarding self-referral this will have a large impact on this group of patients. However the proportion of patients who are asked to come back to the ED at a later stage is small so this action is unlikely to severely impact on ED operations.
- EDs refer patients to other arms of the healthcare network such as aged care facilities and mental institutions. These referrals are not usually a large proportion of ED activity. However they may constitute a significant proportion of the new patients to these facilities so EDs need to take care in policy changes for these classes of patients. In many cases the ED simply acts as a conduit from people in its catchment area to these facilities. Demographic changes in the area are generally slow, but may change dramatically if the boundaries are redrawn. Astute administrators of facilities look past the ED to the source of potential disruptions.
- There has been a concerted effort on the part of government agencies to manage ED demand by spreading patients across a range of services. Examples of such initiatives are internet and telephone-based health advice services. These are actions directly associated with EDs yet not instituted by them (in general).

## 1.6 Thesis scope and key assumptions

The maximum duration of this research was four years under terms of full time PhD registration at the university. The research was funded for three of the four years through an Australian Research Council Linkage Grant. These two factors constrained the duration of the research to somewhere between three and four years. This research was conducted by a single independent researcher with input from both the university and the hospital but no additional resources. This placed some pressure on the researcher to produce meaningful results within the three to four year timeframe.

The time limit was balanced by two conditional constraints. The first was that the study was limited in scope. It was bounded by the walls of the ED. This constraint made it more feasible to make a contribution to ED knowledge within the time limits imposed by the financial and administrative constraints.

The second conditional constraint was that existing data was to be used. While there was obviously the risk that existing data would prove inadequate for research purposes, the study would benefit from not having to collect data since data collection in situ was a time-consuming process. There were two other benefits associated with this constraint. The first was that every patient presentation over several years would be incorporated into the research. This differentiated the study from those that use lesser samples of patient data. The second subsidiary benefit was that the method and results of the study might easily be extended to other EDs where concomitant patient records have been gathered. Since the data used in this study was comprised of patient and operations information generally gathered in EDs it was believed that the study would have wide applicability.

The constraints on the study itself were supplemented by constraints on possible outcomes of the study. Frankston hospital was a partner in the study and the ED staff supported the research, yet it might be infeasible to implement actions indicated by the research. The primary reason for this is that patient well being is considered of paramount importance, so any action that has the potential to impact patient treatment is likely to be handled very conservatively.

The political environment of hospitals provides a second impediment to implementation of findings. Actions may be difficult to implement because changes in ED operations that may affect other parts of the hospital (and vice versa) need to be supported by proponents across the spectrum of hospital staff. This support was only likely to be built through extensive consultation with hospital staff. The very nature of hospital work makes such consultation difficult since staff have extensive day-to-day commitments.

For both the above reasons it was considered imperative that any recommended actions be supported by experimental results. Since it was not possible to experiment with actions in the ED itself, the research had to rely on models to build theories about ED operations. Once both the models and results have been peer reviewed in the public domain and sufficient evidence has accumulated, then implementation may be appropriate and feasible.

More will be said about these issues in Chapter 3 when the methodological framework is discussed in some detail and the research problem formalised. It remains in this chapter to provide a roadmap for the rest of the thesis and to discuss its contributions. The thesis outline is provided in the next section. The discussion of contributions that follows is interjected with comments about work from this thesis that has already been published.

## 1.7 Outline of the thesis

The thesis presentation is relatively straightforward. It is divided into five Parts common to many theses that report on quantitative research. These Parts are:

- Part 1: The Introduction provided by this first chapter.
- Part 2: A review of research issues that is provided in the next chapter. This is largely a literature review, but it is supplemented by a framework for the review and critical analyses of existing work in order to facilitate identification of the research objectives. Several shortcomings within current approaches to the problem of ED overcrowding are identified and used in the formalisation of the research objective at the end of Chapter 2.
- Part 3: Chapter 3 and part of Chapter 4 discuss methodological considerations and the techniques that were used. Justification is provided for placed the work within Scientific Method. One of the thesis contributions is the combination of techniques from the dissociated methods of Data Mining and Management Science. This chapter discusses the rationale for choice and combination of the techniques and leads to the application of the techniques in Part 4. Chapter 4 discusses the preparation of the data for analysis. This is separated from Chapter 3 in order to differentiate the more philosophical discussion and justification of technique selection of Chapter 3 from the more applied focus of Chapter 4 which describes the initial Data Mining stages.
- Part 4: The balance of Chapter 4, and Chapters 5 and 6 make up Part 4. These chapters concentrate on data analysis and experimentation. Chapter 4 discusses initial analyses of the data and provides the motivation for the undirected clustering technique that is applied in Chapter 5. Chapter 5 provides patient clustering results that are applied in a simulation model in Chapter 6.
- Part 5: Chapter 7 gives the conclusions that arise from the research. It describes several extensions to the work and points to some of the limitations.

The thesis is completed with comprehensive Appendices.

## 1.8 Contribution of the thesis

The contribution to knowledge by the research is summarised in Figure 1-13. Chapters are placed within the parts described in the section above and the knowledge contribution of each chapter scaled relative to the first chapter.

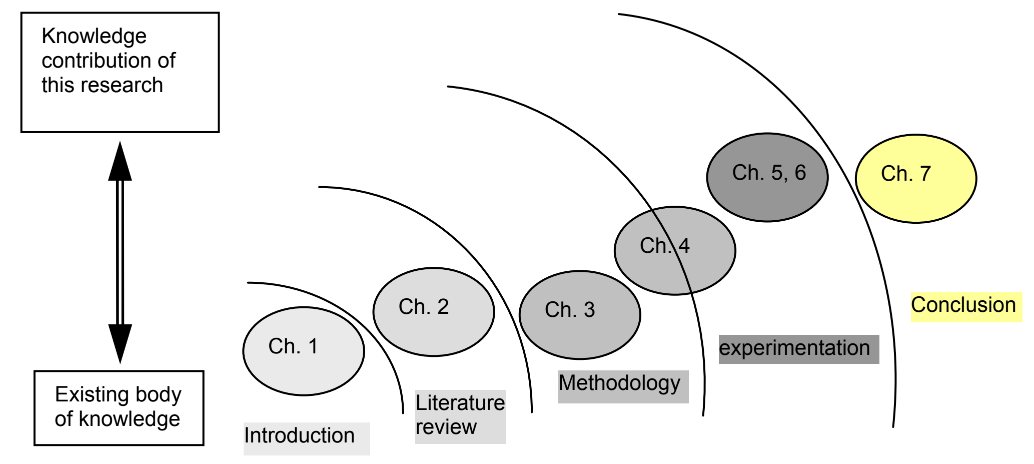



Figure 1-13: The relative contribution to knowledge of each of the Chapters

Chapters 1 to 3 provide background information and assurance that other researchers' works were consulted. Chapter 1 is largely a presentation of existing knowledge free of interpretive comments. The general research problem is identified in Chapter 1 that acts as a guide for the analysis in Chapter 2 of previous research that has been done in the area.

Chapter 2, while a narrative of existing knowledge, is also an interpretation of how the knowledge covers the subject area. It looks critically at what has been achieved towards an understanding of the mechanisms of ED overcrowding (and, by implication, of ED operations as a whole) and identifies where best to target efforts. This critical appraisal and the new frameworks for analysis of the subject area do lift the existing body of knowledge to some extent.

Chapter 3 makes use of philosophical discourse to describe the metaphysical and epistemological setting of the research. Justification is provided for the use of several techniques in the research.

Chapter 4 starts the process of synthesis that continues for the balance of the thesis. The analysis of the data relative to ED Casemix proposals provides insight into the limitation of these approaches and drives thinking towards a new way of looking at the data. Chapter 4 initiates the transition from analysis and evaluation to synthesis of ideas. The analysis of patient length of stay according to ED Casemix proposals forms the preliminary part of a proposed paper on a new ED Casemix system. The treatment clusters of Chapter 5 provide the core element of this new Casemix system.

Chapters 5 and 6 present new work that has been published in a number of fora. The novelty of the work is reflected in the relative positioning of the chapters in Figure 1-13. The undirected patient clustering based on the medical procedures they undergo that is presented in Chapter 5 were recognised by the Australian Resource Centre for Hospital Innovations by an award in 2003 for innovation in healthcare. The work was subsequently published at the peer reviewed Computer Supported Activity Co-ordination Workshop at ICEIS 2004 (Ceglowski, et al., 2004c).

A number of applications of the patient clustering were identified in the course of working with them. These were published at peer reviewed conferences. The utility of the clusters in informing Industrial Engineering analyses were presented at The 5th Asia-Pacific Industrial Engineering and Management Systems Conference in 2004 (Ceglowski, et al., 2004d); new insights into ED operations were published at Hawaii International Conference on System Sciences in 2005 (Ceglowski, et al., 2005b); and two clustering methods were compared at the International Conference on Optimization: Techniques and Applications in 2004 (Ceglowski, et al., 2004a).

Simulation of ED operations, one of the potential applications of patient clusters, is explored in Chapter 6. This work was presented at the 2005 meeting of the European Working Group on Operational Research Applied to Health Services and subsequently published in a special health issue of The Journal of the Operational Research Society in 2006 (Ceglowski, et al., 2005a).

Chapter 7 presents the findings of the research and a number of the other applications of patient clusters where the research was not yet thorough enough to warrant publication. While the insight that ED overcrowding is due to the combination of patient types was included in the Journal of Operational Research publication referred to above, its extension (that blockage is inevitable) was introduced in the Clinical and Investigative Medicine Journal in 2005 (Ceglowski, et al., 2005a).

## 1.9 Chapter summary

Chapter 1 provided reasons and context for the research. It introduced the nature of commonly cited ED problems and emphasised the highly politicised nature of reporting on these problems. It laid the groundwork for the rest of the thesis by defining EDs, describing the political environment in which they operate and providing an overview of ED performance. The listing of the research problem as “What are the mechanisms of ED blockage?” in this chapter provides a focus for the review of published work in the area in Chapter 2.

Chapter 3 will provide the methodology and justify the selection of the techniques that were used. Chapters 4, 5 and 6 will detail the experimental work that was done. The conclusions and implications will be discussed in Chapter 7.

# Chapter 2: Research Issues

The context for the research provided in Chapter 1 gave rise to a general statement of the research problem in Section 1.4 as an investigation into the mechanisms of ED overcrowding and blockage. This chapter will look at previous work that address this or similar ED problems. It will review past work in the parent discipline of healthcare, hospitals and EDs before narrowing the review to the immediate discipline field of within ED research.

Both peer reviewed and industry reports are referred to in this Chapter. Industry reports refer to government and hospital reports. These were an essential source of information about the extent and progress of healthcare analysis and modification, both from political and applied perspectives. The review of the parent discipline may be represented in a classification model that separates the levels of activity in research related to EDs (Figure 2-1). Figure 2-1 depicts research as a nested hierarchy that becomes more focussed on the ED itself. The hierarchy may further be split into two groups – work and initiatives (including political incentives) to manage demand for ED services, and work aimed at removing obstacles to patients leaving EDs.

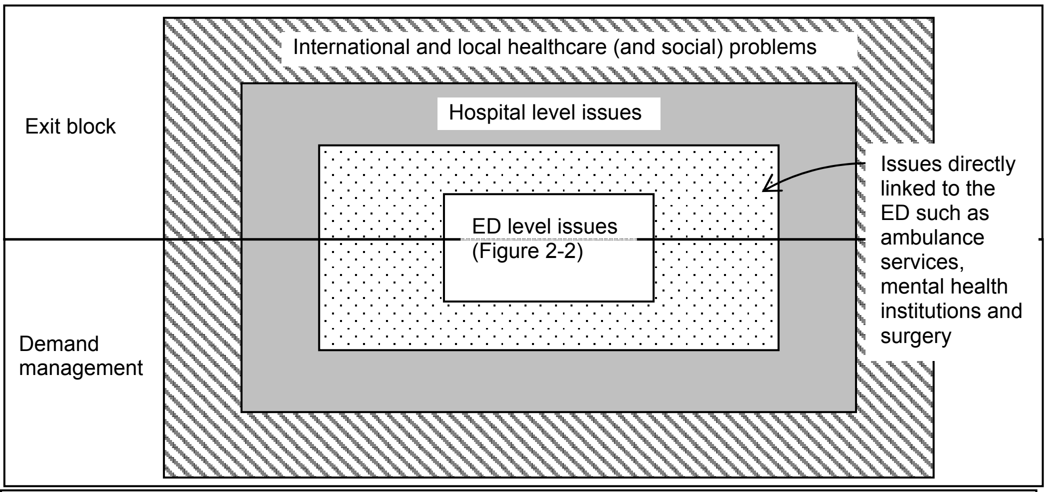



Figure 2-1: A classification model for research involving ED within healthcare

Research in the immediate discipline limits discussion to work within EDs. Many projects have been undertaken in an effort to promote efficiency and effectiveness of EDs and a number of techniques have been applied. These include patient grouping for management purposes, identification of variation within ED processes and simulation of ED activities. The review will proceed according to the classification model of the immediate discipline in Figure 2-2.

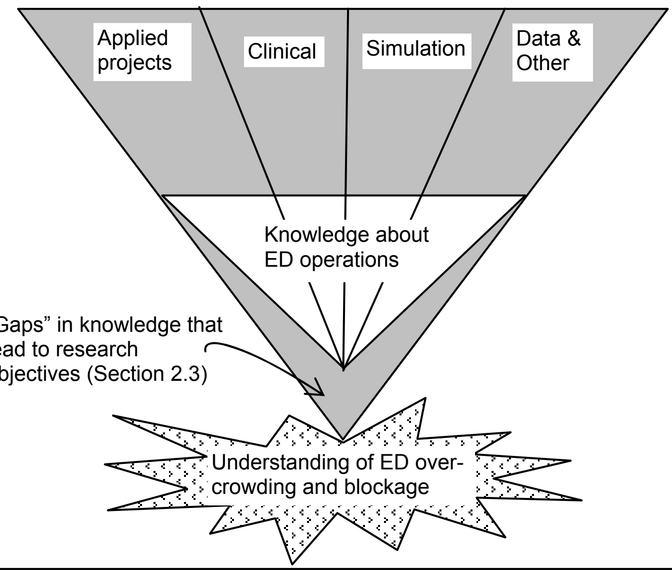



Figure 2-2: A classification model for research within EDs

As the review of existing ED projects and research progresses, certain shortcomings and gaps will be indicated. These provide the motivation for narrowing the general research problem that was stated in Chapter 1 to a more specific objective for the research.

A thorough review of existing research and ED projects will have been presented by the end of the Chapter. Shortcomings in existing knowledge will have been identified to permit development of a specific objective for the research. This leads fairly naturally into discussion in Chapter 3 of the methodology and of the techniques employed to address the objectives of the research.

## 2.1 The ED as part of the healthcare system

During the late 1980s and 1990s there was a great drive to reduce hospital costs as governments strove to reign in the proportion of budgets that were allocated to healthcare. Hospitals were closed, bed numbers were reduced, and staffing levels were minimised in the quest for efficiency.

A number of reviews focussed on the problem of access to medical care, in particular inpatient care, in the late 1990’s and early 2000’s. Similar issues were considered in the UK (Department of Health, 2000; National Audit Office, 2000); The United States (Bradley, 2005; McDonough, 1999; Schafermeyer, et al., 2003; The Committee on the Future of Emergency Care in the United States Health System, 2006; Trzeciak, et al., 2003); Canada (Menec, et al., 1999); New Zealand (Hider, et al., 1998) and Australia (Dwyer, et al., 2001).

These studies[6] agree on three major strategies to address access to healthcare (Dwyer et al., 2001):

- Managing demand for inpatient care
- Improving the efficiency of inpatient care provision (mainly by reducing lengths of inpatient stay)
- Balancing the healthcare system by facilitating the treatment of patients in facilities other than hospitals.

Dwyer (2001) suggested that the research evidence demonstrates any increase in availability of healthcare through efficiency improvements are quickly consumed by increased demand and that the introduction of new services in the primary sector that are intended as substitutes for secondary or tertiary care may be effective, but come with the risk of increasing demand.

The efficiency drives in Australia and elsewhere have led to closer coupling of the healthcare system. This close coupling means that the system is less able to withstand shocks or disruptions because there is little excess capacity to absorb the demand for extra resources. Hospitals now run at 95% bed occupancy or above so there are insufficient excess beds to meet fluctuations in demand. This means that ED patients often have to wait for a hospital bed to become free before they can be admitted, so hospitals are implicated in ED exit block (Bagust, et al., 1999; Fatovich, et al., 2005).

Exit block has been compounded by increased demand. General practitioners have reduced office hours and ceased home visits, so patients have no alternative but to seek help from hospital EDs. Emergency admissions are a large proportion of hospital admissions, so management of emergency demand can impact upon demand for inpatient beds. Emergency admissions constitute about two-thirds of all admissions in the UK (National Audit Office, 2000) and some sixty percent of all medical admissions in New Zealand (Hider et al., 1998). Hider, Kirk et al (1998) noted that New Zealand's increase was primarily related to cardiac and respiratory conditions.

Detailed reviews of research into exit block and demand management are discussed in the next two sections before moving on to an overview of Australian government initiatives both at the national and state level.

---

[6] Studies of the Unites States' healthcare system frequently state these and other issues in terms of health insurance-related, so their perspective is somewhat different to other countries'.

### 2.1.1 Research into Exit block

One of the most significant early works on exit block arose out of collaboration between Casualty Watch (a project of Southwark Community Health Council) and the department of Operational Research at the London School of Economics. It featured a System Dynamics simulation that looked at the interaction of ambulance services with the ED and the role of hospital policy in ED patient treatment time (Lane et al., 2000). It concluded that high rates of hospital occupancy were implicated in admission delays, but admission delays were insensitive to the actual number of beds involved (that is, only the *percentage* of hospital beds that were occupied was important). The hospital/ED system had insufficient excess capacity, rendering it susceptible to crises such as blockage. The cancellation of elective admissions to free up beds for ED admissions was used as a "safety valve" to prevent crises developing in the ED.

Moreno et al (2000) provided a simulation model of the entire hospital environment of a Spanish hospital to predict future hospital waiting times and queue lengths. The model covered outpatients, the ED and central services such as laboratories and cardiology and showed the links between hospital occupancy and exit block.

Scneider et al (2001) claimed that the greatest impediment to ED patient outflow was the lack of inpatient hospital beds for acutely ill patients, a view supported in the Australian setting by Forster et al (2003); while Taylor (2001) maintained that understaffing of inpatient wards as a cost-containment strategy resulted in fewer staffed inpatient beds to accept patients from EDs.

Integrated bed management is the management of all admissions, stays, transfers, and discharges by a hospital. Integrated bed management strives for efficient flow of patients into and out of beds as a way of reducing waiting time for emergency admissions and of limiting cancellations of elective surgery. It was the focus of the second round of the National Demonstration Hospitals Program (Discussed in Section 2.1.3). The factors identified as working against achievement of integrated bed management were the lack of coordination between units; the lack of appropriate information systems; and outdated policies for the allocation of priority and management of beds (Department of Health and Ageing, 2004a).

Hospitals collaborating in the NDHP (cf Section 2.1.3) implemented a wide range of initiatives, including pre-admission clinics, day of stay admission (DOSA), transit lounges, bed management teams, discharge planning projects, and information systems to improve the effectiveness of their bed management. One hospital reported a halving in the number of 12-hour waits and of occasions of ambulance bypass; reduction in cancellations of elective surgery of over 90%; and an increase in day surgery of 23% between from 1995 and 1998. These improvements in performance against access indicators have not been sustained, probably due to further increases in demand (Dwyer et al., 2001).

A range of measures from hospitals across Australia to facilitate access to hospital beds by ED patients were reported by Richardson et al (2003). These measures included rearrangement of staff rosters; increased use of overnight discharge from the ED combined with day procedures for surgery; links with community services for improved discharge of ED patients to outside services; movement of responsibility for the ED to administration within the hospital itself; centralised bed management for the hospital; and development of patient fast tracking services.

Schaming (1998) reported on the use of re-engineering applied to ED structure and operations and Espinosa et al (2004) reported on the use of operations management. They determined that ED operations management best occurs in the context of whole system operations management. The projects describe a range of possible interventions to facilitate transfer of ED patients to hospital beds. These interventions were similar to those reported by Stobhill Hospital.

Stobhill Hospital in Glasgow (Moore, et al., 2000) reported innovation in the way emergency medical admissions were handled. A patient management team was created that was charged with handling the administrative aspects of the patient's hospital stay appointment. The team ensured that patients were moved through the system and were discharged home as early as possible. Arrangements for specialty transfers were improved through daily ward visits by consultants from cardiology, respiratory medicine and elderly care. A fast track service for laboratory investigations was introduced to minimise time waiting for results. The project reported that medical staff and patients perceived the new systems being better than the old.

A consultative project in the Hunter/New England Area Health Service to identify barriers affecting patient flows from presentation to the Emergency Department to discharge from the Medical Inpatient or Coronary Care Unit identified a number of key strategies in the elimination of access block (Patricks, et al., 2005). The majority of these related to improved communication between the ED and hospital bed management services and reduction in handoffs and permissions. These communication issues were also reported in a soft systems approach to knowledge management in emergency care (Edwards, et al., 2005).

The Hunter/New England Area Health Service project reported reduction in access block from 74% in August 2002 to 9.6% in June 2005; reduction in the number of patients waiting greater than 10 minutes from time of arrival to time of triage from 54% to 15%; reduction in the average length of stay in ED for admitted patients from 16 hours to 5.73 hours; and reduction in the average inpatient length of stay from more than ten to less than eight and a half days (Patricks et al., 2005).

Tawney (2005) analysed patient load on hospitals in the Richmond (U.S.A.) metropolitan area and concluded that patients should be discharged from the hospital as early in the day as possible, in order to free beds for incoming patients and so reduce bottlenecks in the patient admit cycle.

Sier, Ramakrishnan et al. (2005) took a slightly different perspective, assuming that service time in the ED was a function of occupancy of hospital wards in a two-level continuous Markhov chain model of ED / hospital interactions. They were able to find steady state distributions of probabilities that the wards would be operating at capacity. These probabilities were used to suggest reconfigurations of beds in the wards to better utilise resources.

#### 2.1.1.1 Critical assessment of previous work on exit block

All of the studies mentioned above have concentrated on the gross movement of ED patients into wards. They have confirmed that exit block is a determinant in ED blockage, and have identified the role of hospital ward admission processes in ED exit block. There have been some highly successful applications of process restructuring methods, such as the instances at Stobhill Hospital and the Hunter/New England Area Health Service. These have merely addressed communication and organisation of activities in the process to facilitate movement of ED patients to wards. Although the projects have created capacity in the ED, they merely provide a buffer against exit block by raising the level of conditions necessary for exit block to occur. The studies do not in general consider upstream effects of ED patient demand on exit block. Research and projects that do consider ED demand are discussed in the next section.

### 2.1.2 Research into managing ED demand

The system dynamics model of Lane, Monefeldt et al (2000) that was discussed in the section above also considered demand pattern scenarios. It concluded that the system could withstand “pulses” of increased demand but the cost was high (doctor utilisation rose to one hundred percent, the elective demand cancellations increased to four days and ED wait time rose dramatically).

Similar work was done using a comprehensive dynamic model of the whole system of emergency and on-demand health care in Nottingham, England (Brailsford, et al., 2004). This study ran scenarios where ED demand was reduced by use of alternate healthcare options for certain patient groups (such as the elderly or people with respiratory ailments), and early discharge of hospital patients. They found that early discharge of patients and seven-day discharging had a minimal effect on ED occupancy, and found that these effects were minimal compared to the effects of keeping patients out of hospital in the first place.

Schull et al (2003) determined the relationship between physician, nursing, and patient factors on ED use of ambulance diversion in Toronto, Ontario, Canada. Data were collected on the duration of ambulance diversion during consecutive 8-hour intervals from January to December 1999 at one ED. Time series methods were used to determine the relationship between ambulance diversion and nurse hours, physician on duty, and boarded patients. The study concluded that admitted patients in the ED were important determinants of ambulance diversion, whereas nurse hours and most emergency physicians were not. The use of diversion was unlikely to be decreased through reduction in the volume of walk-in patients.

An increasing prevalence of high complexity medical problems among ED patients has become an important determinant of ED overcrowding. In a recent report commissioned by the American Hospital Association, the most common reason for going on ambulance "bypass" was an insufficient supply of available critical care beds for critically ill ED patients (Lewin Group, 2002).

Studies of inappropriate emergency admission have produced widely varying estimates of incidence, depending largely on the instruments and methods of assessing inappropriateness. However, about twenty percent of emergency admission for older patients appeared to be clinically inappropriate (Coast, 1996; Goddard, et al., 1999).

Considerable attention has been directed to the issue of 'inappropriate' presentation to Emergency Departments for outpatient care (Bolton, et al., 2000). Most work has not assessed the health outcomes of alternatives, and "no conclusive evidence exists" for assertions that such attendances are more expensive to health care funders than the alternatives (Hider et al., 1998). Hider et al. (1998) concluded that no valid and reliable method had been developed to identify 'inappropriate' attendances. A similar conclusion was reached by an Australian study (Ieraci, et al., 2000).

A Canadian study found that increased emergency medical demand was predictable during most winters (Menec et al., 1999) and a U.K. study modelled the effects of winter demand (Vasilakis, et al., 2001).

Hospital system restructuring further contributes to ED overcrowding. The abrupt elimination of EDs by hospital mergers and/or closures increases the burden on neighbouring EDs (Schull, et al., 2001).

A retrospective, cross-sectional study of clinical and financial records study examined visit characteristics and resource utilization of different levels of frequent use patients. Patients with three to 20 visits were more likely to be admitted to the hospital than patients visiting once or twice (Ruger, et al., 2004). Patients visiting more than 20 times were less likely to require hospital admission and more likely to present with "non-urgent" conditions, have lower severity scores, and leave the ED without medical attention than patients visiting the ED once. The study concluded that many patients previously thought to over utilize the ED for socioeconomic or insignificant medical problems were as sick as less-frequent ED users.

#### 2.1.2.1 Critical assessment of previous work on ED demand

Management of ED demand does not appear to be a solution for ED overcrowding. Apart from the issues of (non) equitable access that would be raised if ED services were “rationed”, the diminishing of demand in any single area seems to be offset fairly quickly by an increase in demand from another area. At best, any measures that seek to limit ED demand are likely to be stopgap measures. Inevitable increases in demand in the future will absorb the slack created by the initiative and overcrowding problems will continue to manifest in EDs. Management of ED demand does not address the mechanisms of ED overcrowding.

### 2.1.3 Australian government initiatives[7]

The Department of Health and Ageing is the Commonwealth government department responsible for healthcare. The Department's function is to lead the development of Australia's health and aged care system. It does this by providing expert policy advice, working with stakeholders, promoting healthy living and communicating information about health and aged care services, managing the Commonwealth's health and aged care program to ensure the provision of quality cost effective care, and safe

[7] Similar projects to those discussed in this section have been conducted in other countries, but this section will limit itself to a review of Australian projects, since the projects in various counties correspond in scope and findings.

guarding health, safety and equity in a way that requires the minimum necessary regulatory burden (Department of Health and Ageing, 2004b).

The Department of Health and Ageing established The Hospital Demand Management Strategy in October 2000 in response to the deterioration of three main indicators of inpatient access (waiting lists for elective surgery, waits for emergency admission and ambulance bypass incidents). The strategy built on extensive consultation with hospitals and involved a new level of cooperation and collaboration between Government and health services.

The Commonwealth established The National Demonstration Hospitals Program (NDHP) to provide funding directly to hospitals to undertake projects. The broad aim of the program was to identify innovations in acute care and related areas of the health system and to promote their uptake. The NDHP selected certain hospitals because of their best practice models for specific areas of patient services and hospital management to work with groups of collaborating hospitals committed to improving their practice in similar areas. Lead hospitals were funded to expand and refine the operation of the model within their organisation; to manage the collaboration, and to enable the collaborating hospitals to employ a project officer to undertake specific projects.

NDHP1 (1995– 1997) was funded to overcome clinically inappropriate waiting times for elective surgery. NDHP2 (1997– 1998) was funded to identify and document principles for integrated bed management, addressing the management of all types of hospital admissions. NDHP3 (1998– 2001) was funded to integrate all services delivered by the acute care sector, including developing links with the primary and community health care sectors. NDHP4 (2002- 2003) aimed to identify innovative options to improve hospital based care for older Australians. In some cases, projects focussed specifically on the interface between EDs and other areas of healthcare (Department of Health and Ageing, 2004a). The Hospital Demand Management Strategy has been extended to 2006- 2007 with additional Government funding of $526 million.

The Hospital Demand Management Strategy worked to strengthen the capacity of the health system by funding growth in hospital activity; expansion of non-bed-based models of care; encouraging best clinical practice; reducing the avoidable use of hospitals (including EDs); attracting and retaining nurses, and through managing access to elective surgery.

With financial support provided by The Hospital Demand Management Strategy the State of Victoria's Department of Human Services established in October 2000 "The Patient Management Project" to be assisted by an industry-based Patient Management

Task Force. The terms of reference included a requirement to identify essential organisational and patient management practices which would maximise the ability of hospitals to respond to the demand for inpatient care and to determine key indicators of good practice, appropriate benchmarks and incentives. An objective of the task force was to engage actively with hospital management and clinicians in dealing with problems of access to emergency services and elective surgery.

Improving the efficiency and effectiveness of public hospital services in Victoria is being addressed by the "Designing Care" program which aims to redesign processes across the whole health system (Victorian Department of Human Services, 2002b). The ED component of "Designing Care" emulates and duplicates ED initiatives that have been successful in other countries and at other hospitals in Australia. These include "fast tracking" of certain patients, decreasing ED volume, and providing increased supervision of junior medical staff (Victorian Department of Human Services, 2002a).

Key prevention interventions included care coordination[8] in the ED and disease management/ case management for patients with chronic heart failure and chronic obstructive pulmonary disease. Care coordination projects demonstrated decreased lengths of stay in the ED and evidence of averted admissions. Most reported high levels of patient and staff satisfaction.

In the first 12 months of implementation (2001– 2002) improvement was noticed in key indicators such as the incidence of ambulance bypass, the percentage of patients admitted within 12 hours, Triage Category 1 patients seen within target and Elective Category 1 patients seen within target. Indicators such as LOS, ED presentations, numbers of acute admissions and bed days utilised, also showed positive trends (Metropolitan Health & Aged Care Services Division, 2003).

An Emergency Access Strategy is currently being developed to identify priority activities to address emergency demand over the next five years. A series of consultation workshops have been completed with health services and stakeholders and the Strategy is currently being developed for formal release in mid 2006 (Statewide Emergency Program Unit, 2006).

---

[8] Care co-ordination refers to ensuring that ED patients are provided with services to facilitate their return to, or maintenance in, the community, by preventing unnecessary and/or inappropriate hospital admissions; minimising repeat presentations of patients; and providing safe and effective discharge from the ED.

## 2.2 Research within EDs

The above sections indicate that the ED overcrowding problem has its roots in major forces within society, including shifts in social structures, demographics, reduced capacity in the hospital sector, and changes in emergency care systems themselves. This section will narrow the review to studies of activities within the walls of the ED. It will look at research and projects that have tried to improve the efficiency and effectiveness of ED operations without dealing explicitly with demand or exit block issues.

There has been much research and some speculation into the use and applicability of industrial methods to healthcare. These have either arisen from an external view of the ED, where analysts apply to ED activities industrial engineering ideas that have been successful in other industries or from an internal view where experts review ED activities from a clinical perspective. The analysts' orientation provides a framework for the review:

- Government agencies or coalitions have initiated projects into improving the efficiency and effectiveness of ED operations. These projects are usually comprised of facilitators and ED workers themselves who seek to identify areas of inefficiency and put in place measures to rectify them.
- Clinicians have tried to group patient "cases" under the principle that similar cases will be treated alike and utilise a particular set of resources. These groupings are commonly called Casemix (Palmer, 1996) and suit situations where the range of cases is small, such as specialist departments.
- Analysts with an industrial engineering (IE) orientation have used time and motion studies to identify opportunities for improvement (See, for example, Hoffenberg, et al., 2001).
- There has been much simulation and systems research into hospitals and healthcare (Jun, et al., 1999; Preater, 2002) in an effort to prevent excessive patient waiting times and the redirection of patients and ambulances to other hospitals.
- Information Science (IS) oriented analysts have had a workflow focus, seeking to understand the flow of data in the ED in order to build computer systems that support the doctors and nurses in their jobs (Nelson, et al., 2004).
- Inspection of ED data for knowledge is in its infancy, but some interesting work has been done.

- Other methods not falling into the framework above have also been used, such as social studies.

The work done using these approaches will be discussed in the sections that follow.

### 2.2.1 Government sanctioned ED projects

Numerous studies and projects have studied the problem of blockage in EDs. ‘Improving patient flows’ was the single biggest project category of Victoria’s Hospital Demand Management Strategy. ED projects up until the end of 2002 included changes in triage processes and reconfiguration of the management of specific patient groups within defined units such as short stay units[9]. The ED triage projects designed to ‘fast-track’[10] patients reported improved ED waiting times and satisfaction for both patients and staff.

The Hospital Demand Management Strategy (HDMS) ran from 2000- 2005 and was discussed in Section 2.1.3. Its successor, the Victorian Statewide Emergency Program develops and implements programs based on successful initiatives trialled under The Hospital Demand Management Strategy. The Program staff work extensively with hospitals and key stakeholders to develop, implement, monitor and evaluate projects and performance in emergency access which include EDs, critical care and neonatal services. The Statewide Emergency Program promotes innovative models of care to address demand pressures within the Victorian health system and acts as an advocate for Emergency Access initiatives within Government (Statewide Elective Surgery and Statewide Emergency Program, 2006).

#### 2.2.1.1 Critical assessment of the government projects

The projects mentioned above have been excellent distributors of “good practice” guidelines from Australian hospitals and from abroad. Successful projects that have demonstrated a positive impact on emergency services are being rolled out throughout the state. These include fast tracking of certain ED patients; integrating medical and nursing triage processes at times of peak demand; substitution of ED with substitute services for targeted groups of patients; short stay observation units; and day treatment centres. The continuing incidences of ambulance bypass and ED blockage infer that the projects have merely “picked the low hanging fruit” in terms of ED process improvements. It may be

[9] Short stay units are units associated with the ED that have beds used for extended treatment of patients who may or may not later be admitted to a hospital inpatient ward.

[10] Fast track is a term applied to the facilitation of almost immediate treatment to patients who present with minor problems. Treatment of these patients can often be concluded quickly freeing up resources for more urgent patients.

said that these initiatives work at a coarse process level and do not address patient treatment processes, so cannot make a lasting difference to understanding or control of ED overcrowding.

### 2.2.2 The Clinical Approach: Casemix

Australian federal and state governments provide funding for public hospitals determined primarily on performance or output, rather than negotiation, history or politics. Clinical and resource homogeneous groups of patients are determined from stored information about patient visits and related to the resources required (Duckett, 1998). Homogenous grouping of patients have become known as "Casemix" to emphasise the grouping based on similar patient "cases".

The Casemix approach has been reasonably successful in predicting resource requirements for inpatient acute care settings, and it now forms a significant part of improvement and management activities (Australian Department of Health and Aging, 2003). However, classification of patients who present to EDs (a hospital department that specialises in providing care for people who are in need of urgent care) has proven to be difficult, with the best groupings only accounting for some 60% of cost (Bond, et al., 1996).

Traditionally, Casemix has been based on a combination of clinical information (diagnoses and procedures) and demographic information (age and sex), to result in homogeneous groups with respect to a target variable such as pattern of illness or treatment (Jelinek, 1995). Generally the similarities between patients relate to diagnosis, working under the assumption that patients with related diagnoses follow a matching course of treatment and utilise comparable resources (Eagar, et al., 1994). Essentially, Casemix strives to yield treatment pathways for patients without explicitly defining the processes incorporated in those pathways – patients are grouped by function (diagnosis), yet the groups are expected to yield a process perspective with associated inputs, outputs and resource requirements.

Patient classifications have been proposed to aid with ED performance evaluation (JM Cameron, et al., 1990). Applications of the Casemix approach to ED patients have involved gathering of data about patients, identification of variables, and parametric modelling of the relationship between variables.

Much work has been done in Australia on determination and agreement of Casemix for inpatient classification (Duckett, 1998; Funding & Financial Policy Branch, 2002; R M Hanson, 1998). Work started in late 2002 on a national ED patient classification, with initial efforts concentrating on identification of appropriate ED data to include (McAlister, 2003). Characteristically, proposals have grouped ED patients according to combinations of age, urgency of complaint, diagnosis, time in ED and outcome of visit.

Several ED Casemix studies have been undertaken in Australia since 1989 (Bond, et al., 1998). The first was the National Ambulatory Casemix Project which produced a Casemix that included 36 ED classes based on diagnostic category, procedure and presence of a doctor. A study in Western Australia between 1990 and 1992 developed Urgency and Disposition Group and Urgency Related Group ED Casemix proposals.

Urgency and Disposition Groups segmented patients by urgency and outcome of visit. Four outcomes were used: i) Admitted, ii) Discharged; iii) Did not wait, iv) Died in ED or dead on arrival. A 5 level measure of urgency (Australasian School of Medicine, 1994) provided 10 groups from the first 2 outcomes. These were supplemented with groups iii) and iv) to give 12 patient groups. The fourth outcome was included in "Admitted" in a later South Australia study to give 11 groups. Urgency and Disposition Groups gave a reduction in variance ($R^2$)[11] on total cost of 47% in Western Australia and nearly 44% in South Australia on data trimmed of outlying points[12]. Urgency and Disposition Groups were considered easy to collect and clinically relevant (Bond et al., 1998).

Urgency Related Groups included Medical Diagnostic Categories within Urgency and Disposition Groups. 29 Urgency Related Groups were created, 13 for admitted patients, 15 for discharged and 1 for "did not wait". This led to $R^2$ of 55% in South Australia and nearly 58% in Western Australia, based on trimmed data (Bond et al., 1998).

---

[11] $R^2$ is the most common statistical measure used to compare patient classifications derived from multivariate regression, where variables are selected for their correlation to resource consumption. In Casemix studies $R^2$ is computed from the difference from average costs of actual patient costs and modelled (Casemix) patient costs. A $R^2$ of 1 is considered perfect and 0 is approximately the $R^2$ that would be expected from a random grouping of patients. $R^2$ can be reduced by the inclusion of more variables, and an $R^2$ of 1 can be achieved if the number of groups equals the number of patients. This impact of adding more groups can be tested by calculating the ratio of groups to observations (Averill, et al., 1998).

[12] $R^2$ may be calculated from *untrimmed* data, where all cases are considered, or from *trimmed* data from which suspected outliers (patients having extraordinary resource usage) have been removed. Although trimming improves $R^2$ by some 10-20%, it can introduce bias and might be used to depict results for one Casemix system favourably, so $R^2$ results for trimmed data need to be viewed somewhat critically (Averill *et al.*, 1998).

Since Medical Diagnostic Categories are not easily accessible in Australia, age was employed as an alternative in Urgency and Disposition /Age Groups in a 1996 South Australian study. Four age groups (under 14; 15-34; 35-64; over 64 years) were added to 7 of the 11 Urgency and Disposition Groups, based on reduced variance when age classes were included. The resulting 32 Urgency and Disposition /Age Groups achieved an $R^2$ of 51% with trimmed data (Bond et al., 1998).

#### 2.2.2.1 Critical assessment of the Casemix approach

"What is still lacking in Casemix development is an emphasis on continuum of care. Furthermore, little attention has been paid to the way Casemix should be used to improve patient care, or to its limitations in addressing patient outcomes and healthcare quality. The wider use of Casemix in determining care paths and in utilisation review is now also emerging in both the public and private sectors, and needs closer clinical scrutiny." (R M Hanson, 1998).

These Casemix proposals have been statistically inferred ED groupings on similar patient costs, so are not as clinically relevant as desired. They can account for 63% of costs, measured as reduction of variance ($R^2$) on trimmed data. The four age groups suggested as an alternative to Medical Diagnostic Categories do not provide for the diversity of presentations and urgencies in each age group, merely indicating a correlation between cost of treatment and the age groups – they are inadequate to describe a significant number of activities within EDs (Table 2-1).

Table 2-1: Comparison of cost variance reduction in ED Casemix (Bond et al., 1996)

| ED Casemix system | Flinders Medical Centre Study (1996) | Perth Study (1992) |
|---|---|---|
| Urgency and Disposition groups (UDGs) | 43.9% | 47.4% |
| Urgency Related Groups (URGs) | 55.3% | 57.6% |

It's been reported that the urgency and Disposition grouping system significantly underestimates the activity in EDs (Stuart, 2004). Urgency, disposition and age do not indicate anything about patient treatment – where patients should best be located, what materials they are likely to require, and how intensive the staffing needs are going to be, for instance. So, while ED Casemix may be of some use in modelling costs, it has not helped provide a simplified model of ED treatment.

These results indicate that, while Casemix thinking has been adequate for situations where patients are of a similar type, such as paediatrics or specialist hospital wards, it has not proved suitable when there is a vast range of patients and variety of presentations, as in EDs.

Casemix proponents have attempted to segment patients along treatment pathways, but failed to find variables that account for a significant proportion of costs. Some effort will be taken in Chapter 4 to emulate these Casemix studies using ED length of stay as an objective function. It will be seen that the relationship between urgency, age, disposal and length of stay is generally weak, and it's concluded that this is because of "administrative", rather than process nature of the classification.

### 2.2.3 Industrial Engineering approaches

In the *Handbook of Industrial Engineering* Salvendy (2001) discussed eight healthcare applications of industrial engineering. These were: methods improvement and work simplification; staffing analysis; scheduling; queuing and simulation; statistical analysis; optimisation; quality improvement; and information systems/ decision support systems. Young et al. (2004) proposed that Lean Thinking; the Theory of Constraints; Six Sigma and Scenario Simulation have a place in improving patient care.

There is little evidence that IE methods have been applied to ED processes beyond the gross movement of patients into and from treatment (Acute Health Division, 2001; Cameron, et al., 2002; Department of Health, 2003; Hospital Demand Management Group, 2003; Richardson, 2003; Taner, et al., 2006).

De Vries (1999) suggested that production control may be applicable to healthcare operations and Vissers (2001) proposed a framework for production control in healthcare organisations. These researchers identified the necessity for iso-process grouping of patients and recognised the complications associated with multidisciplinary patient flow control. They discussed the use of existing Casemix-type mechanisms for production control of hospitals (de Vries, et al., 2000) and concluded that, for a patient classification system to be suitable for production control in hospitals, the system needs to be focused on the homogeneity of the underlying processes.

Walley (2003) applied manufacturing design theory and arrived at concrete suggestions about groupings that may simplify modelling of ED operations. Work with a number of UK hospitals led Walley and his co-researchers to group patients into the seven process flows shown in Figure 2-3.

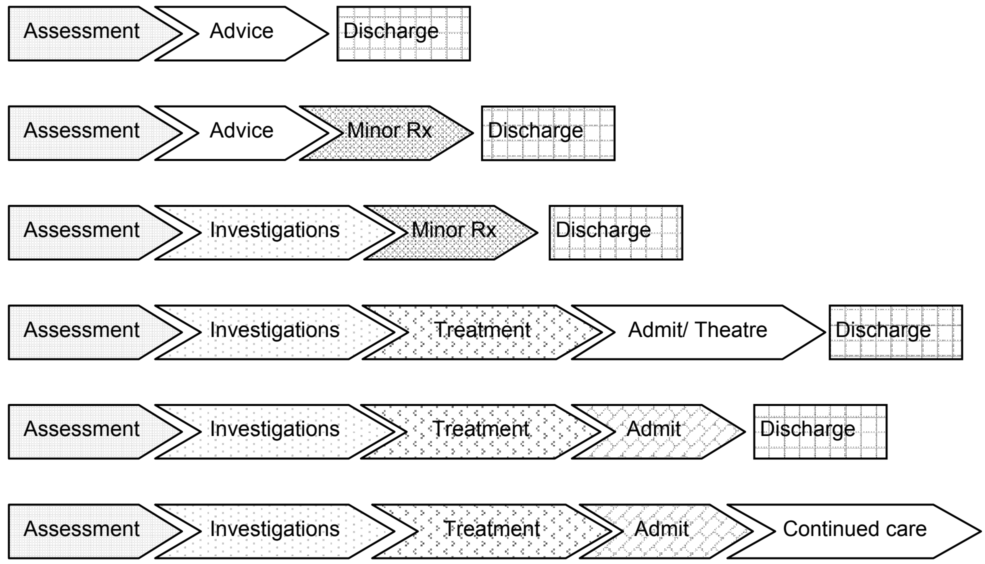



Figure 2-3. Core ED processes from industrial engineering studies (Walley et al. 2001)

Scheduling models have been developed for determining number of staff (Beaulieu, et al., 2000) and optimal shift change over times (Carter, et al., 2001), and simulation has been applied in EDs to identify opportunities for improvement of process in a hospital's Six Sigma project (Miller, et al., 2005)

Cooke et al (2002) suggested that the introduction of a separate stream for minor injuries could produce a thirty to fifty percent improvement in the number of trauma patients waiting over an hour and recommended that departments use a separate stream for minor injuries to decrease the number of patients enduring long waits in EDs. This study was contradicted by a simulation study (Brailsford et al., 2004) that determined the permanent streaming of minor cases was not an efficient use of resources.

The internal factors influencing patient flow, effectiveness, and overcrowding in the ED and the effects of ED reorganisation were studied by comparing patient flow measurements before and after a structural and staff reorganisation of an ED (Miro, et al., 2003). The main reason for each patient remaining in the ED was allocated to factors related to the ED itself; to ED-hospital interactions; to the hospital itself; or to neither ED nor hospital. The study measured the percentage of time the ED was overcrowded and found that the ED reorganisation reduced the average number of patients waiting to be seen from 5.8 to 2.5 and average waiting time from 87 to 24 minutes. It concluded that ED effectiveness and overcrowding were determined not only by external pressure, but also by internal factors.

#### 2.2.3.1 Critical assessment of the Industrial Engineering approaches

In summary, various approaches have been tried by which patients may be grouped. Both industrial engineering and Casemix proponents have attempted to segment patients along treatment pathways, but failed to find appropriate variables. While Walley et al's (2001) "core processes" provide some guidelines for segmentation of patients, they provide little insight into the nature of the treatment patients receive and merely segment patient flows through the ED at a high level. Such approaches may yet yield viable groups, but other avenues should be explored. Chapter 5 introduces one such alternative and describes how the resulting patient groupings led to insights into ED operations.

### 2.2.4 Simulation approaches

A number of issues in healthcare simulation were identified by a panel of simulation practitioners at the 2000 Winter Simulation Conference (Sanchez, et al., 2000). These included the simulation of information technology needs; the difficulty of obtaining data and in modelling physician resources; and the separation of data into non-value added and value added. Problems in tracking doctors and in data collection mean that successful discrete event simulation models are not easy to develop (Carter, et al., 2004), yet simulation is a popular technique for ED studies. Discrete event and dynamic simulation models have been used, often in combination with optimisation methods, to help conceptualise the interaction between patient arrivals, departures and resource-use (Campbell, et al., 2002; De Angelis, et al., 2003; Huang, 1998; Jun et al., 1999). A general framework has been proposed for the formulation of ED simulation models (Codrington-Virtue, et al., 2005).

Recent reviews of simulation in settings similar to EDs were given by Jun et al (1999) and Fone et al (2003). Jun et al surveyed the uses of discrete event simulation between the early 1960's and late 1990's in healthcare clinics that vary from individual practices to EDs and maintained that the breadth and scope of units within hospitals make it impossible to simultaneously address the inputs (patient flow and resource availability) and outputs (patient length of stay and resource utilisation). Fone et al (2003) reported that few papers provided detail about model implementation.

Discrete Event Simulation studies in EDs commonly break the ED into sub-units, assign patients to urgency categories and use these to prioritise access to resources. They generally approximate patient arrival rates and regulate patient flow by events such as completion of triage, admittance to an ED bed and review by doctors (Baesler, et al., 2003; Brailsford, et al., 2003; Connelly, et al., 2004; Komashie, et al., 2005; Macdonald, et al., 2005; Mahapatra, et al., 2003; Miller, et al., 2003; Miro et al., 2003; Samaha, et al., 2003; Wiinamaki, et al., 2003). Discrete event simulation models have been able to assist with identification of bottlenecks and other outcomes (Miller, et al., 2004). Pidd (2005) described a two-model approach for modelling generic hospital systems, where elements such as the ED are modelled in detail, but does not present details or results.

The majority of Operations Research and Management Science (OR/MS) specialists have used generalised distributions to describe arrival rates, lengths of stay and treatment times in simulation and optimisation models (Bagust et al., 1999; Harper, 2002; Hoffenberg et al., 2001).

Some Discrete Event Simulation studies have grouped patients to better emulate ED operations. Harper (2002) formulated a framework for operational modelling and simulation of hospitals that was premised on the classification of patients. In Sinreich and Marmor's work (2004), five patient groups were characterised across five hospitals based on interviews and time studies. Unique process charts were developed for each patient group. These included the duration of activities such as imaging and tests, and the frequency of connections between the activities. The paper concluded that ED processes are better characterised by patient group than by hospital. Evans, Unger et al (1996) had good success in duplicating patient length of stay by grouping patients into 13 categories according to diagnosis and building separate process flows for each group while Condrington-Virtue, Chausselet et al. (2006) describe an ED simulation that uses patients grouped by diagnosis code.

Isken and Rajagopalan (2002) report on a modelling method that has similarities with that in this thesis. They used k-Means clustering to group patients in a hospital into similar pathways that might be used in a simulation model. They identified the difficulty of identifying patient pathways when the patient population is broad but did not add details about the simulation model itself.

#### 2.2.4.1 Critical assessment of the simulation approaches

Overall, it's fair to note that the prevailing response to the complexity of the ED system has been to gather more data and build increasingly complex models - in essence, refining the tools without re-evaluating the logic employed. The general conclusion has been that ED problems cannot be treated in isolation as this simply moves the pressure point within the healthcare system (Acute Health Division, 2001; Lane et al., 2000).

The simulation models (often in combination with optimisation methods) suffer from assumptions about patient arrival, treatment and departure distributions but fail to duplicate actual activities in the ED. This point is reinforced by the difficulty in developing models for problems as straightforward as patient inter-arrivals (Gilchrist, 1985; Jiang, et al., 2004), so these approximations can fail to identify real-life variability in patient presentations.

These models have helped identify measures that shorten patient length of stay in the ED, but this does not necessarily mean that costs will be reduced (Sanchez et al., 2000). Similarly, shortening patient lengths of stay may create some extra capacity and so reduce (for a time, until the excess capacity is offset by increases in demand) incidents of overcrowding, but these are essentially short-term measures that do not address the causes of overcrowding.

Even complicated simulation models only hint at re-enacting real lengths of stay (In one very sophisticated model 31% of patient treatment times had *errors* between 1 and 3 hours, and additional 41% had over 3 hours' error (Connelly et al., 2004)). The inadequacy of current simulation models to address the root cause of blockage might be approached by inclusion of more detail into the models, but such a course of action quickly runs into data limitations. Data is often not available or insufficiently characterised. Identifying the data that needs to be collected in such complex environments is complex in itself. Even once appropriate variables are identified there are practical obstacles to overcome such as high cost of data collection, union agreements that restrict time-motion studies, or the difficulty of locating analysts in the ED where they will not interfere with operations. Even if sufficient data becomes available, detailed simulation models are likely to encounter a utility: complexity conundrum where the model becomes too complex to be comprehensible.

### 2.2.5 Information technology for process control in EDs

Some EDs have ED information systems (EDIS) to assist with patient flow (Dinh, et al., 2006). EDIS provide a range of support from patient workflow management to electronic patient record facilities (The American College of Emergency Physicians, 2003). EDIS systems typically provide for data entry at triage, nursing assessment, doctor assessment and prescription management (Figure 2-4). Patient management is usually facilitated by provision of workflow modules that list patients awaiting treatment, their presenting problem and their severity. EDIS currently assist with patient tracking, workload management and record handling. Additional functionality may be provided through supplementary, particularly wireless, hardware that facilitates patient, patient record, test result and resource tracking (Smith, et al., 1998).

The EDIS may be interfaced with handheld tablets that can display patient records or accept nurse and doctor documentation, orders for prescriptions and follow-up instructions. In theory integrated EDIS workflow can incorporate every step in the patient care process. Human handoffs can be automated. Each step can automatically be logged and tracked. Timing of steps can be determined and acceptable variation in timing and sequencing specified. Human interactions with networked electronic devices such as personal computers, PDAs, CT scanners, lab systems, telephones, IV pumps, and wireless patient tracking tags can be linked to the information system for automation of process control. Physician orders, medications bar-coding, patient registration, and surgery scheduling can be linked and coordinated automatically. Workflow engines should then be able to sequence, monitor, track and reroute any step in each of the patient care processes (Rucker, 2003) and generate sequential event logs for workflow mining. Unfortunately, current EDIS fall well short of this vision.

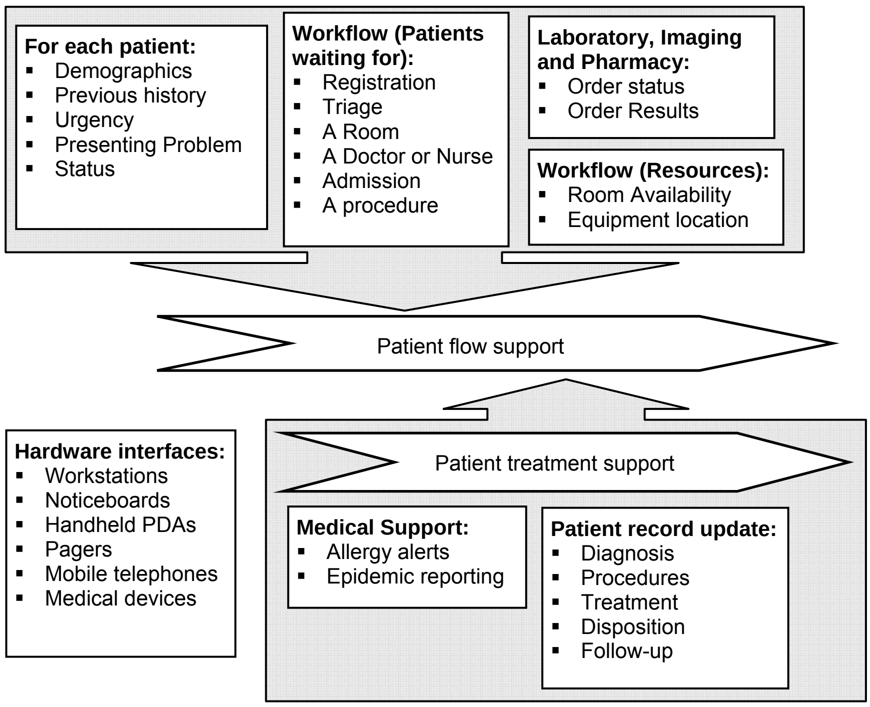



Figure 2-4: Common EDIS components

Workflow information systems are now incorporated into most EDs to facilitate patient flow and help with records management. Timing and location data is accumulated for each patient from their arrival to assessment and bed allocation, through to treatment and disposal. The systems accumulate data and assist with workflow, but do not model clinical processes. Levary (1997) described an information systems approach to re-engineering the ED in which a computerised information board was installed. He also describes the use of group decision making in order to gain the input of ED staff into EDIS design.

A flexible guideline based workflow system was proposed to extend IS capability (Quaglini, et al., 2001). It required prior knowledge about the process a patient would undergo, so was limited to documented "best practice" guidelines for the treatment of certain conditions that only cover a small proportion of ED patient visits (Bridgeman, et al., 1997). While not in an ED, a more recent paper by Ouvry (2002) described workflow analysis and modelling concepts (in a radiology department) that might be applicable to EDs.

Amouh et al (2005) took stakeholder and workflow analysis one step further, building a prototype of a web-based clinical information system. The primary contribution of this system was to replace legacy interfaces with well-recognised symbols in order to enhance clinical safety and quality assurance, and to improve communication by having the information available on a wall display, desktops, and PDAs. A drawback of the web-based solution was that it did not support sophisticated interaction with other information systems in the hospital.

#### 2.2.5.1 Critical assessment of the information systems approaches

Workflow analyses are based on process views (van der Aalst, et al., 2003). Process views of treatment are difficult because of the complexity of symptoms, range of severities and variety of medical specializations involved (Averill et al., 1998; Jelinek, 1995; Walley, et al., 2001). Each patient is different in seemingly unpredictable ways so treatment has to be individually customized. Without some grouping of patients or classification of treatment it is difficult to move EDIS beyond generic ordering, recording and monitoring support for individual patients.

Current EDIS focus on the relatively simple coordination, resource allocation and documentation aspects of ED operations. They do promote reduction of wait, transfer and rework times by improving coordination of staff and resources, but the systems do not optimize patient flow and resource use, nor do they address decision support for clinical aspects of patient treatment. The modelling of ED patient treatment processes is a problem at the centre of these inabilities. EDIS cannot be "process aware" and actively support workflow because models of ED treatment processes simply do not exist.

### 2.2.6 Data analysis approaches

Cullen (2001) used data mining for intelligent feature selection in healthcare. Other data mining in healthcare research relate to investigation of symptoms and treatment (Begg, et al., 2006; Brossette, et al., 2000; Chae, et al., 2003; Isken et al., 2002; Lee, et al., 2002; Lin, et al., 2001; Riano, et al., 2000; Richards, et al., 2001; Williams, et al., 2002, Milley, 2000). Isken and Rajagopalan (2001) describe additional value that van be derived from aggregation of existing variables in hospital databases.

Abston (1999) applied neural networks and other methods to model the pharmacological management of acute myocardial infarction in an ED and concluded that the data most descriptive of and pertinent to clinical decision-making seems to be left out of data collected each day in the clinical setting. Abston's conclusion highlights the difficulty of grouping ED patients according to clinical decisions and underscores the need for a change in approach from classic Casemix models.

Rotstein et al (2002) formulated a dynamic statistical model to forecast the need for allocating additional medical staff, taking into account patient volume. The number of non-trauma presentations to the ED between 1992 and 1995 were analysed using a Gross Linear Model and the marginal benefit to shortening patient length of stay in the ED by adding a physician between noon to midnight was examined for different patient volumes. The addition of a physician decreased patient length of stay by 6.61 minutes for 80 to 119 presentations. However, adding a physician did not have a significant effect for less than 80 or more than 120 presentations. They concluded that consideration of patient volume may also provide ED managers with a logical basis for staffing and resource allocation.

Rajagopalan and Isken (2002) used k- means clustering on data from a hospital in the Midwest of the United States to demonstrate how they could help guide the development of patient-type definitions for the building computer simulation or analytical models of patient flows in hospitals. The paper focussed on important issues that researchers need to address when applying clustering techniques in general and specifically to hospital data.

A comprehensive, parsimonious, clinically sensible, and evidence-based set of chief complaint groupings for paediatric ED visits was discussed by Gorelick et al (2005). Paediatric visits for years 1998 and 2000 were extracted from the National Hospital Ambulatory Medical Care Survey (NHAMCS) and assigned (using a count of recorded complaints) to clusters. The clusters were combined to ensure a minimum of 20 patients in each, and reviewed for clinical sensibility. Fifty-two clusters were generated. The eight most common clusters encompassed 52% of the visits. The top five were fever (11%), extremity pain/injury, vomiting, cough, and trauma (unspecified). The clusters were ranked according to severity and associated with actual resource utilization. Both resource utilization and triage classification increased with increased severity ranking.

Decision Trees (of which Classification and Regression Trees is one of the most widely used) produce models that are easy to understand. Decisions based on an error function are made on how to optimally split each variable to arrive at "pure" variables at the base of the tree (Kennedy, Lee et al 1998). Application of these methods in clinical epidemiology were reviewed by Marshall (2001) and compared to Logistic Regression (another method popular in medical research) by Lemon, Roy, et al (2003). Applications of the methods tend towards identification of symptoms contributing to medical conditions (see, for instance Buntinx, et al. (2001) and the conference proceedings at http://www.salforddatamining.com) but a framework for the use of CART in development of models has been proposed (Harper 2005).

#### 2.2.6.1 Critical assessment of the data analysis approaches

Despite an intensive literature search, no evidence was found of undirected knowledge management techniques on ED data sets. The work by Gorelick et al (2005) approaches a patient clustering method that might have process application, but it is based on diagnosis, not treatment, so does not guarantee segmentation of ED treatment activities.

The shortcomings of CART, Association Mining and similar partitioning algorithms were adequately summarised by Marshall (2001) as "Simple rules may be unlikely to be "discovered" by tree growing. Subgroups identified by trees are often hard to interpret or believe and net effects are not assessed. These problems arise fundamentally because trees are hierarchical. Newer refinements of tree technology seem unlikely to be useful, wedded as they are to hierarchical structure." Possibly the most limiting factor of the Decision Tree methods is the requirement that an objective variable be identified. These observations are revisited in Section 5.6.

### 2.2.7 Other approaches

Habing et al (2001) discussed the need for generic activity patterns in the interaction between patients and care-givers in order to be able to encode the activities in electronic patient records. They describe their "DEMO" method for the elicitation of generic activities and how it was used to describe activities in the ED at the University Medical Center Utrecht (Maij, et al., 2000). The main conclusion from this research was that DEMO expressed the core care activities and the co-ordination of activities in a clear, unambiguous and comprehensible manner.

Tregunno et al (2004) developed a performance framework and set of indicators to reflect the performance interests of multiple stakeholders associated with the management and delivery of emergency ED services in the Canadian province of Ontario. Descriptive and inferential statistics were used to explore the interests of five stakeholder groups. Emergency department performance interests were not homogeneous across stakeholder groups. Differences existed between hospital and non-hospital stakeholders. Physicians rated ED performance measures lower other stakeholder groups. Community-based stakeholders, a group frequently excluded from commenting on ED performance, provided important insights into ED performance related to the external environment and the broader continuum of care. The researchers concluded that evaluation of performance from the perspective of a single stakeholder group could result in unbalanced assessments.

Queuing Theory has often been referred to in editorials on "the ED problem" (Preater, 2002; Goddard and Mills, 2003; Mills, Champion, et al., 2005), but only one reference could be found on a queuing model to reduce patient queuing times. This suggested queuing prioritisation based on social cost would gradually cause "non-essential" users of emergency care to change their habits and visit at off-peak periods when queues might be shorter (Siddharthan, et al., 1996). There has been little process-based research using Queuing Theory. In fact, "How often has Queuing theory been used to design and reengineer our EDs? To our knowledge, never" (Litvak, et al., 2001).

Data Envelopment Analysis (DEA), another method that might be expected to be represented in the ED setting was likewise elusive. No research was uncovered that analysed ED inputs and outputs using DEA.

#### 2.2.7.1 Critical assessment of the "other" methods

These social study approaches overlap somewhat with the soft system methodologies often used during industrial engineering or management science projects. Neither of the above studies addresses ED treatment activities explicitly, and they are of limited assistance with understanding the mechanisms of ED overcrowding. It's likely that the "steady state" assumptions of Queuing Theory would be difficult to justify for ED patient arrivals.

### 2.2.8 Research at Frankston ED

#### 2.2.8.1 Discrete event simulation at Frankston ED

A discrete event simulation model was built for this ED to investigate emergency bed requirements and waiting times arising from unpredictable patient arrivals (Brailsford et al., 2003). Arrival patterns, branching possibilities and service fluctuations were analysed and included in the model which had as distinctive features measurement of ED demand on both hourly and daily bases and the measurement of service durations by both patient urgency and discharge destination.

The model confirmed the hypothesis that patient disposition has a significant influence on the ED system, but it was concluded that waiting time issues in the ED required a wider system-based approach that included influences from outside the ED.

#### 2.2.8.2 Process modelling at Frankston ED

An in depth analysis of the clinical requirements was performed as a preliminary step in integrating clinical decision making into an EDIS (Djorhan et al., 2003). A conceptual framework was created that modelled ED objectives, clinical data, organisation structures, knowledge and work processes. The model was developed using the ARIS[13] method and the ARIS modelling tool. The ARIS method integrates business processes and components of information systems such as data, people, communication, hardware and software. 73 process models, five data models and thirteen objective diagrams were created to represent the requirements for clinical decision making.

#### 2.2.8.3 Critical assessment of the previous research at Frankston ED

The discrete event simulation model was limited to a single resource constraint – that of patient beds, whereas staff, services and other resources also have an impact on ED throughput. The researchers observed that alternative patient groupings should be considered in order to provide a better understanding of patient flow in the ED.

The process modelling provided an excellent knowledge repository for existing processes in the ED. While these models indicated the decision processes involved in the treatment of patients, they did not reflect what the treatment processes were. The work of defining treatment processes was left for this research project.

---

[13] An integrated "architecture of information systems"

## 2.3 Problem development through assessment of previous research

The response to the complexity of ED problems has been to gather more data and build increasingly complex models, refining the tools without re-evaluating the logic employed. This contrasts with the original (Morse, et al., 1951) concepts of OR/MS which emphasised understanding of the data and its context in problem-driven analyses (Figure 2-5). The granularity of research (models) needs to be improved without excessive increase in data requirements or model complexity. Essentially the emphasis should be on improvement in understanding of the problem and context over honing of algorithms and detailed tools which are, after all, "just mathematics".

**OR/MS practice guidelines:**

- Take a system view
- Unearth the real problem
- Live in the application environment
- Check data accuracy onsite
- Advocate correct logic
- Propose creative alternatives
- Help the client with a detailed plan
- Have a deep interest in the client's situation and needs

Figure 2-5 "Good" OR/MS practice (Robinson, 2000)

Cost driven approaches such as patient throughput and resource use are important measures of ED performance, but they do not address the key value adding function of EDs – the transformation of ill and injured patients to a state of comparably good health. So the real problem in EDs is how to improve patient treatment. This does not mean that practitioners need to tell health professionals how to treat patients, in much the same way that Morse and Kimball (1951) did not attempt to tell pilots how to fly aeroplanes, but rather assisted them in finding efficient and effective ways of modifying activities and resource use for the best potential outcome.

This general overview of past research, in combination with the critical evaluations of the research that were provided throughout the chapter, allow narrowing of the broad statement of the problem that was given in Chapter 1 as a question of the mechanisms of ED overcrowding and blockage to more specific objectives. A description of research constraints is provided in the next section as a prelude to a statement of the goal of the research in Section 2.3.2.

### 2.3.1 Description of the research constraints

The first constraint specifies that the ED is part of a system, so may be affected by, and is likely to affect, other components of the system, most particularly the hospital in which it is located, but also other EDs and hospitals in the region. This statement uses "system" in an intuitive (and completely correct) sense as "A group of interacting, interrelated, or interdependent elements forming a complex whole" (Houghton Mifflin Company, 2000). Daellenbach (1994) provides a more formal definition, giving system components; the relationship between them; the behaviour or transformation processes; the environment, including both inputs from, and to-it; and the special interest of the observer in his definition. The next few paragraphs will discuss some of these elements and place them in context of this research.

- **System components** do not have to be physical things. They can be abstract. The component of key interest to the observer is usually system activity.
- **System activity** may be expressed as the transformation of inputs into outputs. In the ED this may be considered the transformation of ill and injured people into ones who are less ill or injured, or on their way to being so.
- **The system environment** is comprised of all the components that affect system behaviour yet are not affected by the system. They are viewed as being outside the system, rather than part of it. Although the system provides outputs to the environment these are not expected to affect the environment in a way that is of interest to the observer. If they do affect aspects of the environment significantly (that is, if there is feedback to the system from its outputs), these should be included in the system itself. The separation between the system and its environment means that each system has a boundary. Remember from Section 1.6 that the research is confined within the walls of the ED, so the system is the ED itself. The hospital, catchment area for patients and political implications constitute aspects of the system environment. The environment is likely to adjust to absorb any excess capacity created in the ED, so, while empirical improvements to ED performance are useful, they are in essence futile endeavours, akin to merely expanding ED resources when needed (of course the financial environment precludes this as it is driven by a political environment conscious of the tax burden it places on its electorate).
- **The person who views the system** has a certain perspective or reason for doing so. This purpose determines which aspects of the system should be studied in detail, that is, which performance measures or indicators about the behaviour of the system should be assembled for observation. The previous work in this area almost always worked from a sample of patients or time, driven by practical issues such as cost and duration of the studies. They were all guided by their particular interest

(or those of their stakeholders) and tried to pay due diligence to ensuring their sampling was relevant.

The second constraint on this research was the undertaking that only existing secondary data would be used in an effort to provide breadth of understanding across all patients and activities in the ED, rather than generating new sub samples. That is, the desire was to have as many patients as possible in the study in order to reveal hidden patterns of activity that recur over time. Stated in another way, it was intended that the information for study would be more representative of actual ED operations by taking a substantially larger sample of patients, even though less information would be available on each patient. It was believed that such a broad-based study would shed light on what information was most pertinent to analysis of ED operations, including an account of information missing from the data. The ambition was to include all patients (over an extended time period) in the study, rather than a more detailed sub sampling of patients (or using a shorter time period).

### 2.3.2 General goal of the research

The analysis of existing research of ED systems in Section 2.1 showed that analysis of patient demand and exit mechanisms did little to clarify the mechanisms of ED overcrowding. The general conclusions were that EDs became overcrowded if the hospital bed occupancy was too high or if too many patients requiring hospital admission arrived at the ED in a short time period.

The analysis of research within EDs in Section 2.2 indicated that a fair amount of work has been done (by consideration of patient flows within the ED) in streamlining processes to facilitate the movement of patients between treatment areas, and in optimising the allocation of resources. Little or no analysis has been done on the nature of patient treatment and the effect that variation within treatment might have on ED operations.

So far the network of constraints has driven consideration towards containment within the ED itself and limited the research to use of existing data. The system and data constraints drive deliberation towards activities occurring in the ED between patient arrival at the ED and patient departure from it. This period may readily be divided into three components: patient arrival; patient residence; and patient departure.

If patient arrival is considered a simple manifestation of the patient at the ED door (the system boundary) without worrying about how the patient got there and patient departures similarly viewed as dematerialisation of the patient from the ED, then patient residence within the ED may be addressed in isolation. Patient residence may be viewed from the perspectives of how efficiently or effectively the patient was treated; the resources consumed; the cost; and so on. A process-orientated view takes thinking towards consideration of activities related to the patient's stay in ED. This leads thinking towards an evolved general problem for research:

---

How do activities between patient arrival and departure influence ED overcrowding and blockage?.............………………………...Statement 2-1

---

While Statement 2-1 hypothesises that certain activities may be implicated in ED overcrowding, the statement is rather nebulous in terms of what those activities may be. Since many of the activities associated with patient stay have been studied in detail, such as patient wait before being seen by a doctor and admission delay, and these have not been implicated in ED overcrowding, Statement 2-1 may be refined so that the research addresses patient treatment - an area not previously studied:

---

How do patient treatment activities influence ED overcrowding and blockage?.......................................………………………...Statement 2-2

---

## 2.4 Summary

Chapter 2 gave a review of research that has been done in the area. The review showed that much research has been done towards understanding ED operations, but the problem has been somewhat intractable. Measures have been implemented in EDs in an attempt to reduce the incidence of extended wait times and ambulance bypass associated with EDs. These attempts have generally sought expert opinion about measures that might benefit ED operations. There has also been work on scheduling staff in ED environments and some proposals for grouping ED patients to facilitate cost estimation or modelling.

Previous research and ED reengineering projects have been driven by preconceived ideas about activities in EDs. They often employ parametric methods to identify correlated factors. As such they are limited by the extent of the analysts' knowledge or observations. While these approaches have added to knowledge about ED operations, none of them adequately illuminate activities involved in the treatment of patients. Patient arrival, reception and movement to treatment areas can be modelled in detail, but activities involved in patient treatment are not modelled in detail. "Treatment" is usually listed in a single amorphous function without further detail. Since patient treatment is the core value-adding activity of EDs, these approaches fail to provide for the management and coordination of the ED's primary work at individual or aggregated patient levels. Without this it is difficult, if not impossible, to identify real opportunities for the improvement and management of processes within the ED.

The constraints on the research and the review of existing work led to questioning whether patient treatment could be implicated in ED overcrowding. If homogenous clusters of ED patients could be extracted from ED data, then the activities involved in treatment would be the same for each cluster, so each cluster could be considered to have matching inputs, outputs and resource consumption. The activities associated with each cluster would comprise activities in the process of treating patients, so process and workflow perspectives could be used to improve understanding of patient flows through the ED. Just such a clustering of patients will be discussed in Chapter 5, but the methodology must first be introduced (in Chapter 3) and the data preparation and analysis described (in Chapter 4) in order to lay a solid foundation for the clustering work.

# Chapter 3: Methodology

This chapter lays out the scientific methodology that was followed, along with its postulates. The chapter is divided into three parts in order to move systematically from discussion of the world view taken in the research through the methods that guided the work to a description of the actual tools used. Section 3.1 looks at the methodological framework for the thesis. It considers metaphysical and logical matters and describes how Scientific Method was applied in this research. Section 3.2 moves from the non-specific discussion of methodology in Section 3.1 to a more practical discussion of the methods and techniques that were used in the research. Section 3.3 is even more specific and applied. It introduces the software tools that were used. The mathematical and conceptual background that underpins the software is supplied to enable a considered evaluation on the appropriateness of the tools to the techniques. Discussion of the data and initial analyses are left for Chapter 4, since this material is extensive in itself.

By the end of Chapter 3 the scene will be set for moving to practical application of the methodological framework. Chapter 4 discusses the data used in the research and initiates data analysis. Knowledge acquired through the initial data analysis is used to redirect thinking towards detection of groups of patients who undergo similar treatment in Chapter 5. These groups are used in a simulation model of the ED in Chapter 6.

## 3.1 Scientific positioning of this research

Science may alternately be described as a collection of propositions, or as the ensemble of activities of the scientist in pursuit of the goal of construction of propositions (McMullin, 1987). The former, as a subset of the latter, is of more general and applied interest because it represents a measure of achievement. The latter, the process of generating knowledge, is of interest to philosophers in particular who seek to understand how knowledge is created.

Philosophers are not the only ones with interest in the general characteristics of science. While philosophers' interest most directly relates to science's function as a knowledge-producing activity, historians want to know how science has reached its present state of development; psychologists want to analyse what types of individuals have been involved in science and how their psychological styles have influenced their work; and sociologists want to understand how social and cultural influences affect science (Kourany, 1987). These various approaches to science are not independent of one another and the boundaries are not clear between them. A comprehensive picture of science may only be produced through complete integration of these approaches. Unfortunately deep controversies exist in the philosophy of science, the history of science and other perspectives that prohibit a single comprehensive picture, so no single definition of "science" exists[14] (Chalmers, 1999).

The only way around this conundrum over the definition of science is to select a perspective from the philosophical, historical, psychological and sociological spectrum. How does one choose? The production of scientific knowledge always takes place in a social context. The professional aims of the scientists, the aims of the funding agencies, the political circumstance and so on influence the orientation of the study. A pragmatic approach would be to consider the scientist involved in the research. The most suitable perspective may be identified from the scientist's expertise and preference in philosophical, historical, psychological or sociological studies. In the case of this thesis the scientist has decidedly little expertise in psychological and sociological studies and a preference for philosophical over historical perspectives. The selection of a philosophical perspective in no way diminishes the importance of the other perspectives nor is it an estimation of the validity of this perspective over any other. It merely reflects the attitude of the researcher.

From a philosophical perspective science is: "a multi-layered complex system involving a community of scientists engaged in research using scientific methods in order to produce new knowledge." (Zalta, 2002). Essential aspects of this somewhat recursive definition are the ideas of "scientific methods" and "new knowledge". As to be expected from previous paragraphs, there is no general concurrence on scientific method or new knowledge among philosophers. Once again an approach needs to be identified within the perspective.

McMullin (1987) suggests a number of possible approaches to the Philosophy of Science. These may roughly be divided into external views of science and internal views. External views impose upon science a theory of what scientific study should look like. There are two main types of external views: a metaphysical one that questions the nature of the realities; and a logical one that provides for validation. The internal view relies upon study of what scientists actually do, rather than what they say they are doing. It is a study of the "science of science". The distinction between the three criteria does not make them mutually exclusive, but offers a way in which consistency of analysis may be

[14] This is most famously postulated by Feyerabend in his work Against Method. Feyerabend stated that there is no universal method by which science is conducted: Science is a collection of theories, practices, research traditions and world-views whose range of application is not well-determined and whose merits vary to a great extent. (Feyerabend, 1975).

checked. The external views are most easily characterised by historic approaches such as the general theories of knowing and being of Plato and Aristotle and the rational reconstruction of a general logic that is intrinsic to scientific inquiry. The external views are placed prior to analysis of procedures followed in science since they provide the assumptions for the internal view. The external views alone are not operationally specific enough to serve as a methodological manual, but the combination of the external and internal views provides a comprehensive methodology. Sections 3.1.1 to 3.1.3 will examine the thesis subject matter through the lens of these views.

### 3.1.1 The external metaphysical view

Metaphysical statements are generally not fallible, testable or provable statements. That is to say, there is no valid set of empirical observations or valid set of logical arguments which could definitively prove metaphysical statements to be true or false. Hence, a metaphysical statement usually implies a belief about the world or about the universe which may seem reasonable but is ultimately not empirically verifiable. A number of aspects will be dealt with below. Each will play a part in describing the methodological placement of the research in this thesis.

#### 3.1.1.1 The nature of reality

The first aspect refers to the nature of reality. It is presumed and accepted in this work that a single unique physical world exists independent of the observers. This places the research firmly in the realist mode similar to that of the Positivist approach to philosophy. It is also presumed that all observation is fallible and has error and that all theory is revisable. That is, it is difficult to know reality with certainty. This post-positivist view of the world is usually ascribed to Critical-Realism (Potter, et al., 2005). It recognises the importance of multiple measures and observations, each of which may possess a different kind of error, and the need to compare these observations to try to get a more balanced view of reality.

This research is placed in a hospital emergency department that is a physical entity. Patients enter and leave the facility, staff go about their work and physical machinery is manipulated. All of these may be observed and measured according to certain agreed conventions. While the observations and measurements are subjective according to the interest of the observer, the scrutiny in this thesis is not considered to have material impact on the activity of the entity because it occurred in the course of normal ED operations (That is, data collection is an ongoing part for everyday ED activities.).

#### 3.1.1.2 Objects and properties

The previous section made some reference to objects in the physical world under study. This section describes the attitude taken towards the nature of these objects in terms of their properties. It's straightforward to propose that hair colour, height and so on are properties of patients, as dimensions of corridors and beds are properties of these inanimate objects. These properties help to describe the object and differentiate it from similar objects. The properties are abstract. They do not exist unto themselves but are rendered relevant in context of application to their associated objects. This line of reasoning makes it reasonable to consider descriptions such as "urgency", "age" and "illness" as properties of patient objects.

This view of properties does raise a difficulty, however. How do these properties change over time? It is hoped that a patient who arrives at the ED and is designated "urgent" will at some later stage have the potential to be reclassified as "non-urgent". This mutation of properties over time is difficult to capture when large numbers of objects are being monitored. The position taken in this research is that initial patient properties will be retained through the time the patient resides in the ED, even though there is implicit understanding that the patient's properties are changing as their treatment progresses. Abstract properties such as "state of recovery" will be omitted. Obviously when patients leave the ED they will not be identical to when they arrived, but for the purpose of this study these changes will be ignored.

#### 3.1.1.3 Data as facts

Having addressed the issue of the world in which the research is placed it is necessary to consider the "facts" that are presupposed in the derivation of insights throughout the research (logic will be discussed under the "external logical view" in the next section). It is significant that this research is based on the use of previously gathered data - there is little direct observation and gathering of facts. The data collections provide "second hand" observations. This leads to two main issues: (1) Are the data facts in themselves statement of facts? (2) What is the degree of confidence in the factual content of the data?

The first issue is dealt with rapidly by classifying the data as statements of fact, rather than facts themselves. It will be accepted that a patient who is recorded as "urgent" is indeed "urgent" without requiring contact with that patient (this is impossible, since the patient has moved through time since their visit to the ED).

The second issue (confidence in the factual content of the statements provided by the data) falls into three categories: 1) if a patient is noted as "urgent" is the assessment correct and/or 2) is the recording of that assessment accurate? 3) if a patient is in a group of "urgent" patients what is the possibility that all the patients in that group were assessed according to equitable criteria? (This questions the reliability of assessment across multiple assessors.)

A similar response may be applied to all these confidence questions. There is no guarantee that the assessment and/or recording are accurate (as an aside it should be mentioned that studies of triage reliability have shown experienced triage nurses to be both reliable and commensurate in their assessments (Gerdtz, et al., 2001; Jelinek, et al., 1996; D Richardson, 1998; Tanabe, et al., 2005)). The assumption in this research is that the nurses are professional in their actions. Even if this is not totally the case, the data reflects the actual triage process. Since this research studies real practice any variations of this nature are considered reflections of what really happens in EDs.

Staff are also assumed diligent in the recording of their actions. The potential for error in the stress laden ED environment is recognised, however. While there is no way of measuring that error within the scope of this thesis, the volume of observations provided in the data give reassurance that errors will be swamped by accurate observations.

Both the nature of reality and the nature of the facts have been considered and metaphysical positions taken, but what of the world portrayed by the data? Do the factual statements provided by the data portray the real world? The position taken here is that the data are statements of fact about the real world. These statements are artefacts that can be manipulated through application of logic in much the same way that facts can be manipulated. Logic is discussed as part of the external logical view in Section 3.1.2.

#### 3.1.1.4 Models of reality

If the statements of fact discussed in the previous paragraphs are used to build a model of reality, how transferable are the results of this model to reality?[15] Since this thesis involves significant amounts of modelling based on the assumed accuracy and transferability of the data to the real world it is necessary to take a position on this issue[16]. The position in this thesis is that the model-derived facts are statements of the virtual model-based reality. Of course, the limitation on the facts produced by the model is that

[15] This issue is discussed at some length in (Wartofsky, 1979)

[16] The use of models in experiments is discussed in Section 3.1.3.5.

they lie within the limits of experimental method. This will be discussed in conjunction with the internal view of the methodology.

The model-based statements of fact act as proxies for the real world. It is recognised that they are approximations, since the model is a simplified representation of the real world, and the model artefacts may have fewer properties of interest than their analogues in the real world. However, the properties in the model are ones of interest to the analyst. Elaboration of the model artefacts to include superfluous properties is considered an unnecessary time-consuming exercise that will not contribute to the confidence in the factual content of the model results. Nonetheless, the statements of fact that arise from the model may only be used to postulate theories and must be tested in the real world before they may be considered factual statements about the real world. The postulation and testing of theories will be considered from the external logical view in Section 3.1.2.

#### 3.1.1.5 Summary of the external metaphysical view

The metaphysical issues associated with this thesis were discussed with the intention of clarifying the position of this work within the Philosophy of Science. Questions dealing with the nature of reality, the facts upon which future theories may be based, and the transferability of model results to reality were discussed.

In conclusion it should be noted that all measurement is considered fallible, so the importance of multiple measures and observations are emphasized in this work. For example, in Chapter 5 the grouping of procedures that arises from one technique is compared to the results from two other techniques and to results from different hospitals.

All observations are theory-laden (driven by prior assumptions of the observers) and the researcher inherently biased by cultural experience, world views, and so on. It is only in the open discussion of these observations and their allied theories that something approaching objectivity may be reached. To this end numerous papers were published and presentations made during the research in order to gather criticism and temper the work.

### 3.1.2 The external logical view

While the last section dealt with the metaphysical aspects of this research thesis within the Philosophy of Science, this section will deal with the logical view. The metaphysical view had, by definition, no inherently provable tenets. It provided positions on aspects of the research that could not be proven or disproved. This section deals with concepts of reasoning, in particular that of cause and effect and logic.

There is little philosophical agreement on what it means to say that one event causes another so some clarification is necessary. This is done in the first three sections, before moving to discuss the logical approach employed in this thesis.

#### 3.1.2.1 Causation

A common view of causation is that an event can be explained if it is linked by a law to some other event[17]. While this view is feasible, it does not differentiate between felicitous occurrences and causation. One strategy is to require "necessitation" for causal events, and limiting simultaneous felicitous occurrences to "accidents" (Bunnin et al., 2003). It's most often said that the earlier of two events is the cause, and the later event the effect. This of course does not mean that the cause is directional in time, but rather that it has some impact in a particular direction. This would imply that, if the effect is absent, then the cause must be absent too. While this is sufficiently clear to use as a guide in simple systems, it becomes more complicated when multiple causes contribute to an effect.

Recent models of probabilistic causation require that causes increase the probability of their effect, but not necessarily give them a high probability (Bunnin et al., 2003). This approach has to guard against the effects of "common cause". For instance there is a probabilistic association between barometers and rain, but the lower reading in a barometer does not cause rain, even if it precedes it. Both the lower reading and the rain are effects of the low pressure common cause.

#### 3.1.2.2 Probability

Probability raises philosophical questions of its own. One objective interpretation of probability is that the propensity for a given result is the number of times an event occurs relative to the total number of "tries" (for instance, the occurrence of "heads" when a coin is tossed a number of times). An extension of this is that a result must be relative to a hypothetical infinite sequence of tries. Another objective interpretation is that the probability of a given result may only be given for a given experimental set-up, freeing probability from any hypothetical reference. These interpretations fail to explain how to move from a count of frequencies in small samples to general probabilities. One possible solution is to move to quantum mechanics, stating that it is impossible to simultaneously know both the probability and the effect. This is too devious a route for this thesis, so the view held is that probabilities are quantities that satisfy the axioms of

[17] This may be considered a statement of the Covering-Law Model of Explanation, an extension of Humean Constant Conjunction (Bunnin, et al., 2003)

Bayesian probability calculus. Widely accepted norms of statistical inference are used to determine correlations. Causation is implied through the application of logic.

#### 3.1.2.3 Teleology, reduction and aggregation

There are three final points related to causation. The first is teleology – the non-causal explanation of phenomena by their future results, for instance that polar bear's white fur act as camouflage. Time provides the key to unravelling such relationships. While the white fur may act as camouflage in the future, in the past the camouflaged bears were the ones that survived, resulting in the present set of facts. It's not always easy to identify the precursor and the result so theories need to be scrutinised for this form of incorrect causation. For example, correlations may be identified between treatment time and urgency, but the urgency causes the treatment to be faster for certain patients (cf. Figure 1-4).

The second point is the reduction of causes to sub causes. It's possible to dissect many causes down to levels of chemistry and physics. While there may be value in doing this in other works, it's not considered beneficial to the analyses in this thesis. Effort has been taken to remain at a similar level of detail when dealing with causal relationships. Of course the systemic effects of accumulated causes may not be ignored, particularly as some of the effects seem chaotic (small events having a significant impact on the system). Rather, the phenomena are dealt with at a human (patient) level on a human time frame of seconds, minutes and hours. Within these guidelines the accumulated impacts of multiple human actions remain at an appropriate level of granularity.

Thirdly, aggregation (the opposite of reduction) may also be used inappropriately. Averages have sometimes been used inappropriately in published works in healthcare, leading to spurious or fallacious conclusions. Care needs to be taken not to ignore the impact of individual causes when dealing with measures of centre (such as averages). It's also a firmly held view of this researcher that, while averages and similar measures provide summaries that have their uses, they are best omitted from calculations where possible by substituting instead actual values. The advent of computers makes this a painless enhancement for many applications. It is a far more accurate and transparent mode of calculation and definitely more appropriate when dealing with accumulations in non-linear systems (Savage, 2003).

The foregoing discussion of cause and probability has been intended as an introduction to the form of logic used in this thesis, rather than a discussion of the epistemology of science (the justification of claims of scientific knowledge). The discussion now moves to logic as it is applied in this thesis.

### 3.1.2.3 Logic and belief

Logic is concerned with the distinction between good and poor reasoning (Bunnin et al., 2003) or the study of consistent sets of belief (Hodges, 2001). Philosophers have traditionally divided logic into "inductive" and "deductive" logic. Inductive logic is concerned with inferences that are probable based on evidence of propositions when the propositions are not conclusive or universal. This largely falls under the discussion of probabilistic cause and effect that was provided in preceding paragraphs and the application of probability theory.

Deductive logic deals with rules for determining when an argument is valid in an attempt to provide conclusive inferences. Conclusive inferences have the property that they cannot be false if the reasons given are true (Popkin, et al., 1993). Another way of saying this is that the use of factual statements as the premises of arguments will yield truthful statements (Chalmers, 1999). Deductive logic has been one of the most actively pursued studies in philosophy in recent years (Popkin et al., 1993).

Unfortunately, however, the inductive and deductive views of logic separate belief into complete belief or absolute refutation of belief. In reality, belief is subject to degrees of intensity, so the clear cut extremes provided by deductive and inductive logic may not necessarily hold. While the terms will be used in this description of methodology as a concise description of the thought processes, the insinuation in this thesis is that the belief that arises from these processes may not be absolute, either because the evidence is not complete, or because the prediction is surprising. In this way the logic is more akin to a Bayesian approach in which "the degrees of belief of an ideally rational person conform to the mathematical principles of probability theory" (Horwich, 1982). The Bayesian idea is that methodological puzzles stem from an all-or-nothing approach to belief and may be resolved by means of probabilistic "logic" of partial belief.

### 3.1.2.4 Summary of the external logical view

Figure 3-1 provides an overview of this section and a working guide for the logical view of this research. Statements of fact (from data, as discussed in Section 3.1.1) are used in the preparation of beliefs or laws according to probability. Typically these arguments take inductive form since the observations are seldom universal but rather arise from mathematical manipulation of the data that might include non-crisp boundaries around groups of individual records (that is, records may be grouped together if they are "similar enough", having certain properties in common, rather than all properties being identical). The "laws" may then be used in the formulation of conclusions that take the form of explanations or hypotheses. The reasoning here is most likely to be deductive, since the arguments move from the generalisations of the "laws" to the specific of certain classes of individuals.

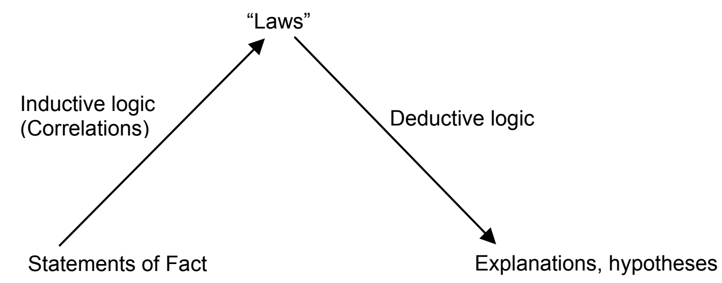



Figure 3-1: The logical view of this research (After Chalmers, 1999)

This section has expanded on the indeterminate concepts of the external metaphysical view. It is still an external view of the creation of knowledge through science but it does start to provide some of the essentials of a methodology. It gives a framework for reasoning that will be used extensively in application of scientific methodology. The scientific methodology will be discussed in context of an internal view of knowledge creation through science.

### 3.1.3 The internal procedural view (what scientists do)

It's the intention in this section to identify a formula by which this research may be conducted in a scientific manner. Unlike the previous two sections it will rely on an "internal" description of how scientists have proceeded in the past. This is used to help formulate a framework of steps that may be followed.

#### 3.1.3.1 Overview of Scientific Method

For hundreds of years scientists have observed, thought about their observations, and then used their insights to iterate through successive cycles until they arrive at some conclusion. Scientific Method is a formalised account of what occurs in this process. The methodology provides a systematic, organized series of steps that ensures maximum objectivity and consistency in researching a problem. It provides a shared basis for discussion and analysis, and helps to promote consistency and accuracy. Scientific Method started to be formalised in the seventeenth century as technological advances led to discoveries about the nature of things that contradicted common beliefs. Separation had to be made between beliefs and theories. Scientific Method prescribes that deliberate experimentation under changing conditions and observations of resultant outcomes provide a way of showing causal connections and providing quantitative information. The essential elements of a scientific method are:

- Quantifications, observations, and measurements;
- Hypothetical explanations of observations and measurements;
- Experiments to test the hypotheses and lead to more data.

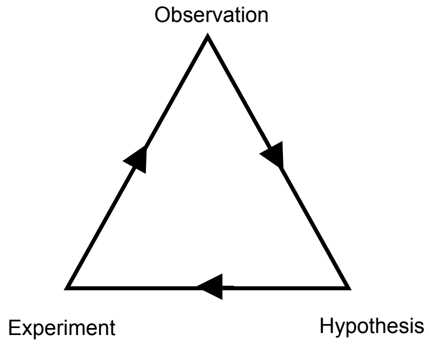



Figure 3-2: A general model of Scientific Method (Chalmers, 1999)

The scientific method may be modelled as an ongoing cycle (Figure 3-2). While this schema is currently accepted as standard Scientific Method, it should also be noted that “the idea that science can, and should, be run according to fixed and universal rules is both unrealistic and pernicious” (Feyerabend, 1975). There is no universal “method” of science, but it is not necessary to assume that scientists should be free to follow their own subjective whims. Historic methods and standards implicit in science are determined to have been successful in retrospect. Lessons can be employed from these and help guide scientists in the development of a systematic approach to knowledge creation and problem solving (Chalmers, 1999).

#### 3.1.3.2 Problem definition

The formulation of problems is at the heart of scientific research (Nickles, 1980). Scientists are most often faced with a set of phenomena and no theory that explains them[18]. Nickles (1980) proposes that logics of discovery exist but not an overarching “recipe” by which discovery research may be conducted. That is, sets of more or less rigorous rules, routines or heuristics exist for discovery (such as curve fitting techniques, statistical methods and heuristic programming procedures), but algorithmic rules about

[18] It’s been proposed that the discovery of ideas leading to theories lies outside the Philosophy of Science (Reichenbach, 1968) or is not logical (N. R. Hanson, 1958), but these are not the perspectives adopted in this work.

how to perform discovery do not (and cannot) exist. He suggests that the absence of general algorithms for generating theories may trouble some philosophers, but valid methods do exist to guide thinking in a rigorous way, so should be considered sufficient for the purposes of research that needs to discover something as opposed to philosophising on *how* something may be discovered or placing discovery in its social context.

#### 3.1.3.3 Hypotheses

Problem definition leads the scientific researcher to the postulation of hypotheses. In Nickles' world the hypotheses indicate some causal relationships in constraints. In more conventional views such as Weatherall (1968), hypotheses may be induced by arguing from the particular to the general or simply through imaginative leaps of insight on the part of researchers or teams of researchers. Gutting (1980) emphasises the "invention" of hypotheses (that start out as "ideas") as a process susceptible to logical analysis, but not necessarily algorithmic prescription. The distinction between Weatherall's abduction and Gutting's insight is considered less important than the context of the hypothesis. Simon (1977) stresses that "hypotheses must be chosen in a context that takes into consideration the decisions that are to be reached and the consequences of those decisions". He goes on to emphasise that hypotheses cannot be tested without considering the discovery processes that generated them.

The perception that Scientific Method merely involves the testing and verification of scientific theories in order to choose between competing theories (Popper, 1968) has been challenged as a distortion in the actual practice of science (Simon, 1977). Similarly Nickles (1980) maintains that more time is devoted to the discovery of "regularities in phenomena" than simply proving that regularities are really there and not products of imagination (that is, more time is spent finding, rather than testing theories)[19].

#### 3.1.3.4 Experimentation

Hypotheses are tested through design and conduct of experiments. But sometimes experiments take on a life of their own and drive thinking in new directions unrelated to the original theory[20]. Careful attention to the details of experiments and their results helps to distinguish between what has been substantiated by the experiments and what

[19] This paragraph starts to touch on epistemological issues that are not relevant to this internal view.

[20] This is the heart of a philosophical movement called Experimentalism (Zalta, 2002).

remains unproven (or, to put a Bayesian perspective on outcomes, how the probability of the theory being true has been perturbed) (Chalmers, 1999).

After any experiment more thinking is always necessary to interpret the results (or lack thereof!). Sometimes a new set of ideas completely replaces the old as dead ends are recognised or new knowledge derived. The cycles of introspection and experimental action must be directed by consideration of the (revitalized) problem in context and a (new) formalised question to be tested. Ideas or definite hypotheses are formulated in the light of available knowledge but there is not necessarily a traceable link between the knowledge and the idea. Friedrich August Kekulé provides a fitting and famous example of the absence of links (or logic) between knowledge and insight in his account of how he arrived at the hypothesis that benzene had a ring molecular structure:

> *"I was sitting writing on my textbook, but the work did not progress; my thoughts were elsewhere. I turned my chair to the fire and dozed. Again the atoms were gambolling before my eyes. This time the smaller groups kept modestly in the background. My mental eye, rendered more acute by the repeated visions of the kind, could now distinguish larger structures of manifold conformation; long rows sometimes more closely fitted together all twining and twisting in snake-like motion. But look! What was that? One of the snakes had seized hold of its own tail, and the form whirled mockingly before my eyes. As if by a flash of lightning I awoke; and this time also I spent the rest of the night in working out the consequences of the hypothesis."(Roberts, 1989)*

#### 3.1.3.5 Experimenting with models

Since this research involves modelling using data, it is important to consider whether the methods used fall within the guidelines of Scientific Method. The observation of data was dealt with in Section 3.1.1 and will not be repeated here, nor will the logical linkages between data, laws and theories. It remains to discuss whether experimentation is possible in a modelled environment. The use of systems of wires and batteries in a laboratory to confirm a theory of physics may be considered totally different to the use of a virtual model that is manifested as streams of impulses in electronic circuits. Such thinking is in danger of falling prey to reductionism (cf Section 3.1.2.3) through distortion of scale.

The models may be viewed as "black box" systems that produce streams of data analogous to those produced by real world observations. There exist rigorous methods by which such systems may be tested to ensure alignment with reality (Kelton et al., 2004). These methods fall under probability theory and will not be discussed here but will be mentioned in conjunction with the specific techniques in later chapters. Suffice to say that models can be constructed that provide output indistinguishable from real world observations.

The key to experimentation with such “real world” models is the predictability of outcomes. If a certain parameter is changed it should produce the same result (output) for identical set-ups of the model. In this way model experimentation is in no way different from physical experimentation. The key is in the rigour under which the experimentation is conducted. It is a necessary step in belief that, if the model reproduces reality sufficiently accurately for known situations, it will produce a factual output for situations that have not yet occurred in reality. This is essentially what is done in the verification and validation of models[21].

Varying inputs and outputs is not the only form of experimentation that models may be used for. The “black box” itself can be viewed from different perspectives. Facts can be gathered together in new ways, manipulated and interrogated for further understanding. This form of experimentation may be considered akin to bending of crystal lattices under an electron microscope. The measures of resultant distortions of the lattices can be used in the formulation of laws that can lead to theories, or be used to support existing theories. In the same way data may be scrutinised from different perspectives to assist with formulation of rules or confirmation of ideas. The tools differ: mathematical computation is used rather than an electron microscope; but the outcomes are identical in the way that they contribute to knowledge and understanding.

It’s not to be considered that model building lies outside of experimentation. It may be termed “preparation for experimentation”, but this is not strictly true. Both physical experimental devices that used wires and batteries and conceptual models invariably progress along a “trial and error” basis or a series of steps that successively improve the utility of the device. Sometimes more information is needed; sometimes domain expertise has to be employed, and so on. But invariably such steps force contemplation about the system under investigation and the experimental apparatus’ relationship to it, so the process of “preparation for experimentation” becomes a form of experimentation in itself. While it’s possible for this cycle of introspection to continue in ever decreasing gyres, it’s pragmatic to stop here under the consideration that further dissection is redundant.

[21] Verification and validation will be discussed in Chapters 5 and 6.

#### 3.1.3.6 Summary of the internal procedural view

This section provided an overview of Scientific Method, emphasising that there is no single method, but rather a style of working that has proved successful in the past. Problem formulation was described as a key part of the process of generating hypotheses and theories that could be tested through experimentation. The simple observation / hypothesis / experimentation cycle of Figure 3-2 now needs to be adapted to incorporate the metaphysical and logical formalities of the external views. This is done below.

### 3.1.4 Linking the internal procedural view to the external views

It remains in this section to reconcile the external and internal views. While the logical view guides and supports Scientific Method, there is some value in making explicit the links between data and observations and other aspects of the views. This is captured in Figure 3-3. Data and observation are aligned through their metaphysical properties of factuality. In essence they both refer to facts – data to statements of fact, and observation to observation of facts. The logical guidelines provide for assessment of laws from these facts. These laws may only be statistical statements of frequency of the occurrence of certain events (such as the number of patients arriving at the ED between particular hours of the day). The inductive nature of these laws is captured in the reproducibility of the measure. It may be an average, in which case the standard deviation and other measures of variability provide the reproducibility, whence the reliability of the law, or it may be the number of occasions on which this number was observed, with a similar implication for reliability.

The laws may be linked to conclusions using deductive logic. While it's known that valid arguments result from true premises, the conclusions in this case need to be viewed sceptically until the truthfulness of the premises (laws) can be verified. This might entail the gathering of more facts and stronger inductive tests. On the other hand, the laws may provide insights that lead to dramatic leaps in thinking – the discovery aspect that was discussed above.

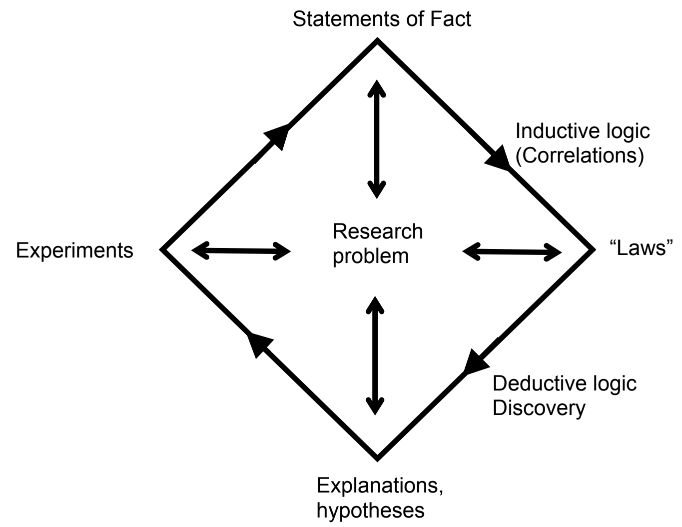



Figure 3-3: Schematic of the Scientific Method used in this thesis

In either event, statements are produced that need to be tested in an open and rigorous manner, or a need is expressed for the collection of additional facts. These are the role of experimentation in Scientific Method. The feedback from experimentation to observation provides more facts for reflexion, and so on. These phases may occur many times in the course of a single day, but they are generally also reflected in the overall pattern of the scientific work pursued in this thesis.

The problem guides every step of the methodology. It dictates the orientation of experimentation and acts as a conduit through which results may be interpreted into either facts or laws. It guides the logic and functions as a short cut between successive iterations around the facts/ laws/ explanations/ experimentation cycle.

In summary, the previous sections have described this thesis in terms of three views: the metaphysical and logical external views and the internal view. These views permitted a structured narrowing of the research context within the strictures of scientific knowledge seeking. The methodology is a series of thought-experiment loops that benefit from the generation of data, inductive conversion to knowledge ("laws") and directed logical enquiry towards (deductive) attainment of a solution for a defined problem. This is really just a structured form of common sense, but one having much greater chance of success. As Thomas Huxley observed, "Science is, I believe, nothing but trained and organised common sense, differing from the latter only as a veteran may differ from a raw recruit; and its methods differ from those of common sense only so far as the guardsman's cut and thrust differ from the manner in which a savage wields his club" (Huxley, 1953).

Scientific Discovery permits leaps of insight not necessarily based on inductive or deductive reasoning. Manifestly unfounded steps in logic may be seen between successive steps of problem formulation as our nimble minds leap around the available information seeking patterns and causal linkages that might be tested. In the next section the methodology will be used to provide methods to solve the research problem.

## 3.2 Method and Technique selection

Section 3.1 gave a high-level view of the guiding principles and steps that were followed in the course of this research. This section describes the methods and techniques that were used in day-to-day work. The methods are discipline specific and typically include a sequence of steps that are generally followed in the course of completing projects within the disciplines. One of the contributions of this research has been the way in which two techniques not commonly associated with one another were combined to provide insight into ED operations. The techniques came from the Data Mining and Management Science disciplines and reflected the researcher's work background with data-driven companies and ongoing interest in business applications of neural networks combined with a belief in the holistic problem solving approach espoused by Management Scientists. Each discipline provides a proven approach to problem solving, supported by the accumulated experience of practitioners who have published their findings in suitable peer-reviewed journals. These methods proved invaluable in guiding the thinking of this research.

Data Mining and Management Science are largely practical in application, so there is emphasis on implementation of the results in the methods, whether this is in the modification of business practices, the clarification of a complex decision, or some other issue related to an organisation's operation. The implementation aspects will be downplayed here because of the research nature of the thesis.

This section gives an outline of each discipline's methodology and techniques. A large number of techniques are available in both Data Mining and Management Science. Guidelines for the selection of appropriate techniques generally include: (1) Fitness to purpose; (2) Match with the problem (dealing with continuous as opposed to discrete data, for example); (3) Whether the technique has a proven record; (4) Whether it can physically deal with the problem; (5) Familiarity with the technique; (6) Availability of suitable tools; and (7) Robustness. The section includes discussion on how the methods directed the technique selection process.

### 3.2.1 Data Mining

The consideration of Data Mining techniques seemed reasonable since Data Mining has been used successfully in healthcare (cf Section 2.2.6).

The abundance of data that is routinely collected and stored in any organisation for a variety of disparate purposes results in a situation that has been described as data rich but information poor (Han, et al., 2001)  Because the quantity of data has expanded beyond the capabilities of our human comprehension it needs to be summarised in coherent ways.  This summarisation can be done in by employing prior knowledge of patterns within the data or by using tools to help "discover" meaningful patterns within the data.  These are termed directed and undirected knowledge discovery respectively. Casemix and other patient classification work that has been done previously (cf. Section 2.2.2) fall into the category of directed knowledge discovery.  Experts applied their perceptions to the data to attempt to find correlations between variables or determine groups of similar patients.  Undirected knowledge discovery typically seeks out "natural" patterns in the data by looking for optimal configurations of variables.

In a typical undirected knowledge discovery exercise a search is initiated for meaningful patterns in data and there is little preconception about possible classifications so analyst bias does not affect the outcome.  This "undirected" search for insight has the necessary precondition that outcomes are unidentified and "ideal" classification unknown[22].  Undirected knowledge discovery has proven a valuable technique for data analysis despite this precondition.  Clustering (the grouping of data records based on similarity across multiple fields or variables) is one of the most commonly used techniques used for undirected knowledge discovery.  Clustering results in a reduction of dimensionality of the data from an apparently almost infinite morass to a manageable number of summarised sub-segments.  The hope is that these sub-segments will provide valuable, non-intuitive insights.

---

[22] While there are various ways in which the quality of classification may be assessed, such as the spread of cases within the group, the degree of separation between groups and the coherence of shape of groups (Han *et al.*, 2001; Vazirgiannis, et al., 2003), these tend to address the certainty of the number and size of groups, rather than give an indication which classification is most natural for the domain.  Even if classification is optimised for a method and confirmed on repeated samples of the data (as recommended in Aldenderfer, et al., 1984), there is no guarantee that the grouping scheme is appropriate.  While the comparison of classifiers has been extensively researched (Jain, et al., 1999; Michie, et al., 1994), most studies approach the problem from the perspective where true classification is known a priori.  The optimised classification methods are compared on their performance relative to known outcomes (Michie et al., 1994).

#### 3.2.1.1 Technique selection

There are a host of clustering techniques available. These range from techniques that count every occurrence and group variables according to the number of matches across records - to techniques that allow approximation of variables in grouping (Han et al., 2001; Kennedy, et al., 1998). Many techniques have proven track records, are robust and are available as part of software tools. Choice of technique is largely dictated by analyst preference within the constraint that the technique be appropriate for the data and problem at hand.

The dimension of the problem (tens of thousands of rows and dozens of columns) and the lack of obvious relationships drove the selection of clustering technique towards Self Organised Feature Mapping (also called Self Organised Mining, abbreviated to SOM). SOM will be discussed in Section 3.3 in conjunction with the tool used for clustering.

The Data Mining phase of the research was largely exploratory and helped build some understanding of the data in order to allow formulation of a narrowed problem. The new knowledge suggested a 'true' experimental environment, one in which:

- The ED could be modelled;
- Conditions could be controlled by changing independent variables;
- Differentiation could be made between: (1) factors that triggered long lengths of stay; (2) factors that promote and enabled particular lengths of stay; (3) necessary and sufficient patient characteristics for certain lengths of stay, and (4) other influences[23].

Such an environment may be achieved through modelling as used in Management Science. An introduction Management Science and the discipline's approach to modelling are given in the next section before describing the choice of modelling technique in Section 3.2.2.1.

### 3.2.2 Management Science

Management Science (MS) is a discipline that applies advanced analytical methods to help make better decisions. It generally applies information technology to decision-making with the aim of understanding and structuring complex situations. It has its origins at the beginning of the 20th century when early industrial engineers, such as

[23] "Length of stay" is used here as an example of the elements that might lead to overcrowding.

Taylor and F. and L. Gilbreth, started to apply scientific approaches to industrial management in areas such as work standards, job design, and time and motion study. Interest in application of the methods of science to management problems received a strong boost during World War II, when the British brought together groups of scientists from various disciplines to solve military tactical and logistics problems. The U.S. military soon adopted this approach to plan operations. In the two decades following World War II this approach to solving management problems in business settings also became known as Operations Research[24] (Moore, et al., 1993). The field of application for assisting decision making also became known as Decision Science.

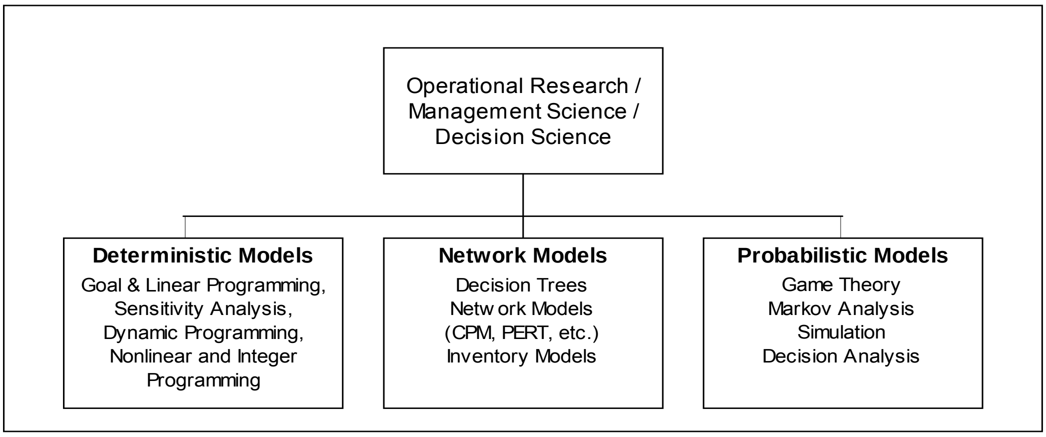



Figure 3-4: Hierarchy of Management Science methods (adapted from Moore et al. 1993)

One of the first principles of Management Science involved analysing problems with the assistance of mathematical simplifications (models). Morse and Kimball (1951) wrote in their book introducing operations (sic.) research, “The task … is to present the quantitative aspects in an intelligible form and to point out, if possible, some of the non-quantitative aspects that may need consideration.” Quantitative techniques (“Experiments” in Scientific Method) were applied to these models to obtain solutions that assisted in decision-making. This fits in well with the methodology chosen for the work discussed in this thesis.

Management Science is characterised by its broad standpoint, tending to adopt an organisational point of view. Practitioners attempt to resolve conflicts of interest among the components of the organisation in order to benefit the whole. This does not mean that every aspect of the organisation need be explicitly studied, but rather that objectives of the study are in line with the overall objectives of the organisation. The steps in a typical

[24] The term Operational Research is most commonly used in Euro-centric societies, while the term Operations Research refers to the same discipline in American-centric societies.

Management Science project may be expressed in terms of the Scientific Method used in this research (Figure 3-5).

| Management Science | Scientific Method |
| --- | --- |
| ▪ Problem definition and data gathering | ▪ .Research Problem |
| ▪ Formulation of a mathematical model | ▪ Elicitation of facts and laws |
| ▪ Translation of the model into computer procedures | ▪ Deductive logic and discovery leading to hypotheses |
| ▪ Testing and refining the model | ▪ Experimentation |
| ▪ Consideration of insights from the model(s) | ▪ Statements of fact |
| ▪ Implementation | ▪ Logic leading to “Laws” |

Figure 3-5: Phases in a typical Management Science or Operations Research project (Hillier, et al., 2001) linked to the Scientific Method of Figure 3-3

The steps in Figure 3-5 provide the framework for the selection of techniques suitable for analysis of the problem at hand. Technique selection is discussed in the next section.

#### 3.2.2.1 Technique selection from Management Science

As can be seen in Figure 3-5, Management Science is based on models. One of the most comprehensive definitions of models is provided by Pidd (1996) as “an external and explicit representation of part of reality as seen by the people who wish to use that model to understand, to change, to manage and to control that part of reality”. This definition indicates that several models are possible for the same situation, according to the perspectives of the researchers. This fits well with the external metaphysical position taken in Section 3.1.

Pidd’s definition also includes the necessity for problem definition and context in the devising of models. Pidd (1998) suggests that the analyst must first decide on the principle elements of the model by considering (1) the nature of the system and (2) the nature of the study.

##### 3.2.2.1.1 The nature of the system

EDs are complex, highly coupled systems (Ceglowski et al., 2005a). This makes logical (or mathematical) models less appropriate as they are likely to be too difficult to formulate and quite likely insoluble (Kelton et al., 2004). EDs have queues of patients waiting for beds and specific numbers of staff to deal with them, so queuing models seem appropriate. However, queuing theory models will probably be inadequate to describe the randomness of patient arrivals and range of treatment times because queuing theory tends to assume steady state and use fitted distributions (Winston, et al., 2001). This drove the decision towards simulation as a way of arriving at probable (rather than mathematically exact) answers. Although EDs are dynamic environments, much information exists about the probability of the changes that might take place. These "nature of the system" considerations suggested both discrete event and systems dynamics as simulation options.

#### 3.2.2.1.2 The nature of the study

The intention of the study was to cast light on ED operations under the constraint that existing data be used, rather than gathering new data. The study was to use existing data about individual patients. This data was to be used in a model with the intention of studying the mechanism of ED overcrowding and blockage. These aspects of the nature of the study directed thinking towards simulation methods. The researcher was familiar with two major simulation methods: discrete event simulation and system dynamics simulation.

The characteristics of the desired model were listed and the two simulation methods compared for degree of match to the desired characteristics. Analysis of the kind detailed in Tables 3-1 and 3-2 suggested that discrete event simulation might be more suitable than system dynamic simulation for this particular study. Discrete event simulation is discussed in Section 3.6 in conjunction with tool selection for discrete event simulation.

Table 3-1: Comparison of discrete event and system dynamics simulation in the healthcare environment (Brailsford, et al., 2000)

| Discrete event simulation | System dynamics simulation |
|---|---|
| Systems (such as healthcare) can be viewed as networks of queues and activities | Systems (such as healthcare) can be viewed as a series of stocks and flows |
| Objects in a system are distinct individuals (such as patients in a hospital), each possessing characteristics that determine what happens to that individual | Entities (such as patients) are treated as a continuous quantity, rather like a fluid, flowing through reservoirs or tanks connected by pipes |
| Activity durations are sampled for each individual from probability distributions and the modeller has almost unlimited flexibility in the choice of these functions and can easily specify non-exponential dwelling times | The time spent in each reservoir is modelled as a delay with limited flexibility to specify a dwelling time other than exponential |
| State changes occur at discrete points of time | State changes are continuous |
| Models are by definition stochastic in nature | Models are deterministic |
| Models are simulated in unequal time steps, when "something happens" | Models are simulated in finely-sliced time steps of equal duration |

Table 3-2: Conceptual Differences Between discrete event simulation and system dynamics (D.C. Lane, 2000)

| | Discrete event simulation | System dynamics simulation |
|---|---|---|
| Perspective | Analytic; emphasis on detail complexity | Holistic; emphasis on dynamic complexity |
| Resolution of models | Individual entities, attributes, decision and events | Homogenised entities, continuous policy pressures and emergent behaviour |
| Data sources | Primarily numerical with some judgemental elements | Broadly drawn |
| Problems studied | Operational | Strategic |
| Model elements | Physical, tangible and some informational | Physical, tangible, judgemental and information links |
| Human agents represented in models as | Decision makers | Bounded rational policy implementers |
| Clients find the model | Opaque/dark grey box, nevertheless convincing | Transparent/fuzzy glass box, nevertheless compelling |
| Model outputs | Point predictions and detailed performance measures across a range of parameters, decision rules and scenarios | Understanding of structural source of behaviour modes, location of key performance indicators and effective policy levers |

## 3.3 Tool selection

This section will introduce the software tools that were used within each of the techniques discussed above. Heavy use was made of SPSS (SPSS Inc., 2001) and Microsoft Excel (Excel Anonymous, 2003) for data preparation and statistical analyses, but these are fairly standard tools so will not be further discussed. Significant decisions were made in the selection of the tool for Self Organised Mapping (SOM) and the software package for discrete event simulation.

There are a multitude of ready-made software tools for performing SOM but Viscovery SOMine (Eudaptics Software Gmbh, 1999a) was chosen for its power, suitability for the task at hand and the intuitive output that it generates. The particular implementation of SOM in Viscovery SOMine is discussed next. This is followed by a brief introduction to the simulation tool that was used in the research.

### 3.3.1 Self Organised Mapping with Viscovery SOMine

The Self Organising Map (SOM) nonparametric method is algorithm-driven and relies on data, rather than domain-specific expertise. The objectives of the method are to minimise diversity within groups and to maximise differences between groups. The method generally employs large datasets, works well with many input variables and produces arbitrarily complex models unlimited by human comprehension (Kennedy et al., 1998). Self-Organizing Maps (SOM) provide a visual understanding of patterns in data through a two dimensional representation of all variables. Records that have similar characteristics are adjacent in the map, and dissimilar records are situated at a distance determined by degree of dissimilarity. The SOM algorithm repeatedly repositions records in the map until a classification error function is minimised (Kohonen, 1995).

In the first step of SOM a two dimensional array of "nodes" is established. The position of each node in the array defines its "weight" relative to each of the variables in the dataset. The weights may be randomly initialised but it is more common to apply extreme values of the variables to nodes as far apart as possible.

Data to be analysed is compared to the array, either record by record or in a batch. The degree of difference between each node $w$ and the input vector components $x_i$ ($i$ = 1 to $n$, the number of components) is calculated using a Euclidian distance analogue as shown in Equation (3-1):

$$d_j = \left\| \mathrm{x}_j - \mathrm{w}_j \right\| = \sqrt{\sum_{i=1}^{n} (x_i - w_{ij})^2} \cdots \text{for each node } j \cdots\cdots\cdots\cdots (eq3-1)$$

The most similar node or node with the minimum distance measure $d_i$ is selected as the winner. The weights of this node remain unchanged but the weights of surrounding nodes are updated to reflect how close they are to the winning node. A learning rule of the form shown in equation (3-2) is generally used.

$$w_{ji}(t+1) = w_{ji}(t) + c\left\lfloor x_i - w_{ji}(t) \right\rfloor \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (eq3-2)$$

Where $w_{ji}(t)$ and $w_{ji}(t+1)$ are weights associated with the node $j$ for each of $i$ variables, *before* and *after* updating respectively.

Nodes nearest the winning node receive most learning while those more remote receive less learning by adjustment of the learning rate parameter, $c$. The parameterisation of $c$ is given in Equation (3-3).

$$c = \alpha(t) \cdot e^{\frac{\left\| r_i - r_m \right\|}{\sigma^2(t)}} \cdots\cdots\cdots\cdots \text{for each node } j \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (eq3-3)$$

Where:

- *α(t)* and *σ(t)* are parameters that range between 0 and 1 to adjust the rate of learning;
- $\|r_i - r_m\|$ is the (radial) distance between the nodes being updated and the winning node $r_m$. The bigger the distance the smaller $c$ will be, hence nodes further away from the winning node are less influenced by the current input. There is usually a predefined limit to how far learning is spread from the winning node. This is called the neighbourhood.

This sequence is repeated for all input vectors to complete a single epoch. The neighbourhood size, α*(t)* and *σ(t)* may be decreased after an arbitrary number of epochs.

The cycle is repeated until weights no longer change significantly or a classification error is satisfactorily small (Smith 1999). Viscovery SOMine employs a variant of Kohonen's Batch-SOM[25] (Kohonen 1995) enhanced with a scaling technique for speeding up the learning process[26] (Eudaptics Software Gmbh, 1999b).

It is a simple matter to program the SOM algorithm but difficult to decide how many clusters are optimal for the data. Viscovery SOMine is made hugely more powerful by combining the SOM algorithm with Hierarchical Grouping to suggest optimum numbers of clusters[27].

As the name suggests Hierarchical Grouping is a form of data grouping. In common with SOM the objective is to place similar objects close together within defined groups (or clusters) and dissimilar objects further from the cluster centre as the degree of dissimilarity increases. With SOM and other divisive clustering techniques the data starts in a single cluster and is divided into smaller and smaller clusters according to Equations 3-1 to 3-3. In Hierarchical Grouping each object or data point is initially a separate 'cluster'. At each progressive stage the algorithm joins together two clusters that are closest together (agglomeration). The algorithm iterates until a single cluster is formed.

Every time a new cluster is formed from the combination of other clusters some level of detail is lost about the individual data points in the cluster (as they acquire the average characteristics of the cluster). Ward (1963) proposed a procedure to quantify this "information loss" as an error of classification calculated at every iteration. Differences in error between iterations give the "step size" of information loss[28].

Viscovery SOMine's implementation of Ward's algorithm uses these changes in error to suggest optimal numbers of clusters for the SOM method. The number of clusters can be changed dynamically to experiment with alternative representations.

---

[25] In contrast to the original SOM algorithm which updates the map after every record, the batch SOM algorithm processes all data vectors and then updates once.

[26] Scaling refers to the gradual growth of the map while holding the ratio of the initial map. This is achieved by increasing the tension upon each growth step of the map. Scaling provides faster processing because the training steps work with smaller maps.

[27] The software performs two versions of hierarchical grouping. Ward clusters are computed according to the hierarchical cluster algorithm of Ward. The hierarchical methods may be used individually or in combination with SOM as described here. The Linkage cluster algorithm combines nodes in the same cluster if the (Euclidean) distance of two adjacent nodes is smaller than the cluster threshold. If the distance is greater, a separator is drawn between the two nodes. If a series of separators forms a closed loop, the nodes inside the loop form a cluster.

[28] An example is provided in Appendix 3-A

The software provides a range of tools that allow evaluation of the cluster quality. These include measures of the distortion and curvature. The distortion measures the fitting of the map with respect to the shape of the data distribution. The curvature indicates how much the map (surface) is "bent" at each node (Eudaptics Software Gmbh, 1999a). The maps can also be inspected to ensure that clusters are regularly shaped and of similar size (both indicators of better clustering than the converse). Other, more formal measures of cluster quality will be discussed in Chapter 6.

The discussion now moves to discuss discrete event simulation and its associated software tool.

### 3.3.2 Discrete event simulation with Simul8

A number of terms need to be defined before entering the discussion on discrete event simulation. Although there is no standard terminology, an effort has been made to use widely accepted terms and definitions (Figure 3-6). To formalise discrete event simulation as it is used in this research, it should be considered as a (valid) model of a system in which the state variable changes only at discrete points in time. The model generates an artificial history of the system (the model is "run") that can be tested for validity and analysed numerically.

**System**: A collection of entities that interact together over time to accomplish one or more goals (Banks, 2001).

**Model**: An abstract representation of a system (Banks, 2001) (note that this is much simplified working definition than the one by Pidd given in Section 3.3)

**Entity**: An object or component of the system that requires explicit representation (Banks, 2001). Entities can be individually identified and processed. They may be permanent (such as workstations in a factory) or temporary (such as objects that are being processed ad leave the system after processing) (Pidd, 1998).

**Attributes**: Properties of a given entity (Banks, 2001).

**State**: The collection of variables necessary to describe the system at any time (Banks, 2001; Chalmers, 1999). The variables are generally attributes of entities in the model.

**Activity**: An activity transforms the state of the system by changing an attribute of an entity (Pidd, 1998).

**Event**: An instant of time in which a significant state change occurs. It is up to the modeller to decide which state changes are significant in the context of the simulation (Pidd, 1998)

**Process**: A sequence of events in the order they will occur (Pidd, 1998)

Figure 3-6: Definitions of commonly used Simulation terms

There is no specified set of steps for building and simulation model but there are several phases (Kelton et al., 2004). These are analogous to those used in almost all Management Science projects (cf. Figure 3-5). The steps are outlined in Figure 3-7 and will be described in the following paragraphs.

1. Understand the system and clarify the goals of the study (the problem definition)
2. Formulate the model representation (mathematical model)
3. Build the model in suitable software (computer model)
4. Verify the model by checking it does what it's designed to do; validate the model by testing whether model outputs match those of the actual situation (Test and refine the model)
5. Design and run experiments and analyse the results (consider insights)
6. Get insight (implement)

Figure 3-7: Steps in a simulation study (as suggested by Kelton, et al., 2004)

The first phase is system understanding and problem formulation. System understanding can be built through visits to the location, consultation with experts and inspection of data records. The Data Mining performed prior to simulation modelling contributed heavily to understanding of patterns of activity within the system. The problem was formulated before the Data Mining study and remained relatively structured and unchanged only in the addition of more information derived from the Data Mining investigations.

The next phase is clarification of the objective(s) of the study. These act as a "guiding light" during model formulation. The simulation model needs to support exploration of ED overcrowding by having features that allow independent variables to be changed and to make distinction between various factors in relation to patient treatment. It needs to be simple enough in concept to comprehend easily to avoid getting lost in the detail of activities in the ED. It needs to be flexible to facilitate experimentation. Simulation runs should not take too long. This facilitates quicker model development and enables cycles of experimentation. It's to be expected that the cycles of experimentation will yield information that contribute to the modification of objectives and suggest adjustments to experimental conditions.

Work can begin on model development once the objectives are formulated. Having selected Discrete event simulation as the appropriate modelling technique (Section 3.2.2.1), an appropriate technique within the broad definition of discrete event simulation needs to be chosen. This will provide features required from the software tool used for modelling.

There are a number of approaches used for discrete event simulation. They are event-scheduling, process-interaction and activity scanning (Banks, 2001). Each of these corresponds to a particular "world view". In Event scheduling the simulation analyst concentrates on events and their effect on system state. The simulation clock stops at the time each event occurs and performs activities associated with that event. Random events are generally "triggered" by the end of an activity according to a probabilistic mechanism.

In a process-interaction view the analyst thinks in terms of temporary entities' life cycles as they flow through the system, demanding and queuing for resources. A process is the life-cycle of one temporary entity. It is a time-sequenced list of events, activities and delays that define the life-cycle of one entity. Since multiple temporary entities may exist in the system at the same time they may compete for resources so processes interact. The analyst generally describes the process flow and the software handles interaction between processes according to specified rules of operation (priority, for example).

Both event-scheduling and process-interaction advance the simulation clock from event to event and so use variable time steps. Activity-scanning uses a fixed time increment combined with rules to decide whether activities can begin at each point in time. The analyst concentrates on the conditions that allow an activity to begin. The software checks these conditions at each clock step. This conceptual difference in handling time provides models that are easier to maintain but likely to run slower (Banks, 2001), so the pure activity-scanning approach has been modified to a "three-phased approach". The three-phased approach combines event-scanning with activity-scanning to eliminate unnecessary scanning for activities or events at every clock step.

In the three-phased approach events have zero time duration but activities may be unconditional or conditional. Unconditional activities may be scheduled in advance, facilitating variable time advance. Scanning for conditional activities occurs after scheduled activities have been initiated. The three-phase approach is particularly good for complex resource problems.

A software tool needs to be selected that supports the three-phased approach adequately. Banks (2001) suggests a number of criteria for selecting discrete event simulation software. Among these are ease of use, power, execution speed and features. Ease of use includes such issues as ease of learning and editing models, vendor support and applicability to the specific problem (possibly through availability of model templates for comparable situations). Power refers to the flexibility of the software to model complex real-life situations without compromising through generalisations or approximations. It also refers to the size of the model that can be built and executed. Execution speed is important because many runs will need to be made, not only in the process of experimenting with the model, but also through the entire model development phase. Model debugging can be wearisome when the software is slow to compile and execute.

Features of software may refer to ease of use, such as zoom and run controls, or to the degree to which graphics can be edited and on-screen three dimensional renditions produced. Features may extend to inclusion of statistical modelling software and optimisation tools.

Like any complex product, simulation software presents value tradeoffs between the desired attributes. It is not always easy to get complete ease of use (a drag and drop graphical interface, for instance) while retaining the desired power and speed characteristics. Graphical interfaces generate overhead, absorbing computer clock cycles and so reducing speed of execution. Graphical interfaces place a limit on the complexity of underlying operations, limiting the power of the simulation unless there is a way to program code at a level below the graphics. Features may add to ease of use while detracting from power and speed.

It's also important that the software that is chosen be widely enough used, to permit sharing of models. This makes models available for scrutiny by peers, possibly one of the most important functions of any decision making technique (Zionts, 1997). Linked to this is the ability of the software to import and export data to other formats. If the software is widely used there is a good possibility that it will support import and export of data from other widely used programs. This is vital when dealing with disparate data sources such as those commonly found in healthcare applications.

Two alternative software tools came to the front when such issues were taken into consideration. They were Arena (Rockwell Software, 2003) and Simul8 (Simul8 Corporation, 2004). Both were widely used and had the necessary attributes. The choice of Simul8 for this work was made based on its slightly wider penetration in ED modelling and for its apparent ease of learning over Arena.

The operation of Simul8 will not be discussed because this enters the realm of software programming and is beyond the scope of this chapter. It is sufficient to say that the software has an intuitive drag and drop interface that facilitates rapid model development but seriously limits complexity. A proprietary language called Visual Logic is provided for programming. Use of this language makes it possible to model the most complex situations.

Simulation of EDs raises some particular issues with respect to independence of the input data. Patients are treated with more urgency in EDs, depending on the severity of their complaint. Severity often correlates with age and frequently indicates whether the patient is likely to be admitted. This means that use of variables such as urgency, age and disposal must be treated with care, since they are unlikely to be completely independent. Issues of data independence will be discussed further in Chapter 4.

## 3.7 Chapter Summary

This chapter set out to explain and justify the methodology of the work presented in this thesis. Section 3.1 narrowed discussion from a broad philosophical nature to that of Scientific Method, the particular methodology selected as appropriate for this research. Scientific Method was introduced and the existence of a school of thought supporting "discovery" mentioned.

Data Mining was outlined in Section 3.2 and the particular technique and tools employed were introduced. Management Science was selected as a method for further exploration of the problem. After a brief introduction to Management Science and modelling in general, justification was provided for the selection of discrete event simulation as the modelling technique. Issues with respect to selection of appropriate software tools were discussed in Section 3.3.

The research is hierarchical in nature. Scientific Method provides the hypothesis/ experimentation methodology and Data Mining the method for exploration of the problem and identification of more targeted problem definitions. Data Mining produces data and knowledge that spark a new discovery / hypothesis / investigation cycle, this time using Management Science to suggest appropriate techniques.

Data Mining and Management Science have defined steps and guidelines about acceptable practice that are more than adequate for the selection of the most appropriate techniques. Data clustering and discrete event simulation are examples of techniques suggested by the Data Mining and Management Science methods respectively. Viscovery SOMine the specific tool used for clustering and Simul8 the tool for discrete event simulation.

The remaining four chapters move from the largely theoretical basis of the previous chapters to a discussion of the actual work performed in the course of this research. The next chapter introduces the data that was used in the research. The main thrust of the chapter will be to provide an understanding of the work done in preparing the data for analysis and assumptions that were made. In the course of doing this it will also give insight into the ED that was being studied, the patients that attend the ED and the deficiencies of both existing Casemix approaches and length of stay approximations in summarising ED activity.

# Chapter 4: Initial analysis of data

Chapters 1 to 3 provided background to the research project. The context of the problem was outlined in Chapter 1. Reference was given to previous research in the area and the research problem formalised in Chapter 2. Chapter 3 supplied the methodology, as well as describing the methods, techniques and tools used in the research. This fourth chapter marks the change from largely theoretical issues to descriptions of the actual work undertaken in the course of the research.

In referring to Figure 3-3 (reproduced below) it can be seen that statements of fact provide the light for inspecting the problem and the means by which knowledge may be extracted in the form of correlations and induced laws. The statements of fact arise from data (as a secondary form of observation of facts, as discussed in Section 3-2). The dataset will be described in this Chapter and bent to the service of yielding knowledge about ED operations at Frankston hospital.

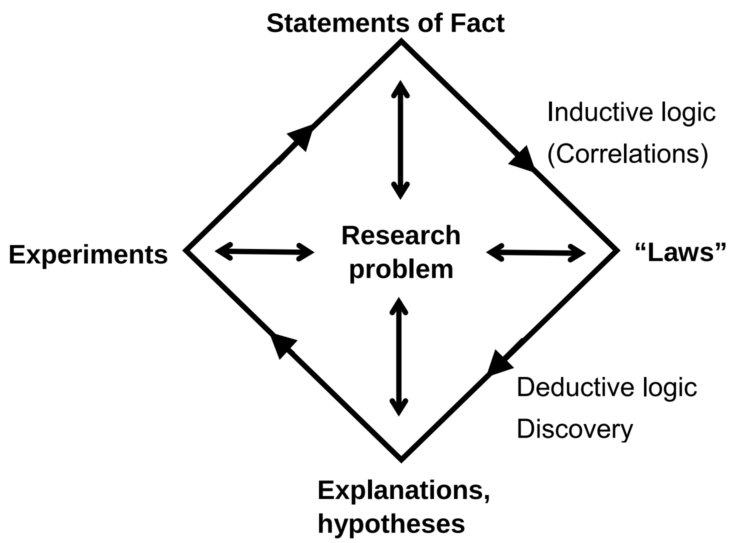



Figure 3-3 (repeated): Schematic of the Scientific Method used in this thesis

Preparation of data for analysis (pre-processing) can constitute up to 60 percent of effort in data mining endeavours (Cabena, et al., 1998). While 60 percent may be a high estimate of pre-processing endeavour in this research, significant effort was nonetheless dedicated to pre-processing before the data was considered fit for analysis. This chapter covers a range of issues associated with pre-processing the ED data before moving on to describe some of the exploratory exercises that were performed in an effort to build understanding about the information the data conveyed.

The chapter starts with a brief description of the data as it was received from the hospital and how it was structured into a form suitable for further analysis. It goes on to describe pre-processing initially as dealing with (1) erroneous data; (2) missing data and (3) unusual values. These three phases do not complete the pre-processing picture, however. Decisions needed to be made regarding data representation before data mining techniques could be applied to the data. These are discussed before the chapter moves on to descriptive statistics. The chapter concludes with an effort to reconcile existing ED Casemix concepts to the data.

By the end of this chapter the data will be in appropriate condition and sufficient knowledge will have been accumulated for the clustering techniques described in Chapter 5.

## 4.1 Data integration

The fully de-identified data analysed in this work came from Frankston Hospital's ED database. This database was separate from that of the rest of the hospital. This complicated tracking of patients from the ED to hospital wards or to services provided by the hospital such as X-ray imaging. The data was provided as text files on CD-ROM. This format made it relatively easy to read and import the data into database, spreadsheet and statistical software tools.

The data was comprised of records of all ED presentations between January 2000 and December 2002. De-identification was necessary to ensure that no ethics guidelines were breached. The records carried a unique ED reference number and a numeric patient identification key instead of patient names. The patient keys were not unique since one patient might have visited the ED numerous times over the period.

The data was provided as two files for each year. The data extraction was performed by the staff at Frankston ED on two separate occasions. This resulted in the files for years 2000- 2001 not having identical fields, field headings and formats to that for 2002. The files had to be aligned so that the number and location of fields was correct, and the field names and formats consistent, before the files could be combined into meta files for years 2000- 2002.

It was challenging to align the alphabetical codes used by the hospital with the numeric codes required in State agency reports (The State provides guidelines to hospitals that are taken from the *National Health Data Dictionary* published by the Australian Institute of Health and Welfare). Hospital IT staff seemed unaware of any translation table that could convert the hospital's in-house codes to those required by the State government so several weeks were dedicated to doing this using "best guess" logic. This exercise proved useful, however, because it forced careful scrutiny of the data within each field and indicated a number of coding problems that will be discussed in the next section. It also gave an indication of which fields were sparsely populated and so unlikely to be suitable for inclusion in a general analysis of data. The tables of aligned codes are provided in Appendices 4-B and 4-C.

The first file for each year contained patient data for every presentation to the ED between 2000 and 2002 (142 825 records). Each record carried demographic information plus details of the visit such as urgency, key time points and disposition (Table 4-1)[29]. The field headings were truncated by the hospital staff that saved the data to CD. It took some effort to devise the full name of the fields since the IT staff seemed unable to recall all the field names or to generate a listing of field names. This probably reflects the pressure that they were under to perform their day-to-day jobs in the hospital and the lower priority placed on this data collection.

Table 4-1: Some of the fields supplied in the patient data file

| **Patient ID** | **Patient Key** |
|---|---|
| AE episode | Unique ED reference number |
| Arrival time* | Date and time first registered or triaged (whichever comes first), by clerical officer, triage nurse or doctor in ED |
| Triage time* | Date and time the patient was first seen by a Triage nurse/ doctor. |
| Registration time* | Date and time the patient was first registered or triaged (whichever comes first), by clerical officer, triage nurse or doctor in the Emergency Department. |
| Time in cubicle* | Date and time that the Treating Nurse first saw the patient. This includes the taking of baseline observations after triage. |
| Doctor seen time* | Date and time that a Medical Officer first assesses the patient. |
| Discharge time* | Date and time that a decision is made regarding patient disposal |
| Departure time* | Date and time the patient physically leaves the Emergency Department. |
| Discharge code | Disposition or disposal of patient – destination after treatment in the ED |
| Presenting problem | Text based description of patient symptoms or diagnosis of patient |
| * Derived from change of status on computer or entered from doctors notes | |

The second data file for each year contained a list of procedures performed in the ED between 2000 and 2002. This file had 494 938 records with two fields. The first contained the ED reference number and the second an abbreviation denoting a single procedure. The ED reference number could be repeated many times, once for each procedure (Table 4-2). As a first step in making this data accessible in a useful form the format of the file was changed so that each ED reference number occurred in a record of its own (Table 4-3).

Table 4-2: Sample of the original treatment file – note repeated ae_episo numbers and procedures

Table 4-3: A sample of the treatment file after aggregation. Ae_episo numbers are still repeated, but the procedures are accumulated into a

[29] A complete list of fields that were provided are given in Appendix 4-A

| | |
|---|---|
| Ae_episo | Procedure |
| 5348000 | ECG |
| 5348000 | ECGM |
| 5348000 | FWT |
| 5348000 | INF |
| 5348000 | IV |
| 5348000 | VB |
| 5348000 | XRAY |
| 5348000 | FWT |
| 5348000 | FWT |
| 5348000 | INF |
| 5348000 | IV |
| 5348000 | IVS |
| 5348000 | VB |
| 5348000 | XRAY |
| 5348000 | DRUG |
| 5348000 | FWT |

| single count | | |
|---|---|---|
| Ae_episo | Procedure | Count |
| 5348000 | DRUG | 3 |
| 5348000 | ECG | 1 |
| 5348000 | ECGM | 1 |
| 5348000 | FWT | 5 |
| 5348000 | INF | 3 |
| 5348000 | IV | 3 |
| 5348000 | IVS | 1 |
| 5348000 | RBG | 1 |
| 5348000 | VB | 4 |
| 5348000 | XRAY | 3 |
| 5348010 | DRS | 1 |
| 5348010 | DRUG | 4 |
| 5348010 | ECG | 2 |
| 5348010 | ECGM | 1 |
| 5348010 | FWT | 1 |
| 5348010 | IV | 1 |

The record was expanded to provide one field for each procedure. These were filled in with counts of procedures for that ED reference number (Table 4-4). The end result was a file with 63 fields. The first contained the ED reference number and the last a count of the number of procedures. The other fields contained 0,1,2,3,4 up to 17 depending on whether that procedure had not been performed, or had been performed once, twice, thrice and so on[30]. Frankston ED coded "O" to mean observation of the patient whereas the Data Dictionary does not provide for this as a procedure, but does give an "other" category not utilised by Frankston ED.

In order to get a comprehensive picture of each ED visit it was necessary to combine the patient and treatment data files. In doing this each record contained patient demographics, their assignments within the ED (urgency, times for key activities and disposal) plus an indication of the procedures they underwent during that visit. Combination of the patient record and treatment files was possible because the ED reference numbers in the patient file matched those unique identifiers in the treatment file. It was relatively simple to merge the files[31].

Table 4-4: A sample of the transposed treatment file. The ae_episo numbers are unique; a separate field is provided for each procedure and the count of procedures recorded. Note: the last 3 rows show unusually heavy procedure usage.

| ae_episo | abg | ct | drs | drug | ecg | ecgm | eye | fwt | gch | hio | vb | vc | vdk | xray | prcnt2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5423722 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |

[30] SPSS provides subroutines that facilitate this transformation. "Aggregate" counts repeated rows (in the case where a procedure was recorded more than once for an ED reference number). "Restructure" converts rows into columns (using the ED reference number to make the distinction between successive records).

[31] Like many database programs, SPSS provides a "merge" function that merges files on a specified key that occurs in both files.

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5423773 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 6 |
| 5423805 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 |
| 5423806 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 6 |
| 5423877 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 5352400 | 1 | 2 | 0 | 2 | 7 | 7 | 0 | 6 | 0 | 2 | 10 | 0 | 0 | 7 | 70 |
| 5353720 | 2 | 2 | 2 | 6 | 3 | 2 | 0 | 3 | 0 | 2 | 9 | 0 | 0 | 5 | 59 |
| 5358260 | 1 | 3 | 0 | 4 | 4 | 2 | 0 | 3 | 1 | 1 | 8 | 0 | 0 | 8 | 63 |

The next section describes how this largely raw data was scrutinised for errors and the decisions that were made in correcting these errors.

## 4.2 Pre-processing issues

With all available data in one file it was possible to start assessing the quality of the data. Data quality is an important consideration because missing, noisy or inconsistent data can distort perceptions during data exploration and may cause erroneous output from Data Mining techniques. Data quality assessment was done in several steps. These are discussed in the next four sections. Once the data was in a for suitable for analysis it was possible to expand the fields to facilitate descriptive investigations. This is discussed in Section 4.2.5.

### 4.2.1 Data errors

Data errors include occurrences of alphabetical entries in numeric field and vice versa; incorrect or impossible entries (non-existent codes in a field that has a finite set of codes, for instance); and unusual values. The latter will be dealt with separately Section 4.2.3.

Many errors could be prevented by the imposition of filters that prohibit input of incorrect values. While such filters are a basic of good database design they are unfortunately often circumvented in order to facilitate data entry speed (at the cost of data entry accuracy). It is sometimes possible to detect the source of the error and to make an assumption about how to correct it. Examples might be when a single letter or digit of a code is incorrect or missing, or if the entry is spelt incorrectly. Unfortunately such measures “second guess” the original data so it’s possible to introduce further errors in the course of correcting assumed errors. For this reason it is important to evaluate the number of errors of each type and assess the impact of corrections as opposed to ignoring the record.

It is sometimes possible to correct data errors by going back to the original documentation. However, this rapidly becomes impractical when the data covers a lengthy period, when there are many records that need to be corrected (several thousand records may only constitute a small proportion of a large database, but even this many records would be unfeasible to correct manually) and when resources for the recovery of paper documentation are limited. The latter was the case in this research. While the hospital was forthcoming in providing electronic records it was not willing to dedicate personnel to matching electronic records with paper patient records, especially with the associated ethical issues this would entail with respect to patient privacy.

It is not always possible to detect errors in an initial pass through the data, particularly if there are many fields. Errors in data and time fields may slip by undetected, for instance. Only when the fields are actually being used for analysis will the errors become apparent. Errors of this sort will be mentioned later in the context in which they became apparent. The actions that were taken will be elucidated at that time.

The first error that was obvious was the occurrence of a "|" character in certain records. Investigation revealed that this was and "end of file" marker that could safely be removed.

A second obvious error was noticed in the encoding of "age". Most records merely had numbers, but some carried "days", "weeks" or 'months" (sometimes abbreviated as uppercase or lowercase initial letters). Conversion of these mixed records to numbers was non-trivial and entailed a custom-built program. After this was completed all ages were given as years or decimal parts thereof.

A number of records from 2001 carried the date 31 DEC 1899 – obviously an error, possibly from a database problem that had been incorrectly rolled back. There were 680 records carrying this date in the date_inc (date in cubicle) field and 737 in the date_see (date first seen by a clinician) field. Since the proportion of records was small (2.9% of the records for 2002) they could be omitted from calculations involving Wait and Treatment Time without seriously biasing the results. These records were flagged as missing, as described in the next section.

### 4.2.2 Missing data

The search for missing data was done in conjunction with the scan for erroneous data. The file was first scanned for fields with possible relevance for analysis. The frequency of entries in these fields was then counted (See column 2 in Appendix 4-A). This gave a measure of how often the field was used. This could be evaluated to decide whether the field was likely to provide sufficient useful information. This process also provided the number of codes in fields that contained codes and it helped both to identify errors in codes and to build an understanding of the data.

Common procedures for replacing missing data include averaging bracketing records or other sub sample of the field, generating a most probable value from generalised patterns derived from similar records or simply using a global “flag” to fill in the missing value (Berry, et al., 2000). The first two alternatives carry the risk of introducing inaccuracies that did not exist before by biasing the data. If there is sufficient data then the last option becomes feasible. There is a good chance that other records will carry similar information to the record that is missing values, so the flagging is unlikely to result in loss (or creation) of information.

There were no missing data in the key fields of interest (sex, age, urgency and disposal). While injury, admission source, admission type, ambulance number, and several other fields had up to 30% missing records, this was consistent with the patient record. The data was not missing – rather “not applicable”. A complete list is provided as part of Appendix 4-A.

There were dates missing from triage, “into cubicle”, “first seen” and disposal fields. The incidence of missing values was less than 1.0 percent so the missing values were merely flagged. This permitted retention of information from other fields that were complete for that record. It was possible to retain the records for most analyses because SPSS and Viscovery SOMine simply ignored records flagged with missing values in analyses fields.

### 4.2.3 Unusual values

Sometimes unusual values are referred to as “noise” (Vazirgiannis et al., 2003). By this the implication is that measurements fall outside the bounds of reliability[32]. The hope is that the errors are randomly distributed so will not skew the data. Non-random or systematic errors may occur in cases where there are technical problems connected with the measurement. An example might be a stopwatch that is consistently slow. Noise was not considered identifiable in the Frankston data because there was no mean value for fields that contained continuous measures, such as age or activity times, so no yardstick existed by which to measure noise. Since noise could not be determined in the Frankston ED data, nor was there any way of telling whether particular values were correct, the data had to be scrutinised for unusual values.

[32] This is normally defined as the number of standard deviations (σ) from the mean for a particular level of confidence. 1.96σ is used for 95% confidence in the mean.

Unusual values are values that are much larger or smaller than expected. The distinction between unusual values and errors is the degree of feasibility. An example might be an age of 120 years in an “Age” field. Although it is not impossible, it’s highly unlikely. Expert input is valuable in the assessment of the feasibility of the values. The Director of Emergency Medicine at Frankston lent his experience to assist with decisions about unusual values.

Unusual values occurred most often in time fields in the Frankston data. In a number of cases the time for a patient activity was negative; indicating that the recorded time for the “end” activity was earlier than that for the “begin” activity.

- Treatment Time had 880 records (0.6%) with negative times, but only 58 of these were greater than one minute. It was considered reasonable to set the times to zero in cases where the magnitude of negative Treatment Time was less than one. The remainder of the records were flagged as “missing”. This meant that the records would not be included in the calculation of average Treatment Time but would still be available for analysis with respect to other fields.
- The Admission delay field appeared to have a systematic error in the recording of physical departure dates resulting in large negative values. 5064 records (3.5%) carried negative Admission delays less than one minute. These were flagged as “missing” rather than omitted from analyses because there were a significant number of records involved.

The contrary issue also occurred with date and time for activities. In one record a Wait Time of 240 hours was recorded. More significantly, in 1457 records from year 2000 the Admission delay was over 100 hours. This was considered highly unlikely by the ED director so these records were filtered out from any analyses involving time. Actually, for all practical purposes, ED residence times beyond 24 hours were viewed sceptically since patients would most likely be moved into the ED short stay ward within 12 hours (in order to meet the State’s performance guidelines).

### 4.2.4 Numerical representation

Various lengths of stay (LOS) variables were used in the analyses: (Figure 4-1). These were calculated from the date and time fields in the data and placed in new fields.

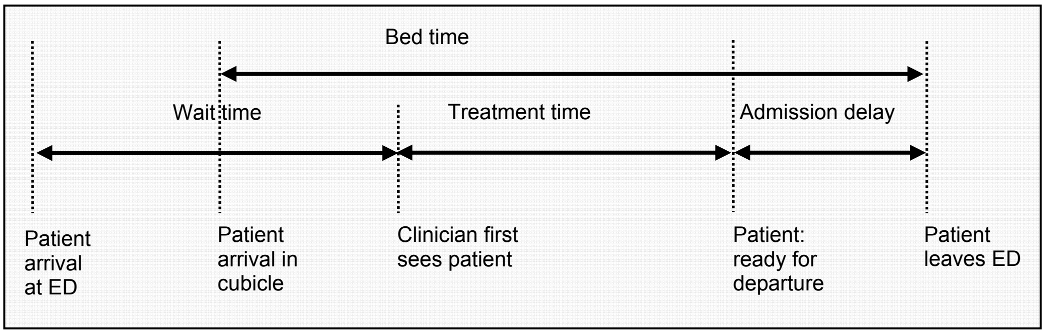



Figure 4-1: Length of Stay (LOS) variables used in the analysis

The four LOS variables are defined as follows[33]:

1) **Bed Time**: The time between patient entering a cubicle and departing from the ED. There is physical resource usage by the patient during this time because the patient occupies a bed in the ED.

2) **Treatment Time:** The time between being first seen by a doctor to being disposed. This is a subset of Bed Time and correlates highly with it ($R^2 = 0.905$). This is because the interval between a patient entering a cubicle and being seen by a doctor was generally negligible in the Frankston ED data.

3) **Wait Time**: The time elapsed between patient arrival and first being seen by a medical practitioner (this includes the time that the patient may wait in the waiting room and the time the patient may spend in a treatment cubicle prior to being seen by a clinician).

4) **Admission delay**: This is the time between when a patient is judged ready to leave the ED (or the decision to admit the patient is made) and the time the patient physically departs from the ED. While it is possible for patients who are discharged home to remain in the ED cubicle after disposal, the incidence of this was insignificant in the Frankston data.

With the LOS variables defined, it is possible to indicate the numerical representation and conventions that were used:

- Although the ED workflow computer system recorded time points to the second, it is unlikely that such precision was justified, so LOS were only considered accurate to within a few minutes and analyses were conducted with LOS rounded to 0.1 hours (a variation of 3 minutes).

[33] The terminology used here is that recommended by Australian College for Emergency Medicine (ACEM) with the exception of "Bed Time" which does not appear in their nomenclature.

- Age was recorded as years and decimal years. This was appropriate for numerical analyses.
- Sex and other fields that had two options were coded as binary. While this can introduce bias in numerical analyses that use distance measures, it was considered a better option than using two classes. Coding "male" as (0,1) and "female" as (1,0), for instance can lead to indecision regions with certain types of classifiers (when data is placed into (0,0) or (1,1) classes, for example).
- Urgency was recorded in 6 categories with integer values ranging from 1 for most urgent to 5 for least urgent. The sixth category was provided for patients who died in the ED or were dead on arrival. This numerical ranking fitted with the logic of the field so was entirely satisfactory for most numerical analyses that used distance measures. It does have the effect of weighting all urgencies equally (because they are all separated by a single unit), however the complications in attempting to build an acceptable weighting scheme for urgency made weighting an unattractive prospect.
- The fields that contained counts of procedures (generally binary since there were few instances where repeated procedures were recorded) were appropriate for use in analyses ranging from counts of occurrence to clustering of similar records. Issues pertaining to the special conditions necessary for clustering binary data will be discussed in Chapter 5.

The data carried a text field where staff noted things such as patient symptoms, working diagnoses, whether the patient was referred by a doctor and so on. The clean-up of this text field for text mining was a time consuming. It will be explained in Chapter 5 when the validation of clustering results is discussed.

### 4.2.5 Data reduction and extension

Data reduction obtains a reduced representation of the data set that is much smaller in volume yet produces (statistically) the same analytical results. There are a number of strategies for data reduction. These include data aggregation, dimension reduction (removing irrelevant fields – possibly through component analysis) and data compression (through use of encoding schemes)

Data was reduced to a single year within the series. The reasoning behind this was that it should eliminate the variation that year-on-year process changes had on ED operations (2000 was particularly intense with respect to process changes under the auspices of the various government led ED initiatives (cf Section 2.2.1)). This was borne out by statistical analyses comparing each year's activities (See Section 4.3). The data from year 2002 also seemed to have fewer problems than the other years' (such as missing and erroneous data described in the sections above). 2002 was also the most recent data so most likely to reflect current ED work practices. It was felt that sufficient patients were provided in a single year's operation to be meaningful.

Data extension is the creation of new fields from existing fields. This may be done by combining the information in more than one field to produce new information. It may also entail the separation of a single field into multiple fields, followed by one or more data reduction strategies. An example of this would be the separation of date and time information into separate fields, with the simultaneous creation of a new "year" field. The date field might then be used to create "day of week", "day of year" or "season" fields and the time data used in "hour of day" fields. These strategies were used extensively with the Frankston data set.

Other additional fields were created as required. For example, the field that recorded injuries sustained by patients was used to create a "yes/no" (binary) field that carried information about whether the patient had sustained an injury or not. In some cases the data was grouped into categories that matched those of prior research. Examples are the segmentation by age into four age groups and the grouping of disposal codes into 4 classes (cf Section 2.2.1 on Casemix studies). These groups are further described in Section 4.4.

## 4.3 Statistical analysis

The data was accumulated in an SPSS database and analysed with SPSS Versions 12.0-14.0 (SPSS Inc., 2001). SPSS readily provides histograms for multiple variables and results can easily be further interrogated for tests that detect differences in both the locations and the shapes of distributions.

Histograms display the frequency of features across all records and so provide an intuitive way of presenting large amounts of complex data and of gaining insight into probability distributions. Histograms give an indication of how well the data agrees with some of the assumptions for linear non-Bayesian modelling such as normal distribution of errors, evenly distributed variance and uncorrelated error terms, and helps guard against using the wrong dependent variables and incorrect evaluation of outliers. With histograms there is no estimation of characteristics because all data (for the period that the data covers) are included in the count. Of course, adequacy of statistical representation needs to be considered if inferences are extended beyond the data set to other time periods or different hospitals and population groups. Histograms will be used extensively in the following sections.

### 4.3.1 Demographic analysis

It was useful to review general data characteristics year-on-year, such as age, sex and differences between injured and non-injured patients to assess whether any single year differs markedly from the others.

It can be seen in Figure 4-2 that the age profiles were similar for the three years considered. This is supported by the Jonckheere-Terpstra Test (p=0.110, two-tailed[34]) non-parametric test for non-normal independent samples[35]. Visual examination indicates three concentrations of age classes: pre-teen; teen to around 60 years and patients over 60 years, in contrast with the four age groups used in Urgency Disposition Age Groups introduced in Chapter 2, but it is possible that the central concentration is bimodal, being comprised of the two age groups described in UDAGs (15-34 and 35-64 years).

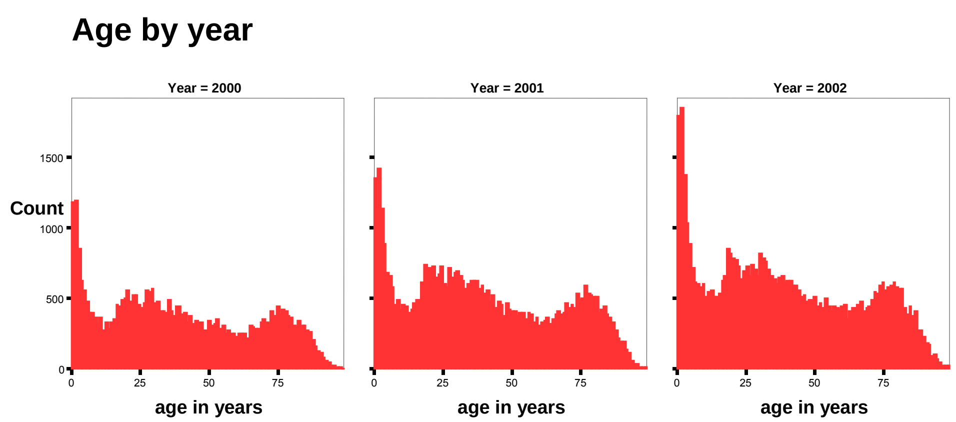



Figure 4-2: Age distribution of presentations for years 2000, 2001 and 2002

[34] There was no a priori expectation as to the direction of difference in distribution therefore two-tailed tests were used.

[35] The Kruskal-Wallis H test, the Median test, and the Jonckheere-Terpstra test are tests for similarity of means over several independent samples. The Kruskal-Wallis H test (an extension of the Mann-Whitney U test discussed in Section 4.4.1) is the nonparametric analogue of one-way analysis of variance and detects differences in distribution location. The Median test, which is a more general test but not as powerful, detects distributional differences in location and shape. The Kruskal-Wallis H test and the Median test assume there is no a priori ordering of the *k* populations from which the samples are drawn. When there is a natural a priori ordering (ascending or descending) of the populations, the Jonckheere-Terpstra test is more powerful.

A cross tabular analysis of urgency by sex for each of the years 2000, 2001 and 2002 indicated that the presentations remained fairly constant with respect to sex within urgency (Figure 4-3). Some 58% of presentations with injury and 48% of presentations not related to injury were male across the three years. It will be seen, however that this inter-year consistency in patient demographics was not repeated for operational measures.

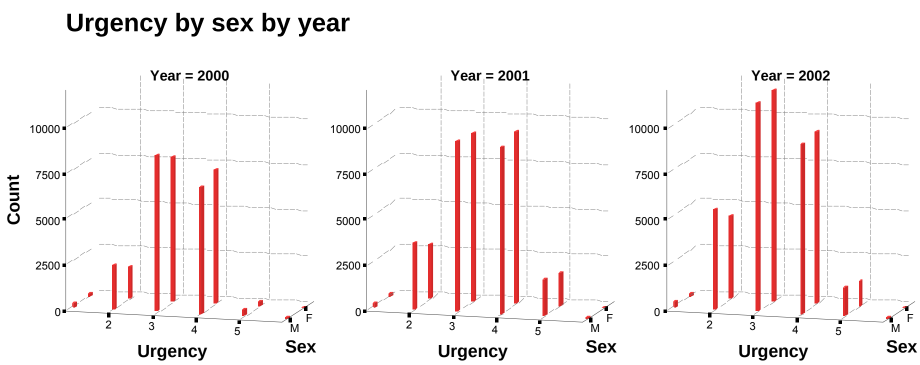



Figure 4-3: Urgency by sex by year showing the proportion of males to females does not vary by urgency

Figure 4-3 shows variation in proportion of people triaged into each urgency category over the three years. There appears to be a shift towards more urgent cases between 2001 and 2002 (Table 4-5). This concurs with the state wide analysis that was provided in Chapter 1.

Table 4-5: proportion of patients in each urgency category by year

| Urgency/ Year | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 2000 | 0.9% | 11.7% | 45.8% | 39.8% | 1.7% | 0.2% |
| 2001 | 0.8% | 13.9% | 38.6% | 38.5% | 7.9% | 0.2% |
| 2002 | 0.9% | 18.0% | 41.6% | 33.9% | 5.4% | 0.2% |

There was a distinct tendency to admit fewer patients over the years 2000 to 2002. This can be seen in the proportion of patients in each disposal group in Table 4-6. It's also worth noting that the proportion of patients who did not wait for their treatment to be complete dropped between 2000 and 2002. This may by symptomatic of the ED treating patients faster.

Table 4-6: Proportion of patients in each disposal group by year. A=Admit; D=Discharge home; DIE= Dead on arrival or in ED; DNW= Did not wait

| **Disposal** | **A** | **D** | **DIE** | **DNW** |
|---|---|---|---|---|
| 2000 | 51.9% | 43.1% | 0.2% | 4.7% |
| 2001 | 46.5% | 49.4% | 0.3% | 3.9% |
| 2002 | 44.4% | 51.9% | 0.2% | 3.5% |

This brief overview of the patient demographics demonstrates the diversity in the catchment population of the hospital. The area is a prime retirement location; there are a high proportion of older people, with age profiles over 60 higher than the state average. There are also more people under the age of 19 than the state average. Land use varies from heavy industrial to residential with large influxes of seasonal visitors to the region. The demographic profile of the data, while interesting, was unable to provide any insight into ED operations. The performance statistics that are discussed in the next section will begin to provide a picture of how the patient characteristics may be associated with ED operations.

### 4.3.2 Analysis of performance measures

A number of performance measures taken from national and state-level government reports were presented in Chapter 1. These included incidence of ambulance bypass; the percentage people seen at EDs within the recommended time (a measure of the Wait Time before treatment commences) and the proportion of patients who experience admission delay. The percentage of people seen within the recommended times (Wait Time) and admission delay was extracted from the data and are discussed in this section.

#### 4.3.2.1 Wait Time

The percentage of people seen within the recommended times (Wait Time) was extracted from the data (Table 4-7). While the mean figures look on the surface to be satisfactory they fail to indicate the instances where Wait Time is unacceptably long. The histograms in Figure 4-4 give a better indication of this.

Table 4-7: Wait Time by urgency for 2002. Minimum, maximum, mean and standard deviation times are given in hours:minutes

| Urgency | Min | Max | Mean | Std dev | Standard time | Percent within standard time |
|---|---|---|---|---|---|---|
| 1 | 0:00 | 0:42 | 0:01 | 0:02 | Immediate | 96.2 (see footnote [36]) |
| 2 | 0:00 | 7:08 | 0:04 | 0:09 | Within 10 minutes | 92.4 |
| 3 | 0:00 | 10:05 | 0:18 | 0:31 | Within 30 minutes | 82.6 |
| 4 | 0:00 | 11:12 | 0:39 | 0:57 | Within 60 minutes | 76.6 |
| 5 | 0:00 | 8:30 | 0:33 | 0:51 | Within 120 minutes | 88.5 |
| 6 | 0:00 | 1:10 | 0:08 | 0:11 | No standard | |

[36] A time of one minute was used here, since "immediate" is ill-defined

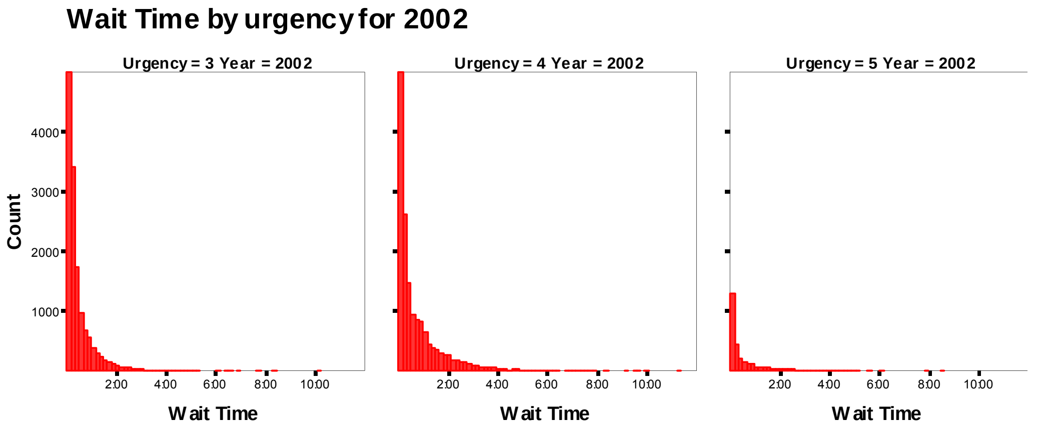



Figure 4-4: Wait Time for urgency categories 3, 4 and 5 for 2002 (y-axis is truncated for ease of comparison)

urgency categories 1 and 2. A significant proportion of patients wait longer than the standard times before being shown to a treatment cubicle. These results can be compared to the results that were published by the hospital (Table 1-10 in Section 1.3.3), as 100, 82 and 56 percent, respectively for urgencies 1, 2 and 3. Differences may be due to inclusion of the 10th minute in this analysis for urgency 1, and so on for urgencies 2 and 3.

#### 4.3.2.2 Admission Delay

Australian states also report on Admission Delay. Recalling from Chapter 1 that the Victorian standard for Admission delay was 12 hours in 2002 (and changed to 8 hours in 2005), it can be seen that the Frankston ED surpasses this on average. However, maximum Admission delays exceed the 12 hour standard (Column 4 of Table 4-8).

Table 4-8: Admission delay over 3 years. Top 3 rows are patients awaiting hospital admission. Bottom 3 rows are patients "lingering" after being discharged home (possibly awaiting transport or other delay factor).

| Year | Count | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| 2000: A | 15 294 | 0:00 | 23:40 | 4:11 | 5:35 |
| 2001: A | 22 359 | 0:00 | 23:58 | 6:53 | 6:49 |
| 2002: A | 24 537 | 0:00 | 23:34 | 6:50 | 4:54 |
| 2000: D | 12 846 | 0:00 | 5:49 | 0:00 | 0:03 |
| 2001: D | 23 704 | 0:00 | 9:06 | 0:00 | 0:06 |
| 2002: D | 28 777 | 0:00 | 19:39 | 0:00 | 0:10 |

### 4.3.3 Summary of the statistical analysis

This section has shown that the key lengths of stay at the ED under study appeared to be within standards set by the state of Victoria. These initial analyses show that

Frankston ED has similar performance characteristics to those reported in Chapter 1 for all state hospitals.

Many other analyses were performed in the course of exploring the data, such as examinations of age breakdowns within sex by injured or non injured patients, and so on. These are not reported here because, although they contributed to holistic understanding of the ED environment, they did not contribute directly to the study of ED treatment. More directed analyses were required to build understanding of ED treatment. Previous Casemix proposals were used as a framework. These are described in the next section.

## 4.4 Reconciling the data with Casemix theories

Casemix was introduced in Chapter 2 and various proposals for ED Casemix were discussed. In this section four hypotheses will be postulated based on those Casemix theories. It needs to be remembered that this analysis is focused on building understanding of ED activities rather than proposing a Casemix.

The method in these sections is to derive hypotheses from the Casemix proposals and then to determine whether the null hypothesis can be disproved, thus providing a basis for further investigation. This section follows the "statements of fact" leading through correlations to "laws" part of the methodology described in Chapter 3. Well accepted statistical tests are used in the detection of correlations.

Casemix attempts to group patients on similarity of "case" and give a range of costs associated with treating typical "cases". Because of the variety of patient presentations in the ED, ED Casemix studies have attempted to group patients on the basis of cost as a replacement for "case". Cost is used as a proxy for complexity and resource usage. The analysis in this section uses independent variables suggested in previous ED Casemix proposals, but replaces "cost" with "length of stay" under the assumption that the longer a patient spends in the ED, the more activities they have associated with them and so the greater their resource consumption.

Neither length of stay (LOS) nor cost is ideal as a proxy for resource consumption. Patients' costs may easily be incorrectly calculated through erroneous assumptions about amount of time clinicians spend on the case or the number of clinicians who are simultaneously involved in treatment, for instance. Patient length of stay may involve considerable "nothing happening" time so not act as a good proxy of clinician "time at bedside" or nurse intensity. Assuming equivalence of cost and length of stay is not perfect, but it does give some direction to analyses.

The various lengths of stay described in Section 4.2.4 were used as dependent variables in the analyses. Independent variables were derived from the Urgency Disposition Grouping and Urgency Disposition Age Grouping proposals described in Section 2.2.2. The ED Grouping and Ambulatory Casemix Project are not considered since the Medical Diagnostic Categories of the former are not available in the Frankston data. The latter has largely been superseded in Australia by the more recent proposals.

The underlying hypotheses in the Urgency Disposition Grouping (UDG) is that resource consumption (actually cost) differs by disposal and there is a detectable difference in resource usage by urgency between admitted and discharged patients and among urgencies within admitted and discharged patients. With length of stay used in place of cost it is possible to deduce several hypotheses:

---

There is no difference in LOS among Admitted, Discharged, Did not wait and "Dead in ED" patients ………………..…………………………………. $H_0^1$

There is no difference in LOS among different urgencies of Admitted patients ……………………………………………………………..…..$H_0^2$

There is no difference in LOS among different urgencies of Discharged patients ……………………………………………………………..….$H_0^3$

---

In reviewing the Urgency Disposition Age Grouping (UDAG) it was apparent that age is considered an important additional variable in predicting patient costs. Once again using length of stay in place of cost led to a hypothesis that there is no difference in resource usage among the UDAG age groups:

1. Under 14 years;
2. between 15 and 34 years;
3. between 35 and 64 years; and
4. 65 years or over

This can be generalised to a fourth null hypothesis:

---

There is no difference in LOS among UDAG age groups ……………….$H_0^4$

---

The analyses will be presented and discussed in the following sections.

### 4.4.1 Analysis of LOS in Admitted, Discharged, Did not wait and "Dead in ED" patients ($H_0^1$)

Disposal codes in the data set were aligned with state wide standards as described in the Victorian Emergency Medical Dictionary (See Appendix 4-C). The standard Victorian Emergency Medical Data codes for disposition were recoded into the four UDG classes yielding 44.4% "admitted" patients, 51.9% "treated and discharged", 3.5% "did not wait" and 0.2% "dead in ED"[37] patients overall, but these proportions did differ over the years. These proportions implied that the latter two codes are probably insignificant from a cost and resource consumption perspective, unless the costs for each of them are over an order of magnitude higher. Since this was unlikely (treatment was terminated early in the case of patients who "did not wait"; and the majority of patients in the latter case arrived dead, requiring only certification) the last two disposition groups were omitted from further analyses.

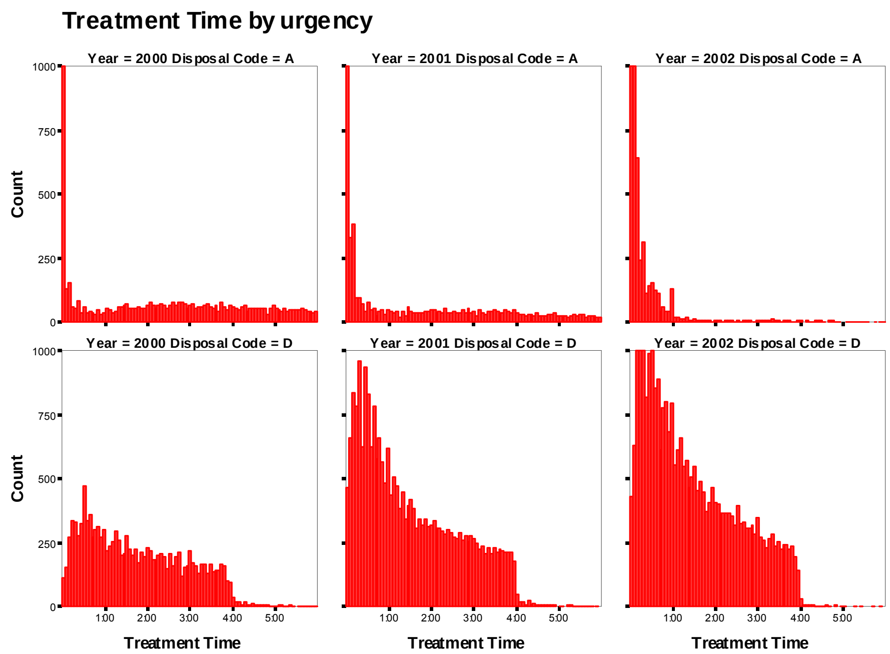



Figure 4-5: Treatment Time for Admitted (top) and Discharged (bottom) patients over 3 years. Note: the y-axes have been truncated for easy comparison of distribution shape.

Figure 4-5 shows a count of Treatment Time (truncated to 6 hours) for patients who were admitted and patients who were treated and discharged. Treatment Time is chosen under the assumption that this is the most resource-intensive time for patients.

[37] "Dead in ED" refers to patients who were dead on arrival to the ED as well as patients who dies in the ED

They are undergoing treatment and the clinicians have not yet made a decision regarding their disposition. There is an immediate and obvious difference in the histograms, both across years and between UDG disposition codes. From 2000 to 2002 there appears to have been a general decrease in the time that patients spend in ED beds receiving treatment. The time distribution of patients treated in the ED and discharged home is artificially truncated at 4 hours, reflecting ED policy of admitting these patients to the ED short stay unit at 4 hours.

The non-normal nature of the distributions suggested use of non-parametric tests to test whether the distributions were similar. Non-parametric statistical tests identified no similarities between Treatment Time for Admitted and Discharged patients in the data (Mann-Whitney $P<0.001$, 2 tailed; Kolmogorov-Smirnov $P<0.001$, 2-tailed for all years)[38]. The spread of LOS for patients probably reflects the diversity of presentations and procedures undertaken in the ED.

Patients who were treated in the ED and discharged home almost all left immediately their treatment was completed. 99.8% of patients who “lingered” in the ED were Admitted patients waiting to be moved to a ward. This remained true across the three years. Figure 4-6 provides a histogram of Admission delay (time a patient occupied a bed after disposition) for patients in 2002. There are two distinct subclasses to the patients. Many of them moved immediately from the ED to another ED, to a ward, or home, as shown by the high count of patients at 0 hours, but a large number (38% over the three years) remained in the ED for some time after a disposal decision has been made. It is worth noting that, although there was a complete spread of ages represented, the latter patients tended to be older than 60 years.

[38] The Mann-Whitney U test is the most popular two-independent-samples test that compares whether two sampled populations are equivalent in location, but it must be remembered that the populations need to be similar in distribution for the test to hold strongly. The observations from both groups are combined and ranked, with the average rank assigned in the case of ties. The number of ties should be small relative to the total number of observations. If the populations are identical in location, the ranks should be randomly mixed between the two samples. The number of times a score from group 1 precedes a score from group 2 and the number of times a score from group 2 precedes a score from group 1 are calculated.

The Kolmogorov-Smirnov Z test is a more general test that detects differences in both the locations and the shapes of two distributions. The Kolmogorov-Smirnov test is based on the maximum absolute difference between the observed cumulative distribution functions for both samples. When this difference is significantly large, the two distributions are considered different.

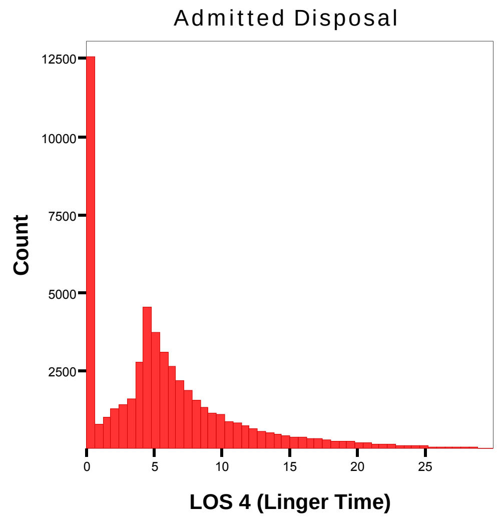



Figure 4-6: Admission delay for Admitted patients in 2002

Admission delay may have been due to medical imperatives (stabilising the patient's condition, for instance) or to other constraints, such as lack of available beds in the designated ward or shortage of porters. Almost no Discharged patients lingered (0.2%), so there was a distinct case for investigating the causes, cost and implications of Admission delay (patients awaiting admission occupying beds in the ED after disposition).

The above analyses suggested that the null hypothesis of no difference in location and dispersion of Treatment Time between Admitted and Discharged groups of patients was not supported, so the Casemix correlation of disposal to patient cost *may* apply to this ED. A similar conclusion may be drawn for the Bed Time of Admitted and Discharged patients because Bed Time is highly correlated with Treatment Time.

The second and third null hypotheses were investigated in the light of these results. This is discussed next.

### 4.4.2 Analysis of LOS by urgency in Admitted and Discharged patients ($H_0^{2, 3}$)

The Kruskal-Wallis (KW) and Median tests did not support the null hypotheses that Bed Time, Treatment Time or Bed Wait Time[39] did not differ by urgency. There were two points of interest that arose in the course of doing this analysis:

[39] "Bed" Wait Time refers to the time between a patient being placed in a cubicle and first being seen.

- The average Bed Wait Time of urgency 5 patients was shorter than those for urgency 4 patients. This anomaly might reflect "fast tracking" and other operational ED initiatives (Table 4-9);
- Mean Treatment Times decreased by urgency category (Table 4-9).

Table 4-9: Mean times for Admitted and for Discharged Patients for 2002 in hours:minutes[40]

| | Discharged Patients | | | Admitted Patients | | |
|---|---|---|---|---|---|---|
| Urgency | Bed Wait Time | Treatment time | Admission Delay | Bed Wait Time | Treatment time | Admission Delay |
| 1 | 0:00 | 2:47 | 0:00 | 0:00 | 0:12 | 5:39 |
| 2 | 0:06 | 2:11 | 0:01 | 0:04 | 0:11 | 7:21 |
| 3 | 0:21 | 1:40 | 0:00 | 0:14 | 0:05 | 6:46 |
| 4 | 0:39 | 1:16 | 0:00 | 0:34 | 0:06 | 6:26 |
| 5 | 0:31 | 0:46 | 0:00 | 0:33 | 0:07 | 4:56 |

There was a difference in Admission delay by urgency for admitted patients. The mean Admission delay for Admitted patients in 2002 ranged from four and a half hours to slightly more than six hours, with a significant difference between urgency groups (KW $P<0.001$ for $H_0$), but there was no trend in median Admission delay by urgency. Admission delay was zero for almost all Discharged patients.

- There appeared to be no significant difference in "Admission delay" (actually this is a "linger" time, rather than related to admission) by urgency for discharged patients (KW - $P=0.254$; Median - $P=0.253$), but it needs to be remembered that patients with a non-zero linger time constituted only 0.1% of the entire dataset, so this result reflected the high proportion of Discharged patients with zero linger time.

### 4.4.3 Difference in lengths of stay between UDAG age groups $H_0^4$

Lengths of stay varied by age group for Admitted patients (KW $P<0.001$ for similarity of the age-group populations), and the median Bed Time for both Admitted and Discharged patients spanned 6 minutes (0.1 hours), from lowest to highest, which may be significant or may be within the precision of time measurement in the ED during normal operating conditions.

As expected from previous analysis of Admission delay for Admitted patients, it's apparent that there was strong indication of inter-group variation for Admission delay in Admitted patients by age group (KW and Median $P<0.001$ for $H_0$).

Table 4-10: Bed Time for Admitted and Discharged patients in 2002 in hours:minutes

[40] Times have been rounded to the nearest 3 minutes (0.1 hours) in the calculations.

| | Discharged Patients | | Admitted Patients | |
|---|---|---|---|---|
| **UDAG age groups** | **Median** | **%** | **Median** | **%** |
| Under 14 yrs | 4:12 | 31.6% | 7:12 | 10.8% |
| 15 to 34 yrs | 9:36 | 31.1% | 10:12 | 19.0% |
| 35 to 64 yrs | 10:12 | 26.7% | 10:12 | 29.5% |
| Over 64 yrs | 15:00 | 10.6% | 12:00 | 40.8% |

### 4.4.4 Discussion of Casemix analyses

This section set out to build an understanding of variables that may be considered for analysis of ED activities. The exploration was guided by four hypotheses derived from previous proposals for ED Casemix. It has been seen that there was support for the use of Disposition, Urgency and Age as variables that may characterise differences in length of stay (and resource use by proxy) from patient to patient.

The Casemix-inspired analysis showed that lengths of stay may vary according to patient Disposition, Urgency and Age but this contributed little to understanding of ED activities. Management of ED overcrowding becomes no less complex if patients are segmented according to these three properties. Each sub-group has the potential to require almost every treatment performed in the ED. That a full spectrum of presentations exists with each of the UDG and UDAG subgroups in the Frankston data was easily seen by looking at small samples of presentation problems and diagnoses. Presentation problems ranged from cardiac arrest to gunshot wounds in one subset of the data (2002 Urgency 1 patients who were admitted). Similar variety of presentations was seen in other samples.

Casemix studies are driven by preconceived ideas about activities in EDs. Experts are consulted or parametric methods employed to relate variables. As such the studies are limited by the extent of the analysts' knowledge and constrained by the data that can effectively be gathered. The resulting models suffer from an absence of clear process descriptions. Some other way of grouping patients was required to help provide a comprehensible summary of ED treatment.

Focus on the ED overcrowding problem as one related to patient treatment provided an ideal basis for creative approaches to ED treatment modelling. A new grouping method was needed that used readily accessible data, was clinically relevant and helped provide insights into ED treatment. Since non-parametric methods make no assumptions about the distribution of patient characteristics or inter-relationships, they provided an avenue for identifying non-intuitive groupings missed by the experts. The next chapter will describe the use of a non-parametric method for building a model of ED patient treatment activities.

## 4.5 Chapter summary

The chapter started with a brief description of the data as it was received from the ED and how it was integrated into a form suitable for further analysis. It went on to describe pre-processing as dealing with: (1) erroneous data; (2) missing data and (3) unusual values. These three phases did not complete pre-processing. Numerous decisions needed to be made regarding data representation before data mining techniques could be applied to the data. Decisions regarding numerical representation of data, addition of fields and combination of fields were described before the chapter moved on to describe the statistical makeup of the data. The chapter concluded with a section on the applicability of existing ED Casemix concepts to the data.

It was found in this chapter that there was little correlation of lengths of stay with urgency, age and disposition. Some characteristics were found in lengths of stay (such as the artificially truncated Treatment Time for patients discharged home and the virtual transfer of Treatment Time to Admission Delay for patients who were admitted to hospital). No distinct grouping with respect to illness was detected by age, urgency and disposition. If these findings are related to the methodology depicted by Figure 3-4 it can be seen that this chapter concentrated on the Facts to Laws to Explanations aspects of the methodology. Experimentation was incorporated in testing different ways of grouping variables. While these steps have contributed to knowledge of the data, it has done little towards clarifying the central problem.

It may be said that the directed searches for patterns of activity in the ED that were used in this chapter were inadequate to address the complexity of ED treatment. A different method to discovering knowledge needed to be tried. Such a different method is introduced in the next chapter.

Chapter 5 describes the use of undirected knowledge discovery as a way of accessing non-intuitive patterns of activity in the ED. Bayesian undirected pattern identification techniques are used in Chapter 5, in direct contrast to the highly directed multivariate methods used for Casemix. An approach is presented for deriving clinically relevant patient groups that are consistent with respect to treatment without making assumptions about the distribution of variables or manner of relationship between them.

# Chapter 5 Clustering ED patients

Sufficient knowledge has been built up in the previous chapters of the research problem and the specific characteristics of the ED under study to permit more detailed investigation of ED activities in this and subsequent chapters. In Chapter 4 it was seen that preliminary investigative techniques such as statistical analysis and expert driven correlation studies (in the form of comparison with existing Casemix proposals) failed to provide an understanding of ED activities sufficient to summarise the nature of ED patient treatment. This chapter will show that it is possible to analyse patient treatment in a comprehensible and useful manner. It will discuss how ED patients may be grouped according to the treatment they receive.

The first section will revisit ED Casemix and provide the rationale for adopting a process-view of ED operations. This will be followed in the second section by application of the Self Organised Mapping technique that was introduced in Chapter 3. The results of "self-organised" patient clustering will be presented. The verification and validation of the results will be discussed and alternative clustering views presented.

By the end of this chapter a reduction in complexity of ED treatment from a myriad of individual patient processes to a small number of treatment types. Treatment type provides the unique basis for the discrete event simulation of the ED that is discussed in Chapter 6.

## 5.1 Revisiting Casemix concepts

Although originally a system for the clinical classification of patients (Eagar et al., 1994), Casemix has been adopted as tool for managing (measuring and reimbursing) medical costs (de Vries et al., 2000; Duckett, 2000; Rodrigues, et al., 2002). Costs are gathered for patients (usually within discrete medical specialities) whose treatments resemble one another. The standard cost is calculated and a measure of variation determined. These constitute a standard that may be used in the monitoring of costs or, in the case of funding mechanisms, be used in the calculation of compensation simply by multiplying the number of patients with the standard, acceptable cost. This idea works reasonably well within specialities because patient treatment is quite consistent. Variations that arise from complications of age or severity may be incorporated into the system through use of multipliers. The number of these so-called "outliers" can be monitored to ensure that the treatment practices are within reasonable limits. Under these circumstances Casemix operates as an effective performance measure against excessive variation in intra-group costs (and treatment itself, by proxy).

This basic premise of Casemix – that patients undergo similar treatment – fails in the ED Casemix proposals considered in the previous chapter. The segmentation of patients was on age, urgency and disposition as independent variables that correlated to cost as a dependant variable. While there is some logic in proposing that treatment differs between patients who are admitted and patients who are not admitted (although, as was seen in Section 4.3.2, the difference manifests as a shift in Treatment Time to Admittance Delay), there is little logic to suggesting that treatment processes vary by urgency or age. On the contrary, it's intuitive to maintain that people of different ages will get the same treatment if they have the same problem (a broken bone, for instance). It's possibly less intuitive that this may be true of different urgencies, but consider a simple laceration which may be a non-urgent cut in the skin or it may be a deep cut that that requires more immediate attention. The treatment is likely to be similar in both cases. It is just delivered faster in the urgent case.

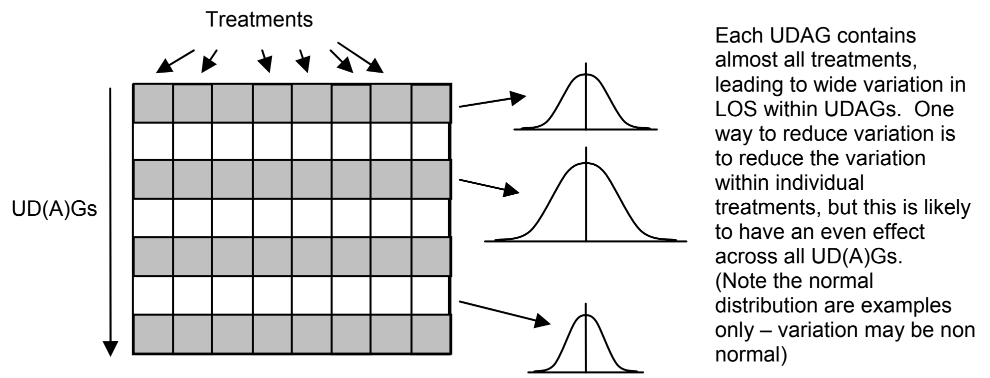



Figure 5-1: Variation of LOS within UDG and UDAG groups

This thinking is summarised in Figure 5-1. The UDG and UDAG proposals segment the set of all possible treatments. There is potential for wide variation within each of the UDG and UDAG segments because the segmentation fails to differentiate between treatments – it only differentiates between patient types. If one was to use this approach for managing ED performance (via costs) then the variability within each of the segments would need to be reduced. Only limited options exist to reduce variation because of the way in which the segments are constructed. Variation must be reduced between patients of similar age, urgency and disposition. The practical implementation of such a measure is infeasible. It would amount to making rules about patients without considering their ailment or injury. The UD(A)G Casemix omit a key consideration in statistical process control – that variation occurs within treatment processes, not patient types.

Another way of saying the above is that the ED Casemix proposals are not process-oriented, while effective performance management requires process segmentation. If ED operations are to be controlled through minimisation of processes variation, then the model of ED operations needs to have a process, rather than patient, orientation. This point is the key motivation to the process oriented views of ED treatment that are discussed in this chapter. The next section moves closer towards process orientation by considering resource consumption views of ED treatment.

## 5.2 Models of resource consumption

To extend the discussion of the above section, consider resource consumption as a function of the procedures employed during treatment, tests performed; time taken at stages of the process; mix of care givers; drugs and materials requisitioned; and so on. If patient cost is determined from an accumulation of these factors it might be considered that cost takes the form of a "sponge" that absorbs resources (Figure 5-2). In this view patients are either grouped by the "size of the sponge" (the amount of care, drugs, and so on) used in the course of their treatment or the 'absorbency of the sponge" (the expense of care, drugs and so on). It's obvious from this model that patients who are vastly dissimilar from a treatment perspective may be placed in the same cost group. Patients with multiple low cost inputs will be grouped with patients who have fewer, but more costly, inputs.

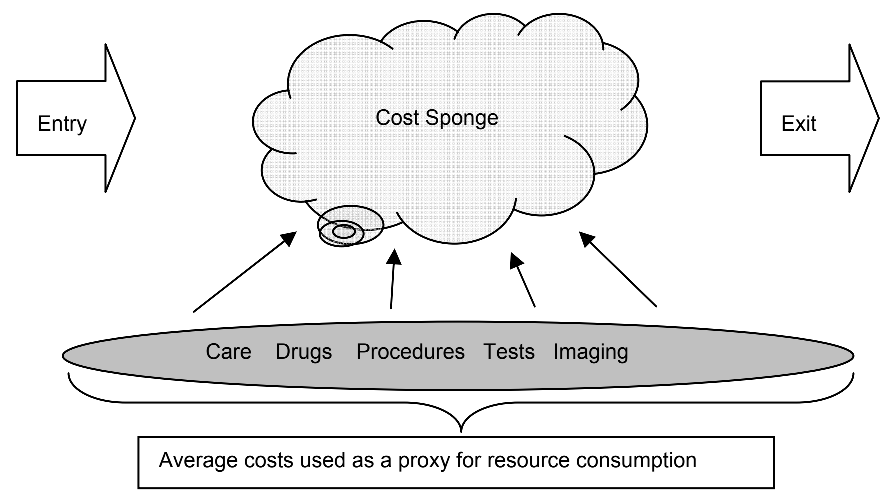



Figure 5-2: depiction of how patients are grouped on cost by "size of sponge" or "absorbency of sponge"

Patients with similar tests, procedures and clinician attention are more likely to bear process resemblance to one another. Each of these aspects might have certain costs associated with them such as drugs, medical supplies and staff time. These costs might be used as a unifying factor through which the total value of the functions may be accumulated (Figure 5-3). While this model is an improvement on the "cost sponge" because it makes the multivariate nature of the costs explicit, it still suffers from two perplexing shortcomings.

1. The first is that the costs of bed time, test, procedure and other functions may trade off with one another in a cost grouping of patients or treatments, disrupting the intended process uniformity of the grouping.

2. The second shortcoming (for this study, in particular) is that the data does not contain the necessary information. The information would be difficult to gather without the use of averages that might well invalidate the method. The hospital does not even keep records of costs at this level so such a data gathering exercise would be akin to instituting a complete "Activity Based Costing" exercise – a task far beyond the scope of this research.

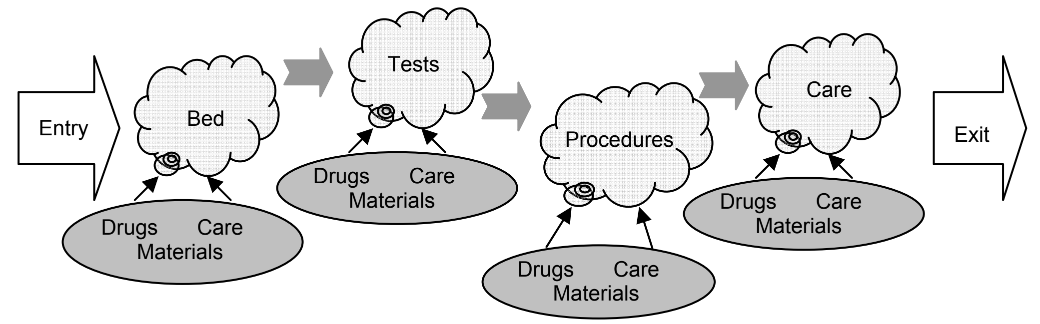



Figure 5-3: Segmentation of patients according to treatment

While the model of Figure 5-3 had several shortcomings it did lead thinking towards the next logical step, but this was a "leap" of deduction (the "discovery" aspect of hypothesis formulation that was discussed in Chapter 3). It was rationalised that the information about tests and procedures contained in the existing data could be used to provide a simplified model of patient treatment. If patients could be grouped by similarity of procedures[41] then the grouping could be considered to be process oriented. Patients with similar procedures would follow similar pathways through the ED and use

[41] In the ED dataset used in this research the term "procedures" includes laboratory and bedside tests, imaging and medical procedures, so the term "procedure" will be used to cover all these activities.

similar resources. This resource/process view would give an idea of the process variation that occurred between patients of similar types. This variation could be studied to see whether it related to patient-specific factors (such as complexity induced by age and/or severity).

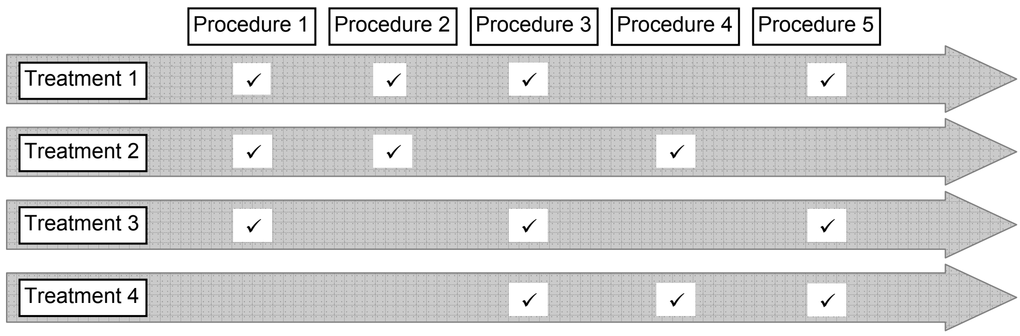



Figure 5-4: Grouping of procedures into "treatment" groups. Note that the sequence inferred in the diagram is illustrative only – precursor / successor information may not be available.

This new model is depicted in Figure 5-4. It indicates that patient pathways are solely determined by the procedures they undergo. Complex patients may follow more than one treatment path simultaneously (consider the case of a person who collapses because of an illness and injures themselves during the collapse – both the injury and the illness need to be treated). While this model is a simplification of the ED activities involved in patient treatment, it is nonetheless a record of the actual procedures patients underwent.

The first step in implementing the model of Figure 5-4 was to determine whether such "treatment" groups existed in the data. There has been almost no research into this issue[42] and expert opinion could not give definitive direction about what principle pathways patients might follow[43]. For these reasons it was decided that the search for patient treatment groups should be undirected. In this way natural patterns that existed in the data could become apparent. As discussed in Chapter 3, Self Organised Mapping

---

[42] Remember from Chapter 2 that projects in EDs haves focussed on separating patients according to pathways but these have generally been based on the time that treatment is likely to take (such as the separation of "fast track" from complex patients). Such "pathways" through the ED lack clinical justification.

[43] Clinical pathways are procedure guidelines for the treatment of certain problems. They are devised by experts through accumulation of best practice knowledge. The ED clinical pathways only cover a small proportion of ED treatments, so are inadequate for assessment of ED operations as a whole.

(SOM) is a powerful technique for such undirected investigations. The application of SOM to this data is described in the following sections.

## 5.3 Self Organised Mapping of ED procedures[44]

Even though there is a wide range of patients and presentations, much of the work in the ED is based on application of a short list of medical procedures. Patient observation, drug orders, laboratory and imaging investigations are examples of such procedures. Just 36 procedures account for 99% of all procedures in Victorian hospitals. Within this almost 17% are classed as "other" (which includes observation of patients by medical staff); 6% are "No procedures"; some 10% are drug administration and over 9% X-ray imaging. Other significant procedures are venipuncture, intravenous catheter access in preparation for infusion of fluid or drugs, and echocardiogram diagnostics (figures derived from Victorian Emergency Medical Database for 2002). Similar statistics were detected for the data used in this research (Table 5-1)

Table 5-1: Overview of ED data used in defining core ED activities. Note that 10 procedures account for the majority of presentations in patients who underwent only one procedure.

| Description | Count of records |
|---|---|
| Two or more procedures (including duplicated procedures) | 44600 |
| one or no procedures (*) | 12211 |
| *Top 10 procedures in records with 1 procedure (99% of *)* | (11537) |
| *Top 30 procedures in records with 1 procedure (99.9% of *)* | (12199) |
| Missing or corrupted records | 95 |
| Total number of records | 56906 |

The hypothesis derived from the model depicted by Figure 5-4 was that variance in patient treatment most often related to the combination, timing and duration of particular clinical procedures. The intention was to group patients on similarity of clinical procedures. This suggested analysis of the procedures that patients underwent on each visit in an attempt to determine common clusters of treatment[45]. These "similarity of treatment" clusters were expected to indicate the primary patient treatments undertaken in the emergency department. The method that was used for identification of "similarity of

---

[44] This Section reproduces work that was originally published online by The Australian Resource Centre for Healthcare Innovation (ARCHI) in 2003 and received an ARCHI award in 2003 for innovation in healthcare. http://www.archi.net.au/ (site search query= "Ceglowski")

[45] The patient records did not carry comprehensive details about the timing of procedures. It was theoretically possible to match patient visit records with requests from other departments such as imaging and laboratories to obtain times of requests and so build up a partial record of procedure times, but this required more dedication from the hospital's staff than they were prepared to accord to this project. The sequencing of procedures was omitted from the clustering part of the research.

treatment" clusters was purely data-driven. Patient data was explored for non-obvious insights using a non-parametric clustering technique which makes no assumptions about the distribution of patient characteristics or inter-relationships. Since it was impossible to cluster patients who only underwent a single procedure (apart from the simplistic grouping by procedure), the records where patients had only one procedure were eliminated from the data set supplied to the clustering algorithm.

The data was cleaned of obvious noise and inconsistencies that related to dates, residence times in the emergency department and errors such as letters in numeric fields (as described in Chapter 4). Software limitations forced reduction of the number of input variables to less than 50. Since the data carried 57 medical procedures, the ten least common procedures were eliminated. This involved less than 1% of all records. The data was then comprised of a case identifier and 47 procedures. The procedures were recorded as integer counts, with zero indicating absence of a procedure. It was possible for a patient to receive repeated applications of a procedure. In practice this was not often the case, except for a generic "observation" procedure which was often repeated. Thus each row of data had an identifier followed by essentially a binary string interjected by the counts between 1 and 5 for the "observation" procedure variable. This did have the effect of weighting "observation" over other variables, but the large number of variables dampened this effect so it was not considered beneficial to normalise the data.

As described in Chapter 3, SOM is a nonparametric method that is algorithm-driven and relies on data, rather than domain-specific expertise. The method seeks to minimise diversity within groups and to maximise between-group differences. These differences are determined using a distance metric to compute relative distance of cases from one another. Self-organizing Maps provide a visual understanding of patterns in data through a two dimensional representation of all variables. Cases that have similar characteristics are adjacent in the map, and dissimilar cases are situated at a distance determined by degree of dissimilarity. The SOM algorithm repeatedly repositions cases in the map until a classification error function is minimised. The method employs large datasets, works well with many input variables and produces "arbitrarily complex models unlimited by human comprehension" (Kennedy et al. 1998).

SOM generated 19 clusters[46] that accounted for the vast majority of patient treatment. The clusters labelled with the procedures that characterised each cluster to

[46] This work has been published with between 14 and 22 clusters. The number of clusters is influenced by the sample of data used in the clustering and the algorithm settings. The 19 clusters reported here was the result of refinement of application of the algorithm to 44298 records

bring the map into the form shown in Figure 5-5. Several interesting things may be noted from looking at the map. The first is that the clusters are generally well-formed. For the most part they have a regular, roughly circular pattern and the sizes do not differ dramatically. These indicate that the clustering scheme might be “natural” for the data. The map had acceptably small quantisation error and map distortion[47].

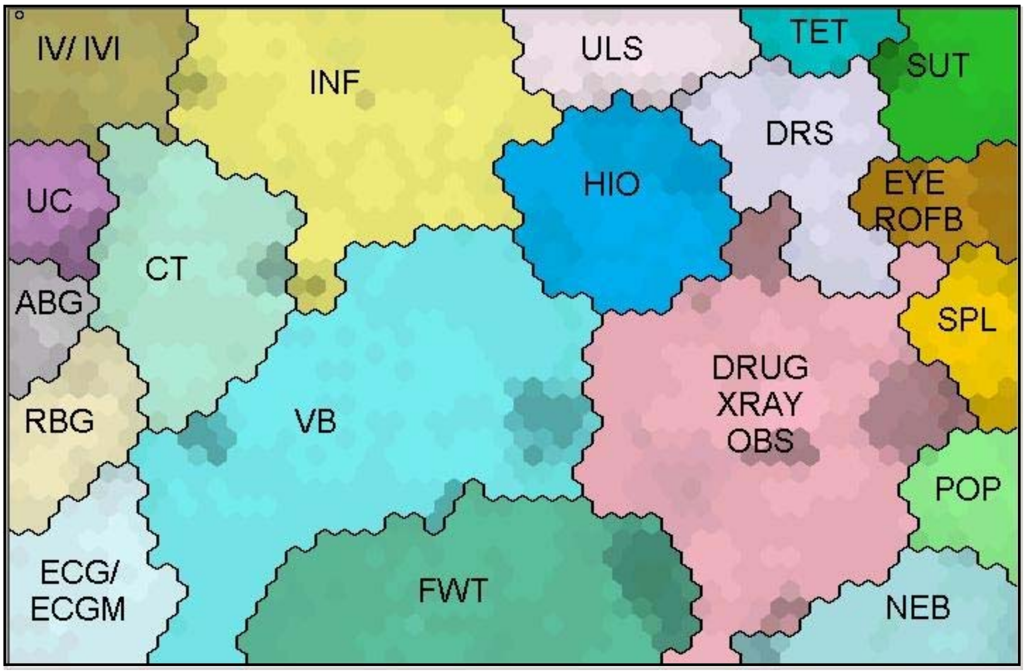



Figure 5-5: The two dimensional visual representation of the 19 clusters produced by Viscovery SOMine. The clusters are labelled with the abbreviations for the primary procedures in each (see Appendix 4-C for a list of procedure abbreviations)

While adding the cluster labels it became apparent that the ones on the right of the map relate to procedures applied in the case of injuries (DRS - dressing; SUT - sutures; POP - plaster of Paris; TET - tetanus injection; and so on) and those on the left relate more to investigations related to illness (ABG - arterial blood gases; RBG - random blood glucose; ECG/ECGM - echocardiogram plus monitoring; and so on). As a related point it may be noted that adjacent clusters are likely to have some logical connection, for instance the proximity of POP - Plaster of Paris with XRAY - X-rays and that of SUT - sutures with DRS - dressing and TET - tetanus injection.

A notable exception to the above is NEB - nebulised medication, placed in the lower right corner of the map. An explanation for this might be that respiratory

from 2002 where patients had two or more procedures. The software settings were: 44 training cycles in normal, exact mode; Tension 0.5, principle plane ratio 100:65; map size 52x39.

[47] This will be further discussed in Section 5.4.1 under cluster verification.

complaints (where nebulised medication is used) are more similar to injuries in their treatment (rapid application of a limited set of procedures without bedside or laboratory tests) than they are to cases of illness.

After this brief look at the overall map it's pertinent to look more closely at the constituents of the clusters. For the sake of simplicity this will first be presented as a table of the fourteen largest clusters with only the primary procedures indicated. Full details of the clusters will be provided in Section 5.5.1 when the clustering scheme is validated. At this stage it's only necessary to gain an overall feel for the clustering.

Table 5-2: Top 14 SOM clusters for patients who have 2 or more procedures

| | | Clusters for patients with 2 or more procedures | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Description** | **Abrv.** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** |
| Venipuncture | VB | X | | X | | o | | | X | | 0 | 0 | | 0 | |
| Observation | O | 0 | X | | 0 | 0 | | | | 0 | X | | | | |
| Infusion of IV fluid (not blood) | INF | | | X | | | | | | | | | | | |
| Full ward test of urine | FWT | | | | X | | | | | | | | | | |
| CT Scan | CT | | | | | X | | | | | | | | | |
| Head Injury observation | HIO | | | | | | X | | | | | | | | |
| Dressing | DRS | | | | | | | X | | | | | X | | |
| 12 Lead ECG + Monitoring | ECG | | | | | | | | X | | | | | | |
| Nebulised Medication | NEB | | | | | | | | | X | | | | | |
| IV Drug Infusion | IVI | | | | | | | | | | X | | | | |
| Ultrasound | ULS | | | | | | | | | | | X | | | |
| Suture, Steristrip, Glue | SUT | | | | | | | | | | | | X | | |
| Random Blood Glucose | RBG | | | | | | | | | | | | | X | |
| X-ray | XRAY | | | | | | | | 0 | | | | | | X |
| Drug (oral/Sublingual/optical/Rectal) | DRUG | | 0 | | 0 | | | | | | | | | | |
| ECG Monitoring | ECGM | | | | | | | | | | | | | | |
| Plaster of Paris | POP | | | | | | | | | | | | | | X |
| % Patients in this cluster | | 14.5 | 22.0 | 10.5 | 8.4 | 4.2 | 3.5 | 3.7 | 5.8 | 4.6 | 4.3 | 2.6 | 4.2 | 2.6 | 2.0 |

Key:
X: over 80% Patients in this cluster underwent this procedure
O: over 60% Patients in this cluster underwent this procedure

Differentiation between clusters may seem trivial if only principal procedures (indicated by "X" in Table 5-2) within each cluster are compared, but it must be remembered that the secondary procedures within each cluster provide insight about underlying patterns and similarities between patients in that grouping. It is these patterns that supply the necessary information about the overlap of process and clinical activities. For example, in Cluster 14, patients often receive some form of drug (clinical treatment), are transported to the X-ray department (an activity supported by typical patient-travel views), undergo examination and have bones set and Plaster of Paris applied (clinical treatment).

This section has described the results of clustering the ED data. It has looked briefly at the characteristics of the clustering scheme. As a last note, the time taken for the clustering was less than 1 hour[48]. This was gratifying, since the time for pattern determination is often excessively long in data mining.

The SOM clusters will be studied in some detail through the rest of this chapter, but it is first necessary to discuss the verification and validation of the clustering results. This is done in the next two sections.

## 5.4 Verification of clusters

Since the self-directed clustering of patient records was a new and untried technique, some effort was expended in ensuring that the results were reproducible and logical. As a first step the clustering was verified. This involved checking whether the clustering had been performed correctly and whether the results could be reproduced. This was followed by validation - determination of whether the clusters indeed modelled the real world. The latter aspect is discussed in Section 5.5.

If the data had carried coded diagnoses then these could have been compared to the clusters to determine whether there was some alignment. Unfortunately this ED did not record diagnoses so this avenue was not available. Other means had to be used. Two groups of tests were performed to verify the clustering scheme. They are discussed in this section in the following order. The first was an estimation of the cluster quality to see whether the clustering was "natural" for the data (in other words, whether it could be considered that the solution surface had a significant local minimum in the region of the clustering scheme). The second was comparison of the SOM method to another clustering method. The method that was chosen for this was k-means, a well accepted "shortest-distance" algorithm for clustering (Kennedy et al., 1998). It was not entirely straightforward to compare the results from two different clustering techniques, so some of these issues and the strategies adopted to overcome problems are discussed.

### 5.4.1 Viscovery SOMine quality measures

A wide variety of algorithms have been proposed for verifying cluster validity (Han et al., 2001 and many others; Jain et al., 1999). These generally set out to determine how many clusters are ideal for the data set and whether a defined clustering scheme fits the data set. As such they are the dual problem of clustering itself, which aims to solve the same problems.

[48] On a dual P4 2.6 GHz processor with 1Gb RAM running Windows XP operating system.

The large number of algorithms for determination of cluster quality attests to the fertility of the field; however the various algorithms can also give different results owing to different emphasis on either intra-cluster similarity or inter-cluster differences (Bandyopadhyay, et al., 2001; Bezdek, et al., 1998; Chou, et al., 2003).

The first section will use what are termed relative criteria for cluster quality measurement (Theodoridis, et al., 1999). The next section will refer to Viscovery SOMine's built-in cluster quality measures. While it's probable that these are similar to one of the well-known indexes of cluster quality[49], the software manufacturer was unwilling to divulge the algorithms used in cluster quality calculations, so the results are presented without discussion of the algorithms. It will be left to the discussion on cluster validation in Section 5.5 to resolve whether the clustering scheme is an appropriate model of the real world rather than entering into discussion over which of the plethora of quality indices provides the absolutely best clustering scheme.

#### 5.4.1.1 Relative cluster verification

Relative criteria use a notion of consistent clustering on repeated clustering algorithm runs using various parameter settings. If the clustering algorithm does not contain the number of clusters as a parameter (as in Self Organised Mapping), then the largest range of parameter values for which the number of clusters remains constant is considered the most natural clustering scheme (Vazirgiannis et al., 2003). In other words, different settings of the clustering algorithm parameters are used in multiple applications of the clustering algorithm to the data. The number of clusters most consistently detected is likely to be the most natural clustering scheme for the data.

The Viscovery SOMine clusters are enclosed by contours - closed lines that mark zones of constant distance to a reference point (the cluster "centre"). These contour "boundaries" may be adjusted through various settings in the software to alter the size, shape and number of clusters. SOM clusters were derived for a number of different parameter settings in Viscovery SOMine. The tension was adjusted to 0.1, 0.5 and 0.9

---

[49] External cluster quality criteria are structured around comparison of the clustering structure with an independent partition of the data built according to intuition about what the clustering structure might be. A number of indices are used to measure the similarity between the clustering structure and the artificial partition. These are the Rand Statistic, Jaccard Coefficient, Folkes and Mallows index, Huberts Γ statistic and the normalised Γ statistic (Vazirgiannis *et al.*, 2003). Internal criteria algorithms evaluate clustering using only quantities and features inherent to the dataset by finding the degree of match between the clustering scheme and the proximity matrix. The Huberts or normalised Γ statistic are commonly used for this (Vazirgiannis *et al.*, 2003).

(on a range of 0 to 1). Tension determines the influence radius of the neighbourhood interaction in the map (the reach of the Gaussian neighbourhood function) during the final stage of the training process. A high tension will result in a map which "averages" the data distribution, while smaller values will allow the map to adapt its shape to finer details as well. In each case 19 clusters were suggested as the ideal number (Figure 5-6).


Figure 5-6: Cluster schemes for different initial parameters, all yielding 19 clusters. Top: Tension set at 0.1 (left) and 0.9 (right). Bottom Modified training schedule (left) and Accurate, exact mode (right)

Since the tension parameter acts only in the last stage of training, other settings were tried for initial and intermediate stages of training. These are shown in Table 5-3 and the results in Figure 5-6. These initial settings all indicated 19 clusters in the data.

These initial tests gave some reassurance that the clustering scheme was “natural” for the data set. The map quality indices were examined for SOM clustering using tension of 0.5 and “Normal Exact Mode” settings for training, as described in the next three sections. The results are discussed in Section 5.4.1.6.

| Table 5-3: Various training settings used in relative cluster quality evaluation[50] | | | |
|---|---|---|---|
| | Normal, exact mode | Modified schedule | Accurate, exact mode |
| Scaling factor | 1 | 1 | 1 |
| Height of initial map | 7 | 7 | 9 |
| Intermediate tension: | 6 | 6 | 8 |
| Number of iterations: | 10;3; 30 | 20; 5; 20 | 20; 5; 60 |
| Wegstein factor: | 0.1;0.1;0.1 | 0.1;0.1;0.1 | 0.1;0.1;0.1 |
| Clusters | 19 | 19 | 19 |

#### 5.4.1.2 Frequency in Viscovery SOMine

The Frequency map indicates how many data records from the source data set have matched each node. Nodes that have not matched any data record are white. Nodes that have matched at least one data record show a shade of red. The shade of red indicates the number of matches - the darker the red the higher the frequency of matches. The map is well adapted if the frequencies are equally distributed.

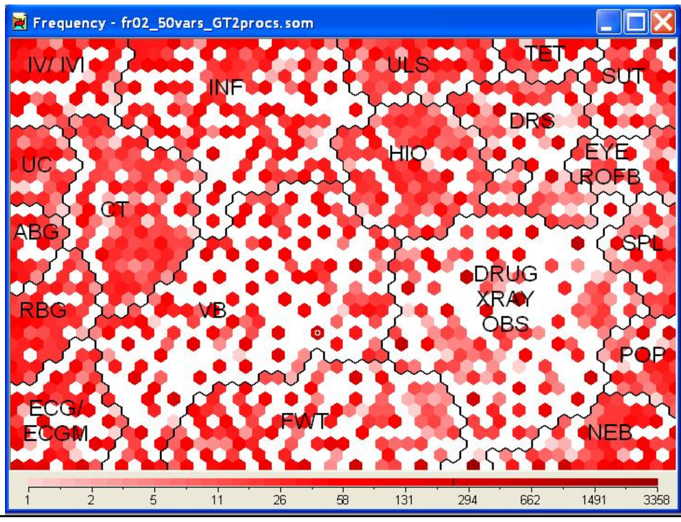



Figure 5-7: Frequency of record matching for the ED data set. The colour scale in the lower part of the window indicates the matching between colours and frequencies.

Figure 5-7 shows that the central region of the map is relatively poorly populated, and that most of the records are matched by nodes located towards the edges. It is of

[50] The Scaling factor specifies the increase in horizontal number of nodes at each growth step (The vertical number of nodes is adjusted according to the desired map ratio.). The initial map height gives the initial number of vertical nodes (the number of horizontal nodes is automatically set from the map ratio). The Intermediate tension is the tension of the intermediate maps. Each schedule contains two parameters that apply to the initial map; all intermediate maps; and to the final map. These are the number of iterations and the Wegstein factor (a convergence parameter in the batch SOM algorithm comparable to the momentum factor as it is commonly used in supervised neural network algorithms).

comfort that high frequencies do not simultaneously occur on both sides of cluster boundaries. This indicates that the boundaries may be well-defined.

While this view does provide some indication of the quality of the cluster scheme, it also helps understanding the high index values for the measures described in the next three sections.

##### 5.4.1.3 Quantisation Error in Viscovery SOMine

The Quantization Error assesses how well the data vectors from the source data are matched by a specific node. This is portrayed as a range of colour across the map from white for no error to dark (green) for a high degree of error. The map is well adapted if the quantisation error is small and regularly distributed.

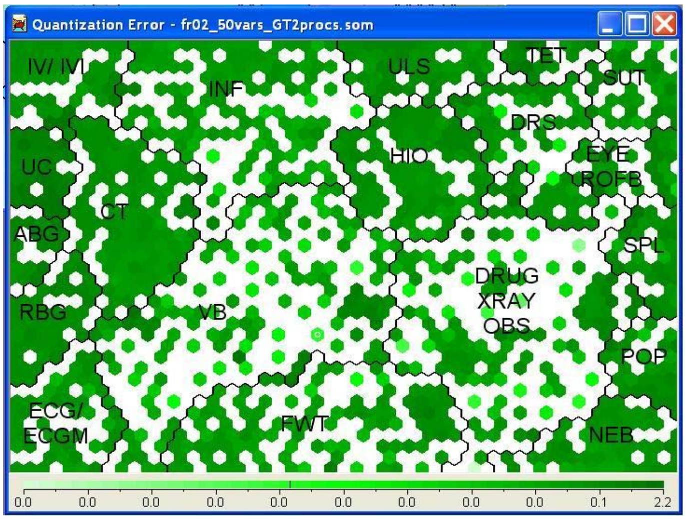



Figure 5-8: Quantisation Error for 19 SOM clusters

Figure 5-8 gives the Quantisation error for the (final) clustering scheme used in this research. It can be seen that the error is small in the middle region of the map, but increases towards the left and right edges, in line with the increase in number of records associated with those nodes.

##### 5.4.1.4 The U-matrix in Viscovery SOMine

The value of the U-matrix Map indicates whether a node is far away or near to the neighbours. The U-Matrix Map colours each node depending on the median distance to its neighbours. Nodes that are far away from each other will have a dark colour. Nodes which belong to a “dense” region of the map will have a light colour. Only the relation between U-Matrix values is important, the absolute values are not. Strings of dark coloured nodes indicate gaps in the map.

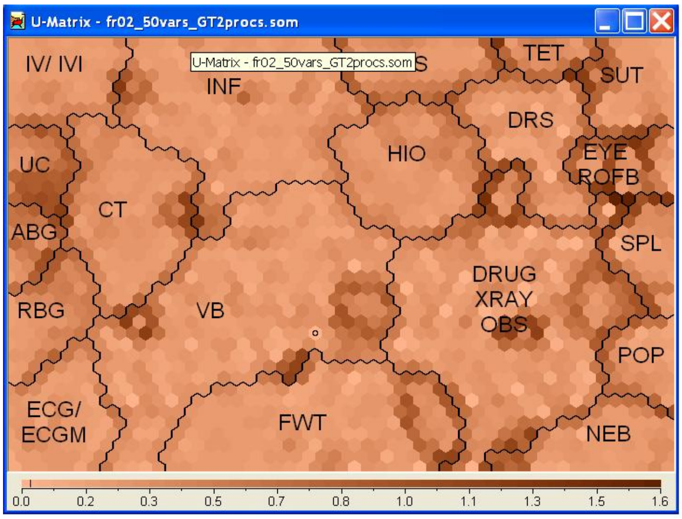



Figure 5-9: The U-matrix for the ED cluster scheme. The colour scale in the lower part of the window helps to match colours against U-Matrix values (the darker the colour, the further the node from its neighbours).

Figure 5-9 shows that U-matrix values are high along many of the cluster boundaries, indicating that the clusters are separated by "natural" boundaries - the nodes are far apart in n-dimensional space, but adjacent in the two-dimensional representation.

#### 5.4.1.5 Cluster curvature in Viscovery SOMine

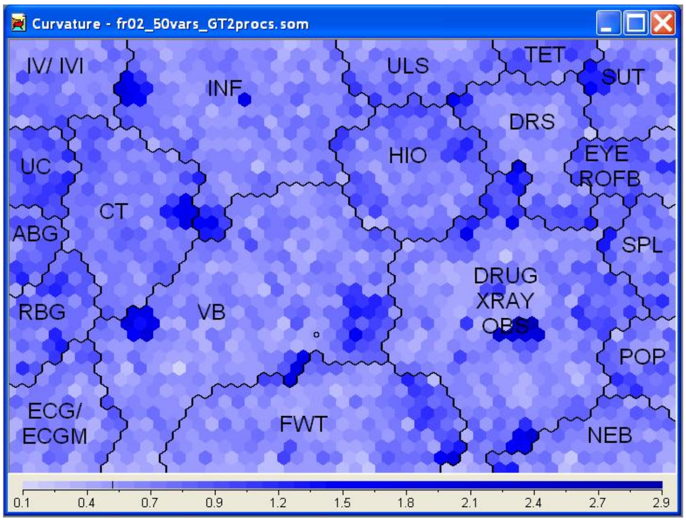



Figure 5-10: Curvature for the ED clustering scheme. The colour scale in the lower part of the window helps to match colours against curvature values.

The SOM is a 2-dimensional surface that approximates the data distribution of the source data set (which is of much higher dimension). The data distribution is not planar but bends through n-dimensional data space, forming curves, saddles, and so on. Curvature is a measure of how much the map (surface) is bent at each node.

Figure 5-10 shows little curvature across most of the map, but there is extreme curvature at a number of nodes. These are probably instances where patient treatment was exceptional in complexity.

#### 5.4.1.6 Discussion of the cluster quality measures

All of the measures of cluster quality presented in this section came from internal Viscovery SOMine algorithms, except the relative evaluation of cluster quality. The relative evaluation provided good indication that 19 was the most likely number of clusters in the data. The Frequency, Quantisation error, U-matrix and Curvature quality indices showed that the map was adequately well formed for it to be considered a reasonable clustering scheme, especially since the maps were a two-dimensional representation of 47-dimensional space.

The two-dimensional nature of these quality measures is substantially more powerful than the single number provided by traditional indicators of cluster quality. Every point of the map can be examined for frequency, quantisation error, curvature and U-matrix values. While Figures 5-7, -8, -9 and -10 may not provide the even colouration of the theoretically perfect map, they are reasonable in the context of high dimensional data with numerous records. The clusters were of similar size, generally circular in shape and free of excessive ambiguity at the boundaries. There were also no unallocated records from the original data set. This means that the clustering scheme was complete for all records in the original data set. This undoubtedly contributed somewhat to the variation of indices seen in the different views.

The next section provides a different form of verification. It compares the SOM clustering to that of an analogous statistical method.

### 5.4.3 Comparison with k-means clustering[51]

This section compares the clustering results from the application of SOM and k-means methods to the data. Several techniques were used to investigate the similarity of the clustering schemes from the two methods. Practical considerations, obstacles and extensions of comparing clustering schemes from different clustering methods are

---

[51] This section largely reproduces work published at the peer reviewed International Conference on Optimization: Techniques and Applications (Ceglowski *et al.*, 2004a) It uses a clustering scheme with 18 SOM clusters due to it being derived only from patients treated and discharged, rather than all patients, but this differs little from the scheme discussed in Sections 5.4.1 and 2.

discussed. It is suggested that hierarchical clustering may provide a quick and accurate means by which clusters may be compared.

The k-means algorithm requires determination of the number of clusters before the algorithm is commenced (whereas Viscovery SOMine makes its own determination). The k-means algorithm repeatedly moves the centres of clusters towards the densest populated regions of input space, aiming to maximise intra-cluster similarity and minimise inter-cluster similarity (Kennedy et al., 1998). Typically the sum of squared error is minimised between cases in clusters and the mean of the cluster.

The k-means algorithm is popular because it has linear time complexity (making it efficient with large data sets), its memory requirements relate only to the sum of number of patterns and number of clusters, and it does not depend upon the order in which cases are supplied. However it is sensitive to initial cluster centre selection and can only produce hyper spherical clusters (Jain *et al.*, 1999).

#### 5.4.2.1 Description of the k-means algorithm

The k-means Algorithm differs from SOM in requiring determination of the number of clusters before the algorithm is commenced (whereas SOM makes its own determination). The algorithm has four steps that repeatedly move the centres of clusters towards the densest populated regions of input space (MacQueen, 1967):

1. Choose the number of initial cluster centres. This first step is a key issue in using this algorithm. It is sometimes possible to set both the number of initial clusters and the number of final clusters. The number of final clusters is arbitrary and needs to be assessed based on empirical evidence of multiple values of clusters.
2. Assign all data points to their closest cluster centre. This is typically done using a distance measure, often Euclidian distance.
3. Recalculate the centre of each cluster as the centroid of all the data points in each cluster (the mean of the cluster).
4. If the new centres are significantly different from the previous ones, repeat steps 2 and 3 until the change in cluster means is less than an amount specified by the user.

#### 5.4.2.2 Considerations in comparing clustering methods

SPSS Software's implementation of k-means was used in this study. The procedure assumes an appropriate number of clusters have been selected and all relevant variables are included. If an inappropriate number of clusters is selected or important variables omitted, results can be misleading (SPSS Inc., 2001). Distances are computed using simple Euclidean distance so scaling of variables is an important consideration (all variables were normalised for this analysis). On the other hand, SPSS software can handle huge data sets easily, imports and exports a range of data formats, and produces detailed results of clustering measures that can be exported or copied to spreadsheet programs – all important considerations for applied data analysis.

Some effort was made to optimise the clustering from each of the methods in order to remove questions about algorithm settings' influence on the comparison of clusters. As this was being done the question arose of getting comparable clusters from different methods. Self Organising Maps could be generated from the data as it stood, but the k-means algorithm required the number of clusters as an input. This problem was addressed by using the number of clusters found through SOM as a reasonable number of clusters in k-means. This had the advantage of making the results directly comparable. While this provided a way around the primary difference between SOM and k-means, the nature of solution space meant that many possible solutions were available. An attempt was made to "force" the k-means into a particular region of solution space by initialising the cluster means at the values obtained for cluster means from SOM.

Since numbering of clusters by the software is arbitrary, a technique needed to be found that permitted quick and accurate alignment of clusters and detection of commonalities between the clustering schemes as well as identification of differences. Four largely heuristic, techniques were attempted:

- Comparison of Case Counts in Clusters
- Graphical Comparison of Cluster Means
- Comparison of k-means Case Allocation against the SOM
- Hierarchical Agglomeration of the Cluster Means

These met with varying levels of success, as will be seen in the next four sections.

#### 5.4.2.3 Comparison of Case Counts in Clusters

All cases were classified according to the results of both methods. This resulted in the addition of two "cluster number" variables to the data set. Since there were almost 10000 records in the data sample it was difficult to scan the list for differences in cluster allocation between Self Organisation and k-means. Even the 18 cluster (columns) by 47 procedure (rows) summary tables of cluster means were daunting to compare. A two way table was implemented to summarise the data. The number of patients in each cluster was counted for to the two schemes. The number of patients from SOM clusters were matched with counts of patients from the k-means clusters and complied into a table.

Each row of the table counted how the SOM cases were classified in the k-means solution. Each column counted how the k-means cases were classified in the SOM solution.

After some patient reordering of rows and columns it was possible to rearrange the table in a way that similar case counts fell on the diagonal where both methods "agreed" on classification (Table 5-5). This quasi proximity matrix allowed alignment of SOM and k-means cluster names. Clusters where the two methods disagreed on classification of cases were added as "orphans" in bottom rows and end columns. It was then possible to rename the SOM and k-means clusters to common names where classification agreed, and allocate additional names where no commonality was apparent (columns 19 to 22 and rows 15 to 18 in Table 5-4).

Table 5-4: SOM / KMeans Cluster Cross tabulation (Count of cases in each cluster)

| Viscovery SOMine Cluster New Names | KMeans Cluster New Names | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 19 | 20 | 21 | 22 |
| 1 | 505 | 53 | 16 | 2 | 0 | 0 | 0 | 1 | 0 | 38 | 9 | 1 | 144 | 2 | 93 | 47 | 386 | 167 |
| 2 | 35 | 964 | 10 | 2 | 0 | 0 | 1 | 1 | 70 | 404 | 1 | 0 | 132 | 1 | 56 | 473 | 19 | 55 |
| 3 | 35 | 16 | 529 | 21 | 1 | 0 | 3 | 3 | 0 | 23 | 2 | 1 | 30 | 101 | 95 | 7 | 121 | 99 |
| 4 | 22 | 35 | 40 | 502 | 5 | 0 | 5 | 3 | 1 | 35 | 0 | 1 | 3 | 1 | 73 | 34 | 117 | 16 |
| 5 | 12 | 16 | 31 | 15 | 216 | 0 | 0 | 1 | 0 | 20 | 0 | 0 | 16 | 3 | 43 | 17 | 0 | 12 |
| 6 | 4 | 15 | 16 | 1 | 1 | 231 | 0 | 26 | 0 | 10 | 0 | 0 | 0 | 25 | 31 | 9 | 51 | 10 |
| 7 | 9 | 9 | 42 | 10 | 29 | 0 | 172 | 29 | 0 | 0 | 0 | 0 | 0 | 7 | 3 | 11 | 18 | 7 |
| 8 | 13 | 3 | 0 | 8 | 0 | 0 | 0 | 475 | 0 | 5 | 0 | 0 | 1 | 2 | 31 | 6 | 0 | 2 |
| 9 | 0 | 22 | 1 | 0 | 0 | 0 | 2 | 1 | 341 | 7 | 0 | 0 | 22 | 0 | 9 | 6 | 2 | 11 |
| 10 | 0 | 10 | 5 | 0 | 0 | 0 | 1 | 0 | 4 | 115 | 0 | 0 | 4 | 4 | 10 | 46 | 10 | 7 |
| 11 | 7 | 8 | 12 | 11 | 4 | 0 | 0 | 4 | 1 | 5 | 136 | 1 | 13 | 3 | 23 | 5 | 7 | 3 |
| 12 | 1 | 0 | 1 | 1 | 8 | 0 | 0 | 9 | 0 | 3 | 0 | 58 | 2 | 16 | 7 | 0 | 15 | 1 |
| 13 | 0 | 27 | 1 | 1 | 0 | 0 | 1 | 0 | 9 | 3 | 0 | 0 | 109 | 0 | 1 | 1 | 0 | 4 |
| 14 | 15 | 8 | 33 | 8 | 17 | 0 | 0 | 39 | 0 | 9 | 4 | 0 | 11 | 218 | 55 | 5 | 28 | 22 |
| 15 | 2 | 5 | 18 | 13 | 10 | 0 | 1 | 19 | 0 | 0 | 2 | 7 | 1 | 22 | 10 | 0 | 15 | 2 |
| 16 | 30 | 15 | 13 | 23 | 24 | 0 | 3 | 34 | 0 | 3 | 1 | 34 | 7 | 6 | 24 | 2 | 17 | 6 |
| 17 | 2 | 8 | 4 | 1 | 4 | 0 | 0 | 0 | 57 | 13 | 0 | 0 | 10 | 1 | 6 | 3 | 5 | 5 |
| 18 | 1 | 6 | 1 | 0 | 1 | 0 | 1 | 0 | 9 | 69 | 0 | 0 | 9 | 1 | 15 | 32 | 4 | 8 |

This somewhat tedious process led to 14 clusters being found where there was agreement in classification counts and 8 where there was none apparent. It needs to be remembered that this technique gave no guarantee of similarity of cluster components. It relied on the assumption that agreement in counts implied agreement in cluster makeup. This analysis sought merely to align the cluster names.

#### 5.4.2.4 Graphical Comparison of Cluster Means

It's common to plot variables in order to visualise ones that are emphasised over others. This method relies on the human ability to readily match patterns visually. Graphical matching was quite successful in identifying similar clusters obtained using SOM and k-means (Figure 5-11 provides an example). It is both time consuming and exhausting to match cluster profiles in this way, even with a total of only 36 patterns and the benefit of being able to plot accurate graphs quickly in spreadsheet software. The technique does not lend itself to automation.

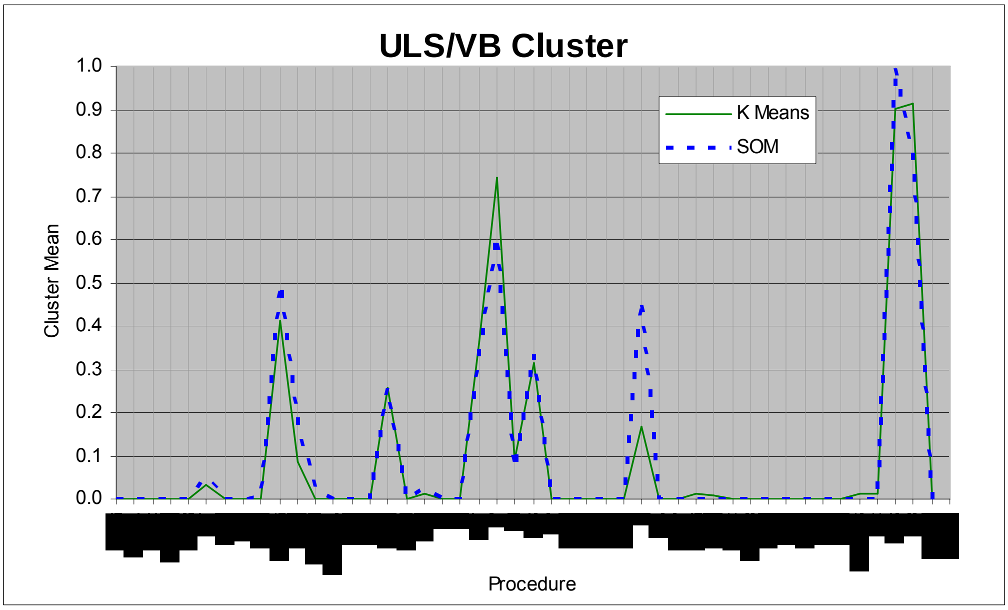



Figure 5-11: Sample graphical comparison of cluster means

Use of the Count Comparison technique described in the section above greatly aided the search for similar patterns within clusters and helped indicate similarity of clusters that was not immediately apparent from comparison of the graphs.

#### 5.4.2.5 Comparison of k-means Case Allocation against the SOM

Cluster allocation to cases using k-means were associated with the original SOM cluster allocations and viewed in Viscovery SOMine. As expected, the SOM cluster allocation to cases overlays perfectly on the original clusters (on the left of Figure 5-13). It can clearly be seen that the cluster allocation from k-means has less agreement since many colours occur within each bounded region (right of Figure 5-12).

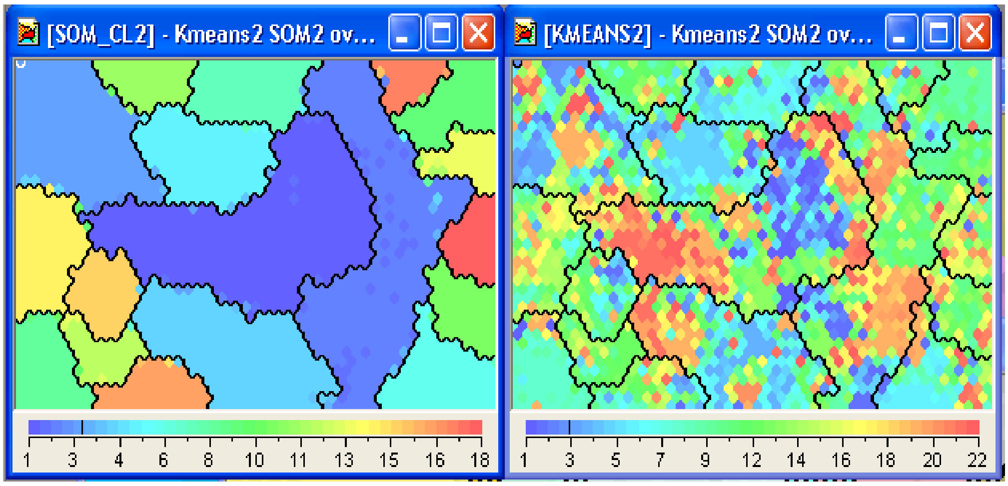



Figure 5-12: Overlay of k-means cluster allocation of cases on the SOM allocation

The scale below each picture refers to the cluster numbers. Hence the SOM has clusters numbered from 1 to 18 while the k-means clusters run from 1 to 22 with 15, 16, 17, 18 omitted as a result of the previous two exercises where it was found that there was little overlap in these clusters between the two methods.

It needs to be remembered that the k-means cluster means were initialised at the Self Organised cluster means, so some degree of agreement in final clustering was expected. This overlay method produced the quickest and most direct method of cluster comparison, but it failed to provide the cluster component verification insight given by graphical comparison of the cluster means.

#### 5.4.2.6 Hierarchical Agglomeration of the Cluster Means

The cluster means from each method were combined into a single data set. This data set had 36 records (one for each cluster from each technique). Each record carried the mean occurrence of 47 procedures in that cluster. Hierarchical Agglomeration was applied to this data set in the hope that clusters with similar characteristics would be grouped together. SPSS centroid clustering using Pearson Correlation[52] was used with the result shown in Figure 5-13. The cluster names that resulted from the alignment exercise of Section 5.4.2.3 were used, with k-means clusters indicated by a “K” prefix and Self organising clusters by a “S” prefix.

[52] Pearson correlation is one of the dissimilarity measures for interval data in SPSS’ Hierarchical Cluster Analysis. It is the product-moment correlation between two vectors of values.

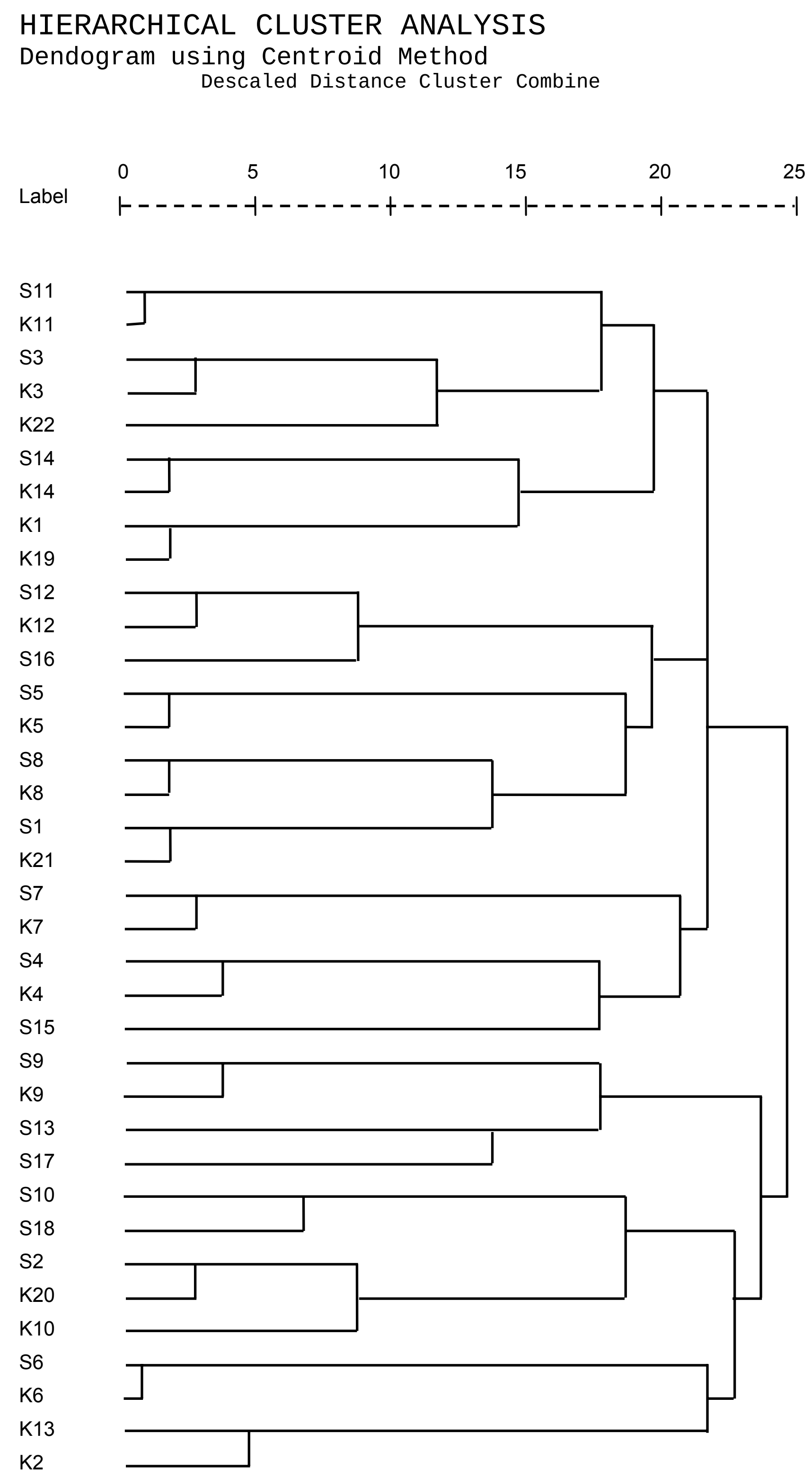



Figure 5-13: Dendogram of clusters

From the alignment of clusters with the same numerical suffix in Figure 5-14 it can be seen that this technique confirmed the alignment of clusters that was done previously according to count of cases in Section 5.4.2.3. That is, S11 is grouped with K11, S3 with K3 and so on. There are several instances where a third cluster was added, as K22 was to the K3/S3 group, S16 to K12/S12 and S15 to K4/S4. It's also interesting to see that K2 and S2 have been separated by quite a distance, denoting dissimilarity while S1 and K21 have been found similar. This is borne out by the graphical comparison of the cluster means for S1 and K21 shown in Figure 5-14.

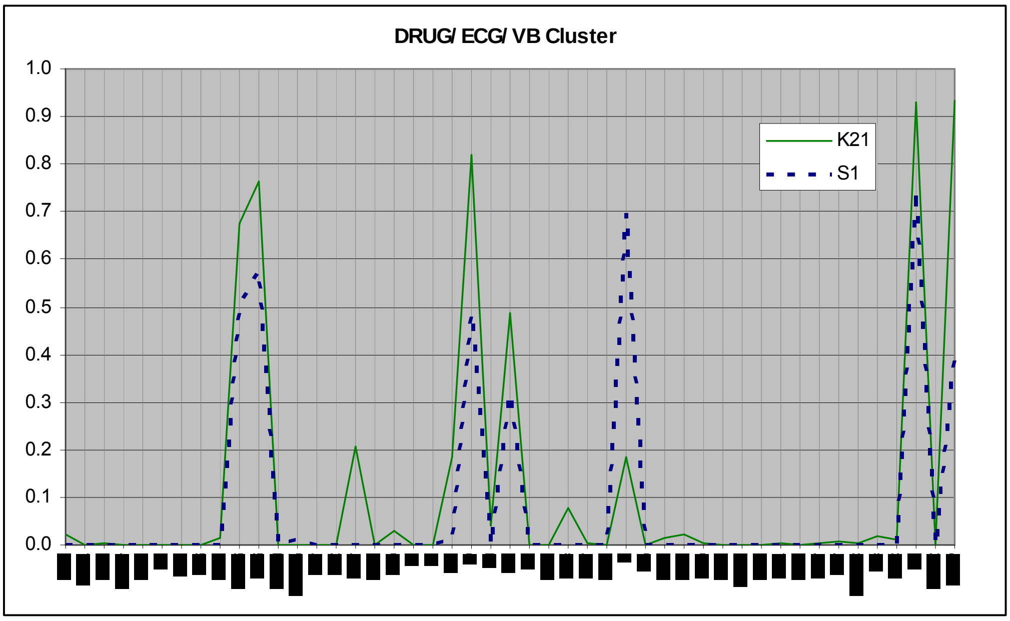



Figure 5-14: Graph of cluster means for k-means cluster 21 and Viscovery SOMine cluster 1

#### 5.4.2.7 Summary of the SOM / k-means comparisons

This section has discussed a number of techniques in which the SOM cluster scheme was compared with that from k-means clustering. The underlying presumption was that independent verification of clusters from different methods is a useful supplement to cluster quality investigations that relate to a single method. Application of different methods may seem unnecessary duplication in the eyes of some analysts, since clustering quality depends on the requirements of the analysis and whether the ultimate clusters are accepted by experts. However, all analysts will acknowledge the more data is manipulated and investigated, the better the chance of uncovering some hidden knowledge. Repeating clustering using a separate method gives this opportunity. Multiple methods not only permit confirmation of some clusters but also proposal of alternate clusters that may be interesting.

In referring specifically to the cluster comparisons in this section, it is possible that better agreement would have been gained on some clusters between the two methods if the number of clusters for k-means was adjusted. It may be that k-means was forced to split clusters because of higher than optimal number of clusters being specified as a parameter. However it may also be that the split clusters are better representations of emergency department treatment practices.

The results verify that clusters of procedures exist in ED data. Cluster schemes may vary, but the clusters do appear to be reproducible and well formed. It remains to summarise this section on verification before moving on to cluster validation.

### 5.4.1 Summary of cluster verification

Cluster quality verification approaches only give an indication of the quality of clusters so, although they assist experts in evaluating the clustering results, they provide no evidence that the clusters are representations of actual circumstances. A number of verification approaches were used in the verification of the ED procedure groups. While none of them was able to conclusively determine that the clustering was "correct", they did indicate that the clustering was reproducible and that the clusters were well formed and likely to contribute new knowledge about the processes that generated the data. The true test of any clustering scheme is the degree to which it constitutes a mapping of the real world. This is done through a process of validation. Validation is discussed in the next section.

## 5.5 Validation of clusters

With some assurance that the clusters derived from SOM were reproducible and representative of ED patients (for the year 2002 at least), attention was turned to the problem of deciding whether the clusters modelled the real world. The approaches discussed in the sections that follow take the view that the SOM clusters represent one view of reality that may or may not be distorted by the modelling method. A second view of the same reality was sought and related to the SOM clustering for confirmation or refutation of the SOM scheme.

Five techniques are discussed in this section. The first two were studies of the clusters, first from the perspective of whether they were "interesting", then from a naive perspective. The third was from an expert perspective, to determine whether the groups of procedures were feasible couplings of procedures in real life. The fourth technique was the compilation of another view of ED operations through examination of patient presentation data. The last examination was through comparison of the SOM results with those from the data from a number of other EDs in the state.

### 5.5.1 "Interestingness"

A usual strategy in nonparametric modelling is to withhold some data from the training algorithm to ensure that some "unseen" data remains upon which to test whether the resulting model has learnt generalised characteristics of the data or merely learnt the data set. The model is considered adequate if the proportion of correct outputs is similar for both the data used for training and the unseen data. However, this strategy is only possible when there is a known outcome or dependant variable. In a situation where the ideal output is unknown it's only possible to check whether the patterns are of interest in the context of the investigation.

The evaluation of "interestingness" (Han et al., 2001 use this term in reference to limitation of the number of uninteresting patterns returned by the process) adopted here bears some resemblance to validation according to the logical utility of the clusters that is described in Section 5.5.2. Accordingly, this section will restrict discussion to aspects of the clusters that relate to verification of the clustering scheme[53]. Some of the points in the paragraphs below have already been alluded to in Section 5.3 as illustrations of the clusters, but the paragraphs below will be more oriented towards validation of the cluster scheme.

#### 5.5.1.1 Simplicity

Simplicity is an evaluation of the number of variables included in each cluster. If too high a proportion of the input variables are included in the cluster, then it is likely that either the clustering scheme is too complex for human comprehension, or the clustering scheme is not a significantly simplified view of the input space. In other words, the more complex the structure of the cluster, the more difficult it is to interpret, so the less interesting it is likely to be.

The abbreviated cluster representation of Table 5-2 indicates that the SOM clusters contain limited numbers of variables at significant levels, so the clusters were all

[53] The aspects in this section have been adapted from the interestingness measures described by (Han et al., 2001) for patterns achieved from Association mining – a technique renowned for producing excessive patterns because it counts all instances of pairings or variables, many of which contain little knowledge. The use of the measures with respect to SOM clusters might be considered as verification of rules of the form "Procedure A occurs at high levels in Cluster 1 implies Procedure B will also occur at high levels".

relatively simple to interpret (the cluster centres were not close together and the boundaries were well defined).

#### 5.5.1.2 Novelty

Novel clusters are those that contribute new information. If the knowledge conveyed from a cluster may be implied from another cluster, then one of them may be considered redundant. The small numbers of SOM clusters indicated that redundancy was unlikely. The nature of the SOM clustering ensured novelty. The clusters were characterised by the incidence of one or two procedures at high levels (close to, or at 100%). These procedures did not occur in other clusters at these high levels. This is immediately apparent in looking at the diagonal pattern across clusters of primary procedures in Table 5-2.

#### 5.5.1.3 Certainty

Certainty is the measure associated with each pattern that assesses the "trustworthiness" of the cluster. A measure of certainty may be given by

$$\text{Certainty} = \frac{\text{\# records in the cluster containing primary variables V1 and V2} \ldots \text{Vn}}{\text{Total \# records containing variable V1 and V2 etc.}} \ldots\ldots\ldots (Eq5-4)$$

Certainty was calculated for the SOM clusters by first identifying which procedures "defined" the cluster. That is, which procedures had the highest probability of occurring in each cluster. These procedures defined the major axis in n-dimensional space for the SOM distance. The certainty was then be interpreted as the degree to which the records in the cluster were oriented in this direction in n-dimensional space. If the certainty was low it implies that other procedures may have combined together to produce a similar net vector to the primary procedures of that cluster. This would mean that records were misclassified or that the cluster was dispersed.

Table 5-5: Cluster certainty for procedures that occur at 80% or more in the clusters

| Cluster | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Procedure1 | VB | O | INF | FWT | CT | HIO | DRS | VB | NEB | IV | ULS | DRS | RBG | SPL | EYE | POP | UC | ABG | TET |
| Procedure2 | | | VB | | | | | ECG | | IVI | | SUT | | XRAY | | XRAY | | | |
| Procedure3 | | | | | | | | ECGM | | o | | | | | | | | | |
| Primary procedure count (000's) | 5.3 | 7.7 | 3.7 | 3.7 | 1.9 | 1.6 | 1.6 | 2.2 | 2.0 | 1.7 | 1.2 | 1.5 | 1.1 | 0.6 | .06 | 0.8 | 0.6 | 0.5 | 0.5 |
| Total in cluster (000's) | 6.4 | 9.7 | 4.7 | 3.7 | 1.9 | 1.6 | 1.6 | 2.6 | 2.0 | 1.9 | 1.2 | 1.9 | 1.1 | 0.7 | 0.7 | 0.9 | 0.7 | 0.5 | 0.5 |
| Certainty (%) | 82 | 79 | 79 | 98 | 105 | 100 | 100 | 86 | 100 | 92 | 100 | 80 | 100 | 84 | 86 | 89 | 91 | 100 | 100 |

It can be seen from Table 5-5 that the certainty was always greater than 84%, even when the primary procedures in the cluster were as ill-defined as O - observation. This lends considerable confidence to the idea that clusters are characterised by a small number of key procedures.

#### 5.5.1.4 Utility

Utility is a measure of the potential usefulness of the pattern. It can be estimated by a utility function such as the percentage of records containing the primary variables for which the clustering is true. This might be described as:

$$\text{Utility} = \frac{\#\text{ records in the cluster containing primary variables V1 and V2}\ldots\text{Vn}}{\text{Total }\#\text{ records containing variables V1 and V2,}\ldots\text{Vn as primary variables}} \ldots..(Eq \cdot 5-5)$$

The Utility differs from Certainty in the section above in the focus on primary variables in the denominator. While Certainty gives an indication of the differentiation of the cluster from other clusters in the scheme, Utility gives an indication of the "cohesiveness" of the cluster. That is, Utility indicates whether the records in the cluster are simular to one another.

Calculation of utility for a number of clusters (Table 5-6) showed that the support was relatively high for most of them. It was lowest for clusters that were characterised by a single procedure that occurred in other clusters, such as O - observation in cluster 2; VB - venipuncture (puncture of a vein through the skin in order to withdraw blood for analysis, to start an intravenous drip, or to inject medication or a radiopaque dye) in cluster 1; and DRS - dressing in cluster 7.

It can be seen from the table that almost all of the patients who received less general procedures were placed in the cluster characterised by those procedures. Examples are EYE - eye examination in cluster 15 and ULS - ultrasound in cluster 11.

Table 5-6: Cluster utility for procedures that occur at 80% or more in the clusters

| Cluster | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Procedure1 | VB | O | INF | FWT | CT | HIO | DRS | VB | NEB | IV | ULS | DRS | RBG | SPL | EYE | POP | UC | ABG | TET |
| Procedure2 | | | VB | | | | | ECG | | IVI | | SUT | | XRAY | | XRAY | | | |
| Procedure3 | | | | | | | | ECGM | | o | | | | | | | | | |
| Primary procedure count (000's) | 5.3 | 7.7 | 3.7 | 3.7 | 1.9 | 1.6 | 1.6 | 2.2 | 2.0 | 1.7 | 1.2 | 1.5 | 1.1 | 0.6 | 0.6 | 0.8 | 0.6 | 0.6 | 0.6 |
| Total in cluster (000's) | 21.6 | 24.4 | 7.9 | 7.4 | 2.7 | 1.8 | 4.3 | 3.7 | 2.2 | 1.7 | 1.2 | 1.9 | 1.5 | 0.6 | 0.6 | 1.0 | 0.6 | 0.6 | 0.6 |
| Utility (%) | 24 | 32 | 47 | 50 | 72 | 85 | 38 | 60 | 93 | 100 | 96 | 79 | 74 | 96 | 100 | 83 | 99 | 86 | 94 |

#### 5.5.1.5 Discussion of cluster interestingness measures

These interestingness measures are generally used in an environment where the clustering algorithm produces a large number of patterns. The number of patterns needs to be reduced in order to make the results of the technique assimilable. Threshold figures are set for the interestingness measures. Patterns that do not surpass these threshold figures are rejected as "uninteresting". This is clearly not the situation here, where the algorithm produced only 19 clusters. Nonetheless, it was valuable to contemplate how the clusters fared on the measures in order to achieve a level of understanding of the usefulness of the knowledge that might be conveyed by the clustering scheme. The SOM clusters fared well on Simplicity, Novelty, Certainty and Utility measures.

### 5.5.2 Were the clusters logical?

The next step in the validation of the clustering scheme was to look at the procedures that were grouped together from a naive perspective and consider whether the grouping made sense. This is discussed below.

While many clusters appeared to be simplistic grouping of procedures (such as the linking of X-rays to fractures and plaster of Paris), other less obvious groups of procedures were identified. One example is provided in Table 5-7. This cluster was characterised by patients who receive sutures accompanied by a dressing. A number of other procedures were associated with this treatment. Most patients received some form of medication. Patients were sometimes X-rayed to determine whether there was a fracture in addition to the tissue damage. Laboratory investigations were rarely performed in conjunction with this treatment.

Common sense would dictate that X-rays and Plaster of Paris would frequently be paired as activities of a single process, and this is seen in Cluster 16. Similarly, it would be expected that ECG and ECG monitoring occur as part of the same process, as seen in Cluster 8. Beyond these simplistic observations it was not possible to evaluate the clinical appropriateness of the cluster components. This required expert input, as discussed in the next section.

Table 5-7 Procedures in treatment of emergency department patients requiring sutures

| Matching records | | 4.19% |
|---|---|---|
| CT | CT Scan | -* |
| DRS | Dressing | **0.81** |
| DRUG | oral, sublingual, topical, rectal drug administration | 0.47 |
| FWT | Full ward test urine | - |
| INF | Infusion IV fluid (ex blood products) | - |

| | | |
|---|---|---|
| IV | Peripheral IV catheter | 0.06 |
| IVS | IV/IM/SC injection | 0.25 |
| NEB | Nebulised medication | - |
| O | observation | 0.41 |
| POP | Plaster-of-Paris | - |
| RBG | Random blood glucose | - |
| SUT | Sutures | **0.99** |
| XRAY | X-ray imaging | 0.15 |
| * This may be interpreted as the mean proportion of patients in the cluster who underwent these procedures | | |

### 5.5.3 Expert opinion

Once it seemed that the clustering was logical from a naïve perspective, the clustering scheme was discussed with the Director of Emergency Medicine at the hospital. By looking at the full output of the clusters (Table 5-8[54]) he confirmed links between the grouping of procedures and likely presentations by patients. With this support for the clinical relevance of the clustering two last cluster validations were performed. These are discussed in sections 5.5.4 and 5.5.5.

[54] Decimal figures are given without the leading zero in order to fit the width of the table in the page.

Table 5-8. Proportion of patient records that carry procedures in SOM clusters

| Cluster | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Records (000's) | 6.4 | 9.7 | 4.7 | 3.7 | 1.8 | 1.6 | 1.6 | 2.6 | 2.0 | 1.9 | 1.2 | 1.9 | 1.1 | 0.7 | 0.7 | 0.9 | 0.7 | 0.5 | 0.5 |
| % | 14.5 | 22 | 10.5 | 8.42 | 4.18 | 3.51 | 3.67 | 5.82 | 4.59 | 4.27 | 2.65 | 4.19 | 2.56 | 1.65 | 1.62 | 2 | 1.48 | 1.16 | 1.21 |
| ABG | | | .0 | | | | | | | | | | | | | | .1 | 1.0 | .0 |
| ARTL | | | | | | | | | | | | | | | | | .07 | | |
| BAC | .03 | | | | | | | | | | | | | | | | .01 | .01 | .02 |
| CPAP | | | | | | | | | | | | | | | | | .01 | | |
| CPR | | | | | | | | | | | | | | | | | .02 | | |
| CT | .01 | | | | .99 | .21 | | | .01 | .01 | .05 | .01 | .13 | .01 | .01 | .01 | .20 | .08 | .04 |
| CVL | | | | | | | | | | | | | | | | | .04 | | |
| DIG | | | | | | | | | | | | .04 | | | | | | | |
| DRS | | .01 | | | .01 | .10 | 1.00 | | | .02 | .01 | .81 | .02 | .14 | .34 | .11 | .01 | | .68 |
| DRUG | .52 | .75 | .60 | .63 | .54 | .58 | .57 | .61 | .71 | .62 | .49 | .47 | .47 | .59 | .77 | .48 | .42 | .48 | .45 |
| ECG | .48 | .11 | .32 | .21 | .56 | .38 | .03 | .99 | .28 | .53 | .17 | .03 | .58 | .05 | .01 | .03 | .59 | .73 | .10 |
| ECGM | .01 | | | | .12 | .13 | | 1.00 | .07 | .19 | .03 | | .26 | | | | .33 | .33 | .02 |
| ENEMA | | | .01 | | | | | | | | | | | | | | | | |
| ETT | | | | | | | | | | | | | | | | | .17 | .01 | |
| EYE | | | | | | | | | | | | | | | .86 | | | | |
| FWT | .01 | | .27 | .98 | .21 | .11 | .01 | .09 | .05 | .22 | .26 | .01 | .33 | | | .01 | .35 | .16 | .04 |
| GCH | | | .02 | | | | | | | | | | | | | | | | |
| HIO | .01 | | | | | 1.00 | | | | | .02 | | .08 | .02 | .01 | .01 | .07 | .02 | .07 |
| IC | | | | | | | | | | | | | | | | | .01 | | |
| ID | | | | | | | .01 | | | | | | | | | | | | |
| INF | .03 | .02 | .99 | .03 | .36 | .25 | .05 | .31 | .11 | .52 | .37 | .02 | .33 | .05 | .01 | .05 | .58 | .60 | .09 |
| IV | .56 | .04 | .80 | .31 | .71 | .37 | .12 | .68 | .34 | .92 | .58 | .06 | .64 | .18 | .03 | .18 | .76 | .46 | .19 |
| IVI | .01 | | | | .09 | .02 | | | .08 | 1.00 | .08 | | .10 | .01 | | .02 | .24 | .17 | .03 |
| IVS | .42 | .09 | .68 | .18 | .39 | .26 | .18 | .51 | .23 | .24 | .36 | .25 | .40 | .18 | .06 | .19 | .51 | .57 | .37 |
| LP | | | | | .03 | | | | | | | | | | | | | | |
| NAS | .01 | | | | | | | | | | | | | | | | | | |
| NEB | | | | | | .01 | | | 1.00 | | | | .03 | | | | .05 | .11 | |
| NGT | | | | .03 | | | | | | | | | | | | | .05 | | |
| NUC | | | | | | | | | | | | | | | | | | | |
| o | .74 | .99 | .54 | .66 | .64 | .22 | .57 | .47 | .72 | .83 | .53 | .41 | .61 | .72 | .26 | .55 | .72 | .38 | .44 |
| POP | | | | | | | | | | | | | | .18 | | 1.00 | | | .01 |
| RBG | | | | | | | | | | | .01 | | 1.00 | | | | .09 | .51 | .01 |
| RED | | .02 | | | | | | | | | | | | | | | | | |
| RoC | | | | | | | | | | | | | | | | | | | |
| RoFB | | | | | | | | | | | | | | | .28 | | | | .02 |
| RoS | | | | | | | .01 | | | | | | | | | | | | |
| SPA | | | | | | | | | | | | | | | | | | | |
| SPL | | | | | | | | | | | | | | 1.00 | | | | | .01 |
| SPR | | | | | | | | | .02 | | | | | | | | | | |
| SUT | | | | | | .08 | | | | | | .99 | .01 | .05 | .03 | .02 | | | .46 |
| TET | | | | | | | | | | | | .02 | | | | | | | 1.00 |
| TRANS | .02 | | | | | | | | | | | | | | | | .03 | | |
| UC | | | | | | | | | | | | | | | | | .91 | | |
| ULS | | | | | | | | | | | 1.00 | | | .01 | | .01 | .03 | .02 | |
| VB | .82 | .06 | .80 | .56 | .79 | .50 | .10 | .87 | .40 | .77 | .75 | .04 | .79 | .08 | .03 | .12 | .77 | .78 | .13 |
| WALK | | .01 | | | | | | | | | | | | | | | | | |
| XRAY | .41 | .39 | .44 | .35 | .55 | .46 | .37 | .73 | .49 | .58 | .25 | .15 | .48 | .84 | .05 | .89 | .59 | .66 | .30 |

### 5.5.4 Validation of SOM clusters through text mining

It was mentioned in Chapter 4 that the data carried a (free-form) text field used for recording symptoms and working diagnoses. In the absence of diagnosis data it was considered that the text field might yield similar information that could be compared to the clusters. It was hoped that the suitably encoded text could be searched for patterns of phrases or key words. Resulting patterns could be compared to the SOM clusters to determine whether there was some agreement in the way these separate views interpreted the real world represented by the data.

Since this is a long section, a brief introduction will assist the reader. The data used for the text mining exercise is described; some of the problems indicated and pre-processing to get the data into a suitable state outlined. A simple ED ontology was devised to provide structure for the analyses that follow. This is described in Section 5.5.4.3 as a prelude to the data analysis in the following sections.

The text analysis according to the ontology is described in Section 5.5.4.4 and clustering of the text in the next section. Section 5.5.4.5 includes problems encountered in clustering the large data set that was generated during the analysis and the results given of some of the strategies used to overcome these problems. The section concluded that the text analysis gave some indication that the SOM clustering could be related to patient symptoms and presentation problems, but absolute correlation could not be claimed between the SOM clusters and presentation text.

#### 5.5.4.1 The data for text mining

While the objective of this study was simple, it was tedious to achieve. The presenting problem is a free-form text field of unknown length in the EDIS, but truncated at 100 characters in the data. A number of specific issues were encountered:

- The text field was completely free form. There was no spell checking, nor uniformity in abbreviations or descriptions.
- The text was a mixture of lower and uppercase without consideration of grammatical norms.
- The same words were separated by spaces in some instances, and by slashes, commas, colons or other creative punctuation in other instances.
- Many variations were detected in spelling of words and a number of non-standard as well as conventional acronyms were used. This meant that there was no standardisation of words, spelling, abbreviations or terminology. For instance, one

of the most frequent symptoms was "vomiting and diarrhoea". This was alternately listed and "V&D", "V&Ds", "V and D", "V/D" and so on.

- There were also numerous spellings of both words when they were used in full, and sometimes the words or abbreviations were placed in opposite order[55].

#### 5.5.4.2 Data pre-processing

Only records from 2002 were used in order to contain the size of the analysis. The data was converted to uppercase to make it more uniform. In a first effort at converting the text to a standard format, the text column was imported with its case identifier into a word processor and misspellings of words corrected. This was necessary since SPSS does not have text functions such as spelling correction and parsing and the file was too large for Excel. An attempt was made to standardise the abbreviations throughout. All words were separated with spaces and then split into columns with the intention of searching each column for common words.

Having the words in columns in SPSS did make it possible to identify most common words in each column and so start to gain an understanding of information contained in the text. But this exercise was time-consuming and tedious and of only limited success because the same word could occur in every column. A framework was needed to ensure that words were grouped together. It was considered that an ontology for the ED might provide such a framework. This is described in the next section.

#### 5.5.4.3 Creating an ED ontology

The exercise described above resulted in a list of common words (with clinical abbreviations such as COAD, PV and PR treated as words). It was hoped that these words could be overlaid on an existing medical ontology because medical ontologies are well developed (See Burgun, et al., 2005 for an overview of medical ontologies). This would provide essential dimension reduction and several "levels" for analysing the data.

---

[55] The difficulties in performing analyses on this text support the implementation of certain rules and conventions when entering text into the presentation problem field in the EDIS. Measures as simple as spell checking could assist greatly with electronic management of patient records. There is potential to design a structured presentation problem entry system that allows point and click functionality. One idea is that the triage nurse can click on a picture of the body to denote affected part, indicate cause and severity. A structured entry system will assist uniform data capture while allowing clinical record keeping to take precedence over other gathering of statistics (for the Accident Research Centre at Victorian EDs). Nurses would be able to keep cause and symptoms separate yet have faster data entry.

Ontologies such as openGALEN, the UMLS Semantic Network, SNOMED CT, the Foundational Model of Anatomy and MENELAS, as well as two general ontologies, openCyc and WordNet were studied with a view to “overlaying” the common ED words onto the ontological structure. It did not prove feasible to do this because the ontologies did not relate sufficiently to the text on hand. They were either too medically specific or too detailed with respect to body part descriptions.

Since the text descriptions of presentation problem included body part affected, degree of pain, exact medical term, cause of symptom and symptoms, it was decided to construct a taxonomy that could provide the necessary dimension reduction, yet be sufficiently rigorous to extend into an ontology for ED presentations. The structure shown in Table 5-9 was arrived at after study of most common words and likely format of the text field. It follows the general logic of a patient presenting with symptoms that have a certain level and act upon a body part that may or may not be a part of a larger body structure and be on one or other side of the body. These patient characteristics are followed by details of the problem that might give some indication about its nature. These details include the cause, whether some object, animal or other third party was involved, and if and how the patient was referred. The patient urgency and treatment were supplemental fields that were determined from the patient treatment record and the SOM clustering, respectively.

Table 5-9: Taxonomy of common ED presentation problems

| Presentation problem | Example |
|---|---|
| has_symptom | Ache, swelling, etc. |
| which_has_degree | High, low, big, small, exacerbated, etc. |
| which_acts_on | Abdomen, limb, head, tissue, blood |
| with_anatomic_part | Foot, ankle, arm, hand, eye, neck, etc. |
| which_has_selector | Left, right, bilateral, both |
| was_caused_by | Fall, hit, intake, etc. |
| with_utility | Vehicle, creature, object, drug |
| referred_by_or_to | Paediatrician, psychiatric, procedure, LMO, etc. |
| with_mode_of_referral | Patient request, letter, ref, etc. |
| The above were supplemented with two existing data fields: | |
| has_treatment_priority | Urgency |
| has_treatment | Treatment cluster from data mining of procedures |

#### 5.5.4.4 Text analysis

After some searching for a suitable text analysis tool a decision was made to use a trial version of Wordstat from Provalis Research. This software has facilities for building a dictionary with included and excluded words, synonyms and phrases. It has stemming algorithms, and can transform word frequencies from counts to binary as well as identifying common words and phrases. The trial version was fully functional but limited to 30 days’ use.

The dictionary was initialised with the high-level categories described in Table 5-9. Subcategories were created to cater for the most frequent occurrences within the categories. Individual words were associated directly with the subcategories. The only exception was the nesting of *with_anotomic_part* category under the *which_acts_on* category to permit grouping of body parts into broader classifications. The final list of categories and sub-categories is provided in Table 5-10.

Table 5-10: Categories and subcategories from ED text data

| | | |
|---|---|---|
| SYMPTOM / BLEED | SYMPTOM / CARDIA | SYMPTOM / COLLAPSE |
| SYMPTOM / DEHYDRATION | SYMPTOM / DIABETIC | SYMPTOM / DIARRHOEA |
| SYMPTOM / FEVER | SYMPTOM / HYPERTENSION | SYMPTOM / INFECTION |
| SYMPTOM / INFLAMMATION | SYMPTOM / INJURED | SYMPTOM / MENTAL |
| SYMPTOM / PALPITATIONS | SYMPTOM / PREGNANT | SYMPTOM / RESPIRATORY |
| SYMPTOM / APPENDIX | SYMPTOM / UNWELL | SYMPTOM / VOMIT |
| | | |
| LEVEL / GENERAL | LEVEL / HIGH | LEVEL / LOW |
| LEVEL / LOWER | LEVEL / NO | LEVEL / POST |
| LEVEL / SUDDEN | LEVEL / WITH | LEVEL / EXACERBATED |
| | | |
| BODY / ABDOMIN | BODY / BLOOD | BODY / HEAD |
| BODY / LIMB | BODY / TISSUE | |
| | | |
| SELECTOR / LEFT | SELECTOR / RIGHT | SELECTOR / BILATERAL |
| SELECTOR / BOTH | | |
| | | |
| CAUSE / BURN | CAUSE / FALL | CAUSE / FOREIGN |
| CAUSE / HIT | CAUSE / INTAKE | CAUSE / BITE |
| | | |
| UTILITY / DRUG | UTILITY / OBJECT | UTILITY / VEHICLE |
| | | UTILITY / CREATURE |
| | | |
| REFERRED / LMO | REFERRED / PAEDIATRIC | REFERRED / PROCEDURE |
| REFERRED / PSYCHIATRIST | | MODE |

The text field was supplied to Wordstat as a single document comprised of a number of statements (one for each patient record). The link was retained between each text record and its case identifier through a linkage in Wordstat's associated Simstat software. A succession of analyses was performed using Wordstat. The dictionary was updated after each trial so that the categories absorbed all common words, their misspellings and abbreviations that appeared in the text field[56]. An extract is provided in Table 5-11:

Table 5-11: Sample of dictionary terms

| | | |
|---|---|---|
| CAUSE | | |
| | BITE | |
| | | STING (1) |
| | | STINGS (1) |
| | BURN | |
| | | BURNED (1) |
| | | BURNS (1) |
| | | SCALD (1) |
| | | SCALDED (1) |
| | | SCALDING (1) |

[56] The final dictionary is in Appendix 5-A

| | | |
|---|---|---|
| | | SCALDS (1) |
| | FALL | |
| | | FAL?? (1) |
| | | FALL (1) |
| | | FALLEN (1) |
| | | FALLING (1) |
| | | FALLS (1) |
| | | FELL (1) |
| | | FELLS (1) |

Wordstat provided facility to output a table of word counts for each record. Since the list of common words extended to hundreds of words even after the dictionary had been extensively refined, the output was limited to a count of categories and sub-categories.

#### 5.5.4.5 Clustering text

Numerous attempts were made to link the columns of text to procedure-based treatment clusters. First the Wordstat output was converted into SPSS and combined with the full Frankston patient data for 2002 (demographics, visit detail and procedures and SOM cluster number).

The limit of 50 variables imposed by Viscovery SOMine made it difficult to overlay the text variables on the SOM clusters. Viscovery will not overlay files using only the case identifier, but requires components of the original map in order to do the association. It was attempted to reduce both the number of procedures and number of text variables in order to get the total variables to less than 50 so that the association could be performed. This met with only limited success.

In another approach a map was built using the single variable "SOM cluster number". This allowed 49 text variables to be associated with the map. Agreement was seen between presentation problem and the treatment cluster, in particular for dislocated or broken limbs, head injuries and respiratory problems. Correlations were indicated between cardiac problems and fevers (Table 5-12).

Table 5-12: Word associations derived from overlay on SOM treatment clusters

| **Cluster number** | **Commonly associated words (not a complete listing)** | **Procedures in cluster (brackets indicate less than 20% incidence)** |
|---|---|---|
| 1 | Unwell, Abdomen | DRUG, ECG, IV, IVS, O, VB, XRAY |
| 2 | Unwell, Injured, Left, Right Body Limb | DRUG, (ECG), (IVS), O, (VB), XRAY |
| 3 | Intake, general, appendicitis, diarrhoea, vomit (blood) | DRUG, ECG, (FWT), INF, IV, IVS, O, VB, XRAY |
| 4 | Low, dehydrated, diarrhoea, vomit, fever | DRUG, ECG, FWT, IV, (IVS), O, VB, XRAY |
| 5 | Cardia, collapse, mental | CT, DRUG, ECG, (ECGM), (FWT), INF, IV, (IVI), IVS, O, VB, XRAY |
| 6 | Fall, hit, intake, post, ref_ paediatrician, ref_psyche, drug, vehicle | (CT), (DRS), DRUG, ECG, (ECGM), (FWT), HIO, INF, IV, IVS, (o), (SUT), VB, XRAY |
| 7 | Tissue, burn, mode | DRS, DRUG, (IV), (IVS), O, (VB), XRAY |
| 8 | Abdomen, sudden, collapse, palpitations, unwell | DRUG, ECG, ECGM, (IV), (IVS), O, (VB), XRAY |
| 9 | Exacerbated, infected, respiratory | DRUG, ECG, INF, IV, IVS, NEB, O, VB, XRAY |
| 10 | Dehydrated, inflamed | DRUG, ECG, (ECGM), (FWT), INF, IV, IVI, IVS, O, |

| | | |
|---|---|---|
| | | VB, XRAY |
| 11 | Bleed, pregnant, low, with, ref_LMo, appendicitis | DRUG, (ECG), FWT, INF, IV, IVS, O, ULS, VB, XRAY |
| 12 | Head, injury | DRS, DRUG, (IVS), O, SUT, XRAY |
| 13 | Collapse, diabetes, mental | (CT), DRUG, ECG, ECGM, FWT, INF, IV, (IVI), IVS, O, RBG, VB, XRAY |
| 14 | Limb (arm, leg, etc), fall | (DRS), DRUG, (IV), (IVS), O, (POP), SPL, XRAY |
| 15 | Head (includes eye), bite, burn, foreign, object, lower | DRS, DRUG, EYE, O, RoFB, VB, XRAY |
| 16 | Limb, fall, ref_paediatrician, ref_procedure (removal of cast, etc.) | (DRS), DRUG, (IV), (IVS), O, POP, (VB), XRAY |
| 17 | Intake, hypertension | (CT), DRUG, ECG, ECGM, (ETT), FWT, INF, IV, IVI, IVS, O, UC, VB, XRAY |
| 18 | High, low, no, cardia, creature, (injury) | ABG, DRUG, ECG, ECGM, (FWT), INF, IV, (IVI), IVS, (NEB), O, RBG, VB, XRAY |
| 19 | Injured, foreign, fall, head, limb | DRS, DRUG, (ECG), (HIO), (INF), (IV), IVS, O, SUT, TET, (VB), XRAY |

Correspondence analysis was tried in SPSS. A two dimensional table was built that listed the count of words for each procedure. Analysis of this table led to similar results to the above, with key words having high counts in the cells where they intersected with appropriate procedures. It was interesting to note the similarity in counts between key words and the paired procedures ECG/ECGM and SPL/SUT. Some observations are included in Table 5-13.

Table 5-13: Word associations from correspondence analysis of words and procedures

| Procedure | Word Categories |
|---|---|
| CT | Cause/hit; symptom/cardia, collapse; utility/vehicle |
| DRS | Body/tissue; cause/burn, foreign; symptom/injured |
| DRUG | Cause/bite, burn, foreign; selector/left, right; symptom/fever; utility/creature |
| ECG/ECGM | Body/abdomen; cause/intake; level/sudden; symptom/collapse, hypertension, palpitations |
| EYE | Body/head; cause/foreign |
| FWT | Body/blood; symptom/appendicitis |
| HIO | Body/head; cause/hit; utility/vehicle |
| INF | Body/blood; symptom/dehydrated, diabetic, diarrhoea, vomit |
| IV | Symptom/appendicitis |
| NEB | Body/abdomen; level/exacerbated; symptom/infected, respiratory |
| O | Body/head; cause/foreign; referred/psyche |
| POP | Body/limb; cause/fall; referred/paediatrician, procedure; symptom/injured |
| RBG | Symptom/diabetes |
| SPL/SUT | Body/limb; cause/fall, hit, selector/left, right; symptom/injured |
| TET | Cause/bite, burn, hit |
| UC | Body/abdomen; cause/intake; referred/LMo; symptom/cardia, collapse, dehydrated |
| ULS | Symptom/pregnant |
| VB | Body/blood, symptom/cardia, pregnant |
| XRAY | Body/limb; cause/fall, hit, referred/procedure; selector/left, right; symptom/inijured; utility/vehicle |

Another clustering approach was tried on the word categories alone. The word category columns were entered as variables in a hierarchical agglomeration (Ward's method). This resulted in two general groups of words that appeared to relate to injured and ill patients. Within the injured patients there appeared to be segmentation into bone and tissue related key words. The ill patients segmented into sick and very sick subgroups. Within the very sick group respiratory presentations appeared to be distinct from cardia and other presentations. The sick group seemed divided into infected and fever-related words. One possible grouping from this analysis is presented in Table 5-14.

Table 5-14: Term clustering from hierarchical agglomeration of word categories

| Injured | | Ill | | | |
|---|---|---|---|---|---|
| Bone | Tissue | Very sick | | Sick | |
| | | Respiratory | Cardia et al | Infections | Fevers |
| Cause/fall | Cause/bite | Ref/paediatric | Level/lower | Level/high | Cause/intake |
| Utility/vehicle | Cause/burn | Symptom/resp | Symptom/cardia | Level/post | Symptom/diarrhoea |
| Cause/foreign | Body/tissue | Level/exac | Level/sudden | Ref/procedure | Level/general |
| Utility/vehicle | Utility/creature | Symptom/infect | Level/with | Symptom/bleed | Symptom/vomit |
| Referred/psyche | Symptom/injured | | Symptom/pregnant | Level/no | Symptom/fever |
| Utility/drug | Selector/left, right | | Symptom/bleed | Symptom/unwell | |
| Cause/hit | Body/limb | | Selector/bilateral | Ref/LMo | |
| Utility/object | | | Symptom/appendix | Symptom/inflamed | |
| Body/head | | | Body/blood | Level/low | |
| | | | | Mode (letter, etc.) | |
| | | | | Selector/both | |

#### 5.5.4.6 Summary of the text mining validation

This section described at some length another view of the ED data provided by text mining. The text mining exercise confirmed links between presentation problem and procedures and SOM clusters, and so implied the linkage between the SOM clusters and patient treatment in the real world. The link between the text and the SOM treatment clusters was difficult to confirm with certainty because of the dimensions of the data file (hundreds of columns by thousands or records), none the less, this validation gave some confidence to the validity of the SOM clusters.

### 5.5.5 Comparison with other ED's[57]

The verification and validation exercises described so far in this chapter provided a large measure of comfort that the SOM clusters summarised actual ED treatment activities. A last validation was performed using ED data from several other hospitals.

#### 5.5.5.1 The Victorian Emergency Medical Data

The Victorian Emergency Medical Data set (VEMD) was used in this study. The data was made up of 984686 de-identified records of all ED presentations in 2002 across 31 anonymous campuses throughout the state of Victoria. Each record contained demographic particulars and details of the visit such as "apparent severity of complaint", "key time points" and "disposition", plus all medical procedures performed.

Data sets from five similar-sized campuses were selected for clustering with Viscovery SOMine. Random samples of approximately 10 000 cases were extracted from all cases where patients underwent more than one procedure. The software limit of

[57] This work was presented to clinicians and administrators at Casemix 2003 in Sydney, Australia.

50 input variables meant that 13 least-used procedures had to be omitted from the analyses, as was the "NONE" procedure. These exclusions totalled less than 1% of procedures in cases where patients had more than one procedure. Procedure "OTHER" was retained as a variable but omitted from the clustering since it did not appear to add information nor improve the clustering. Results of SOM on the VEMD data set are discussed next.

#### 5.5.5.2 Clustering results on the Victorian Emergency Medical Data

Between 13 and 27 clusters were identified across the five data sets. These clusters accounted for all patients whose treatment involved two or more procedures (This was generally around 60% of all patient presentations). As can be seen in the (truncated) example in Table 5-15, the clusters tended to be defined by a single key procedure that all patients in that cluster undergo (NEB – nebulised medication). The clusters were further characterised by allied procedures most commonly performed with the defining procedure (XRAY, DRUG, VB, ECG, IV, FWT at all three campuses, with IVS at two campuses).

Table 5-15: Nebulised medication procedures across three campuses

| Campus | | NNAR | INDW | NBQW |
|---|---|---|---|---|
| % Patients | | 2.9% | 2.4% | 3.6% |
| **Procedure Description** | | | | |
| Nebulised Medication | NEB | **1.00** | **1.00** | **1.00** |
| X-ray | XRAY | 0.43 | 0.26 | 0.47 |
| oral/ sublingual/ topical/ rectal drug admin. | DRUG | 0.81 | 0.89 | 0.80 |
| Venipuncture | VB | 0.28 | 0.21 | 0.29 |
| 12 Lead ECG | ECG | 0.16 | 0.14 | 0.15 |
| Peripheral IV catheter (IV access) | IV | 0.28 | 0.22 | 0.24 |
| Full ward test - urine | FWT | 0.06 | 0.09 | 0.06 |
| IV/ IM/ SC infusion | IVS | 0.13 | | 0.12 |

In the example given in Table 5-16, it can be seen that there was much agreement across campuses regarding the reporting of "Head Injury observation" (HIO), despite the varying percentage of patients (second column of the table). The campus in the last row displays anomalous Random blood glucose (RBG) and Spirometry (SPR) that may be a function of the clustering algorithm or indicate different patient and treatment profiles.

Table 5-16: Head Injury observation across five campuses

| Campus | % Patients | HIO | XRAY | IV | IVI | VB | DRS | SUT | ECG | FWT | INF | DRUG | CT | IVS | RBG | SPR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NBQW | 4.2 | **1.0** | 0.5 | 0.4 | 0.0 | 0.5 | 0.1 | 0.0 | 0.4 | 0.1 | 0.2 | 0.6 | 0.2 | 0.2 | 0.0 | 0.0 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NMXW | 3.4 | **1.0** | 0.3 | 0.1 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NNAR | 2.3 | **1.0** | 0.4 | 0.5 | 0.0 | 0.4 | 0.1 | 0.1 | 0.3 | 0.2 | 0.2 | 0.5 | 0.1 | 0.3 | 0.2 | 0.0 |
| INDW | 0.9 | **1.0** | 0.4 | 0.4 | 0.1 | 0.3 | 0.2 | 0.2 | 0.1 | 0.3 | 0.1 | 0.5 | 0.1 | 0.2 | 0.1 | 0.0 |
| ILWR | 0.6 | **1.0** | 0.4 | 0.3 | 0.0 | 0.4 | 0.2 | 0.1 | 0.3 | 0.3 | 0.1 | 0.4 | 0.2 | 0.1 | 0.5 | 0.5 |

Other typical defining procedures for clusters common across multiple campuses were (figures in brackets indicate likelihood of procedure):

- 12 Lead ECG (1.0), with Peripheral IV catheter and Venipuncture (0.6);
- 12 Lead ECG and ECG monitoring (1.0), with Venipuncture (0.9);
- Peripheral IV catheter and IV drug infusion (1.0), with Venipuncture (0.7);
- Suture, Steri-strip, glue (1.0) with Dressing (between 0.6 and 0.9);
- Plaster of Paris (1.0) and X-ray (0.9) with Drug administration (around 0.5);
- Splint (1.0), X-Ray (0.8) with Drug administration (between 0.2 and 0.6);

These Clusters each comprised between 2 and 9 percent of patients and added up to between 20 and 30 percent of patients. In addition to these widespread clusters, there are typically two to three large clusters at each campus that provide for some 25 percent of presentations. These large clusters often include Drug administration (DRUG), Venipuncture (VB) and Full ward test (FWT) or 12 Lead ECG (ECG), but the proportions differ between campuses.

#### 5.5.5.3 Summary of the comparison of SOM clustering across EDs

This section described how similar SOM clusters were detected in the data from a number of EDs. The cross-campus clusters described in this section have a number of applications. Most obviously, the clusters give insights into how EDs are recording treatment of patients. This can be used as an aggregated level to study where coding practices are different and identify whether patients are being treated differently at that location or whether further training is needed to ensure uniform coding practices.

The cross campus SOM clusters were similar in style to the SOM clusters obtained for the ED under study in this thesis. This seems to confirm the idea that procedure based clusters provide a valid view of ED treatment, and did not arise as a vagary of the particular data set in the study. It remains to summarise Chapter 5 and preview Chapter 6.

## 5.6 Chapter summary

This chapter set out to describe how clustering of ED patients according to the procedures they underwent helped inform thinking about the nature of ED treatment.

Process-based thinking was used in order to derive a simplified model of emergency department operations. It was described how this “process-focussed” model of ED operations directed thinking towards the grouping of procedures and how this resulted in definitive clusters of procedures. These SOM clusters were verified and validated through a number of studies.

A number of other studies were conducted in conjunction with the SOM clustering of the data but not discussed in this chapter because they did not add new knowledge. Attempts were made to achieve rule-based segmentation using both Classification and Regression Trees (CART) and Association Mining. These efforts were markedly less successful than SOM clustering. In the case of CART, absence of a procedure was recognised significant. This did not make clinical, nor process, sense. In addition, identification of an appropriate objective variable was difficult. No “pure” leaves could be detected, regardless of objective variable (different lengths of stay, urgency, age, sex, individual procedures, and so on) and input variables that were used. Association Mining yielded gross clusters that did not account for the overlap of procedure use in different patient types. This (and other) shortcomings of Association Mining is well known and drives a considerable area of research known as Workflow Mining (Agrawal, Gunopulos, et al. (1998); Angluin and Smith (1983); Cook and Wolf (1998)). The use of CART and Association Mining within SOM clusters is considered in Chapter 7 as potential extensions to the research.

Manipulation of the SOM clusters led to insights into the potential of using SOM clusters for activity based costing, guiding industrial engineering studies and design of ED information systems. These are discussed in Chapter 7 since the investigations were only of an exploratory nature. One of the most interesting extensions, though, was the idea that the SOM clusters might be incorporated into a simulation model of the ED. It was thought that the clusters of patient procedures could be used to summarise patient treatment activities and so add to the knowledge gained from traditional patient flow / resource constrained approaches to discrete event simulation of EDs. This simulation work is described in the next chapter.

# Chapter 6: Treatment-based simulation

The last two chapters have taken discussion towards a process-focussed view of patient treatment. In Chapter 4 the fields in the ED data were analysed singly and in various combinations in an effort to uncover knowledge about ED treatment. Although some information was gleaned from the data set, it was of little practical use in building a simplified model of ED treatment. Chapter 5 extended the investigation by placing the analyses into a process context. This strategy yielded the knowledge that it is possible to group patients according to the record of procedures they received in the course of their treatment. These groups, or SOM clusters, as they were referred to in Chapter 5, could be viewed as treatment processes that were related to patient symptoms and had analogues at other EDs. The SOM clusters provided a way of summarising ED treatment in a concise and comprehensible manner.

This chapter further extends the discussion of ED treatment towards analysis of ED overcrowding by describing how the inclusion of SOM clusters in a discrete event simulation model of the ED provided insights into the mechanism of ED overcrowding. As is common with Management Science projects, much of the learning came about in the construction, verification and validation of the model, rather than the completed model itself.

To refer back to the model of Scientific Research that was described in Chapter 3, it may be seen that the previous chapters included multiple cycles through experimentation, observation (correlations) and hypothesis formation through deduction or discovery. Problems or inconsistencies that arose in the course of verifying and validating the clustering needed to be overcome through deductive or inventive hypotheses. Each one of these exercises contributed to the knowledge about the data set and the system that generated it. This chapter will continue this trend, with the model being taken through several iterations, each an improved (on the basis of verification and validation results) model of reality.

The chapter starts with discussion of resource constrained discrete event simulation models. This will be couched in general terms to avoid repeating the information about ED models that was provided in Chapter 2. This discussion will lead naturally to the idea that treatment activities may be included in a discrete event simulation without traditional resource constraints.

The building of the simulation model occurred in three phases. The initial phase explored which stochastic elements might be included. During verification of the initial model the importance of variable numbers of beds in reproducing queue times of patients was recognised. This led to a second, system dynamics inspired model that allowed for adaptive behaviour by ED staff (increasing the number of treatment sites) when the ED approached blockage. While the second model was being validated, a tool called HillMaker (cf Section 1.3.3) became available that permitted the number of patients in the ED to be counted at any time of the day. The new information derived from this tool was incorporated into a third "black box" model that sought to replicate the number of patients in the ED without attempting to model patients in beds. This final model was calibrated to match the actual ED data closely.

The model building process and analysis of the outputs produced some interesting results regarding the mechanisms of ED blockage. These are discussed at the end of the chapter.

By the end of the chapter a comprehensive picture will have been built up of the mechanism of ED overcrowding and some solutions explored to mitigate ED blockage. This chapter also concludes the experimentation aspect of this thesis and leads into the conclusions, discussion of new knowledge gained from the work, unexplored new insights and future work that is envisioned.

## 6.1 Resource constrained discrete event simulation

The stochasticity built into simulation allows analysts to mimic complex systems and accumulate a level of understanding about real-life operations. The most typical application of the technique is in the identification of bottlenecks in processes. Invariably, these bottlenecks are caused by random tendencies of entity inter-arrival, variation in work times, or issues related to the resources required for the work. Through examination of system operation and bottlenecks the analysts may build understanding of how to manage the system and so construct and compare alternative system structures.

Most frequently, the resources required to perform a task constrain the amount of work that can be done. These "resource-constrained" models provide for disruptions that occur owing to variation in productivity, availability and effectiveness of resources. While these three attributes are generally calculable for equipment and resources, they are less easily estimated for human staff. It's quite possible to generate some sort of distribution for each of attributes for staff, but the task is fraught with potential for error. These errors can accumulate rapidly if staff are grouped into classes owing to a shortage of suitably detailed data (that is, similar productivity, availability and effectiveness distributions are used for sets of people). More relevantly, in the ED environment in

Australia it's almost impossible to gather the necessary information because of worker's unions being concerned about the uses to which such measurements may be put.

In an environment such as the ED where the most critical resources are invariably the clinical staff, simply using simple distributions for work times and grouping staff into resource sets by skill or qualification is bound to lead to difficulties in calibration of the model to match reality. For example, patient treatment times may vary according to the people involved in the treatment (interns or experienced doctors, for instance); the number of people involved in the treatment (urgent patients are likely to be more "resource intensive" than non-urgent patients); or other issues.

One way of addressing the data limitations of resource constrained models is to conceive a model that does not rely on resource constraints to limit throughput. Staff resource requirements can be "assumed away" by using patient treatment time. Treatment times include delays and efficiencies owing to the troublesome ED staff attributes that were discussed in the paragraphs above. By using treatment time, it becomes unnecessary to gather data about the productivity, availability and efficiency of ED staff. Treatment time needs to be defined before this concept can be implemented. This is done in the next section.

## 6.2 Treatment time

As was discussed in Chapter 2, patient-related activities occur in several phases in the ED. In the first phase the patient arrives at the ED and their urgency is assessed. In the next phase the patient is shown to a bed and treated. In the last phase disposal of the patient is decided and the patient leaves the ED. The patient may spend a significant time waiting between the phases or during them. How are these waiting times to be considered with respect to treatment, since the patient is not receiving active attention but may be waiting access to resources or merely under observation?

One of the ways of determining where treatment starts and when it ends is to consider treatment time as the interval between the patients entering the ED treatment area until they leave it. This means that treatment will start when the patient is shown to an ED treatment chair, bed or cubicle (hereafter called a "bed"), and end when they physically depart. While there may be waiting associated with the time the patient spends in an ED bed, and accordingly, little use of other resources, in particular attention from clinical staff, the patient still occupies a resource (the bed) and the staff still have a duty of care to monitor the patient's condition, even if they do not actually directly work on the patient[58]. In this research this time is the difference between the date and time the patient was shown to an ED and the date and time the patient bed physically departed the ED [59]. This will be called "ED time" for the remainder of this thesis[60].

It was policy in the ED under study for patients to retain their bed even if they moved around the ED for X-ray imaging or other procedures. Patients were also not moved between beds, except for resuscitation patients who were stabilised in resuscitation beds then moved to other available beds (to ensure that the resuscitation beds remained available for urgent cases). It will be seen later in this chapter that the data indicates that these guidelines were frequently pretermitted, but at this stage it is adequate to assume a "one patient, one bed" policy.

The use of ED time as a "resource-less" delay process in the simulation model greatly simplifies the data requirements for the model and places the modelling within the limits of the "data-restricted" nature of this research as opposed to in-situ research. Obviously ED time is not completely resource unconstrained – it depends upon the availability of a bed "resource". This brings its own set of accompanying complications that will be discussed further in Section 6.4.

While ED time is a useful construct for the conceptual model, it can quickly be seen that merely modelling patient arrival, bed occupancy and departure is unlikely to provide any new knowledge. The problem is how to allocate ED time to patients in something other than a random fashion as they arrive at the ED so that the model can provide an insight into ED operations. Some form of segmentation of patients seems a logical way in which the model may be progressed to a more useful conceptual level. The process-focussed SOM clusters of Chapter 5 provide a convenient patient segmentation. The application of these to simulation is further described in the next section.

---

[58] It may also be seen from this that there are hidden activities associated with patient presence in the ED (such as ongoing monitoring of their condition, answering their questions, checking that they do not wander around, and so on) that are difficult to capture in resource constrained models.

[59] This is close to the Australasian College for Emergency Medicine's (ACED) definition of "patient care time". The difference between "time in ED" and the standard definition is that the standard definition starts at the time of medical assessment and treatment beginning. There may be a wait between the time a patient is shown to the ED bed and the time the patient is first seen by a doctor. In the ACED definition this wait is included with "waiting time".

[60] "ED Time" is a convenient abbreviation that is separate from the Bed Time, Wait Time, Treatment Time and Admission Delay terms defined in Section 4.2.4. It is not meant to imply that there is no queuing for treatment.

## 6.3 Patient groups in discrete event simulation

Correlations were sought in Chapter 5 between urgency and disposal, and length of stay. Patients receive different levels of attention according to their urgency and treatment needs so it seemed that the model should include these variables. Further analysis of how the variables were interconnected was needed to assist with a process segmentation of patients. The next two sections describe analyses that were done to provide insights into how urgency and disposal might be included in the model.

### 6.3.1 Analysis of clusters by urgency

Numerous analyses were done of the SOM treatment clusters by urgency. One of these was the percentage of patients, by urgency, by treatment (Table 6-1).

Table 6-1: Percentage of patients in each urgency by SOM cluster (treatment)

| Urgency<br><br>SOM Cluster | 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|
| 1 | 0.7% | 26.5% | 44.8% | 25.7% | 2.2% | 100.00% |
| 2 | 0.1% | 9.8% | 41.4% | 42.0% | 6.6% | 100.00% |
| 3 | 0.7% | 18.3% | 52.6% | 27.4% | 1.0% | 100.00% |
| 4 | 0.2% | 12.6% | 54.8% | 30.8% | 1.5% | 100.00% |
| 5 | 2.3% | 29.1% | 52.9% | 15.2% | 0.4% | 100.00% |
| 6 | 1.2% | 28.4% | 53.8% | 16.1% | 0.6% | 100.00% |
| 7 | 0.1% | 7.0% | 27.6% | 55.2% | 10.2% | 100.00% |
| 8 | 2.0% | 65.0% | 27.2% | 5.6% | 0.2% | 100.00% |
| 9 | 1.6% | 29.0% | 57.7% | 11.3% | 0.4% | 100.00% |
| 10 | 2.4% | 33.0% | 41.7% | 22.3% | 0.6% | 100.00% |
| 11 | 0.5% | 10.7% | 45.8% | 40.7% | 2.2% | 100.00% |
| 12 | | 3.7% | 24.1% | 65.9% | 6.3% | 100.00% |
| 13 | 1.3% | 30.9% | 46.0% | 21.2% | 0.5% | 100.00% |
| 14 | 0.4% | 8.8% | 36.8% | 48.5% | 5.5% | 100.00% |
| 15 | | 10.6% | 38.6% | 43.7% | 7.1% | 100.00% |
| 16 | .1% | 5.1% | 36.4% | 51.7% | 6.7% | 100.00% |
| 17 | 18.1% | 27.1% | 40.3% | 13.5% | 0.9% | 100.00% |
| 18 | 7.0% | 50.3% | 35.3% | 7.4% | | 100.00% |
| 19 | 0.2% | 12.7% | 32.1% | 47.7% | 7.3% | 100.00% |
| Total | 1.1% | 20.8% | 43.6% | 31.3% | 3.3% | 100.00% |

It can be seen from the table that all treatments existed in all urgencies. Some treatments were markedly skewed towards urgent categories (such as cluster 17 – typically characterised by hypertension or the intake of poison or drugs; and cluster 18 which was characterised by patients injured in motor vehicle accidents or having cardiac problems).

The variation of the proportion of patients receiving treatments by urgency seemed to indicate that urgency/ treatment groups might be a useful patient segmentation for the simulation model. Analyses similar to that above were performed on disposal. This is discussed next.

### 6.3.2 Analysis of treatment by disposal

Table 6-2 shows the percentage patients in each disposal by SOM treatment cluster. As expected, admitted and discharged patients made up the bulk of presentations. Table 6-2 also shows that all treatments existed in all disposal categories but some were skewed towards admittance (such as clusters 17 and 18 - seen above as likely to be high urgency cases; and cluster 10 which was characterised by patients who collapsed after having cardiac problems), and some towards discharge home (such as clusters 12 and 19 which were similar treatments entailing dressing of wounds, but cluster 12 usually involved sutures, whereas cluster 19 included a tetanus injection).

Table 6-2: Percentage of patients in each disposal by SOM cluster (treatment)

| Disposal<br><br>SOM Cluster | A (admitted) | D (Discharged) | L (left before treatment complete) | X (DOA; died in ED) |
|---|---|---|---|---|
| 1 | 63.6% | 35.4% | 0.9% | |
| 2 | 21.8% | 77.3% | 0.9% | |
| 3 | 81.0% | 18.4% | 0.5% | 0.1% |
| 4 | 49.2% | 50.0% | 0.8% | |
| 5 | 89.7% | 9.9% | 0.4% | |
| 6 | 61.9% | 36.9% | 1.2% | |
| 7 | 20.0% | 79.7% | 0.3% | |
| 8 | 87.8% | 11.7% | 0.5% | 0.1% |
| 9 | 53.3% | 46.3% | 0.4% | |
| 10 | 85.6% | 13.5% | 0.8% | |
| 11 | 78.2% | 21.6% | 0.2% | |
| 12 | 9.9% | 89.5% | 0.6% | |
| 13 | 77.8% | 22.1% | 0.1% | |
| 14 | 31.5% | 68.4% | 0.1% | |
| 15 | 7.5% | 91.9% | 0.6% | |
| 16 | 30.4% | 69.6% | | |
| 17 | 87.1% | 11.9% | | 1.1% |
| 18 | 92.2% | 6.4% | 0.4% | 1.0% |
| 19 | 28.6% | 70.8% | 0.6% | |
| Total | 53.0% | 46.3% | 0.7% | |

Patients who left without completion of treatment were quite evenly spread over the clusters. Death in the ED was more likely to occur with patients in clusters 17 and 18. This latter point cross-validated the clustering scheme with the treatment/ urgency analysis.

The varying proportion of disposals by treatment indicated that this patient segmentation might be useful.

### 6.3.3 Linking treatment with ED time

The above analyses (and the information from numerous other examinations of ED time by SOM treatment cluster, by urgency and by disposal) provided the necessary information to link SOM treatment clusters to the “ED time” concept. Urgency dictated how fast a patient started to receive treatment, and disposal determined whether patients had to wait for hospital admission after treatment. These indicated that urgency and disposal were largely independent of treatment from a process perspective, suggesting that ED time should be segmented by these attributes. Analysis of ED time by urgency, disposal and treatment indicated that the distributions varied somewhat and might be suitable for defining process times in the simulation model (Figure 6-1).

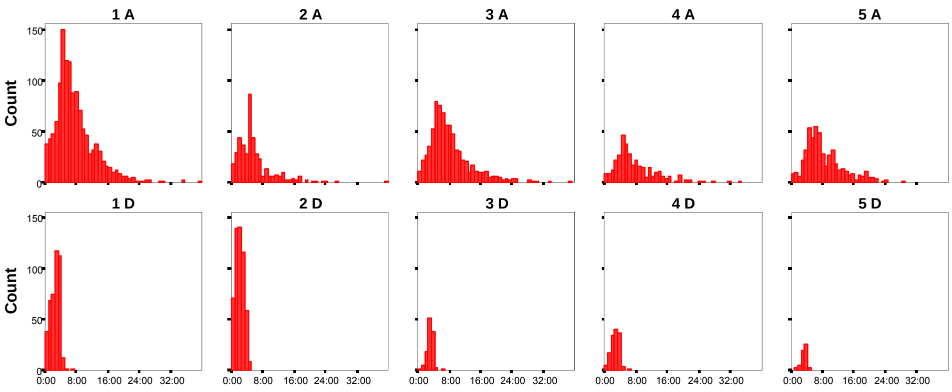



Figure 6-1: Histograms of time in ED for the five largest SOM clusters by Admitted (top) and Discharged (bottom) disposal for patients having urgency=2. The effect of admission delay can clearly be seen for Admitted patients as a tail on the top distributions

Patient types defined as unique combinations of urgency, disposal and treatment were chosen as the patient segmentation for the simulation models. As illustrated in Table 6-3, out of 401 theoretically possible patient types (all possible combinations of 5 urgencies, 20 treatments[61] and 4 disposal codes, plus patients categorised as "dead on arrival"), only 251 occurred in the data and just 161 accounted for 99% of patients. Note also that 80% of patients could be accounted for by just 47 combinations of patient types based on the combination of urgency, treatment and disposal.

Table 6-3: Number of patient types existing in the data

| % of Patients | Number of urgency, disposal, treatment combinations |
|---|---|
| 100% | 251 |
| 99% | 161 |
| 95% | 96 |
| 80% | 47 |
| 60% | 24 |

A discrete event model had been previously built for the ED in this study and supplemented by formalised process diagrams of all ED activities (cf Section 2.2.8). These models focussed on patient flows within generalised processes but failed to provide

[61] 19 treatments from the SOM clusters, plus a single treatment pathway for patients who had none or one procedure recorded.

insight into variation of patient treatment and its effect on the ED system. The models described in the following sections seek to complement these by providing a high level, abstracted view of ED operations. The treatment-focussed discrete event simulation approach encouraged a systems-wide view by ignoring the (distracting) physical movement of patients and instead concentrating on how patient and treatment differences affected overcrowding. The next section formalises the simulation model specifications.

## 6.4 Specifications for the ED discrete event simulation model

The following specifications help systemise the development of the models discussed through the rest of this chapter. They act as guidelines for all the models so may be regarded as common issues. The text will indicate where these specifications were modified.

### 6.4.1 The simulation problem

The foregoing discussions suggest that the simulation problem was to build a useful model of ED operations using existing data and knowledge derived from the patient treatment groups of Chapter 5. The model will be considered useful if it lends insight into the mechanism of ED overcrowding beyond the trivial "system full" explanation. The "existing data" constraint suggested that it was necessary to conceive of a model that did not require data to be gathered about resource utilisation.

### 6.4.2 Simulation project objective

It's usual with simulation to look for process variations that can lead to bottlenecks in systems. Process times are monitored under numerous runs using different random samples of the various distributions used in the model. The average work times or resource utilisation is then calculated along with a confidence interval at a particular confidence level (often 95 or 99 percent).

This objective discussed in Chapter 3 indicated that an atypical simulation experiment was required. Rather than the "usual" operating conditions, the objective was to seek out conditions for "unusual" conditions. The objective was to scrutinise infrequent and catastrophic events (ED blockage) that occurred outside the typical confidence levels of normal operation. To use linear programming terminology, the model was the dual of typical simulation experiments – it was neither a steady state nor terminating study of operations, but an investigation of rare events.

### 6.4.3 Expected benefits of the simulation model

It was hoped that a better understanding could be achieved of how ED overcrowding and blockage develops. This would permit development of strategies to alleviate overcrowding frequency and severity.

### 6.4.4 Scope of the simulation model

Since patient registration and triage were well understood and largely optimised, it was reasonable to model only the stage between patient placement in a treatment bed and their physical departure from the ED. This simplified the system to consideration of whether treatment sites (most commonly ED beds) were physically occupied. Queues developed if all sites were occupied. Resources such as imaging equipment and clinical staff were not explicitly modelled.

Hospital / ED interactions were not modelled since they were outside the scope of the model, but it was recognised that hospital activities could affect ED operations.

Different types of beds existed in the ED and there were rules about the classes of patients that should be put in each[62], particularly with respect to urgency and presentation problem.

### 6.4.5 Level of the simulation model

A high level view of the ED was acceptable, provided it could capture the essential elements of ED operations. The model entities simulated ED patients. The initial model had an equal number of treatment sites to the real-life ED, but did not attempt to be a "scale model" of the ED.

Minutes are the valid time unit for EDs (as opposed to hours in hospital wards and weeks in rehabilitation wards), so the distributions were built in minute increments and the model was set to record minutes.

Since understanding of ED operations for a particular year was required, existing data was sampled where adequate data existed, rather than generating generalised (approximate) distributions of variables. In this way the model could be used to retell the past.

[62] The "business rules" in the ED under study carried the proviso that they could be ignored if necessary, so adult patients might be placed in beds nominally reserved for paediatric patients when all adult beds were filled, for example.

### 6.4.6 Simulation model assumptions

Only 2002 data was used in the model under the assumption that it was representative of other years. While the ED operates 24 hours a day, every day of the year, a full year of simulation was assumed necessary in order to include (a reasonable number of) rare events (such as urgent resuscitation patients and ED blockages).

As described in Section 6.2, it was assumed that ED time catered for resource constraining of patient treatment.

The model was started empty and "warmed up" for a lengthy period prior to data collection. It was assumed that this "steady state" strategy was likely to generate more accurate results than attempting to initialise the model, since little was understood about how the initial parameters interacted in real life.

A usual way to determine appropriate warm-up time is to look for decreased variation in a key statistic but, since the models were not designed to evaluate key statistics, this technique was deemed inappropriate. The infrequency of certain events suggested that a long warm up period would be suitable. The simulation models were warmed up for a year. A year warm-up was decided by checking whether the distributions of sampled variables appeared to match those of the actual data. Both warm-up and operational runs sampled historic data from the same year.

Early incarnations of the model used generalised distributions for ED times. These proved inadequate during validation because the tails of the distributions could produce excessively long ED time values, so historic data was sampled rather than approximating the distributions. This strategy vastly improved the validation results. It was assumed that this did not affect the generalisability of the results.

Arrivals to the ED were based on triage time. In reality, patients arrived at the ED, underwent triage and then registered before being placed on a waiting list for a bed and treatment. The data was more complete for date and time of triage, so this was preferred over the date and time of registration. Generally the wait between registration and triage was very short (and sometimes the order was changed for urgent patients) so it was believed that this assumption would lead to little error.

The patient arrival mode (ambulance, car, and so on) was not considered to have an impact on arrival rate.

Only the four disposal types in the Casemix studies discussed in Chapters 2 and 4 were modelled (admit, discharge, died in ED and "did not wait"). The 17 discharge codes (Refer Appendix 4-B) carried in the data were allocated to one of these four types. It was assumed that this summarisation of disposal would not materially affect results because admission and discharged represented the bulk of original codes. The balance related to patients that were transferred to other hospitals, nursing homes or other institutions. These were incorporated into the "Admit" type since the patients were occupying an ED bed while awaiting admission. They were just not being admitted at Frankston hospital.

### 6.4.7 Model operation

The models were controlled through the Simul8 interface using three buttons: start, stop and reset. Simul8 called data from Excel spreadsheets that had to be open at the time the model was run. The models and model operation was documented within the Simul8 software (Appendix 6-A).

### 6.4.8 Control inputs

The models were not designed to have adjustable input parameters. All distributions were pre-built and called from within the model. Separate random number streams were used for all distribution sampling to prevent correlation of results. Multiple replications were performed using different sets of random number streams.

### 6.4.9 Output reports

ED time was an input to the system and queue time was regarded as an output of the system. Arrival time, queue time, treatment time and patient type data were collected for every patient that passed through the system. This was exported to a spreadsheet and analysed in Excel and SPSS.

Simulated times in ED by patient type were graphically compared to actual data (Figure 6-2). This gave a quick and easy way of searching for errors and inconsistencies because both the number of records (inter-arrival time and throughput related) and the distribution of times (a measure of the accuracy of the ED time distributions by patient type, treatment, urgency and disposal) could be instantly evaluated. Ultimately the similarity of the simulated and actual data was confirmed using a Kolmogorov-Smirnov test[63].

---

[63] The Kolmogorov-Smirnov test detects differences in both the locations and the shapes of the distributions. It is based on the maximum absolute difference between the observed cumulative distribution functions for both samples. When this difference is significantly large, the two distributions are considered different.

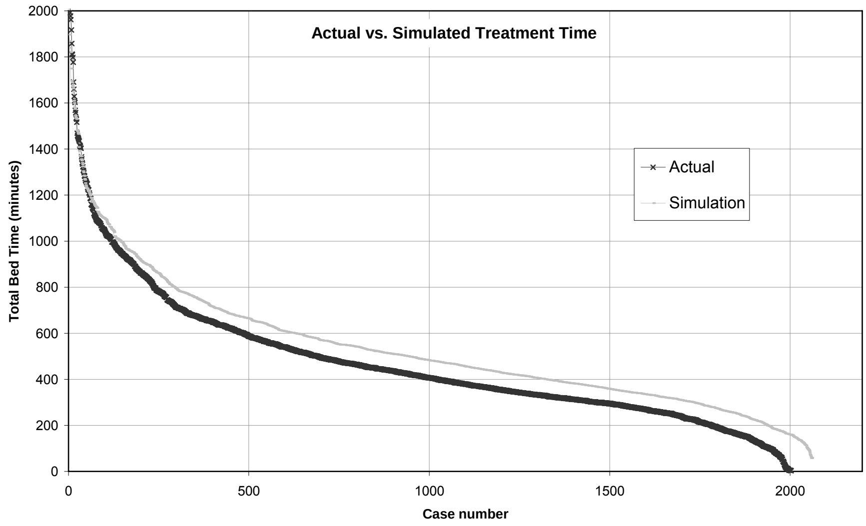



Figure 6-2: Comparison of patient time in EDs (sorted from highest to lowest) against actual times for patients of urgency 3 who were admitted to a hospital ward for treatment of symptoms typically related to intake induced vomiting and diarrhoea (patient type 3103). This graph intentionally depicts a run where the simulated data do not match actual data

Typical assessments of process efficiency such as average length of stay and resource utilisation and their associated confidence intervals were considered irrelevant to the analysis (they could be calculated directly from the original data, in any event). Rather, the instances of excessive patient wait were considered of interest (Figure 6-3) since it was believed that the period leading up to these instances would provide clues about the conditions necessary for ED blockage to develop.

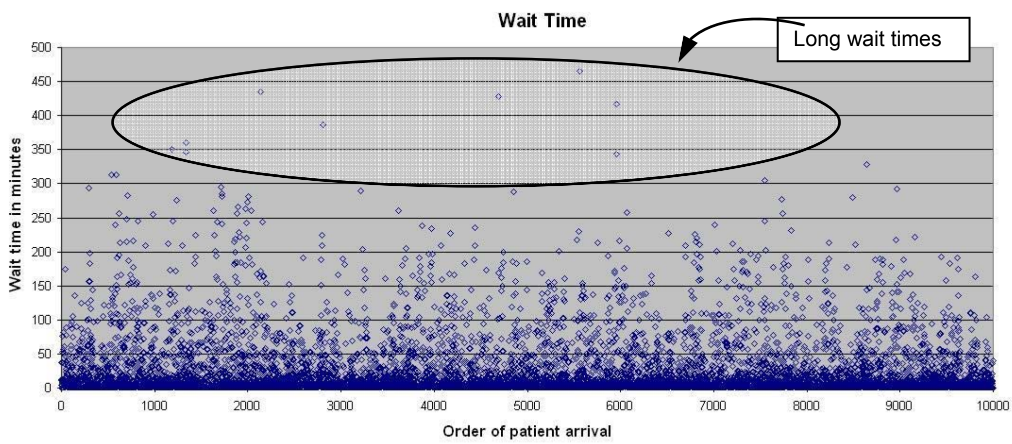



Figure 6-3: Graph of wait times in sequence of patient arrival at the ED. Long waits were relatively infrequent. These long waits were the focus of this research.

## 6.5 The initial model

The model was designed to generate a large variety of patient types according to urgency, treatment and disposal. Patients arrived in the ED at inter-arrival periods sampled from actual data (but in different sequence from the actual arrivals, depending on the random number sequence used for the sampling). They were apportioned urgencies and disposal within urgency according to historic distribution. Patients of each urgency/disposal type were streamed into one of 20 treatment pathways according to the distribution profiles noted for that urgency/disposal/treatment combination. The 20 pathways consisted of 19 treatment groups from SOM clustering and a single pathway for patients who had no procedures or only one procedure. A separate process was provided for patients classed as "Dead on arrival".

While the sequence of steps followed in the ED was to allocate patient urgency first, followed by their treatment and then by disposal, this orientation of patient types required information about patient disposal by urgency/treatment group. The problem can be seen from two simple calculation: 1) five urgencies allocated to 20 treatments, giving 100 groups for which to generate disposal distributions, 2) as opposed to five urgencies allocated to four disposals, giving less than 20 groups over which to generate treatment distributions (certain urgency/disposal combinations were highly unlikely, such as urgent patients who left before treatment was complete, or non-urgent patients who died in the ED). The latter sequence spread records more evenly across the treatments. It was found that insufficient records were present in many urgency/treatment groups to build reasonable disposal distributions, so the sequence was adjusted to allocate urgency first followed by disposal and then treatment by urgency/disposal group.

Patient ED time was drawn from historic distributions for that urgency, disposal and treatment combination. Data were sparse for some patient types (patients who died in the ED, for example) so generalised distributions were used for ED time of these patient types (1% of patient types).

The time it took for bed changeover from one patient to the next was not known. Generalised distributions had to be developed for bed turnover based on expert opinion.

The model may be viewed as a sequence of sampled distributions (Figure 6-4). Three kinds of beds were incorporated into the model and patients were streamed into beds according to the business rules. The three kinds and numbers of beds were:

- Three resuscitation beds,

- 28 general treatment beds (these included five paediatric beds, eight acute beds, six observation beds, five general beds, one isolation bed and three triage beds, but these sub-types were not modelled),
- Ten treatment chairs used for non-urgent patients who needed little treatment. A separate site was provided for patients who were dead when they arrived at the ED since they were not placed into beds, but rather remained on trolleys while awaiting certification and processing.

While the logic of the model was straightforward, its construction in Simul8 (Version 11 from the Simul8 Corporation) was complicated by the presumption of physical patient flow inherent in the software. Programme code was written to query the data, update patient characteristics and ensure that patients received priority to beds based on urgency. Beds were modelled as replicated workstations rather than resources. The model had run times of minutes on a standard 'gaming' PC, despite the heavy sampling overhead.

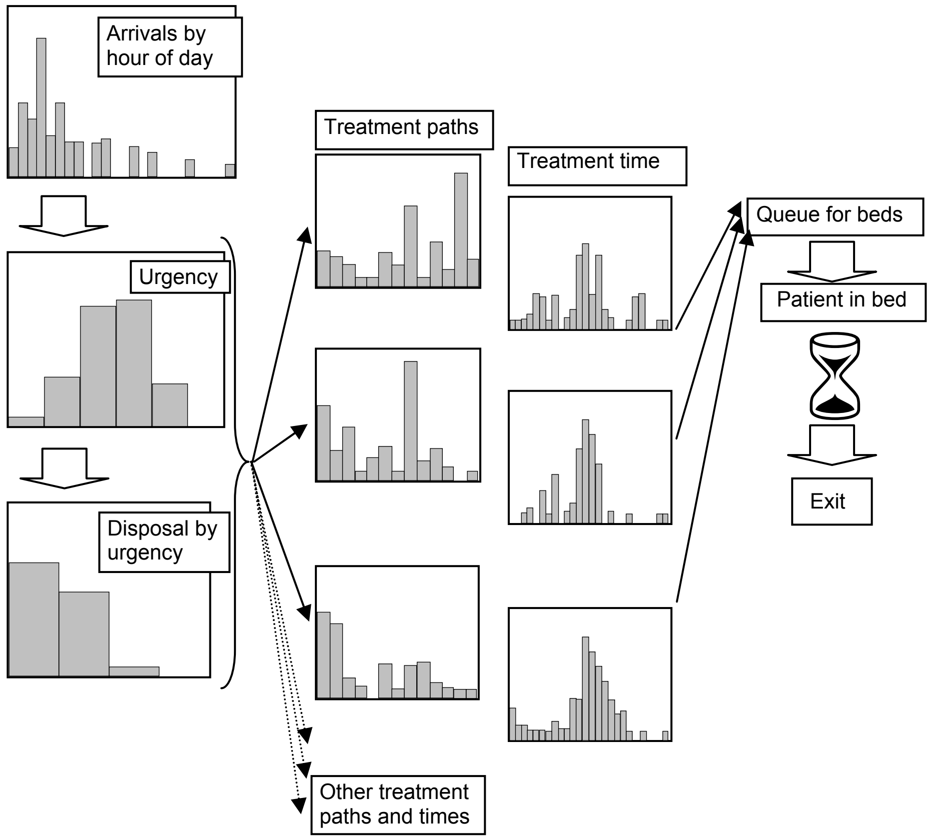



Figure 6-4: Schematic view of the simulation. Rather than following the physical movement of patients the simulation tracks the state of ED treatment sites as being 'occupied' or 'free'. The bulk of the simulation is dedicated to allocation of generic urgency, disposal, treatment cluster labels to patients and individual bed times.

### 6.5.1 Verification of the initial model

Like any software development process each successive stage of simulation model development represents an opportunity for error. It's normal for a model to require debugging before it will run[64]. Once the model is complete and running satisfactorily (verified) it needs to be determined (through a validation process) whether the model is sufficiently accurate within the intended application of the model (Sargent, 2005). Both these steps relate to model credibility – whether or not potential users have confidence in the information received from the model.

The goal of verification is to establish that the simulation program works correctly. The steps are: 1) a structured walk-through where one programmer explains the software to another in an effort to discover errors in the logic or syntax; 2) diagnostic simulation runs to test whether each transaction (sampling of probability distributions, for instance) within the model generates appropriate responses; 3) comparison to a well understood problem (such as a non-probabilistic system) where the results can be calculated mathematically and compared to simulated output; 4) trace analysis of every event in the model to get a detailed view of how each temporary entity moves through the model (Sargent, 2005).

Most simulation software have built-in tools to assist with debugging and trace analysis. Trace analysis can also be done interactively as the model progresses, either by pausing the model at set times or by watching how key variables, attributes, queues and so on change over time (Banks, 2001). Animated views of the simulation where there is an on-screen depiction of activities, such as the movement of temporary entities or resources as they occur, can help with all of these verification tasks (Kelton et al., 2004). These features are available in Simul8 and were used in verification of the model.

Discussion of model design with colleagues showed that the logic was sound but the concept was foreign. The number of patients arriving per hour was confirmed, the proportions of patient types checked for correctness, and the ED time sampling assessed for corrections. Entities were traced through the model to ensure that they followed the correct pathways.

The rules by which patients were distributed to bed types were tuned to get the entity travel looking as though it reproduced reality. For instance, early incarnations of the model simply utilised resuscitation beds all the time because all urgency 1 patients

[64] It's worth noting that Simul8 gets around compile errors by not reporting on errors. It most often simply ignores the line or block of code. This means that error-ridden models will still run. Modellers have to rely on the verification process to detect these errors.

were directed to these. This was corrected by ensuring only urgent cardiac, breathing and similar problems were treated in resuscitation beds. This was done by discussing with the ED physician which types beds should be used for different patient types or treatments. It was implemented by using a spreadsheet reference table of patient types and treatment locations (Table 6-4)

Once the 'inputs' to the model were verified (the model was generating ED time distributions that did not differ from the actual data under the Kolmogorov-Smirnov test), validation of the queues was started. These queues were considered as outputs of the system since they were not explicitly modelled but arose from the interaction of patient ED times. Good match between the simulated queues and the actual data would indicate that the model adequately reproduced real operating conditions.

Table 6-4: Reference table (Job Matrix) used in the simulation of patient type, treatment location and ED time distribution

| Urgency | Disposal | Treatment | Patient Type | Treatment Site | ED time distribution |
|---|---|---|---|---|---|
| 1 | 1 | 17 | 1117 | WC Resuscitation Bed | PDP1117 |
| 1 | 1 | 18 | 1118 | WC Resuscitation Bed | PDP1118 |
| 1 | 1 | 19 | 1119 | WC Resuscitation Bed | PDP All Urg1 |
| 1 | 1 | 20 | 1120 | WC Resuscitation Bed | PDP All Urg1 |
| 2 | 1 | 1 | 2101 | WC General Treatment Bed | PDP2101 |
| 2 | 1 | 2 | 2102 | WC General Treatment Bed | PDP2102 |
| 2 | 1 | 3 | 2103 | WC General Treatment Bed | PDP2103 |
| 2 | 1 | 4 | 2104 | WC Resuscitation Bed | PDP2104 |
| 2 | 1 | 5 | 2105 | WC General Treatment Bed | PDP2105 |
| 2 | 1 | 6 | 2106 | WC Resuscitation Bed | PDP2106 |
| 2 | 1 | 7 | 2107 | WC Resuscitation Bed | PDP2107 |
| 2 | 1 | 8 | 2108 | WC General Treatment Bed | PDP2108 |

The validation of queues involved comparing the simulated number of patients queuing for beds and the time for which they queued with the actual number and time. Once again the results were compared graphically at first. These initial comparisons showed that this model was unable to reproduce patient queues. The modelling concept was revisited as described in the next section.

## 6.6 The System Dynamics- inspired model

Models typically "evolve" as the modellers review their model and seek to improve the representation of reality it provides. This is in total accord with the models of Scientific Research and Management Science described in Chapter 3. This section describes the evolution from the first "resource unconstrained" ED model. The evolution was aimed at producing a model with output that better matched observed reality. The model was analysed from a System Dynamics perspective to try to see what factors could impact on patient queue time.

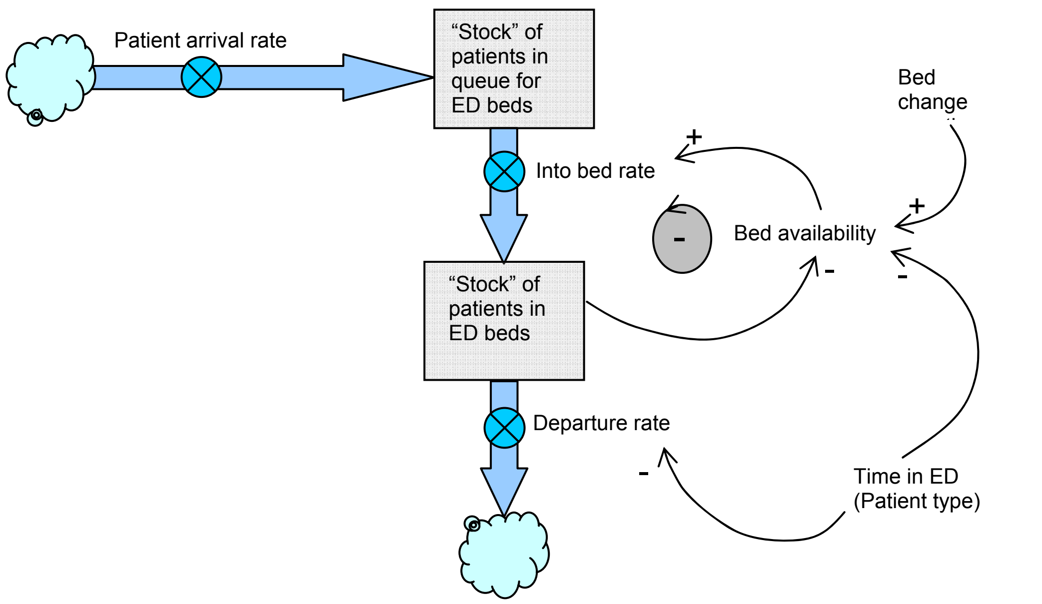



Figure 6-5: A System Dynamics view of the Discrete Event Simulation model. Patient flows are depicted by double arrows and flow rates are affected by the "stopcocks"). Clouds represent (infinite) patient sources and sinks, and boxes give the "stocks" (or number) of patients in certain states. Causal links are shown by single arrows. The circle with "-" inside indicates a balancing loop among bed availability, patient entry into beds and patients in beds.

The Systems Dynamics perspective (Figure 6-5) provided the insight that the queue for beds was linked to a critical feedback loop through the stock of patients in beds, bed availability and the rate at which patients might enter beds.

- The bed change over time affected bed availability.
- Bed availability was also influenced by ED time, a function of patient type.
- The variables that affect ED time were admittance delay, the treatment time itself and patient severity (urgency served as a proxy for this).

Bed change over time was only likely to vary by tens of minutes, an order less than ED time, so was unlikely to be unduly implicated in loss of bed availability. Since admittance delay, the treatment time itself and patient severity existed in the data (and had been checked for correctness) it was considered that they could not be influencing the incorrectness of the queues unduly, so the problem must lie with the number of beds that were available. The feedback loop implied that any variation in bed stock could have a radical (non-linear) impact on bed availability (because of the stochastic nature of the ED time variable). This was contrary to the linear relationship between number of beds and patient queues that had been assumed. It was decided that the number of ED beds was far more critical in the model than previously assumed.

The exact number of beds within the ED was not known with any degree of certainty. The number of beds was uncertain because staff adapted processes to facilitate patient throughput, particularly when the ED was reaching capacity. For instance, the number of "treatment chairs" used for non-urgent patients were increased, or patients awaiting transport to hospital wards were placed in trolleys in corridors, freeing up treatment beds. Data about the number of patients actually in treatment at any given time was not available, so it was impossible to determine the extent to which such flexibility had been employed.

### 6.6.1 Adjustments to achieve the "system dynamics" model

It was known that ED staff anticipated blockage. Movement of ED status from "green" to "yellow" as the ED approached a state of ambulance bypass had been observed on several occasions. Anecdotal evidence suggested that the ED staff adopted a number of strategies to decrease the chance of the ED actually moving into bypass. One of these was the "creation" of extra treatment facilities. More patients were treated in treatment chairs. The number of chairs was increased and the range of ailments treated in chairs was broadened. Patients were moved onto hospital trolleys and placed in corridors while awaiting hospital admittance and various other initiatives were implemented that provided additional beds. It was generally not an option to increase the rate at which patients moved through the ED (by increasing the number of staff or the speed with which staff dispensed treatments).

This coping behaviour was reflected in the queue data. The queue times formed a smooth upward curve when sorted from shortest to longest while the model suggested an abrupt transition from almost zero wait to long queues (Figure 6-6). Initially it was thought that this was due to noise in the actual data attributable to variations in human processes such as the time taken to show patients to beds, making decisions about which bed to use, bed changeover time, or variability in the recording of the time that patients entered the ED bed. The idea that staff were anticipating and coping with impending blockage (and being somewhat successful in doing so!) seemed a more feasible explanation for the difference between modelled and actual queue times.

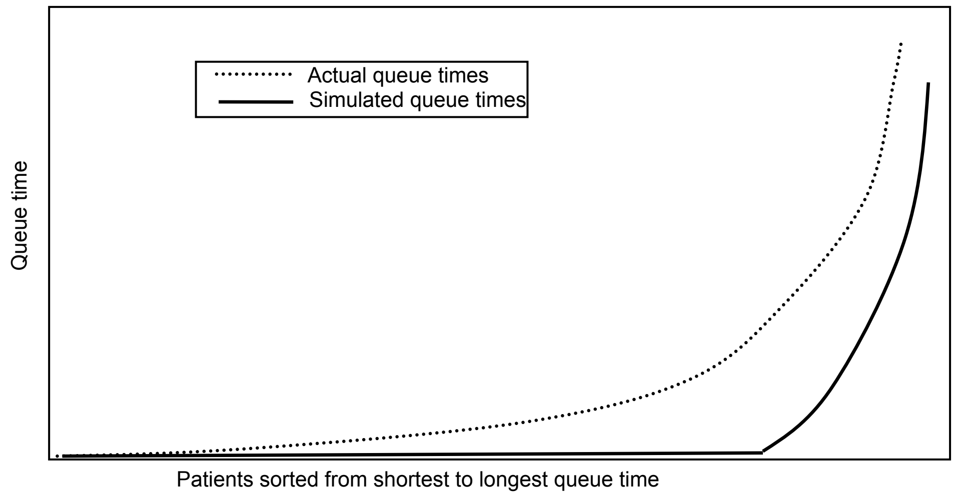



Figure 6-6: Schematic of Actual and Simulated queue times showing the shape variation in distributions

The model was adjusted to model staff coping behaviour by allowing additional beds to be created when needed. A queue time "trigger" was incorporated to signal the need for extra beds.

### 6.6.2 Validation of the adjusted model

As no changes had been made to the input side of the model, it was unnecessary to verify the model again apart from ensuring that the logic and encoding of the queue triggers was correct. With verification completed it was possible to move into the validation phase of model construction. Verification was a comparison of the conceptual model with its computer representation. Validation was a comparison of the computer model to the analyst's view of the real world.

There are a number of frameworks for validation. Pidd (1998) suggests "Black Box" and "White Box" validation depending on whether the model represents a known reality or not. Banks (2001) refers to: 1) face validity, a test of whether a model appears reasonable on its surface to knowledgeable observers; 2) validation of model assumptions about how the model simplifies and approximates reality, and whether the data is an accurate and reliable[65] representation of activities, both conceptually and quantitatively; and 3) validation of the input-output transformation of the model (how it transforms input parameters).

[65] Reliable here refers to acceptable error in measurement between successive measures of the same circumstance, whereas accuracy refers to how "correct" the measurement is.

The model was validated using a combination of Pidd's and Banks' validation steps. The model was considered a "black box" and the transformation of inputs to outputs examined without consideration of the internal workings. After some calibration good match (with Kolmogorov-Smirnov significance) of simulated to actual queue times was achieved[66]. A range of queue time distributions were tested for this trigger, the best being a fixed portion of 10 minutes and a sampled time from a gamma distribution centred at 20 minutes.

It was understood that calibrating queue lengths through the use of queue triggers did mean that queue time was no longer a "pure" output, however the model still appeared to be contributing to new knowledge about ED operations, so this limitation was accepted.

HillMaker (cf Section 1.3.3) permitted calculation of the average number of patients in the ED over any given time period. This was opportune since all efforts at calculating the number of patients in the ED through Markov Chain routes had encountered problems owing to missing and erroneous data in the patient arrival field, the patient departure field or both (cf Section 4.2). While these data problems were not a problem for the clustering of patients or the construction of ED time distributions (they merely impacted on the accuracy of the calculations), they were fatal when complete time series were required.

HillMaker indicated that, in addition to the ED staff expanding capacity to pre-empt blockage, the ED regularly held patients in excess of the number of treatment sites. These investigations and the model modifications that resulted are discussed in the next section.

## 6.7 The "black box" model of ED operations

This section will describe some of the changes made to the simulation model as a result of new information made available through analysis of the data using HillMaker software. HillMaker produces graphical output of average patient numbers derived from

---

[66] Validation is generally combined with calibration of the model (Banks, 2001). As described above validation is the process of comparing the model and its behaviour to the real system and its behaviour. Calibration is an iterative comparison of the model to the real system while making adjustments to parameters to ensure that features match as closely as possible. An example of calibration was adjustment of the queue trigger point distribution until the model queue time matched the time observed in real life. Calibration was performed through repetitive cycles of model comparison and model revision. Each model revision might incur more verification, so the process was not completely self-contained.

patient arrival and departure times. The data had to be cleaned prior to submission to the software so the figures may be understated, depending on the number of records that were deleted because they had missing or erroneous data. Figure 6-7 gives the graph for ED occupancy in two-hour slices by day of week. On average the peak ED occupancy was around 33 beds, so the ED was theoretically large enough, however the 75th percentile showed that ED occupancy was regularly higher than this and could even rise as high as 47 patients.

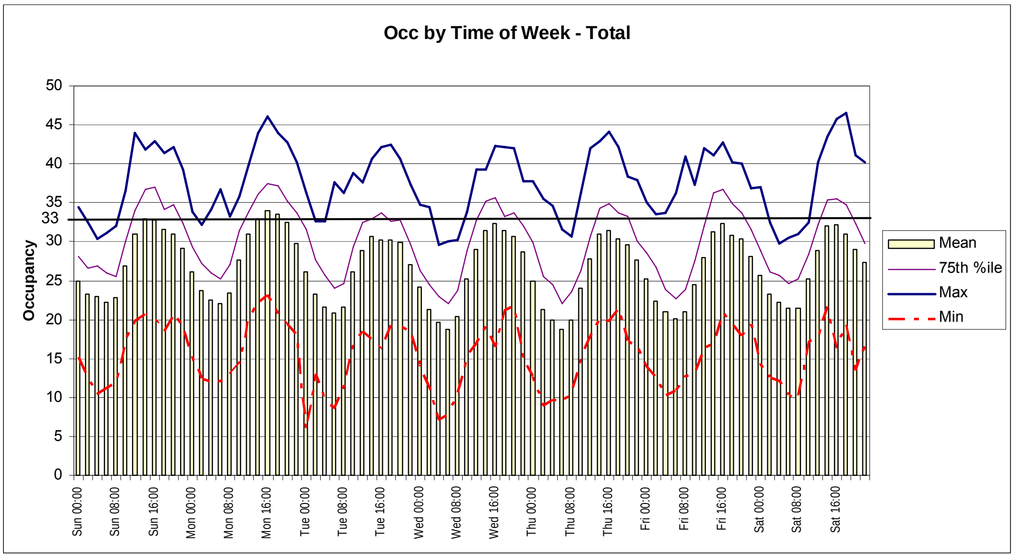



Figure 6-7: Occupancy in the ED (between being shown to a bed and physically departing the ED by day of week). The typical 'camel hump' of occupancy by day can be seen as arrivals gradually increase through the morning and peak in early evening.

The frequency with which large numbers of patients were observed in the ED indicated that patients were not only undergoing treatment: some of the extra ED patients were in treatment chairs, in consultation rooms, being treated in triage beds or other temporary sites, but most of the "extra" patients were probably travelling to, or waiting outside, imaging centres or other specialised treatment rooms. Even though ED time included the time patients took to move and queue within the ED it did not allow for the stochastic impact of these patient flows on bed occupancy. The model needed to be amended to cater for the variability of patient numbers in the ED. The modifications that were introduced are discussed in the next section.

### 6.7.1 Adjustments to achieve the "black box" model

The HillMaker analyses suggested that the simulation model needed to be adjusted to provide more flexibility in number of patients that the ED could hold. New rules were needed that determined when and how many extra patients should be let into the ED. It would have been reasonable to identify treatments that contained procedures linked to patient travel; such as imaging and plaster of Paris, but this would have entailed substantial new work beyond the limits of this thesis' data constrained nature. Instead the rules were built using existing knowledge about the pattern of ED occupancy.

The new rules were designed to allow a total of 47 patients into the ED (the maximum observed in the HillMaker analyses of the 2002 data). The difficulty with generating these rules was that they tended to create capacity that was accessed by the model. The model concept was completely removed from access to beds to number of patients in the ED.

The model was rebuilt to hold 27 acute patients. Six extra patients were allowed access to treatment if they had queued more than five minutes for a bed. These six secondary sites dictated whether the average queue time was more or less correct. The model also allowed 11 tertiary patients into the ED if they had queued for between 30 minutes and 450 minutes (a distribution was built by trial and error giving a 0.001% chance of a long wait). 11 was chosen because the actual data showed a maximum of 47 patients in the ED.

### 6.7.2 Verification and validation of the "black box" model

Since the philosophy of the model had changed from attempting to model patient queues as an output to modelling the number of patients in the ED verification needed to be done on the queue time "inputs" before validation on the number of patients in the ED could be commenced.

#### 6.7.2.1 Verification of the "black Box" model

The patient queues were verified in the same way that treatment times had been verified in the original model. This "black box" model gave an accurate representation of patient queue times (Figure 6-8).

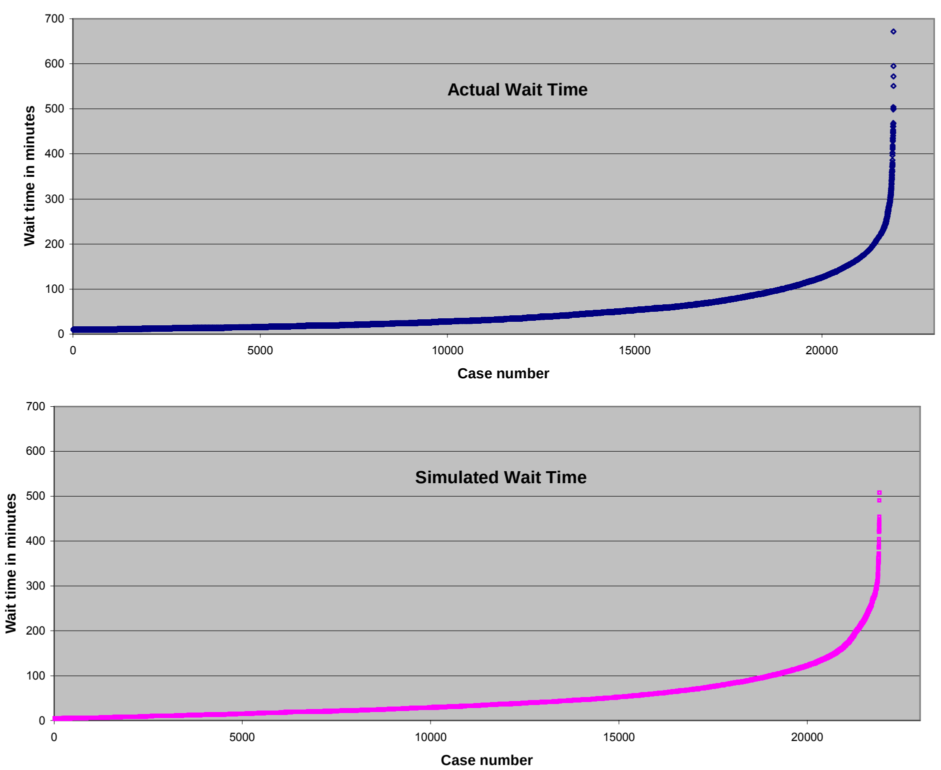



Figure 6-8: Actual vs. simulated queue times for 22000 patients with highest wait times, sorted by wait time, showing the success of the "black box" patients in ED simulation strategy. Wait times for other 32000 patients (to the left of the graphs, but not shown here) differed by a maximum of less than 6 minutes.

### 6.7.2.2 Validation of the "black Box" model

The mean number of patients in the ED peaked at around 36 patients in the model (Figure 6-9), whereas (as was seen in Figure 6-7) the average peaked at 33 patients in the actual data. It's possible that this difference is owing to the records that were omitted from the HillMaker analysis because of missing information. Since the trends and shapes of the distributions matched well it was considered the "black box" model was able to replicate the number of patients in the ED well enough for experimental investigations to continue.

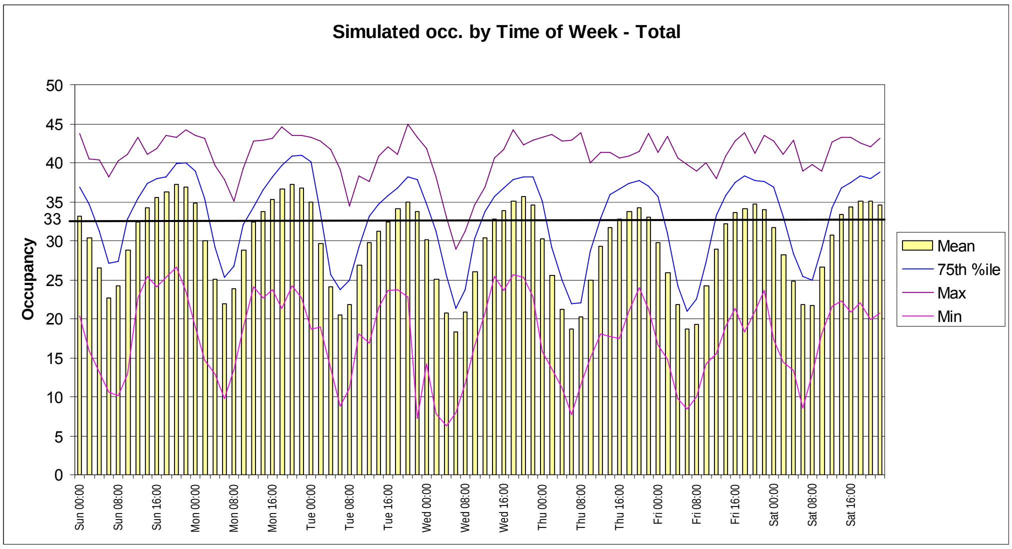



Figure 6-9: HillMaker graphical output of Simulated ED occupancy for 2002 showing that simulated occupancy is more than that calculated from actual data (Figure 6-5) but the general shape of the graphs and trends are quite similar indicating that the "black box" model may provide an accurate representation of ED operations.

## 6.8 Insights from the models

It's been mentioned that the model building process was probably more valuable than the resultant model itself. The data had to be examined closely from multiple perspectives in the course of building distributions for the model and while performing verification and validation. These examinations forced thinking away from the parameters of previous ED studies. While many ED studies focus on the patients who spend the most time in the ED, it was seen in this research that this could happen to almost any patient type. Obviously ED time was higher for certain patient types, but these patients did not constitute a large proportion of ED workload. ED workload seemed more affected by the volume of patients and these could be linked to certain predominant patient types.

A simple weighting of the number of patients in each patient type with the average ED time for that patient type showed that certain patient types were contributing heavily to the ED workload. Table 6-5 presents a sample of these. It is notable that the heaviest users were all awaiting admission to a hospital ward. The data records that the decision to admit these patients was made early in their treatment, but the ED was "forced" to continue treating them because of the delay in moving them to a hospital ward. The treatment and symptoms of these patients give an indication of which wards were implicated in the admission delay.

| Table 6-5: Patient types with the highest cumulative weighted impact on the ED. The symptoms in brackets implicate hospital wards that might be involved in the admission. | | | | | |
|---|---|---|---|---|---|
| Urgency | Treatment cluster (Typical symptoms) | Disposal | Average ED time in minutes (T) | Number of Patients (N) | Weighted impact (TxN) |
| 3 | 3 (Intake related vomiting, Diarrhoea) | Admit | 476 | 2003 | 953428 |
| 3 | 1 (general malaise) | Admit | 438 | 1828 | 800664 |
| 2 | 8 (cardiac or respiratory) | Admit | 524 | 1516 | 794384 |
| 2 | 1 (general malaise) | Admit | 457 | 1252 | 572164 |
| 4 | 3 (Intake related vomiting, Diarrhoea) | Admit | 505 | 980 | 494900 |
| 3 | 5 (collapse, mental) | Admit | 541 | 877 | 474457 |
| 3 | 4 (Fever Vomiting, Diarrhoea) | Admit | 445 | 1012 | 450340 |
| 4 | 1 (general malaise) | Admit | 454 | 909 | 412686 |
| 4 | 2 (Injury to limb or head) | Discharge | 115 | 3368 | 387320 |
| 4 | 20 (1 or no procedures) | Discharge | 107 | 3538 | 378566 |

The contents of the ED were examined when queues formed. It was noted that long queue times occurred when the ED contained sufficient patients with long ED times. Generally the bulk of these long ED time patients were awaiting hospital admission. This is rather self-evident and has been well-explored in research studies. Obviously EDs become blocked when all possible treatment sites become occupied. The duration of blockage relates to how long the ED "residents" remain in the ED. If they all simultaneously leave, possibly by being moved to wards, then the blockage is likely to be short lived. If, as is more usual, they leave slowly, then the queues have time to accumulate sufficient people so that all slack is removed from the system. It becomes a simple system where each departure is replaced by the next person in the queue.

It was possible to observe short inter-arrival times (high arrival rates) and smooth ED operation, while occasions were noticed where the arrival rate was not as high, yet the ED became blocked. The simulation exercise described in this chapter led to a conclusion that, rather than the length of the queue or the duration of ED stay of individual patients, the constituents of ED arrivals were important.

---

Certain patient types had a propensity for long ED stays. If these patient types occurred in the queue sufficient numbers, then the ED would become prone to becoming overcrowded. If sufficient numbers of these patient types moved from the queue into ED beds, then there was a chance that blockage would result.

---

The patient types most likely to cause blockage are those listed at the top of Table 6-5. These are high volume patient types where the ED time is significant, often due to substantial admission delay. The ED director suggested that the wards implicated in the admission delays were isolation wards, because of the contagious nature of the typical presentations.

## 6.9 Chapter summary

This chapter started with a discussion about conventional simulation "scale models" that attempt to reproduce all essential aspects of reality, including resource constraints. They appeal because the one-to-one correspondence to the observed world aids model verification. Unfortunately, "the map is not the territory" (Roy 1989). Models that look like the ED yet fail to emulate real–life complexity are not necessarily the best aids to understanding ED operations.

The chapter went on to describe a unique approach to simulation of hospital EDs using the clustering of patients described in Chapter 5. These groups were used in an abstract representation of the ED as a system that was not defined by staff constraints. Several iterations of the model were described in the chapter culminating in a model that sought to reproduce the number of patients in the ED, rather than consider ED beds. The last, "black box" model was able to match the number of patients in the ED behaviour to the real life data from the ED.

The modelling process forced close scrutiny of the data from numerous perspectives, as distributions were built to support the high level of stochasticity in the system. This scrutiny contributed to insights about ED operations. In particular it was noticed that certain patient types (combinations of urgency, disposal and treatment) were more likely to have long residence times in the ED. When these patient types occurred simultaneously in large enough numbers the ED became blocked (unable to accept any new patients for treatment).

This concludes the experimentation part of the thesis. The next chapter will present some conclusions, extensions that are suggested by the work and limitations of the work.

# Chapter 7: Conclusions, extensions and limitations

This thesis explored overcrowding in emergency departments. The objective of this Thesis was to understand the mechanisms of ED overcrowding internal to the ED. It was hypothesised that knowledge about ED treatment existed within routinely gathered data, but links that might reveal patterns of significant behaviour were hidden by the volume and complexity of data being gathered. An undirected clustering technique was proposed as a means of accessing this “hidden” knowledge.

Chapter 5 described the implementation of an undirected clustering technique and the resulting patient treatment groups. The patient treatment groups were incorporated into a discrete event simulation model in Chapter 6. This amalgamation of Data Mining and simulation provided several new insights into ED operations.

Three novel conclusions in particular arise from the research described in this thesis:

1. Clustering can be combined with discrete event simulation to provide insight into systems at a level higher than material flow, but containing none of the speculative cause-effect linkages inherent in system dynamics models.
2. The research indicates that “reengineering ED processes” will not provide a solution for ED overcrowding and blockage. Emphasis should rather be placed on transforming the view of ED blockage from “an avoidable result arising from the failure of operational procedures” to “an inevitable occurrence that must be managed in a structured fashion in concert with hospital wards”.
3. It should be noted that management planning for crises such as ED blockage includes the optimisation of operations within the ED, but also extends beyond this narrow scope.

These conclusions will be discussed in more detail in the next section. The second half of this chapter is dedicated to extensions that are available owing to the work in this thesis. Briefly stated they are:

1. How patient treatment groups could support Industrial Engineering initiatives in EDs.
2. The use of procedures in an Activity Based Costing simulation of ED costs;
3. Implications for ED information systems of the process based view of ED treatment described in this thesis.

A discussion on the validity of Data Mining methodology as an extension to generally accepted Management Science methodology is provided to round out the conclusions of, and extensions to, the research..

The last section of the chapter discusses the major shortcomings of the work and provides direction for future work that was not addressed as one of the extensions of the research earlier in the chapter.

## 7.1 Insights from the research

This section provides discussion of the thesis conclusions. Each section will give justification and argument for the conclusion stated in full at the end of each section.

### 7.1.1 Insights from combining clustering with simulation

This section will deal with the conclusion that inclusion of treatment clusters in a simulation model can result in a model that is conceptually between traditional "object-tracking" or "resource-driven" discrete event simulation models and a system dynamics "stock and flow" model.

The data analysis described in Chapter 4 and clustering techniques described in Chapter 5 led to the identification of a number of patient treatment types. Patients were grouped in each of these types according to similarity of medical procedures. In essence these patient treatment groups constituted a high level way of segmenting ED operations along process lines – something that Industrial Engineering, Management Science and other investigators have been attempting for many years. The utility of this new partitioning was that it focussed on segmentation of treatment by process, rather than by patient. It not only emphasised inter-process variations (between different treatments), but also allowed for intra-process variation (within treatments of similar type). It also recognised – and this is a key idea – that *the procedures used in treatment was largely unaffected by patient urgency*.

The clusters of medical procedures in treatment groups suggested a different approach to simulation modelling. Rather than attempting to follow each patient through each step of their treatment and have resource availability regulate throughput, as in other discrete event simulations of EDs, it became feasible to add patients to a "stock" of patients awaiting a particular treatment. It became reasonable to model the state of beds in the ED as "occupied" or "ready". This state-based concept, while inherent in all discrete event simulations, is often obscured by focus on the impact of patient travel and resource constraints on patient throughput. The state-based approach facilitated analyses that looked at the system as a whole, and did not look for bottlenecks of patient flow through the ED. Viewing the system in this holistic way encouraged examination of its inflows and outflows, rather than just its internal operation.

Examination of system inflows and outflows is much more a system dynamics concept than discrete event. It's also a perspective of interconnectedness that can sometimes be neglected in queuing models. The examination of inflows and outflows tends to take one past directly connected events to more remote phenomenon in an effort to understand the dynamics of the system. Looking at the reasons for patient beds being in a state of "occupied" or "ready" forced an understanding of the dynamics of the system beyond simple queues. It became apparent that "stocks" of certain types of patients were accumulating for treatment. Examination of these "stocks" led to the realisation that, not only were the queues dynamic, but that their make-up directly affected future events in the system. The particular mix of patients in each queue was more important than the number of people waiting for treatment or currently in treatment. If there were a high proportion of patients in the queue who were likely to be admitted to hospital, then there was a distinct possibility that all ED treatment sites would be occupied by patients awaiting admission to a hospital ward.

---

Because of its high level, treatment-based perspective, the simulation model provided the necessary key to identifying why and when the ED was likely to become blocked. The types of patients most likely to initiate this situation could be identified and the hospital wards most likely to cause blockage could be implicated. Rather than identification of a sequence of process bottlenecks the model had uncovered the precursors most likely to result in ED blockage.

---

### 7.1.2 ED blockage is an inevitable occurrence[67]

It was described in the previous section that an unfortunate (but not improbable) combination of certain types of patients causes ED blockage. An extension of this idea is that certain combinations of patients in critical numbers will overwhelm any ED, regardless of the size of facility or available resources. Increased size and resources only provide additional "ceiling space" that can absorb shocks to the system – they do not guarantee that the system cannot be overwhelmed.

[67] The material in this section is based on work previously published in (Ceglowski *et al.*, 2005a)

In 1984 Charles Perrow (1984) published a book about the special characteristics of complex interlinked technological systems that make accidents in them inevitable. He analysed the way failures interact and the way systems are tied together with the objective of gaining a much better understanding of why accidents occur in complex tightly coupled systems such as nuclear power and chemical plants, *and why they always will*. While EDs are not interlinked technological systems in the sense of the nuclear power plants in Perrow's examples, they are *complex* (as opposed to linearly interactive) and *tightly coupled* systems. EDs as *complex systems* are characterised by:

- proximity of units not in production sequence (such as adjacent beds in an ED ward);
- common-mode interactions between components not in production sequence (one unit serving multiple processes – for example, one ED nurse providing care to a number of patients in adjacent cubicles);
- having unintended feedback loops (for example, the impact of an X-ray machine on patient queues or the impact of the number of patients experiencing admission delay on the number of patients in ED waiting area and their waiting time); and
- processes that are not fully understood (such as the variability in time to stabilisation for different patients).

EDs as *tightly coupled systems* have:

- time dependent processes;
- invariant sequences of activities (for example, patient care processes);
- little interchange possible between resources or between equipment; and
- the overall design of the system only allows one way to reach the process goal (for example, particular treatment protocols).

The above signals that EDs are indeed tightly coupled complex systems[68]. The complexity and coupling characteristics of ED systems make crises such as ED overcrowding inevitable. To use Perrow's terminology, ED blockage is a *normal accident*. The term signals that, given the system characteristics, multiple and unexpected

[68] Re-engineering initiatives have actually resulted in tighter coupling of the system by removing slack from the system.

blockage accidents are inevitable and present an integral characteristic of the system[69], leading to the conclusion:

> There will always be a finite possibility that certain combinations of patient types or other effects that disrupt processes in the tightly coupled complex ED system will occur. When they occur they will overcome all and any measures in place to ensure efficient running of the system – ED blockage is inevitable.

### 7.1.3 Moving beyond optimisation of ED operations

The above section described the inevitability of ED blockage events. This research has provided insights into one set of likely precursors of ED blockage (in the form of combinations of patient types). The patient type precursors make it possible to forecast impending blockage. The challenge that remains is in projecting the forecast far enough ahead to be able to mitigate and manage the blockage, and to ensure a smooth recovery from blockage when it does happen. This suggests a different paradigm for ED reengineering.

The potential and real consequences of disruptive events such as earthquakes, floods and other natural disasters have been the focus of crisis research for many years. If, instead of a pure efficiency attitude, hospital administrators embraced the inevitability of ED overcrowding and blockage, then steps may be taken to manage the problem. The theory of crisis management is developing rapidly. A crisis-aware view of ED overcrowding may leverage off the considerable amount of research that has been conducted in recent years into crisis management.

A three-stage approach to crisis management is often referred to (Ross Campbell, 2004; Coombs, 1999):

- Preparation for, and mitigation of, crises;
- Response to the crises once they have occurred; and
- Recovery after the immediate crises front has passed.

The mitigation, response and recovery stages refer respectively to activities that take place before, during and after a crisis. Preparation includes activities such as estimation of the vulnerability to crises; establishment of communication protocols;

[69] "Normal" is not a statement of frequency, but rather an indication of inevitability.

formulation of plans; and allocation of responsibility. Mitigation in the sense of ED crises might include demand management strategies, early warning systems; and excess capacity retention within EDs.

Response to crises generally revolves around stopping the effects of the crisis as soon as possible. Plans previously put in place are activated in order to try to prevent incidents escalating and to reduce the ill-effects of the situation. ED responses might include measures to assist staff with decision making in times of high pressure; options for temporarily increasing staffing; and facilitation of patient admittance to wards.

Recovery is the implementation of strategies to facilitate fast and orderly recovery from the crisis. ED measures might include focussed bed changeover; rapid materials assessment and replacement; and staff recuperation time.

The crisis management framework of mitigation, response and recovery provides one dimension for managing ED blockage crises. A second dimension may be provided by consideration of wider ED system effects, such as patient demand and inflows to EDs; patient handling within EDs and patient outflows from EDs. These two dimensions produce nine aspects for which crisis management strategies need to be put in place (Figure 7-1).

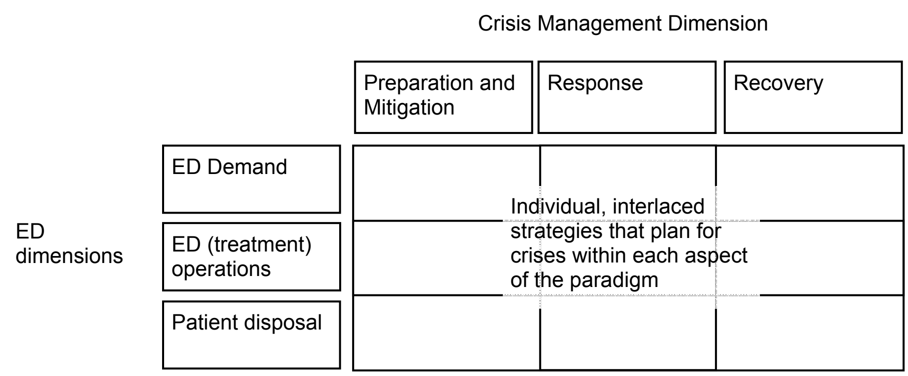



Figure 7-1: A crisis-management framework to address ED blockage

There is also scope for defining classes of crises. For instance, a minor crisis event may be deemed to have occurred when patient type arrivals at the ED reach a particular threshold, while a more serious crisis event may be anticipated if a certain proportion of ED treatment sites are occupied by particular patient types. A critical crisis event may be called when ED blockage persists for a lengthy period[70].

[70] Many EDs currently use a colour coded system analogous to this.

Each of the crisis / ED dimensions addresses a different aspect of ED blockage. They all call for responses that extend far beyond mere optimisation of ED operations, leading to the conclusion:

---

> Strategies that address preparation and mitigation, response and recovery for each of the dimensions of ED demand, ED operations and patient disposal are likely to be far more comprehensive than current activities aimed at preventing ED blockage. If the strategies also consider various levels of crises within each aspect they are likely to be robust to crises that result from concurrent triggering events throughout the system (such as increased demand coinciding with illness in ED staff or extensive delay in readying hospital ward beds).

---

## 7.2 Extensions to the research

Having covered the dominant conclusions of this thesis as the utility of newly discovered knowledge in providing a holistic view of the ED system; the inevitability of ED overcrowding; and the necessity for the reengineering solution to move beyond internal efficiency and effectiveness analyses of ED operations, it is pertinent to briefly discuss some extensions to the work. There was insufficient time in the research project to illuminate them fully so the discussions that follow are somewhat speculative. Nonetheless it is considered that each of the extensions discussed are practicable suggestions that could enhance ED reengineering, management and decision making.

### 7.2.1 Treatment oriented Industrial Engineering in EDs[71]

There are a number Industrial Engineering (IE) techniques that are facilitated by the process nature of the treatment clusters introduced in this thesis. These IE techniques have been of only limited use to date since ED treatment processes have not been engaged comprehensively by any previous Casemix or ED research. Several IE methods will be discussed in this section:

1. Statistical Process Control;
2. Fishbone Diagrams;

---

[71] The work described in this section was previously published at the peer reviewed 5th Asia-Pacific Industrial Engineering and Management Systems Conference held between 12th and 15th December 2004 on the Gold Coast of Australia.

3. Process Charts;
4. Flow Diagrams; and
5. Multidimensional Analyses.

While the following paragraphs draw upon several analogies that "objectify" patients in order to draw the parallel with industrial processes for which the methods are well tested, it needs to be emphasised that the patient is also a customer of the ED. The well-being, satisfaction and comfort of the patient are of paramount importance.

#### 7.2.1.1 Statistical Process Control

Statistical Process Control (SPC) is a collection of techniques used to monitor data that is collected in the course of process execution (Salvendy, 2001). A "Magnificent Seven" of common tools have been proposed for Statistical Process Control that can address almost all quality related problems (Ishikawa, 1986). These seven include Fishbone Diagrams (described in Section 7.2.1.2), and a range of graphical tools for identification of possible causes of quality problems, such as histograms, Pareto charts, (Sherwart) Control Charts and Scatter Diagrams. Tools such as these that rely on repeated measures of activities may have to be adapted to deal with the varying nature of patient health and response to treatment (that is, patients are not uniform products to bring to a consistent quality, but an ever varying range of humans who respond differently to identical treatments).

Patient treatment groups make it more feasible to use SPC tools in a targeted way to learn about the treatment activities that generate the most work (Table 7-1), those that cost the most and those most likely to result in complications.

Table 7-1: A Pareto assessment of work generated by each core treatment

| | | Treatment Number | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Top 10 single procs. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Percentage Patients* | 20.0 | 4.7 | 14.7 | 8.1 | 5.4 | 3.4 | 3.3 | 3.5 | 2.7 | 4.2 | 2.4 | 2.6 | 3.5 | 1.8 | 2.0 |
| Number of procedures | 1 | 6 | 5 | 7 | 8 | 6 | 10 | 11 | 13 | 9 | 13 | 11 | 6 | 8 | 11 |
| Simple work index | 20.0 | 28.6 | 73.5 | 56.7 | 43.2 | 20.4 | 33.3 | 38.5 | 35.1 | 37.8 | 31.2 | 28.6 | 21.05 | 14.4 | 22.0 |

* Missing percentage lies in low volume single and low volume multiple procedure treatments

The reengineering of ED work practices can then address the biggest problem areas first before moving to solve smaller or emergent problems. This is in stark contrast to the "general investigation of work habits" that has been implemented in the past in the hope of finding relationships in work patterns. The application of industrial engineering can at last focus on specific problem areas within the larger ED context.

#### 7.2.1.2 Fishbone Diagrams

Fishbone diagrams are a manifestation of the Quality Movement (Ishikawa, 1986) that graphically depict linked "causes" for a given outcome. The diagram starts with an effect or outcome at the head. Fishbone bones depicting levels of causes propagate from the spine connected to the head. Recommendations exist for defining the major fishbone bones, such as the 4M's (manpower, machines, methods and materials) (Salvendy, 2001). Figure 7-2 is an example of the considerations associated with successful treatment of a patient who has experienced an injury that requires sutures but does not have major complications (Treatment 12 from Table 7-1). All patients in this treatment group receive sutures (SUT) and most (80%) need a dressing (DRS). About half the patients need some form of medication (DRUG) and some require observation (OBS) to ensure that their condition has stabilised. A minority (10%) of patients will require X-ray imaging (XRAY) or peripheral intravenous access (IV).

Treatment groups make the use of Fishbone Diagrams feasible because the specific set of medical procedures is known for each treatment. The Statistical Process Control methods described in the previous section may usefully be employed to identify where Fishbone Diagrams may yield most benefit. Clinicians can ensure that elements critical to treatment of particular classes of patients are identified. Rather than attempting to build a Fishbone Diagram for every activity in the ED, or being limited to modelling single procedures, analysts can relate groups of procedures in a logical manner. The resulting Fishbone Diagrams are likely to further understanding of each treatment and complexities associated with certain classes of patients.

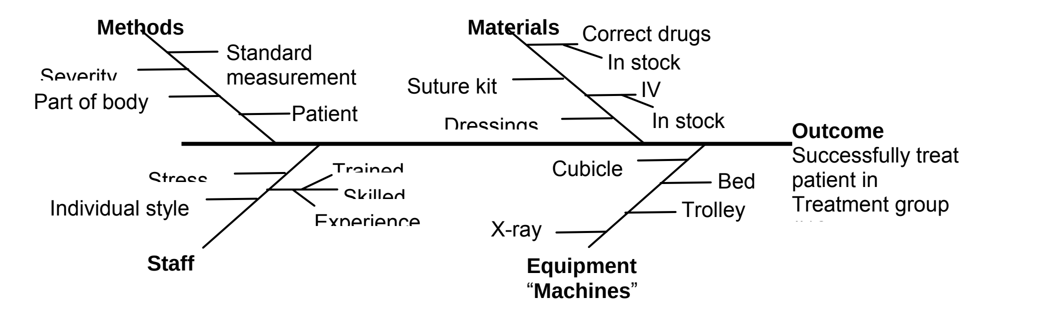



Figure 7-2: Fishbone Diagram for improvement of quality of patient treatment

#### 7.2.1.3 Process Charts

Process Charts are tools used to follow the progress of products or people through a process. They facilitate identification of opportunities for process improvement by linking each activity in the process to one of five activity types: operation, movement, inspection, storage or delay[72] (Salvendy, 2001). The documentation details every significant activity. Process Charts are intended for high-level analyses, so detailed times are usually not needed for "operations" and "inspections". Times for "storages" and "delays" can be estimated by experts or derived from existing data, rather than painstakingly measured.

Process Charts can be used to identify process improvements based on reduction of the number of operations, inspections or storages, or in reduction in time in storage, transport and delays. Such work has been done for aspects of ED operations, such as the ordering of X-rays, and for patient admission to hospital wards from EDs (Department of Health 2003), but it has yet to be done at a treatment level, primarily because of the absence of clinically relevant process models.

Patient movement along a treatment or staff activity can be documented in Process Charts providing a variety of views of the process. There are fairly generic activities for all non-urgent patient treatments. Doctors visit a central station to review the list of waiting patients on a workstation screen. They select an appropriate patient based on urgency and presenting problem. Doctors then move to the storage rack that holds the patient files, finds the correct one and reads it while progressing to the patient's bedside (usually).

The example in Figure 7-3 shows these activities and a few of those involved in a simple treatment sequence. Most patients in this simple treatment receive some form of medication and are observed to ensure that this has the desired effect. The doctor travels quite some distance in treating this type of patient and there are delays while waiting for delivery of requested drugs. Since 10% of urgency 1 patients, 20% of admitted patients and 30% of discharged patients follow this treatment it would be beneficial to address these travel and wait issues. The treatment of patients after the last step depicted in Figure 7-3 differs according to the set of medical procedures undertaken. Similar analyses could be conducted for other treatments.

[72] Rework is a concept that is used for products, but applies equally when a single patient needs repeated applications of the same medical procedure.

| # | Details of Present / Proposed method (select one) | Operation | Transport | Inspection | Delay | Storage | Time (sec) | Distance (m) | Simplify? | Shorten? | Change sequence? | Combine? | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Select patient | ○ | ⇒ | □ | D | ∇ | 30 | 0 | | n | | y | |
| | Pull patient record | ○ | ⇒ | □ | D | ∇ | 20 | 0 | | y | | y | |
| | Read patient record | ○ | ⇒ | □ | D | ∇ | 50 | 0 | | n | | | |
| | Walk to cubicle | ○ | ⇒ | □ | D | ∇ | 30 | 50 | | ? | | | |
| | Make diagnosis | ○ | ⇒ | □ | D | ∇ | 300 | 3 | | n | | | |
| | Order drug | ○ | ⇒ | □ | D | ∇ | 60 | 20 | | y | y | y | |
| | Note on patient record | ○ | ⇒ | □ | D | ∇ | 20 | 0 | | n | y | y | |
| | Await drug | ○ | ⇒ | □ | D | ∇ | 250 | 20 | | ? | | | |
| | Instruct nurse to administer drug | ○ | ⇒ | □ | D | ∇ | 50 | 0 | | | y | y | |
| | | ○ | ⇒ | □ | D | ∇ | | | | | | | |

| 3 | | | | | | | AN |
|---|---|---|---|---|---|---|---|
| HEADER DETAIL .......SAMPLE ONLY | | | | | | | |
| | **SUMMARY** | | | | | | |
| | OPERATIONS | TRANSPORTS | INSPECTIONS | DELAYS | STORAGE | TOTAL STEPS | |
| CURRENT | 4 | 0 | 2 | 1 | 0 | 7 | |
| PROPOSED | 3 (record at patient) | 0 | 2 | 1 | 0 | 6 | |
| SAVINGS | 1 | 0 | 0 | 0 | 0 | 1 | |

Figure 7-3: Sample Process Chart for section of a Treatment

While Fishbone Diagrams facilitate conceptual understanding of the interconnection of factors involved in patient treatment, Process Charts provide a logical understanding of the activities involved.

#### 7.2.1.4 Flow Diagrams

Flow Diagrams are maps of operator's movements. They are often associated with Process Charts (Konz et al., 2000; Salvendy, 2001). Flow Diagrams focus on distance travelled and minor movements, such as bending to reach into a cupboard. Analyses of this nature can assist with facility design and layout. Although consensus design has been used in the layout of healthcare facilities (The American Institute of Architects, 2001), there has been little workflow analysis of ED layout of the form depicted in Figure 7-4. The mapping of doctor and nurse movements on flow diagrams can be linked to specific treatments, as shown on the right of the diagram.

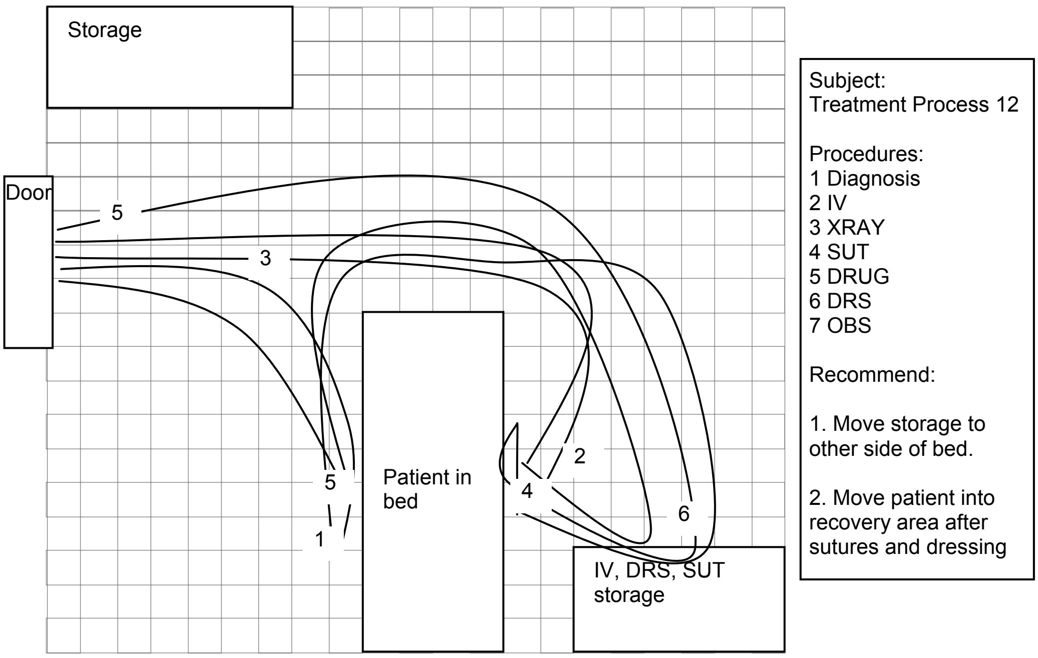



Figure 7-4: Sample Flow Diagram showing doctor and nurse movements allied to a given set of procedures used in a treatment process

Process Diagrams and Fishbone Diagrams provide conceptual models of the treatment process. Flow Diagrams link the treatment process to the physical layout of EDs. Multidimensional Analyses (discussed in the next section) extend these concepts.

#### 7.2.1.5 Multidimensional Analyses

The above approaches all facilitate efficiency and quality improvements of single treatment groups. The approaches fail to address the interactions between tasks and resources that arise from simultaneous processes. Many patients undergo treatment in the ED at the same time. This means that there is a mix of treatments occurring simultaneously at different stages of completion for separate patients. Some of these treatments may share resources (X-ray equipment, for example), and/or require resources in a specific order (such completion of X-ray imaging and analysis before the application of plaster-of-Paris). It may be that processes require similar materials at the same time (such as medications for various patients). Doctors and nurses have to divide their attention and time among several patients, ordering tests, waiting for results, evaluating new patients among others.

It is possible to analyse which treatments are in process at any given time in the ED, and so describe the combination of procedures that are likely to be required simultaneously. This can be used to build a high level picture of ED operations at any time of day and structure resources accordingly. Tools such as Activity Relationship and

Precedence Diagrams that have played a valuable part in location of materials (Francis, et al., 1992); layout of workstations (Muther, 1973); and balancing of flow lines (Konz, 1994) may be applied to aid analysis of these simultaneous and unsynchronised treatment processes.

#### 7.2.1.7 Summary of treatment oriented Industrial Engineering

This section described how treatments may be used to guide Industrial Engineering studies. The application of several popular Industrial Engineering tools was discussed. An assembly line analogy for the ED may assist in the implementation of such tools: In this analogy patients are processed from an "ill" state to a "well" state. The patients travel through the ED having medical procedures "installed" with specialised equipment and medical staff "operators".

To expand the analogy further, patients are received, placed in a cubicle and receive attention from experts. Staff travel to and from the patient (or different staff visit the patient) and the patient is moved to alternative workstations for specialist procedures. Certain medical procedures are already co-located in EDs, such as plaster-of-Paris (POP) and X-ray imaging (XRAY), but other efficient co-locations of medical procedures may be derived by following patients through individual treatments. Specialist workstations associated with distinct treatments (akin to dedicated production lines in manufacturing facilities) could provide ED administrators with an avenue for improved knowledge management and staged training of staff, but they do carry the risk of under-utilisation because of the unpredictable flow of patients into treatments.

It must be noted that demand prediction remains an issue. Even after all treatments are elucidated and optimised, and their interaction fully understood, there will still be a requirement to know in advance which treatments patients are going to require. Patients will need to be "streamed" into the correct "production line" as soon after arrival as possible. This may require multistage, multiple criteria reception processes, ubiquitous computer support, allied decision support and knowledge management systems. An information system that could support these requirements is described in the next section.

### 7.2.2 How treatment clusters may support ED information systems design

In Chapter 1 it was discussed how information systems currently targeted at emergency departments fail to proactively support patient flow and resource allocation because they approach emergency operations from an administrative rather than process perspective. In other words, patients tend to be grouped according to arrival sequence, urgency, demographic variables and diagnosis. These groups do not facilitate decision support activities because they have no predictive function. Treatment clusters do have predictive properties that may be combined with traditional clinical groupings to provide a high level of decision support.

While the treatment clusters have broken down the mass of patients into process-oriented groups, it is possible that the application of other data mining methods such as CART and Association Mining within these subgroups could supply rule-based information that could assist with further segmentation of patients 'on the fly". These rules could include further variables, such as patient age, sex, severity and symptoms. The discussion in this section can be viewed from the perspective of such subgroups, but explicit discussion will be limited to level of treatment clusters comprised of groups of procedures. The sequencing of these procedures[73] permits three conceptual views of emergency department operations to be developed:

- A procedure-based view;
- A treatment process view; and
- A workload view that integrates the above two views.

These views and their applications are described in the next three sections.

#### 7.2.2.1 The Function View

The "Function" view analyses operations according to individual procedures and yields the workload due to a specific procedure at any given time (Figure 7-5). Two useful applications arise from this view. The first application is demand forecasting. The number of patient presentations is well characterised and can be predicted for any time of day with a reasonable level of confidence. Patient presentation forecasts could be combined with data about procedure use to derive a predicted demand for each procedure. It's reasonable to expect that the system could be combined with resource or other constraint information that enable it to detect whether the emergency department is susceptible to becoming overloaded. This forecasting application of the function view could also be used to give material requirements and trigger material ordering reminders.

[73] Sequencing of treatment groups was not done in the course of this research because the data did not carry timing information.

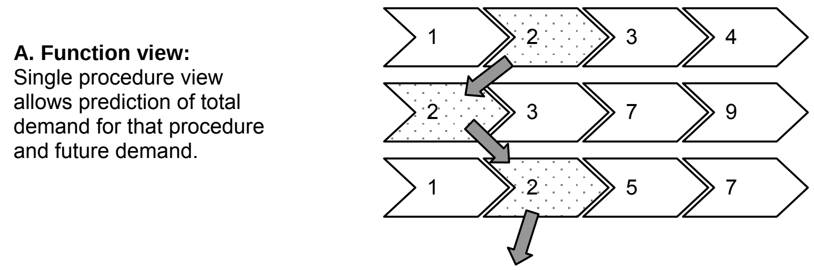



Figure 7-5: The function view (numbers denote individual procedures)

A second application is in determining training requirements. The function view can help in planning and in directing training to reduce risk associated with a shortage of a specific skill set. The skills essential for each procedure can be listed. This can be linked to personnel who have the necessary skills to give an overview of the emergency department knowledge base, used to inform a training schedule or used in staff scheduling.

#### 7.2.2.2 The Process View

The process view arises from the sequence of procedures used in each treatment. It depicts patient treatment as a sequence of value-adding activities (Figure 7-6). This perspective could be used to assist with ED management activities as described below.

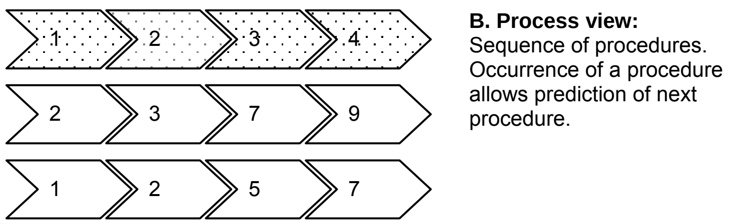



Figure 7-6: The process view (numbers denote individual procedures)

Triage nurses have a good idea of the procedures that will be performed on a patient and so order interventions that should be performed by nurses on duty once the patient is transferred to a cubicle (Djorhan et al., 2003). If this existing knowledge were to be integrated with treatments it should be possible for patients to be allocated to a group of treatments at triage. This would facilitate early identification of resource requirements, transport needs and potential problems, and update of the function view. As patient treatment proceeds the set of possible treatments becomes reduced through elimination until the patient is regarded as an instance of a single treatment (Figure 7-7). Markov or Bayesian models for patient state transitions, both within clusters and through the emergency department could facilitate optimisation of patient placement and movement activities.

The concept of Figure 7-7 provides an avenue for configuring ED information systems[74], not only to support the particular treatment practices at an emergency department, but also to evolve over time as more is learnt about specific treatments. Such configurable decision support is inconceivable in the context of existing ED information systems.

The ED ontology that was introduced in Section 5.5.4.3 provides a framework for data structuring that could inform the design of the input screens. Data structured in a hierarchical ontology will enhance data analysis possibilities and could, over time, improve the predictability of patient allocation to treatment pathways.

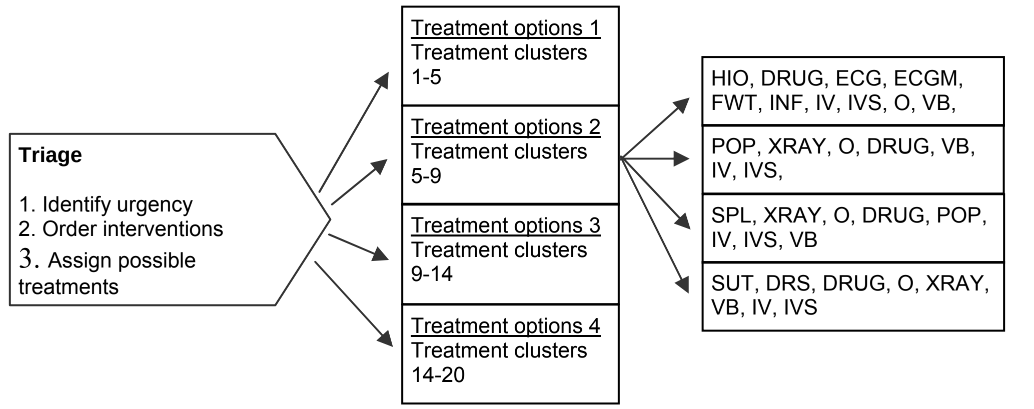



Figure 7-7: Patient streaming into treatment clusters as more treatment progresses

#### 7.2.2.3 The Workload View

The "workload" view is a combination of the function and process views (Figure 7-8). It carries information about the quantity and type of procedures currently in progress. Ideally an information system incorporating workload "intelligence" would be able to "pre-book" resources, optimise patient placement and transfers, and maximise resource

[74] Configurable systems arise from a desire to build general purpose systems that can readily be specifically tailored for individual needs (Shim, et al., 2002). This issue is most readily apparent in the implementation of generic enterprise systems, where the most challenging aspect is often adaptation of the basic system to specific needs (Johnston, 2002). Enterprise systems are often described through reference models that describe the business processes and structure of the system through use of function, data and organisation artefacts. Application reference models depict all possible system capabilities but do not guide system configuration for particular instances (Rosemann, et al., 2003).

use, as well as providing a range of likely scenarios to assist with staffing and other management decisions.

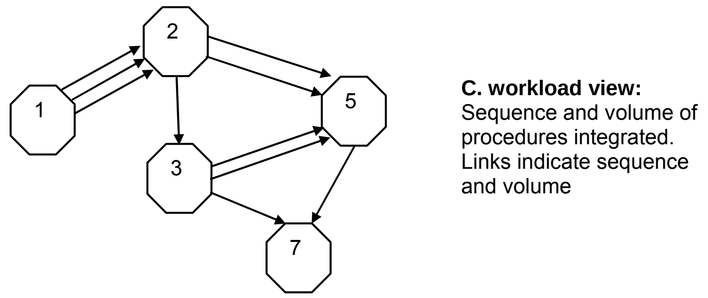



Figure 7-8: The workload view combines the function and process views (numbers denote individual procedures)

Even with perfect information about treatment process, it's likely that the optimisation of the dynamic ED situation "on the fly" would be complex. It may be useful to consider the co-ordination problem being analogous to a restaurant. The number of customers attending a restaurant is uncertain and the mix of demand unknown (the meals that they will choose). Restaurant staff have a range of specialist roles, such as reception, waiting on tables, recommending wine, clearing tables, preparing specialities of food, and so on, in much the same way the emergency departments have a range of specialists and support staff. Restaurants have tables or stations whose use needs to be optimised, similar to patient beds and certain resources such as x-ray machines that service the emergency department. Food courses should be served in particular order, just as procedures have specific sequence during treatment. By leveraging off existing restaurant knowledge the workload view could make robust and dynamic decision support available for hospital emergency departments.

#### 7.2.2.4 Summary of treatment focussed Information Systems design

Three views that arose from the process nature of the treatment clusters were discussed in the sections above. Information Systems applications of the function, process and workload views were postulated. Some of these applications may immediately be realised, such as those associated with the function view. Others, such as integrated optimisation of equipment, people and materials, may be some way off.

While existence of common and specific treatment processes is exciting from the Information Systems perspective, clinicians may not share the enthusiasm, burdened as they are with the responsibility for human lives. The treatment decision support described in this section may bring closer emergency department information systems where “The personal, moral, and legal responsibility for timely care no longer rests solely with the doctor or nurse” (Rucker, 2003), but such systems can only be developed with the support and sanction of healthcare professionals.

### 7.2.3 Activity Based simulation of ED costs[75]

Procedures may be used as cost drivers in Activity Based Costing (ABC) models for the ED. Treatment procedures provide an “activity” cost drivers that could replace proxies such as “doctor’s time” currently used in costing models. The section describes a costing model that combines Monte Carlo sampling of procedure costs with information about procedures.

#### 7.2.3.1 The overall model

The model consisted of three spreadsheets. These were a spreadsheet that estimated the most likely ratio of procedures; a spreadsheet that estimated the most likely cost of medical procedures; and a spreadsheet that combined the ratio of procedures with the cost of the procedures to arrive at a cost estimate for ED operations. The function, applications and possible extensions of these spreadsheets are described in the sections below.

#### 7.2.3.2 The procedure sampling component

This sheet utilised the count of number of presentations by hour of day to give an average, mean and standard deviation for relative number of procedures at any hour of the day. The average number of procedures was obtained from a full year and almost a million records, so it was assumed that the central limit theorem applies and the ratio is normally distributed for each procedure (Table 7-2).

Table 7-2: A sample of the description of average number of uses for each procedure

| Procedure | ABG | ART | BAC | CPAP | CPR |
|---|---|---|---|---|---|
| Average % per day | 1.34% | 0.09% | 0.14% | 0.11% | 0.02% |
| Std_dev | 0.29% | 0.03% | 0.08% | 0.04% | 0.01% |

Average procedure ratios are stable by hour of day (Ceglowski et al., 2005b) so only a single average was needed of the proportion of each procedure. The output of this sheet was a single table listing all the procedures and their relative likelihood of being used in an hour, day, or other time period (Table 7-3).

[75] A copy of this spreadsheet is included in the CD attached to this thesis

| Table 7-3: Some procedures and associated likelihood | |
|---|---|
| Total | 100.00% |
| ABG | 1.35% |
| ART | 0.09% |
| BAC | 0.13% |
| CPAP | 0.11% |
| CPR | 0.02% |
| CT | 1.18% |
| CVL | 0.05% |

#### 7.2.3.3 The cost sampling component

The second sheet calculated an average cost for each of the VEMD procedures. The sheet was loaded with a spread of costs for each procedure and the likelihood of that cost occurring. Triangular distributions were used owing to the limitations on cost information. Triangular distributions only require an estimate of the lowest cost; the most likely cost; and the maximum likely cost (Table 7-4)

Table 7-4: Sample of triangular probability distributions for several procedures

| | ABG | ABG | ART | ART | BAC | BAC |
|---|---|---|---|---|---|---|
| | Probability | Cost | Probability | Cost | Probability | Cost |
| Cumulative* probability/Min Cost | 0 | 10 | 0 | 5 | 0 | 28 |
| Cumulative probability /Most likely cost | 0.2 | 20 | 0.2 | 10 | 0.2 | 44 |
| Cumulative probability /Max Cost | 0.8 | 50 | 0.8 | 20 | 0.8 | 150 |

* This is not a true cumulative probability, but a shifted accumulation of probabilities – a lookup trick for Excel that forces the “lookup” command to match the correct number, since “lookup” looks for the lowest bound.
For example, if the probabilities are (0.1, 0.6, 0.3), the true cumulative probability is (0.1, 0.7, 1.0) but the Excel 'trick' is (0, 0.1, 0.7)

The triangular (or other type, if sufficient data is available) distributions for each procedure were repeatedly sampled by generating random probabilities and looking up the associated cost (Table 7-5).

Table 7-5: Monte Carlo sampling showing the random probabilities and the cost looked up from Table 7-4 for three procedures: ABG, ART, BAC.

| ABG Random probability | ABG Cost | ART Random probability | ART Cost | BAC Random probability | BAC Cost |
|---|---|---|---|---|---|
| 0.112827 | 10 | 0.718276 | 10 | 0.162227 | 28 |
| 0.657646 | 20 | 0.889742 | 20 | 0.345335 | 44 |
| 0.474764 | 20 | 0.835884 | 20 | 0.619894 | 44 |
| 0.774667 | 20 | 0.633026 | 10 | 0.586417 | 44 |
| 0.640279 | 20 | 0.185221 | 5 | 0.98491 | 150 |
| 0.81129 | 50 | 0.694899 | 10 | 0.856235 | 150 |
| 0.975336 | 50 | 0.620696 | 10 | 0.374245 | 44 |
| 0.805115 | 50 | 0.449142 | 10 | 0.225183 | 44 |

| | | | | | |
|---|---|---|---|---|---|
| 0.774084 | 20 | 0.443765 | 10 | 0.200953 | 44 |

The number of iterations necessary for assurance of a stable mean was estimated by plotting the running average of costs. Iterations were terminated when the average cost stabilised. The average cost and other statistical features were then determined across all iterations (Table 7-6)

Table 7-6: Average costs and other features for three procedures

| | | ABG | | ART | | BAC |
|---|---|---|---|---|---|---|
| Average cost | | 23.92 | | 10.83 | | 65.41 |
| Min cost | | 10.00 | | 5.00 | | 28.00 |
| Max cost | | 50.00 | | 20.00 | | 150.00 |
| Std Dev | | 13.90 | | 4.76 | | 47.05 |

The output of this sheet was a single table that lists the procedures and their most likely cost (Table 7-7).

Table 7-7: An extract from the table that gives procedure average cost

| Procedure | Average Cost: |
|---|---|
| ABG | 23.92 |
| ART | 10.83 |
| BAC | 65.41 |
| CPAP | 23.36 |
| CPR | 10.88 |

#### 7.2.3.4 The cost estimation component

The total cost sheet simply combines the results of the previous two sheets. An estimate of the total number of procedures (in a time period, say) is used in the calculation of the number of procedures of a certain type. The number of procedures is multiplied by the average cost to give a total cost for each procedure. The sheet sums the total procedure costs to give an overall total cost (Table 7-8).

Table 7-8: An extract from the cost estimation sheet showing different costs associated with different numbers of procedures in the top row

| | | **Total Cost** | $72,910,163 | $729,102 | $7,291,016 | $56,665,394 |
|---|---|---|---|---|---|---|
| Procedure name | Procedure ratio | Number of procedures as a proportion of total procedures (from 2002 count) | Total cost on 2 244 112 procedures (actual count in 2002) | Total cost on 10 000 procedures | Total cost on 100 000 total procedures | Total cost on 1 000 000 procedures |
| XRAY | 8.81% | 197770 | $10,857,195 | $108,572 | $1,085,720 | $ 8,438,155 |
| OTHER | 16.23% | 364318 | $13,598,366 | $135,984 | $1,359,837 | $10,568,578 |
| DRUG | 9.89% | 221996 | $5,339,700 | $ 53,397 | $ 533,970 | $ 4,149,987 |
| VB | 8.85% | 198541 | $4,940,443 | $ 49,404 | $ 494,044 | $ 3,839,686 |

| | | | | | | |
|---|---|---|---|---|---|---|
| IV | 8.24% | 184853 | $4,661,254 | $ 46,613 | $ 466,125 | $ 3,622,702 |
| NONE | 6.15% | 137995 | $1,778,806 | $ 17,788 | $ 177,881 | $ 1,382,479 |
| IVS | 5.04% | 113119 | $2,709,585 | $ 27,096 | $ 270,959 | $ 2,105,875 |
| HIO | 4.42% | 99267 | $2,390,980 | $ 23,910 | $ 239,098 | $ 1,858,257 |

#### 7.2.3.5 Summary of the Activity Based simulation of ED costs

This section described a cost estimation system for the ED that is based on the number of procedures. The system utilises the relative stability of procedure ratios to allow estimates of costs over different time periods. Since procedures are a measure of work undertaken in the ED the system is activity based. The activity component could be accentuated by linking procedures to treatment clusters.

A major shortcoming of the system at this stage has lain in the cost estimation (the total amounts are overstated). Insufficient data was available to build sufficiently accurate distributions. The triangular distributions were largely derived from government estimation of costs for procedures. Inaccuracies arose owing to the width of some of the government pricing schedules and because the schedules were linked to ICD classifications, making them far more granular than the simple procedure-level discussed here. It's probable that better cost estimates could be achieved at a process level (that is, by treatment) within the ED environment. Urgency and age factors might need to be included to provide sufficient detail to the cost estimation.

The discussion of conclusions and extensions closes in the next section with a discourse of how Data Mining techniques such as should be included in the Management Science toolkit.

## 7.3 Clustering as a Management Science technique

This chapter has summarised the new knowledge about ED overcrowding that was derived from this research. It provided several potential extensions of that knowledge. The research results published in this thesis were heavily based on a clustering technique commonly employed in Data Mining. The technique yielded non-intuitive, high-level segmentations of ED work processes that would probably have been impossible to identify through selective data analysis or on-site observation. These treatment groups were used in simulation modelling, a technique most commonly used in Management Science. This synergistic relationship between Data Mining and Management Science could be applied to other problems where process definition or customer segmentation is difficult to encapsulate.

Although there was no generally accepted formalism for the field of Data Mining in its early years, and much misinformation has been disseminated by certain purveyors of Data Mining products, it is now generally accepted that Data Mining refers to a methodology for discovering knowledge from vast repositories data. The volume of data makes it difficult to achieve insights from traditional investigative techniques such as measures of centre, scatter plots and correlation studies. The Data Mining methodology may be considered to be comprised of five major stages:

1. Building an understanding of the problem
2. Gathering data related to the problem
3. Preparing the data for analysis
4. Building models that provide insight into relationships within the data
5. Analysing the results and implementing business changes or iterating the Data Mining process.

The origins of Management Science also lie with analysis of data (Morse et al., 1951), emphasising the data understanding and data context in problem-driven analyses. The work described in this thesis was based on these values, with emphasis on understanding of the problem before formulation of algorithms to address the problem. This was achieved by identification of the real problem, extraction of additional insights from existing data (through the Data Mining methodology), and application of appropriate logic

The inclusion of Data Mining in a Management Science analysis may be less than popular in modern Management Science, because of a view that it is "data-led", rather than "problem-led" modelling. The objection to data-led modelling lies in the idea that the models may not be appropriate to the problem context or may ignore some important aspect of the problem. The process of Data Mining emphasises the necessity for proper problem formulation and understanding of the data in context. Interaction with domain experts is also encouraged. These problem formulation, understanding of the data in context and the use of domain experts aspects of Data Mining act as countermeasures to building models that bear insufficient links to reality. Data Mining methodology is in fact a far more rigorous approach to dealing with the data/model interaction than any Management Science provides[76].

---

[76] Some of the best regarded MS/OR texts only dedicate 0.1 to 1 percent of their pages to the issue of data (Hillier *et al.*, 2001; Pidd, 1996; Taha, 1997; Winston *et al.*, 2001)).

While it may seem from the layout of this thesis that the Data Mining modelling led directly to the simulation model, this is not strictly correct. At least a year was spent interpreting the results of the Self Organising Map and exploring possible applications for the new knowledge. This process led gradually to the idea that the patient treatment groups may provide a new way of looking at ED simulation models. The incorporation of the patient treatment groups into a discrete event simulation model was facilitated by the understanding of the problem brought about through the rigor of the Data Mining methodology. It was found that the steps taken during Data Mining to understand the problem and its context and to interpret the modelling results had provided the necessary background for a broader Management Science study of the problem.

It can be seen that a similar combination of Data Mining and Management Science may be used in a wide variety of problems. In fact, wherever there are large repositories of data, Data Mining could be the first stop for Management Science practitioners before application of the wide variety of tools at their disposal. The Data Mining methodology would encourage them to appraise the problem (possibly in new ways) and provides a systematic way in which the data may be described and investigated. The Data Mining techniques may reveal new, hitherto unknown information about the problem and its context. The methodology blends easily into sequential projects because of its iterative nature. This cyclic prescription also provides the opportunity for restarting the project while incorporating learning from the first iteration.

With the expectation in the computer age that more and more Management Science problems will be either data-based or be accompanied by a large amount of data it's necessary for Management Science practitioners to be cognisant of the best ways to deal with data. Rather than formulating their own response to this issue they would do well to consider adopting Data Mining as their preferred methodology for dealing with data issues. Data Mining is proven and widely accepted. The toolset is large and growing, and multiple vendors supply excellent packaged software products that simplify the difficult tasks of data preparation for, and translation between, methods.

The Data Mining methodology provides a panoply of techniques specifically intended for dealing with large and complex collections of data. These techniques use mathematical methods often quite removed from descriptive statistics, but the traditional statistical methods are not excluded. The expanded methods include algorithms particularly suited to complex, non-linear and ill-defined problems. These algorithms, powered by fast modern computers, make exploration of hugely complicated solution spaces feasible. Such tools are essential in the information-centric world in which Management Science now operates.

## 7.4 Limitations of the research as an indicator of future work

While the vision for future applications of treatment clusters appears bright, there are several important issues that need to be addressed before they can be considered mature enough for implementation in ED settings. Some of these issues are discussed in this section.

A significant issue pertaining to this work is that treatment clusters have not been verified in situ.

- Time has to be spent following patients in an actual emergency department to detect how the recorded procedure data matches actual treatment practises. There is currently a single large procedure named either "observation" or "other", depending on the database. The component activities need to be isolated and data captured separately about them so that treatment clusters can be further clarified.
- The treatment clusters cannot be aligned with Ambulatory Classification schemes or **Diagnosis-Related Groups** (**DRGs**) because these classifications rely on diagnosis, rather than treatment. The assumption of similar treatment is inherent in their construction from similarity of diagnosis whereas the treatment clusters arrive directly at commonality of treatment. While there are indications that the treatment clusters align with patient symptoms (cf Table 5.12), the absence of diagnosis information from the data makes alignment of diagnoses and treatment clusters impossible for this data set. It is an avenue that could to be explored if appropriate data sets become available or through in situ observations.
- The clusters have not yet been named since this requires clinical expertise outside the scope of this research. Naming may evolve from in situ observations of ED activity.
- In comparing treatment clusters from the data of a number of different emergency departments it was seen that the selection and ratio of procedures was sometimes different (Ceglowski, et al., 2004b) (cf Section 5.5). This may be due to clustering, coding or treatment issues. Clustering differences can arise because specific characteristics in the data drive the clustering optimisation algorithm towards separate solutions for different data sets. These can usually be detected and overcome by adjustment of parameters. Coding issues relate to interpretation of procedure definitions. These may vary from hospital to hospital but can be addressed by clearer, agreed guidelines. Treatment differences may arise because of different patient profiles or innovation in treatment at certain campuses. In situ

cross-campus comparisons would provide the opportunity for identifying the reasons behind the differences.

- At present, drug administration is separated only by method of administration (oral, sublingual, intravenous, nebulised and so on), not by type of drug. Treatment clusters should carry more detail about the type of drug, but this may place an unacceptable data-entry burden on staff.

The simulation model that was built for the ED intentionally did not include resources in order to keep the model simple[77]. Omission of resources from the model made it possible to focus on the treatment processes and their impact on ED workload. On the other hand, the omission did mean that the impact of staffing and other resources that might otherwise constrain throughput were hidden.

Since the simulation model of this research was intended to be used merely to build an understanding of the mechanism of ED overcrowding it was sufficient to match the general pattern of output as described in Section 6.7.2. If the model were to be used for forecasting or similar applications, thorough statistical investigation would need to be carried out into the nature of the overcrowding events. This would include definition of overcrowding and blockage. Questions that would arise at this point would be whether to base the definitions on the number of people in the ED; the time patients wait before being seen by doctors; or other measure? The frequency and timing of overcrowding and blockage events would then need to be simulated. Depending on the definition of overcrowding that was being used this may require a large number of replications in order to generate a statistically significant sample.

Possibly the greatest impediment to using the treatment clusters for process-based decision support, however, is the belief in medical circles that definition of treatment process, prediction of resource requirements and delivery specifications are not possible. While exact identification of these elements may not yet be possible, treatment clusters move in the correct direction and it may be that the objections raised by clinicians are "a cover for not having to accept guidelines and protocols to defend medical autonomy" (de Vries et al., 1999).

---

[77] The idea behind the "resource-free" mode was discussed in Section 6.2 and will not be repeated here.

## 7.5 Closing comments

While the research was initiated in 2002, the problem of overcrowding has not diminished in the intervening years. The subject matter has not become “dated” in the past four years, nor has the problem of ED overcrowding been “solved”.

This thesis has contributed to the issue by providing a new perspective of ED operations. It discussed the extent and context of the problem of ED overcrowding and summarised the range of approaches that are being used to address the problem within a framework of external and internal; lay and clinical. The data-driven analysis of ED treatment operations synthesised with discrete event simulation that was introduced in this thesis was a new approach. As such it has provided unique insights. Not only has it confirmed that exit block is the most likely direct cause of ED overcrowding, it has also suggested that the mix of patients types in, and arriving at, the ED are the most likely precursors of ED overcrowding. It has concluded that there will always be a finite chance that a mix of patient types will occur who require admittance to hospital or have long ED treatment times, and consequently are likely to block the ED.

With the insights provided by this research it is now possible to see that short stay units linked to the ED provide extra capacity to absorb shocks to the ED system by increasing the number of “blockage” patient types that need to concurrently occupy the ED before overcrowding sets in, but this does not eliminate the possibility that a critical number of “blockage” patient types will arrive and subsequently occupy the ED. In addition, efforts to limit ED attendance merely lower the probability that critical numbers of “blockage” patients will simultaneously arrive at the ED.

The arguments above suggest that it will not be possible to eliminate ED overcrowding. What we now need to do is to determine acceptable levels of risk that overcrowding will occur. Once the relationship between patient types and hospital wards is determined for a hospital, the capacity to admit ED patients and the size of the short stay ward can be determined based on how risk adverse the hospital is to ED overcrowding.

The solution to the ED overcrowding problem lies within our conceptual grasp – the challenge remains in getting the necessary political and administrative will to cooperate in implementing the necessary regulatory, funding and operational framework to address the problem (at a given level of risk, of course!).

## References


Abston, K. C. (1999) Using the Electronic Medical Record to Predict the Pharmacological Management of Acute Myocardial Infarction. PhD, Department of Medical Informatics, University of Utah, Salt lake City.

Acute Health Division (2001) *Emergency Demand Management: A New Approach*. Victorian Government Department of Human Resources, Melbourne.

Agrawal, R., D. Gunopulos, et al. (1998). Mining process models from workflow logs. Sixth International Conference on Extending Database Technology, Valencia, Spain.

Aldenderfer, M. S., and Blashfield, R. K. (1984) *Cluster Analysis* Sage Publications, Beverly Hills.

Amouh, T., Gemo, M., Macq, B., Vanderdonckt, J., Gariani, A. W. E., Reynaert, M. S., Stamatakis, L., and Thys, F. (2005) Versatile Clinical Information System Design for Emergency Departments *Information Technology in Biomedicine, IEEE Transactions on* 9, 174-183.

Angluin, D. and C. H. Smith (1983). "Inductive Inference: Theory and methods." *Computing Surveys* **15**(3): 237-269.

Anonymous (2003) *Microsoft Office Excel 2003*. Microsoft Corporation.

Australasian School of Medicine (1994) National Triage Scale *Emergency Medicine Australasia* 6, 145-146.

Australian College for Emergency Medicine (1998) *Acem Guideline P15: Guidelines on Emergency Department Design*. Australian College for Emergency Medicine, Melbourne.

Australian College for Emergency Medicine (2001) *Policy Document Po2: Standard Terminology*. Australian College for Emergency Medicine, Melbourne.

Australian Department of Health and Aging (2003) *Annual Report 2002-'03*. Australian Department of Health and Aging.

Averill, R. F., Muldoon, J. M., Vertrees, J. C., Goldfield, N. I., Mullin, R. L., Fineran, E. C., Zhang, M. Z., Steinbeck, B., and Grant, T. (1998) *The Evolution of Casemix Measurement Using Diagnosis Related Groups (Drgs)*. 3M Health Information Systems, Wallingford, CT.

Baesler, F. F., Jahnsen, H. E., and DaCosta, M. (2003) "The Use of Simulation and Design of Experiments for Estimating Maximum Capacity in an Emergency Room." Paper presented at the The 2003 Winter Simulation Conference, New Orleans, Louisiana, 7 - 10 December.

Bagust, A., Place, M., and Posnett, J. W. (1999) Dynamics of Bed Use in Accommodating Emergency Admissions: Stochastic Simulation Model *BMJ* 319, 155-158.

Bandyopadhyay, S., and Maulik, U. (2001) Nonparametric Genetic Clustering: Comparison of Validity Indices *IEEE Transactions on Systems Man and Cybernetics Part C- Applications and Reviews* 31, 120-125.

Banks, J. (2001) *Discrete-Event System Simulation* (3rd ed.) Prentice Hall, Upper Saddle River, NJ.

Barraclough, S., and Gardner, H. (2002) *Health Policy in Australia* (2nd ed.) Oxford University Press, South Melbourne.

Beaulieu, H., Ferland, J. A., Gendron, B., and Michelon, P. (2000) A Mathematical Approach for Scheduling Physicians in the Emergency Room *Health Care Management Science* 3, 193- 200.

Begg, R., Kamruzzaman, J., and Sarkar, R. (2006) *Neural Networks in Healthcare: Potential and Challenges* Idea Group Publishing, Hershey, Pa.

Berry, M. J. A., and Linoff, G. S. (2000) *Mastering Data Mining* John Wiley and Sons, New York.

Bezdek, J. C., and Pal, N. R. (1998) Some New Indexes of Cluster Validity *Systems, Man and Cybernetics, Part B, IEEE Transactions on* 28, 301-315.

Bolton, P., Mira, M., and Sprogis, A. (2000) Oranges Are Not the Only Fruit: The Role of Emergency Departments in Care to Primary Care Patients *Australian Health Review* 23, 132-136.

Bond, M., Baggoley, C., and Erwich-Nijhout, M. (1996) *Costings in the Emergency Departments*. A Report for the Commonwealth Department of Health and Family Services, Bedford Park, South Australia.

Bond, M., Baggoley, C., Erwich-Nijhout, M., and Phillips, D. (1998) Urgency, Disposition and Age Groups: A Casemix Model for Emergency Departments *Emergency Medicine Australasia* 10, 103-110.

Bradley, V. M. (2005) Placing Emergency Department Crowding on the Decision Agenda *Nursing Economics* 23 14-24.

Brailsford, S., Churilov, L., and Liew, S. K. (2003) "Treating Ailing Emergency Departments with Simulation: An Integrated Perspective." Paper presented at the International Conference on Health Sciences Simulation, Orlando, Florida, 19-23 Jan.

Brailsford, S., Lattimer, V., PTarnaras, and Turnbull, J. (2004) Emergency and on-Demand Health Care: Modelling a Large Complex System *Journal of the Operational Research Society* 55,

Brailsford, S. C., and Hilton, N. A. (2000) "A Comparison of Discrete Event Simulation and System Dynamics for Modelling Healthcare Systems." Paper presented at the ORAHS, Glasgow Caledonian University.

Bridgeman, T., Flores, M., Rosenbluth, J., and Pierog, J. (1997) One Emergency Department's Experience: Clinical Algorithms and Documentation *Journal of Emergency Nursing* 23, 316-325.

Brossette, S. E., Sprague, A. P., Jones, W. T., and Moser, S. A. (2000) A Data Mining System for Infection Control Surveillance *Methods of Information in Medicine* 39, 303-310.

Bunnin, N., and Tsui-James, E. P. (2003) *The Blackwell Companion to Philosophy* (2nd ed.) Blackwell, Malden, MA ; Oxford.

Burgun, A., and Bodenreider, O. (2005) (Bio)Medical Ontologies. In *Medical Informatics:Advances in Knowledge Management and Data Mining in Biomedicine* (Chen, H., Fuller, S., and McCray, A., eds.). Kluwer.

Buntinx, F., D. Knockaert, et al. (2001). "Chest pain in general practice or in the hospital emergency department: is it the same?" *Family Practice* **18**(6): 586-589.

Cabena, P., Hadjinian, P., Stadler, R., Verhees, J., and Zanasi, A. (1998) *Discovering Data Mining: From Concepts to Implementation* Prentice Hall, Englewood Cliffs, NJ:.

Cameron, J., Baraff, L., and Sekhon, R. (1990) Case-Mix Classification for Emergency Departments *Medical Care* 28, 146-158.

Cameron, P. A., Scown, P., and Campbell, D. A. (2002) Managing Access Block *Australian Health Review* 25, 59-68.

Campbell, D., and Cooper, P. (2002) "Using Computer Simulation Modeling to Inform Management Decisions in a Public Hospital." Paper presented at the ARCHI Toolkit Seminar “Bed Management -Designing Patient Flows”, Sydney.

Campbell, R. (2004) *Crisis Control : Preventing & Managing Corporate Crises* (Rev. ed.) Viking, Camberwell, Vic.

Carter, M. W., and Lapierre, S. D. (2001) Scheduling Emergency Room Physicians *Health Care Management Science* 4, 347-360.

Carter, M. W., and Blake, J. T. (2004) Using Simulation in an Acute-Care Hospital: Easier Said Than Done. In *Operations Research and Heathcare* (Bradeau, M. L., Sainfort, F., and Pierskalla, W. P., eds.). Kluwer, Boston.

Ceglowski, A., Churilov, L., and Wassertheil, J. (2004a) "Lessons Learnt from Comparison of Self Organised and K-Means Clustering on Hospital Emergency

Department Data." Paper presented at the International Conference on Optimization: Techniques and Applications, Ballarat, Australia, 9-11 December.
Ceglowski, A., Churilov, L., and Wassertheil, J. (2004b) "Process Focused Patient Clustering for a Hospital Emergency Department." Paper presented at the Casemix 2004, Sydney, 10-13 Oct.
Ceglowski, A., Churilov, L., and Wasserthiel, J. (2004c) "Data Driven Process Modelling for a Hospital Emergency Department." Paper presented at the Computer Supported Activity Co-ordination Workshop at ICEIS 2004, Porto, Portugal.
Ceglowski, A., Churilov, L., and Wasserthiel, J. (2004d) "Process Mining Informed Industrial Engineering in Hospital Emergency Departments." Paper presented at the The 5th Asia-Pacific Industrial Engineering and Management Systems Conference (APIEMS), Gold Coast, Australia.
Ceglowski, A., Churilov, L., and Wassertheil, J. (2005a) Don't Panic - Prepare: Towards Crisis-Aware Models of Emergency Department Operations *Clinical and Investigative Medicine* 28, 320-322.
Ceglowski, A., Churilov, L., and Wassertheil, J. (2005a) Combining Data Mining and Discrete Event Simulation for a Value-Added View of a Hospital Emeregency Department *Journal of the Operational Research Society* Special Issue,
Ceglowski, A., Churilov, L., and Wassertheil, J. (2005b) "Knowledge Discovery through Mining Emergency Department Data." Paper presented at the Hawaii International Conference on System Sciences (HICSS), Hawaii, 3-7 Jan.
Chae, Y. M., Kim, H. S., Tark, K. C., Park, H. J., and Ho, S. H. (2003) Analysis of Healthcare Quality Indicators Using Data Mining and Decision Support System *Expert Systems with Applications* 24, 167-172.
Chalmers, A. F. (1999) *What Is This Thing Called Science?* (3rd ed.) Hackett Pub., Indianapolis.
Chou, C.-H., Su, M.-S., and Lai, E. (2003) "A New Cluster Validity Measure for Clustrs with Different Densities." Paper presented at the IASTED International Conference on Intelligent Systems and Control, Salzburg, Austria, June 25-27.
Coast, J. (1996) Appropriateness Versus Efficiency: The Economics of Utilisation Review *Health Policy* 36, 69-81.
Codrington-Virtue, A., Wittlestone, P., Kelly, J., and Chaussalet, T. J. (2005) "An Interactive Framework for Developing Simulation Models of Hospital Accident and Emergency Services." Paper presented at the 2nd Conference of the International Council on Medical and Care Compunetics, The Hague, The Netherlands, 1–3 June.
Codrington-Virtue, A., Chaussalet, T., Millard, P., Whittlestone, P., and Kelly, J. (2006) "A System for Patient Management Based Discrete-Event Simulation and Hierarchical Clustering." Paper presented at the 19th IEEE Symposium on Computer-Based Medical Systems (CBMS'06).
Coleridge, J. T., Cameron, P. A., White, J. B., and Epstein, J. (1993) Profile of Emergency Department Attendances *Emergency Medicine Australasia* 5, 18-25.
Connelly, L. G., and Bair, A. E. (2004) Discrete Event Simulation of Emergency Department Activity: A Platform for System-Level Operations Research *Academic Emergency Medicine* 11, 1177-1185.
Cook, J. E. and A. L. Wolf (1998). "Discovering models of software processes from event-based data." *(ACM) Transactions on Software Engineering and Methodology* **7**(3): 215-249.
Cooke, M. W., Wilson, S., and Pearson, S. (2002) The Effect of a Separate Stream for Minor Injuries on Accident and Emergency Department Waiting Times *Emerg Med J* 19, 28-30.
Coombs, W. T. (1999) Ongoing Crisis Communication : Planning, Managing, and Responding Sage Publications, Thousand Oaks, Calif.
Cullen, P. (2001) Feature Selection Methods for Intelligent Systems Classifiers in Healthcare. Ph.D, Interdisciplinary, Loyola University of Chicago, Chicago.

Daellenbach, H. G. (1994) Systems and Decision Making: A Management Science Approach Wiley, Chichester.
de Angelis, V., Felici, G., and Impelluso, P. (2003) Integrating Simulation and Optimisation in Health Care Centre Management *European Journal of Operational Research* 150, 101-114.
de Vries, G., Bertrand, J. W. M., and Vissers, J. M. H. (1999) Design Requirements for Health Care Production Control Systems *Production Planning and Control* 10, 559-569.
de Vries, G., Vissers, J., and de Vries, G. (2000) The Use of Patient Classification Systems for Production Control of Hospitals *Casemix* 2, 65-70.
Department of Health (2000) Shaping the Future Nhs: Long Term Planning for Hospitals and Related Services (Consultation Document on the Findings of the National Beds Inquiry).
Department of Health (2003) *Improving the Flow of Emergency Admissions*. NHS Modernisation Agency, London.
Department of Health and Ageing (2003) *Australian Health Care Agreements 1998- 2003 Performance Report*. Department of Health and Ageing.
Department of Health and Ageing (2004a) *National Demonstration Hospitals Program (Ndhp)*. Department of Health and Ageing, Canberra.
Department of Health and Ageing (2004b) *2003-04 Annual Report for the Department of Health and Ageing*. Department of Health and Ageing.
Department of Health and Ageing (2005) *The State of Our Public Hospitals, June 2005 Report*. Department of Health and Ageing.
Dinh, M., and Chu, M. (2006) Evolution of Health Information Management and Information Technology in Emergency Medicine *Emergency Medicine Australasia* 18, 289-294.
Djohan, V. (2002) Towards Integrated Clinical Process Modelling in an Acute Emergency Department, Information Technology, Monash University, Melbourne.
Djorhan, V., and Churilov, L. (2003) "Business Interactions in an Acute Emergency Department in Australia: A Clinical Process Modeling Perspective." Paper presented at the The 6th Pacific Asia Conference on Information Systems (PACIS 2002), Tokyo, 2-4 Sep.
Duckett, S. J., Jackson, D., and Scully, B. (1997) *Paying for Hospital Emergency Care*. Acute Health Division, Department of Human Services, Melbourne.
Duckett, S. J. (1998) Casemix Funding for Acute Hospital Inpatient Services in Australia *The Medical Journal of Austalia* 168, S17-21.
Duckett, S. J. (2000) The Development of Australian Refined Diagnosis Related Groups: The Australian Inpatient Casemix Classification *Casemix* 2, 115-120.
Dwyer, J., and Jackson, T. (2001) *Literarture Review: Integrated Bed and Patient Management*. The Patient Management Task Force.
Eagar, K., and Hindle, D. (1994) *A Short Introduction to Casemix* Dept. of Human Services and Health, [Canberra, A.C.T.].
Edwards, J., Hall, M., and Shaw, D. (2005) Proposing a Systems Vision of Knowledge Management in Emergency Care *Journal of the Operational Research Society* 56, 180-192.
Espinosa, J., Case, R., and Kosnik, L. (2004) Emergency Department Structure and Operations *Emergency Medicine Clinics of North America* 22, 73-85.
Eudaptics Software Gmbh (1999a) *Viscovery Somine* (Standard Edition 3.0 ed.). Eudaptics Software Gmbh, Wien.
Eudaptics Software Gmbh (1999b) *Viscovery Somine User Manual* (Standard Edition 3.0 ed.). Eudaptics Software Gmbh, Wien.
Evans, G. W., Unger, E., and Gor, T. B. (1996) "A Simulation Model for Evaluating Personnel Schedules in a Hospital Emergency Department." Paper presented at the The 1996 Winter Simulation Conference.

Fatovich, D. M., and Hirsch, R. L. (2003) Entry Overload, Emergency Department Overcrowding, and Ambulance Bypass *Emergency Medicine Journal* 20, 406-9.

Fatovich, D. M., Nagree, Y., and Spivulis, P. (2005) Access Block Causes Emergency Department Overcrowding and Ambulance Diversion in Perth, Western Australia *Emergency Medicine Journal* 22, 351-354.

Feyerabend, P. (1975) *Against Method* Verso, London.

Fone, D., Hollinghurst, S., M Temple, A. R., N. Lester,, Weightman, A., Roberts, R., Coyle, E., Bevan, G., and ():, S. P. (2003) Systematic Review of the Use and Value of Computer Simulation Modelling in Population Health and Heathcare Delivery *Journal of Public Health Medicine* 25 325-35.

Forster, A. J., Stiell, I., Wells, G., Lee, A. J., and Walraven, C. v. (2003) The Effect of Hospital Occupancy on Emergency Department Length of Stay and Patient Disposition *Academic Emergency Medicine* 10, 127-134.

Francis, R. L., McGinnis, L. F., and White, J. A. (1992) *Facility Layout and Location : An Analytical Approach* (2nd ed.) Prentice Hall, Englewood Cliffs, N.J.

Funding & Financial Policy Branch (2002) *Casemix Funding in Victoria*. Victorian Department of Human Services.

Gerdtz, M. F., and Bucknall, T. K. (2001) Triage Nurses' Clinical Decision Making. An Observational Study of Urgency Assessment *Journal of Advanced Nursing* 35, 550-561.

Gilchrist, R. (1985) Some Aspects of Modelling Operational Problems in the National Health Service *The Statistician* 34, 209-214.

Goddard, M., McDonagh, M., and Smith, D. (1999) *Acute Hospital Care: Final Report*. Centre for Health Economics.

Goddard, P. W. and T. M. Mills (2003). "Models of congestion in hospitals." *The Australian Mathematical Society Gazette* **30**(3): 127-141.

Gorelick, M., Alpern, E., and Alessandrini, E. (2005) A System for Grouping Presenting Complaints: The Pediatric Emergency Reason for Visit Clusters *Academic Emergency Medicine* 12, 723.

Gunal, M. M., and Pidd, M. (2005) "Simulation Modelling for Performance Measurement in Healthcare."

Gutting, G. (1980) The Logic of Invention. In *Scientific Discovery, Logic, and Rationality* (Nickles, T., ed, pp. xii, 385. D. Reidel Pub. Co. (Kluwer Boston in U.S.A. and Canada), Dordrecht, Holland ; Boston.

Habing, N., Dietz, J., and Zwetsloot-Schonk, B. (2001) Activity Patterns in Health Care: Identifying Building Blocks for the Cpr *ACM SIGGROUP Bulletin* 22 9-15.

Han, J., and Kamber, M. (2001) *Data Mining : Concepts and Techniques* Morgan Kaufmann; International Thomson, San Francisco.

Hanson, N. R. (1958) *Patterns of Discovery* Cambridge University Press, Cambridge.

Hanson, R. M., ed (1998) *Casemix: Evolution, Not Revolution (Editorial)*. The Australian Medical Association, Sydney.

Harper, P. (2002) A Framework for Operational Modelling of Hospital Resources *Health Care Management Science* 5, 165-173.

Hider, P., Kirk, r., Bidwell, S., Weir, R., Cook, L., and Tolan, C. (1998) *Acute Medical Admissions: A Critical Appraisal of the Literature*.

Hillier, F. S., and Lieberman, G. J. (2001) *Introduction to Operations Research* (7th ed.) McGraw-Hill, Boston.

Hodges, W. (2001) *Logic* (2nd ed.) Penguin, London.

Hoffenberg, S., Hill, M. B., and Houry, D. (2001) Does Sharing Process Differences Reduce Patient Length of Stay in the Emergency Department? *Annals of Emergency Medicine* 38, 533-540.

Horwich, P. (1982) *Probability and Evidence* Cambridge University Press, Cambridge [Cambridgeshire] ; New York.

Hospital Demand Management Group (2003) *Hospital Demand Management*. Victorian Government Department of Human Services.

Houghton Mifflin Company, ed (2000) *The American Heritage Dictionary of the English Language* (Fourth ed.). Houghton Mifflin Company, Massachusetts.
Huang, X.-M. (1998) Decision Making Support in Reshaping Hospital Medical Services *Health Care Management Science* 1, 165-173.
Huxley, T. (1953) Readings in Philosophy of Science (Wiener, F. P., ed. Chas Scribner's Sons, New York.
Ieraci, S., Cunningham, P., Talbot-Stern, J., and Walker, S. (2000) Emergency Medicine and 'Acute' General Practice: Comparing Applies with Oranges *Aust. Health Review* 23, 152-161.
Ishikawa, K. (1986) *Guide to Quality Control* (2nd revised ed.) Asian Productivity Organization, Tokyo.
Isken, M. W. and B. Rajagopalan (2002). "Data mining to support simulation modeling of patient flow in hospitals." *Journal of Medical Systems* 26(2): 179-197.
Jain, A. K., Murty, M. N., and Flynn, P. J. (1999) Data Clustering: A Review *ACM Computing Surveys (CSUR)* 31,
Jelinek, G. A. (1995) *A Casemix Information System for Australian Hospital Emergency Departments*. A Report to the Commissioner of Health, Western Australia, Perth.
Jelinek, G. A., and Little, M. (1996) Inter-Rate Reliability of the National Triage Scale *Emergency Medicine Australasia* 8, 226-236.
Jiang, H., Lam, L. P., Owens, B., Sier, D., and Westcott, M. (2004) "Predicting Emergency Department Status." Paper presented at the The International Conference on Optimization: Techniques and Applications, Ballarat, Australia, 9-11 December.
Jun, J. B., Jacobson, S. H., and Swisher, J. R. (1999) Application of Discrete-Event Simulation in Health Care Clinics: A Survey *Journal of the Operational Research Society* 50, 109-123.
Kelton, W. D., Sadowski, R. P., and Sturrock, D. T. (2004) *Simulation with Arena* (3rd ed.) McGraw-Hill Higher Education, New York, NY.
Kennedy, R., Lee, Y., Van Roy, B., Reed, C., and Lippmann, R. (1998) *Solving Data Mining Problems through Pattern Recognition* Prentice Hall.
Kohonen, T. (1995) *Self-Organizing Maps* Springer, Berlin.
Komashie, A., and Ali, M. (2005) "Modeling Emergency Departments Using Discrete Event Simulation Techniques."
Konz, S. A. (1994) *Facility Design : Manufacturing Engineering* Holcomb Hathaway, Scottsdale, Ariz.
Konz, S. A., and Johnson, S. (2000) *Work Design : Industrial Ergonomics* (5th ed.) Holcomb Hathaway, Scottsdale, Ariz.
Kourany, J. A., ed (1987) Scientific Knowledge : Basic Issues in the Philosophy of Science. Wadsworth Pub. Co., Belmont, Calif.
Lane, D. C. (2000) You Just Don't Understand Me: Modes of Failure and Success in the Discourse between System Dynamics and Discrete Event Simulation. London School of Economics and Political Science, London.
Lane, D. C., Monefeldt, C., and Rosenhead, J. (2000) Looking in the Wrong Place for Healthcare Improvements: A System Dynamics Study of an Accident and Emergency Department *Journal of the Operational Research Society* 51, 518-531.
Lee, I. N., Liao, S. C., and Embrechts, M. J. (2002) Important Variable Selection Techniques with Multiple Solutions for Medical Information Applications *Medical Informatics and the Internet in Medicine* 27, 253-266.
Lemon, S. C., J. Roy, et al. (2003). "Classification and Regression Tree Analysis in Public Health: Methodological Review and Comparison With Logistic Regression." *Annals of Behavioral Medicine* **26**(3): 172-181.
Levary, R. R. (1997) Re-Engineering Hospital Emergency Rooms: An Information System Approach *International Journal of Health Care Quality Assurance* 10, 179-191.

Lewin Group (2002) Emergency Department Overload: A Growing Crisis. The Results of the American Hospital Association Survey of Emergency Department (Ed) and Hospital Capacity. The American Hospital Association, Falls Church, VA.
Liaw, S.-T., Hill, T., Bryce, H., and Adams, G. (2001) Emergency and Primary Care at a Melbourne Hospital: Reasons for Attendance and Satisfaction *Australian Health Review* 24, 120-134.
Lin, F. R., Chou, S. C., Pan, S. M., and Chen, Y. M. (2001) Mining Time Dependency Patterns in Clinical Pathways *International Journal of Medical Informatics* 62, 11-25.
Litvak, E., Long, M. C., Cooper, A. B., and McManus, M. L. (2001) Emergency Department Diversion: Causes and Solutions *Academic Emergency Medicine* 8, 1108-9.
Macdonald, S. J., Karkam, I., Al-Shirrawi, N., Chowdhary, R. K., Escalante, E. M., and Afandi, A. (2005) "Emergency Department Process Improvement." Paper presented at the The 2005 Systems and Information Engineering Design Symposium.
MacQueen, J. B. (1967) "Some Methods for Classification and Analysis of Multivariate Observations." Paper presented at the 5-th Berkeley Symposium on Mathematical Statistics and Probability, Berkeley.
Mahapatra, S., Koelling, C. P., Patvivatsiri, L., Fraticelli, B., Eitel, D., and Grove, L. (2003) "Pairing Emergency Severity Index 5-Level Triage Data with Computer Aided System Design to Improve Emergency Department Access and Throughput." Paper presented at the The 2003 Winter Simulation Conference, New Orleans, Louisiana, 7 - 10 December.
Maij, E., Reijswoud, V. E., Toussaint, P. J., Harms E.H., and Zwetsloot-Schonk, J. H. M. (2000) A Process View of Medical Practice by Modeling Communicative Act *Methods of Information in Medicine* 39, 56-62.
Marshall, R. J. (2001). "The use of classification and regression trees in clinical epidemiology." Journal of Clinical Epidemiology **54**(6): 603-609.
McAlister, S. (2003) Work on the National Minimum Data Set for Non- Admitted Patient Emergency Department Care (Naped Nmds), Melbourne.
McDonough, J. E. (1999) *Heathcare Policy: The Basics*. The Access Project, Boston.
McMullin, E. (1987) Alternative Approaches to the Philosophy of Science. In *Scientific Knowledge : Basic Issues in the Philosophy of Science* (Kourany, J. A., ed, pp. viii, 399. Wadsworth Pub. Co., Belmont, Calif.
Menec, V., Roos, N., Nowicki, D., MacWilliam, L., Finlayson, G., and Black, C. (1999) *Seasonal Patterns of Winnipeg Hospital Use*.
Metadata Online Registry (2006) *Non-Admitted Patient Emergency Department Care Nmds*. Australian Institute of Health and Welfare, Canberra.
Metropolitan Health & Aged Care Services Division (2003) *Hospital Demand Management Strategy 2001–2002: Summary of Findings from Project Annual Reports*. Victorian Government Department of Human Services, Melbourne.
Metropolitan Health and Aged Care Services Division (2005a) *Your Hospitals: A Six-Monthly Report on Victoria's Public Hospitals (January to June 2005)*. Victorian Government Dapartment of Human Services, Melbourne.
Metropolitan Health and Aged Care Services Division (2005b) *Your Hospitals a Six–Monthly Report on Victoria's Public Hospitals January to June 2005*. Metropolitan Health and Aged Care Services Division.
Michie, D., Spiegelhalter, D. J., and Taylor, C. C. (1994) *Machine Learning, Neural and Statistical Classification* Prentice Hall, Englewood Cliffs, N.J.
Miller, M. J., Ferrin, D. M., and Szymanski, J. M. (2003) "Simulating Six Sigma Improvement Ideas for a Hospital Emergency Department." Paper presented at the The 2003 Winter Simulation Conference, New Orleans, Louisiana, 7 - 10 December

Miller, M. J., Ferrin, D. M., and Messer, M. G. (2004) "Fixing the Emergency Department: A Transformational Journey with Edsim." Paper presented at the The 2004 Winter Simulation Conference, Washington D.C.
Miller, M. J., and Ferrin, D. M. (2005) "The Application of Simulation Methodology in a Hospital's Six Sigma Project." The Winter Simulation Conference, IEEE
Milley, A. (2000). "Healthcare and data mining." *Health Management Technology* **21**(8): 44.
Mills, T. M., L. Champion, et al. (2005). “A review of queueing models in the emergency room.” The First International Conference on Health and Social Care Modelling and Applications, Adelaide, Nosokinetics Group.
Miro, O., Sanchez, M., Espinosa, G., Coll-Vinent, B., Bragulat, E., Milla, J., and Wardrope, J. (2003) Analysis of Patient Flow in the Emergency Department and the Effect of an Extensive Reorganisation *Emerg Med J* 20, 143-148.
Moore, A., McQuay, H., Derry, S., McQuay, M., and Moore, M. (2000) Finding a Better Way to Manage Emergency Admissions: Reorganising the Medical Admission Arrangements at Stobhill Hospital, Glasgow. Bandolier, Glasgow.
Moore, L. J., Lee, S. M., and Taylor, B. W. (1993) *Management Science* (4th ed.) Allyn and Bacon, Boston.
Moreno, L., Aguilar, R. M., Martin, C. A., J.D. Pineiro, Estevez, J. I., Sigut, J. F., and Sanchez, J. L. (2000) Patient Centered Simulation to Aid Decision-Making in Hospital Management *Simulation* 74, 290-304.
Morse, P. M., and Kimball, G. E. (1951) *Methods of Operations Research* (1st , rev. ed.) Published jointly by the Technology Press of Massachusetts Institute of Technology and Wiley New York, Cambridge.
Muther, R. (1973) *Systematic Layout Planning* (2d [rev. and enl.]. ed.) Cahners Books, Boston.
National Audit Office (2000) Inpatient Admissions and Bed Management in Nhs Acute Hospitals.
Nelson, R., and Millet, I. (2004) "Data Flow Diagrams Versus Use Cases – Student Reactions." Paper presented at the The Tenth Americas Conference on Information Systems, New York.
New South Wales Department of Health (2003) *Annual Report 2003-04*. New South Wales Department of Health.
Nickles, T. (1980) Introductory Essay: Scientific Discovery and the Future of Philosophy of Science. In *Scientific Discovery, Logic, and Rationality* (Nickles, T., ed), pp. xii, 385. D. Reidel Pub. Co.
Hingham, MA.
Ouvry, A. S. (2002) Workflow Analysis and Modeling in Medical It Projects.
Palmer, G. (1996) Casemix Funding of Hospitals: Objectives and Objections *Health Care Analysis* 4, 185-193.
Patricks, Y., Hudson, P., Turrell, A., Jeayes, A., Thompson, S., Smillie, J., Hetherington, P., and Wyborn, K. (2005) *Removing the Access Block* (21 October ed.). Australian Resource Centre for Healthcare Innovations, Hunter/New England Area Health Service.
Perrow, C. (1984) Normal Accidents : Living with High-Risk Technologies Basic Books, New York.
Pidd, M. (1996) *Tools for Thinking : Modelling in Management Science* Wiley, Chichester [England] ; New York.
Pidd, M. (1998) *Computer Simulation in Management Science* (4th ed.) Wiley, New York.
Popkin, R. H., and Stroll, A. (1993) *Philosophy* (3rd ed.) Made Simple, Oxford.
Popper, K. R. (1968) *The Logic of Scientific Discovery* ([3d (revised)] ed.) Hutchinson, London,.
Potter, G., and López, J. (2005) *After Postmodernism : An Introduction to Critical Realism* Continuum, London ; New York.

Preater, J. (2002) A Bibliography of Queues in Health and Medicine *Health Care Management Science*
Quaglini, S., Stefanelli, M., Lanzola, D., Caporusso, V., and Panzarasa, S. (2001) Flexible Guideline-Based Patient Careflow Systems *Artificial Intelligence in Medicine* 22, 65-80.
Rajagopalan, B., and Isken, M. W. (2001) Exploiting Data Preparation to Enhance Mining and Knowledge Discovery *IEEE Transactions on Systems Man and Cybernetics Part C- Applications and Reviews* 31, 460-467.
Reichenbach, H. (1968) *The Rise of Scientific Philosophy* University of California Press, Berkeley.
Riano, D., and Prado, S. (2000) A Data Mining Alternative to Model Hospital Operations. In *Medical Data Analysis*, pp. 293-299. Springer-Verlag, Berlin.
Richards, G., Rayward-Smith, V. J., Sonksen, P. H., Carey, S., and Weng, C. (2001) Data Mining for Indicators of Early Mortality in a Database of Clinical Records *Artificial Intelligence in Medicine* 22, 215-231.
Richardson, D. (1998) No Relationship between Emergency Department Activity and Triage Categorisation *Academic Emergency Medicine* 5, 141-145.
Richardson, D., Ruffin, R. E., Hooper, J. K., Hammett, R. J. H., Robinson, B. G., Ashby, R. H., Fatovich, D. M., Cameron, P. A., Campbell, D. A., and Hill, K. N. (2003) Responses to Access Block in Australia *Medical Journal of Australia* 178, 103-111.
Richardson, D. B. (2004) A New Definition of Emergency Department Overcrowding Using Point Occupancy *Academic Emergency Medicine* 11, 2004 SAEM Annual Meeting Abstracts.
Roberts, R. M. (1989) *Serendipidty, Accidental Discoveries in Science* John Wiley and Sons, New York, NY.
Robinson, R. (2000) A Business Executive's Guide to Modern Or: Survey of Opportunities to Boost Profit, Reduce Cost and Increase Productivity *OR/MS Today*
Rockwell Software (2003) *Arena Version 7.01*. Rockwell Software.
Rodrigues, J. M., Paviot, B. T., and Martin, C. (2002) Drg Information System, Healthcare Reforms and Innovation of Management in the Western Countries During the 90s: Where Are the Key Success Factors? *Casemix* 4, 16-21.
Rotstein, Z., Wilf-Miron, R., Lavi, B., Seidman, D. S., Shahaf, P., Shahar, A., Gabay, U., and Noy, S. (2002) Management by Constraints: Considering Patient Volume When Adding Medical Staff to the Emergency Department *The Israel Medical Association Journal* 4, 170-173.
Rucker, D. (2003) Finally, a Tool to Re-Engineer Health Care: The Workflow Engine. Montgomery Research, Inc., San Francisco.
Ruger, J. P., Richter, C. J., Spitznagel, E. L., and Lewis, L. M. (2004) Analysis of Costs, Length of Stay, and Utilization of Emergency Department Services by Frequent Users: Implications for Health Policy *Academic Emergency Medicine* 11, 1311-8.
Salvendy, G. (2001) Handbook of Industrial Engineering : Technology and Operations Management (3rd ed.) Wiley, New York.
Samaha, S., and Armel, W. S. (2003) "The Use of Simulation to Reduce the Length of Stay in an Emergency Department." Paper presented at the The 2003 Winter Simulation Conference, New Orleans, Louisiana, 7 - 10 December.
Sanchez, S. M., Ferrin, D. M., Ogazon, T., Sepulveda, J. A., and Ward, T. J. (2000) "Emerging Issues in Healthcare Simulation." Paper presented at the The 2000 Winter Simulation Conference.
Sargent, R. G. (2005) "Verification and Validation of Simulation Models." Paper presented at the Winter Simulation Conference, 4 Dec.
Savage, S. L. (2003) *Decision Making with Insight* Thomsom ; Brooks/Cole, Belmont, CA.

Schafermeyer, R., and Asplin, B. (2003) Hospital and Emergency Crowding in the United States *Emergency Medicine* 15, 22-27.
Schaming, J. S., Gulati, A., and . . Quality and the Health Care Continuum. (): (1998) Health Care Quality Improvement in the Emergency Department: A Reengineering Approach *Topics in Health Information Management* 18, 70-80.
Schneider, S., Zwemer, F., and Doniger, A. (2001) New York: A Decade of Emergency Department Overcrowding *Acad Emery Med* 8, 1044- 50.
Schull, M., Szalai, J., and Schwartz, B. (2001) Emergency Department Overcrowding Following Systematic Hospital Restructuring: Trends at Twenty Hospitals over Ten Years *Acad Emerg Med* 8, 1037-43.
Schull, M. J., Lazier, K., Vermeulen, M., Mawhinney, S., and Morrison, L. J. (2003) Emergency Department Contributors to Ambulance Diversion: A Quantitative Analysis *Annals of Emergency Medicine* 41, 477-480.
Siddharthan, K., Jones, W. J., and Johnson, J. A. (1996) A Priority Queuing Model to Reduce Waiting Times in Emergency Care *International Journal of Health Care Quality Assurance* 5, 10-16.
Sier, D., Ramakrishnan, M., and Taylor, P. G. (2005) A Two-Time-Scale Model for Hospital Patient Flow *IMA Journal of Management Mathematics* 16, 197-215.
Simon, H. A. (1977) *Models of Discovery: And Other Topics in the Methods of Science* D. Reidel Pub. Co., Dordrecht, Holland ; Boston.
Simul8 Corporation (2004) *Simul8*. Simul8 Corporation, Boston.
Sinreich, D., and Marmor, Y. N. (2004) "A Simple and Intuitive Simulation Tool for Analyzing Emergency Department Operations." Paper presented at the The 2004 Winter Simulation Conference, Washington D.C.
Smith, M. S., and Feied, C. F. (1998) The Next-Generation Emergency Department *Annals of Emergency Medicine* 32, 65-74.
SPSS Inc. (2001) *Spss for Windows* (12.0-14.0 ed.), Chicago.
Statewide Elective Surgery and Statewide Emergency Program (2006) *The Statewide Emergency Program*. Department of Human Services, State Government of Victoria, Melbourne.
Statewide Emergency Program Unit (2006) *Statewide Elective Surgery and Statewide Emergency Program*. Metroploitan Health and Aged Care Services, Melbourne, Australia.
Stuart, P. (2003) "A Model for Measuring the Casemix Activity and Economic Costs of Hospital Access Block." Paper presented at the ACEM 20th Annual Scientific Meeting, Perth.
Stuart, P. (2004) A Casemix Model for Estimating the Impact of Hospital Access Block on the Emergency Department *Emergency Medicine Australasia* 16, 201-207.
Taha, H. A. (1997) *Operations Research : An Introduction* (6th ed.) Prentice Hall, Upper Saddle River, N.J.
Tanabe, P., Travers, D., Gilboy, N., and Rosenau, A. (2005) Refining Emergency Severity Index Triage Criteria *Academic Emergency Medicine* 12, 497.
Taner, T., and Antony, J. (2006) Applying Taguchi Methods to Health Care *Leadership in Health Services* 19, 26 - 35.
Tawney, B. (2005) "Analyzing the Patient Load on the Hospitals in a Metropolitan Area." Paper presented at the The 2005 Systems and Information Engineering Design Symposium.
Taylor, T. (2001) Threats to the Health Care Safety Net *Acad Emerg Med* 8, 1080-7.
The American College of Emergency Physicians (2003) *Emergency Department Technology*. The American College of Emergency Physicians, Irving, Tx.
The American Institute of Architects (2001) *Guidelines for Design and Construction of Hospital and Health Care Facilities* The American Institute of Architects, Dattal.
The Australian Institute of Health and Welfare (2006) *Australian Hospital Statistics 2004-05 (Health Services Series No. 26)*. The Australian Institute of Health and Welfare.

The Committee on the Future of Emergency Care in the United States Health System (2006) *Hospital-Based Emergency Care: At the Breaking Point*. Institute of Medicine (IOM), Washington DC.
The Department of Human Services (2004) *Design Guidelines for Hospitals and Day Procedure Centres*. The Department of Human Services.
The Metropolitan Health and Aged Care Services Division (2003) *Directions for Your Health System: Metropolitan Health Strategy*. Victorian Government Department of Human Services.
Theodoridis, S., and Koutroumbas, K. (1999) *Pattern Recognition* Academic Press, San Diego.
Tregunno, D., Baker, G. R., Barnsley, J., and Murray, M. (2004) Competing Values of Emergency Department Performance: Balancing Multiple Stakeholder Perspectives *Health Services Research* 39,
Trzeciak, S., and Rivers, E. (2003) Emergency Department Overcrowding in the United States: An Emerging Threat to Patient Safety and Public Health *Emergency Medicine Journal* 20, 402-406.
van der Aalst, W. M. P., ter Hofstede, A. H. M., and Weske, M. (2003) Business Process Management: A Survey. In *Business Process Management (Proceedings of Bpm2003)*, pp. 1-12. Springer-Verlag, Berlin.
Vasilakis, C., and El-Darzi, E. (2001) A Simulation Study of the Winter Bed Crisis *Health Care Manag. Sci.* 4, 31-36.
Vazirgiannis, M., Halkidi, M., and Gunopulos, D. (2003) *Uncertainty Handling and Quality Assessment in Data Mining* Springer, London ; New York.
Victorian Department of Human Services (2000) *Annual Report 1999-00*. Victorian Department of Human Services.
Victorian Department of Human Services (2001) *Annual Report 2000-01*. Victorian Department of Human Services.
Victorian Department of Human Services (2002a) *Summary of Findings from Project Annual Reports: Hospital Demand Management Strategy 2001–2002*. Metropolitan Health & Aged Care Services Division, Melbourne.
Victorian Department of Human Services (2002b) *Designing Care*. Victorian Department of Human Services.
Victorian Department of Human Services (2003) *Annual Report 2002-03*. Victorian Department of Human Services.
Victorian Department of Human Services (2004) *Annual Report 2003-04*. Victorian Department of Human Services.
Vissers, J. M. H., Bertrand, J. W. M., and De Vries, G. (2001) A Framework for Production Control in Health Care Organizations *Production Planning and Control* 12, 591-604.
Walley, P., Watt, A., Davies, C., Huang, A., and Ma, K. (2001) *A Study of Demand for Emergency Access Health Services in Two Uk Health Regions*. Warwick Business School, Warwick.
Walley, P. (2003) Designing the Accident and Emergency System: Lessons from Manufacturing *Emerg Med J* 20, 126-130.
Ward, J. (1963) Hierarchical Grouping to Optimise an Objective Function *Journal of the American Statistical Association* 58, 236-244.
Wartofsky, M. W. (1979) *Models : Representation and the Scientific Understanding* D. Reidel Pub. Co., Dordrecht, Holland ; Boston.
Weatherall, M. (1968) *Scientific Method* English Universities P., London.
Wiinamaki, A., and Dronzek, R. (2003) "Using Simulation in the Architectural Concept Phase of an Emergency Department Design." Paper presented at the The 2003 Winter Simulation Conference, New Orleans, Louisiana, 7 - 10 December.
Williams, G., Baxter, R., Kelman, C., Rainsford, C., He, H. X., Gu, L. F., Vickers, D., and Hawkins, S. (2002) Estimating Episodes of Care Using Linked Medical Claims

Data. In *Al 2002: Advances in Artificial Intelligence*, pp. 660-671. Springer-Verlag, Berlin.

Winston, W. L., and Albright, S. C. (2001) *Practical Management Science* Duxbury, Pacific Grove (CA).

Young, T., Brailsford, S., Connell, C., Davies, R., Harper, P., and Klein, J. H. (2004) Using Industrial Processes to Improve Patient Care *BMJ* 328, 162-164.

Zalta, E. N., ed (2002) *Stanford Encyclopedia of Philosophy*. Center for the Study of Language and Information Stanford University, Stanford, CA.

Zionts, S. (1997) "Decision Making: Some Experiences, Myths and Observations." Paper presented at the Multiple criteria decision making : The Twelfth International Conference, Hagen, Germany.

**Appendix 1-A**

Australasian College for Emergency Medicine
ABN 76 009 090 715

# POLICY DOCUMENT

# STANDARD TERMINOLOGY

## 1. INTRODUCTION

Terminology related to emergency medicine as defined in this document is applicable to Australasia and is internationally recognisable. It will apply to all Fellows and trainees of ACEM for both verbal and written communications and the use of terms such as accident and emergency medicine, emergency medicine specialist, emergency doctor, emergency room doctor, accident and emergency department or casualty is to be actively discouraged. It is not in the interests of the community for a health care facility without acute inpatient beds and services to use the terms emergency department, emergency, accident, or similar terms when referring to or signposting the service it provides for acute or urgent care.

## 2. EMERGENCY MEDICINE

Emergency medicine is a field of practice based on the knowledge and skills required for the prevention, diagnosis and management of acute and urgent aspects of illness and injury affecting patients of all age groups with a full spectrum of undifferentiated physical and behavioural disorders. It further encompasses an understanding of the development of prehospital and inhospital emergency medical systems and the skills necessary for this development.

### 2.1 Notes

This is the definition agreed to by the American College of Emergency Physicians, the Australasian College for Emergency Medicine, the British Association for Accident and Emergency Medicine and the Canadian Association of Emergency Physicians contained in the Charter of the International Federation for Emergency Medicine

(October 1991). The National Specialist Qualification Advisory Committee of Australia recognises Emergency Medicine as a principal specialty, as does the Australian Medical Council and the Medical Council of New Zealand.

## 3. EMERGENCY PHYSICIAN

An emergency physician is a registered medical practitioner trained and qualified in the specialty of Emergency Medicine. The recognised qualification of an emergency physician in Australasia is the Fellowship of the Australasian College for Emergency Medicine (FACEM).

### 3.1 Notes

A trainee for the FACEM is known as registrar in emergency medicine. The term senior registrar in emergency medicine is reserved for an emergency physician holding a recognised senior registrar post. The term research fellow in emergency medicine is reserved for an emergency physician holding a recognised research post.

## 4. DEPARTMENT OF EMERGENCY MEDICINE

A Department of Emergency Medicine is the pyramidal structure for the medical staff within a hospital who are responsible for the provision of medical care plus management teaching and research in emergency medicine.

### 4.1 Notes

The director of a Department of Emergency Medicine is known as Director of Emergency Medicine.

The Director of Emergency Medicine has overall clinical and administrative responsibility for all patients in the Emergency Department as per the ACEM Policy Document "Guidelines for Responsibility in Emergency Departments". All staff in the department are responsible to the director on operational matters. This does not preclude policy and ethical responsibility which staff members may have to others in the hospital. Senior medical staff other than the department director are known as Staff Specialist in Emergency Medicine, Specialist in Emergency Medicine, Consultant in Emergency Medicine, Emergency Physician or Deputy or Assistant Director of Emergency Medicine.

# 5. EMERGENCY DEPARTMENT

The Emergency Department (ED) is the dedicated area in a hospital that is organised and administered to provide a high standard of emergency care to those in the community who perceive the need for or are in need of acute or urgent care including hospital admission. The features of an Emergency Department include the following.

## 5.1 Structure

The Emergency Department must be part of a recognised hospital and be licensed or otherwise recognised as an Emergency Department by the appropriate State or Territory authority. It must be purpose designed and include a dedicated area with the capacity for advanced life support including mechanical ventilation designed and used for the reception and stabilisation of critically ill patients.

## 5.2 Nurse Staffing

There must be registered nurses on duty in the Department at all times. There must be a nursing structure with a senior nurse with appropriate emergency nursing qualifications and experience being responsible for the organisation and operation of the nursing services. Designated nursing staff must be available 24 hrs per day to perform triage.

## 5.3 Medical Staffing

The Emergency Department must have a medical director who should be an Emergency Physician. There must be 24 hour per day on-site access to medical officers, and there must be 24 hour per day on-call access to a designated senior doctor for clinical support. This senior doctor should also be an emergency physician, and must act with the authority of the medical director. It is recognised that both the medical officers and senior doctors may be called to other parts of the hospital, but they must have a primary commitment to the Emergency Department.

## 5.4 Patient Care

The Emergency Department must provide for the reception, triage, initial assessment and management of the full range of patients presenting with acute illness and injury. Where the range of care is limited (for example, to paediatrics), pre-hospital and other policies will be in place to ensure appropriate presentation. The department will be able to provide or arrange extended care beyond the initial phase for most patients depending on hospital infrastructure.

### 5.5 Network Role

The Emergency Department will take an appropriate role in local and regional patient care networks commensurate with its role delineation. Networking and transfer arrangements must be in place for patients whose clinical needs cannot be met within the hospital.

### 5.6 Access to Other Specialist Consultation

An Emergency Department must have adequate specialist cover for opinion and/or referral 24 hour per day in such specialties as in general surgery, orthopaedic surgery, general medicine, anaesthesia, intensive care and paediatrics. Adequate arrangements must be in place for specialist care and/or transfer for those patients requiring specialist care in fields such as neurosurgery, ophthalmic surgery, vascular surgery, and psychiatry. The Department must also have access to an appropriate range of allied health professionals.

### 5.7 Access to Support Services

There must be 24 hour per day access to pathology, radiology and operating theatres services.

### 5.8 Other Processes

The Emergency Department must have a formal quality improvement program including review of morbidity, mortality, and recognised Emergency Medicine Clinical Indicators, and submission of data to a recognised hospital quality program such as ACHS EQuIP. There must be a dedicated clinical and management information system which records both presentation details and recognised clinical indicators. The medical records system, contingency arrangements, rostering practices and credentialling processes must be appropriate and must meet relevant standards. There must be a formal complaints process and provision of continuing medical education.

## 6. ARRIVAL TIME

The first recorded time of contact between the patient and the Emergency Department staff. A recording accuracy to within the nearest minute is appropriate. There should be no delay between the physical arrival in the ED of a patient who is seeking care and their first contact with staff.

## 7. TIME OF MEDICAL ASSESSMENT AND TREATMENT

Although important assessment and treatment may occur during the triage process, this time represents the start of the care for which the patient presented. A recording accuracy to within the nearest minute is appropriate. Usually it is the time of first contact between the patient and the doctor initially responsible for their care, often recorded as “time seen by doctor”. Where a patient in the ED has contact exclusively with nursing staff acting under the clinical supervision of a doctor, it is the time of first nursing contact, often recorded as “time seen by nurse”. Where a patient is treated according to a documented, problems specific, clinical pathway, protocol, or guideline approved by the Director of Emergency Medicine, it is the earliest time of contact between the patient and staff implementing this protocol. This is often recorded as the earlier of “time seen by nurse” or “time seen by doctor”.

## 8. DEPARTURE TIME

This is the time the patient physically leaves the Emergency Department, representing the end of the episode of emergency treatment. This includes patients who are discharged home, transferred to another hospital, die in the Emergency Department, transferred to another part of the hospital for definitive care, or are admitted to a ward, including an observation ward which may be located in the ED. It does not include patients sent to another area for treatment when return to the Emergency Department is expected, nor does it include patients statistically admitted to beds within the Emergency Department but still receiving care from the same staff. Accuracy to within the nearest minute is appropriate.

## 9. READY FOR DEPARTURE TIME

This represents the time when, in the opinion of the treating doctor, no further emergency medicine care is necessary. This time is significantly more subjective than arrival time or departure time, but maybe useful in a single hospital setting for comparative purposes.

## 10. INPATIENT BED REQUEST TIME

This represents the time when a formal request is made to obtain an inpatient bed for a patient requiring admission to hospital. This time is significantly more subjective than arrival time or departure time, but maybe useful in a single hospital setting for comparative purposes. Different hospital systems collect this time in different ways and it may be before or after the Ready for Departure Time.

## 11. WAITING TIME

This is the difference between arrival time and time of initial medical assessment and treatment. A recording accuracy to within the nearest minute is appropriate.

## 12. ASSESSMENT AND TREATMENT TIME

This is the difference between the time of initial medical assessment and treatment and ready for departure time. A recording accuracy to within the nearest minute is appropriate.

## 13. PATIENT CARE TIME

This is the difference between the Time of Medical Assessment and Treatment and the Departure time. It represents the time for which the patient receives medical care from Emergency Department staff. A recording accuracy to within the nearest minute is appropriate.

## 14. TOTAL ED TIME

This is the difference between the arrival time and departure time. A recording accuracy to within the nearest minute is appropriate.

## 15. ADMISSION DELAY TIME

This is the difference between the ready for departure time and the departure time for patients who are admitted to hospital, die in the Emergency Department, or are transferred to another hospital for admission. This time is significantly more subjective than waiting time or assessment and treatment time, but maybe useful in a single hospital setting for comparative purposes.

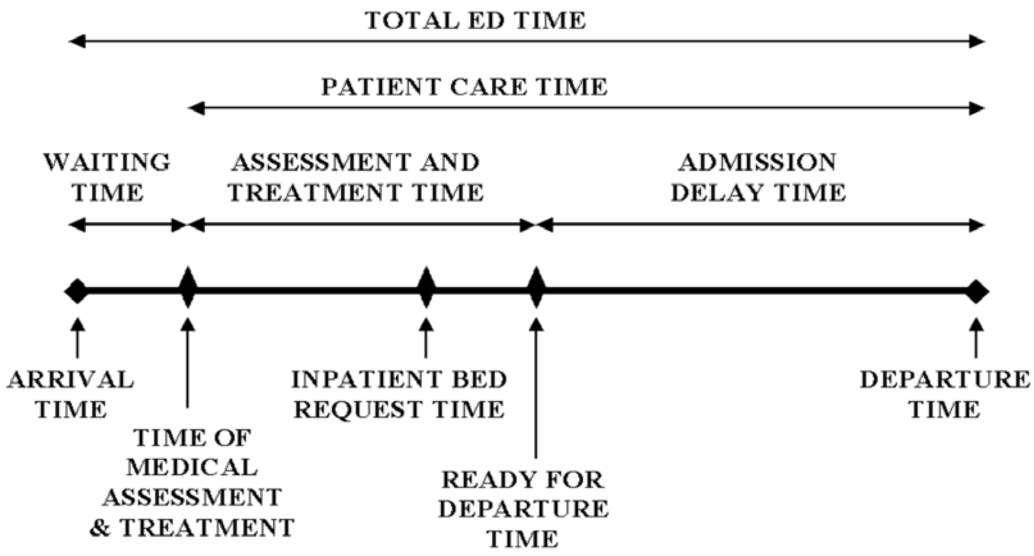
## 16. ACCESS BLOCK

This refers to the situation where patients in the ED requiring inpatient care are unable to gain access to appropriate hospital beds within a reasonable timeframe. It is expressed as the proportion of patients requiring formal admission to hospital who have a total ED time greater than 8 hours. It is the percentage of all patients admitted, planned for admission but discharged from ED without reaching an inpatient bed, transferred to another hospital for admission, or dying in the ED whose Total ED time exceeds 8 hours.

## 17. ED OVERCROWDING

This refers to the situation where Emergency Department function is impeded primarily because the number of patients waiting to be seen, undergoing assessment and treatment, or waiting for departure exceeds either the physical or staffing capacity of the Emergency Department.

## 18. DIAGRAMMATIC REPRESENTATION




P02 November 1993
Revised November 2000
Revised September 2001

Adopted by Council November 1 993
Adopted by Council November 2000
Adopted by Council September 2001

# Appendix 1-B

### ED data collection

Most of the data studied in Chapter 1 comes from the Non-admitted patient emergency department care data set (NMDS) or its predecessor[78] (Metadata Online Registry, 2006). The NMDS is part of mandated reporting requirements to the Commonwealth Government for certain classes of EDs. State and territory health authorities provide the NMDS data to the Australian Institute of Health and Welfare for national collation each year. The Australian Institute of Health and Welfare cleans the data, records the changes and forwards the data to the Commonwealth Department of Health and Ageing.

> *"The scope of this National Minimum Data Set (NMDS) is non-admitted patients registered for care in emergency departments in selected public hospitals that are classified as either Peer Group A or B in the Australian Institute of Health and Welfare's Australian Hospital Statistics publication from the preceding financial year. The care provided to patients in emergency departments is, in most instances, recognised as being provided to 'non-admitted' patients. Patients being treated in emergency departments may subsequently become 'admitted'. The care provided to non-admitted patients who are treated in the emergency department prior to being admitted is included in this NMDS."*(Metadata Online Registry, 2006)

Performance standards are defined for non-admitted patients and linked to the money that hospitals receive from government bodies. The following statement is important to note since it impacts heavily on how NMDS-derived statistics should be viewed.

> *"Care provided to patients who are being treated in an emergency department site as an admitted patient (e.g. in an observation unit, short-stay unit, 'emergency department ward' or awaiting a bed in an admitted patient ward of the hospital) are excluded from the emergency department care NMDS since the recording of the care provided to these patients is part of the scope of the Admitted patient care NMDS"* (Metadata Online Registry, 2006)

It is possible for EDs to meet the performance requirements by reassigning patients from 'non-admitted' to 'admitted' in an observation unit, a short-stay unit or an

[78] The NMDS Supersedes the Non-admitted patient emergency department care NMDS NHIG, Standard.

'emergency department ward'. In the process the ED statistical reports become somewhat ‘polished’.

The Institute’s annual reporting of statistics on Australia’s hospitals presents detailed information on hospital care and hospitals, summaries of changes over time, and comparisons between public and private hospitals. The 2003-04 report included for the first time comprehensive statistics about patients who presented to selected public hospital emergency departments, covering patient demographics, triage categories, waiting times, durations of care and a range of other data. (The Australian Institute of Health and Welfare, 2006).

## Appendix 3-A

To use Ward's original example, consider the set $X$= (2, 6, 5, 6, 2, 2, 2, 2, 0, 0, 0) with $n$ = 11 elements. Visual inspection leads one to expect that three or four clusters may be optimal (by grouping the 2's, the 5 and 6's and the 0's into clusters). Ward's "error sum of squares" (Equation 3.4) can be calculated for the options and compared to the zero error if each object remained ungrouped.

$$ESS = \sum_{i=1}^{n} \left( x_i - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right) \right)^2 \quad \ldots\ldots (eq3.4)$$

For 1 cluster: $ESS_r = (2-2.5)^2 + (6-2.5)^2 + (5-2.5)^2 + (6-2.5)^2 \ldots + (0-2.5)^2 = \underline{50.5}$

For 2 clusters: $ESS = (2-1.0)^2 + (6-5.1)^2 + (5-5.1)^2 + (6-5.1)^2 \ldots + (0-1.0)^2 = \underline{10.9}$

For 3 clusters: $ESS = (2-2)^2 + (6-5.1)^2 + (5-5.1)^2 + (6-5.1)^2 \ldots + (0-0)^2 = \underline{0.2}$

For 4 clusters: $ESS = (2-2)^2 + (6-6)^2 + (5-5)^2 + (6-6)^2 \ldots + (0-0)^2 = \underline{0}$

For 11 clusters: $ESS = (2-2)^2 + (6-6)^2 + (5-5)^2 + (6-6)^2 \ldots + (0-0)^2 = \underline{0}$

The difference between successive ESS values gives an indication of the error loss between steps. The changes provide an indication of the best 'natural' grouping of data. In the example above, two clusters are a marked improvement on the single cluster. Three clusters provide low error (and so only a small amount information loss). The zero error for four clusters indicates this is a natural grouping for the data with no information loss.

Appendix 4-A

### Frankston ED Data:

Field code headings in supplied data:

| | | | |
|---|---|---|---|
| ae_refno | | ED reference number | |
| patient_id | | Unique Key | |
| ae_episode | | ED episode number | |
| ip_episode | 56.5% admitted | Inpatient episode number | Only if patient admitted |
| hosp_c | 75.8%1; 24.2%3 | Campus Code | Frankston is 2220 |
| c_urnumber | | Patient Identifier | Non unique |
| origin | 99.6%1 | Country of origin | At least 12 errors VEMD is 4 digit code, this is 1-2 |
| meth_a | 70%PC,26%RC | Method of arrival | *See lookup table* |
| pres_problem | Text based | Presentation problem | Text based |
| fin_cond_cod | 81%CSTD, 12% CHOST-R | Financial code | Codes don't exist in "Fin Classification" table supplied by Frankston |
| adm_so | 86% "1" 10% "2" | Admission source | *See lookup table* |
| adm_ty | 98% "1" | Admission type | 1 - emergency presentation<br>2 – planned return visit<br>*See table for others* |
| arr_date | | Arrival Date | Date first registered or triaged (whichever comes first), by clerical officer, triage nurse or doctor in ED |
| time_triage | | Triage time | Time the patient was first seen by a Triage nurse/ doctor. |
| time_regist | Derived from change of status on computer /entered from doctors notes | Registration time | Time the patient was first registered or triaged (whichever comes first), by clerical officer, triage nurse or doctor in the Emergency Department. |
| time_incub | | Time in cubicle | Time that the Treating Nurse first saw the patient. This includes the taking of baseline observations after triage. |
| time_seen | | Doctor seen time | Time that a Medical Officer first assesses the patient. |
| time_discharge | | Discharge time | Time disposal decision recorded |
| time_depart | | Departure Time | Time the patient physically leaves the Emergency Department. |
| dch_co | 11 codes | Discharge code | *See Appendix D* |
| trfr_re | 94% blank | Transfer reason | *See Appendix D* |
| dpt_tpt | 38%PC,32%O | Departure Transport Mode | *See Appendix D* |
| dpt_ref | 45% "NA" | Referred to on Departure | *See Appendix D* Need help with table |
| trf_esc | 95% blank | Escort Source | The work location or source of the assistant(s) accompanying transferred patient<br>*See Appendix D* |
| tfr_rsn_txt | 99.9% blank | Reason for Transfer | Text based |
| amb_nu | 70% blank | Ambulance number | Probably only for transfers ? |
| inj_ca | 70.4% blank | Injury Cause | *See Appendix D*<br>Need help with table |
| human_ | 70.4% blank | Human Intent | Only for injury cases |
| inj_pl | 70.4% blank | Place Injury Occurred | *See Appendix D* |
| inj_ac | 70.4% blank | Activity when injured | *See Appendix D* |
| wrk_diag | | Same as pres_problem | Text based |
| nat_inj | 70.4% blank | Nature of Main Injury | *See Appendix D* |
| body_re | 70.4% blank | Body region | *See Appendix D* |
| operat | 40 codes | | Probably doctor code |
| ongoin | 68.3%Y/ 31.7%N | | |
| comments | | | Text based |
| admit_ | 98% blank, 60 codes | Admit From | 4 digit code for Victorian hospitals from VEMD Sect 8 |
| disch_ | 90% blank, 60 codes | Discharge To | 4 digit code for Victorian hospitals from VEMD Sect 8 |

# Appendix 4-B

Admission Source (changes in Care Type within this hospital):

| | |
|---|---|
| 0 | Change from Alcohol and Drug Program |
| 1 | Change from NHT/Non-Acute |
| 2 | Change from Designated Rehabilitation Program/Unit: Level 1* |
| 3 | Change from Family Choice: Awake Attendant Care§ |
| 4 | Change from Other (Acute) Care |
| 5 | Change from Approved Mental Health Service or Psychogeriatric Program* |
| 6 | Change from Designated Rehabilitation Program/Unit: Level 2* |
| 7 | Change from Designated Rehabilitation Program/Unit: Level 3* |
| 8 | Change from Palliative Care Program |
| 9 | Change from Geriatric Evaluation and Management Program* |

Admission Type

| adm_type | adm_type_desc | 98_99type |
|---|---|---|
| 1 | Emergency Presentation | 1 |
| 2 | Return visit - planned | 2 |
| 3 | Unplanned attendance for continuing condition | 3 |
| 4 | Outpatient or Outpatient Clinic | 4 |
| 5 | Privately referred and privately treated | 5 |
| 8 | Pr-Arranged admission - clerical, clinical,nursing | 0 |
| 9 | Patient in transit | 9 |
| 10 | Dead on arrival | 10 |
| 986 | Prearranged admission - clerical only98_99 | 6 |
| 987 | Pre-arranged admission nursing & clerical98_99 | 7 |
| 988 | Pre-arranged admission - full clerical | 8 |

Arrival Mode / Departure Transport Mode

| Code | Transport Mode | Frankston meth_a; dpt_tptED Code |
|---|---|---|
| 1 | Air ambulance - fixed wing aircraft for all or any part of journey. Excludes where air plane is helicopter (2) | AIR |
| 2 | Helicopter | HELI |
| 3 | Ambulance service - MICA | MICA |
| 4 | Ambulance service - road car | RC |
| 6 | Community/public transport (includes council / philanthropic services) | PT |
| 7 | Private car | PC |
| 8 | Police vehicle | POL |
| 9 | Undertaker | UND |
| 10 | Ambulance service - private ambulance car - MAS / RAV contracted | PRV |
| 11 | Ambulance service - private ambulance car - hospital contracted | ASP |
| 19 | Other | O |

Discharge Code (Also see VEMD 2003 data definitions)

| dch_code | hcs_code (VEMD) | 98_hcs | VEMD Description |
|---|---|---|---|
| ACT | 0 | 0 | Residential care facility (includes nursing home, hostel, psychogeriatric nursing home, residential care respite bed) |
| DTA | 0 | 0 | |
| D | 1 | 1 | Home |
| AW | 2 | 2 | Ward (Includes HITH and Medical Assessment and Planning Unit; Excludes Emergency Medical Unit and Short Stay Observation Unit) |
| AR | 3 | 3 | Short Stay Observation Unit (Includes Chest Pain Evaluation Unit; |

| dch_code | hcs_code (VEMD) | 98_hcs | VEMD Description |
|---|---|---|---|
| AS | 3 | 0 | Excludes Emergency Medical Unit and Medical Assessment and Planning Unit) |
| AT | 4 | 4 | Another hospital campus (also record Transfer Destination) |
| T | 4 | 4 | |
| AOR | 5 | 5 | Left at own risk, after treatment started |
| | 6 | 6 | There is no code 6 |
| AD | 7 | 7 | Died within ED |
| DIE | 7 | 7 | |
| DIED | 7 | 7 | |
| DOA | 8 | 8 | Dead on arrival |
| DTM | 9 | 9 | Mental health residential facility (Excludes psychogeriatric nursing home, use 0) |
| MHT | 9 | 9 | |
| AE | 983 | 3 | Emergency Medical Unit (Excludes Medical Assessment and Planning Unit and Short Stay Observation Unit) |
| | 10 | | Left after clinical advice regarding treatment options |
| DNW | 11 | | Left at own risk, without treatment |
| | 12 | | Correctional/Custodial Facility |
| | | | |

## Departure status

| code | Desc |
|---|---|
| 1 | Discharge to home, nursing home |
| 2 | Admission to ward (including HITH) |
| 4 | Transfer out of this hospital to another hospital (also record Transfer Destination) |
| 5 | Left at own risk, after treatment started |
| 6 | Left before being seen by doctor (or definitive service provider) |
| 7 | Died within ED |
| 8 | Dead on arrival |

## Reason for Transfer

| Frankston TRFR_RE Code | VEMD Code | Description |
|---|---|---|
| B-ICU | 1 | ICU bed not available |
| B-CCU | 2 | CCU bed not available |
| B-GEN | 3 | General bed not available |
| SPE | 4 | Specialty not available |
| PREV | 5 | Previous patient of destination hospital |
| INS | 6 | Insured/Compensable |
| REQ | 7 | Patient preference |
| OTH | 9 | Other reason |
| | | Note: No code 8 |

## Referred to on departure

| Frankston ED dpt_ref code | VEMD Code | Description |
|---|---|---|
| ED | 1 | Review in ED - scheduled Planned return to ED |
| EDR | 2 | Review in ED - as required Return to ED if problems persist |
| O | 3 | Outpatients |
| L | 4 | LMO Referred to local doctor |
| M | 5 | Medical Specialist |
| OS | 6 | Other Specialist Health Practitioner Physiotherapist, Dentist, etc. |
| RDNS | 7 | Home Nursing Services RDNS |
| SC | 8 | Specialised Community Service; Detox Centre, Rape Crisis Centre, Crisis |

| Frankston ED dpt_ref code | VEMD Code | Description |
|---|---|---|
| | | Assessment Team, |
| S | 9 | Aged Care Assessment Service Dedicated ACAS teams which are able to assess eligibility for community & residential aged care programs. |
| NR | 16 | No referral Treatment complete |
| Q | 17 | Not known |
| | 18 | Other |
| NA | 19 | Not applicable Admission to inpatient bed; (Ward or MAPU), Emergency Medical Unit, Short Stay Observation Unit, Transferred, Died, Dead on Arrival, Left at own risk, Left after Clinical Advice regarding Treatment Options. |

## Departure Reference

| VEMD Codes | Frankston Codes | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| 1 | ED | 702 | 1.2 | 1.2 | 1.2 |
| 2 | EDR | 775 | 1.4 | 1.4 | 2.6 |
| 4 | L | 20958 | 36.8 | 36.8 | 39.4 |
| 5 | M | 1167 | 2.1 | 2.1 | 41.5 |
| 19 | NA | 25820 | 45.4 | 45.4 | 86.8 |
| 16 | NR | 7024 | 12.3 | 12.3 | 99.2 |
| 3 | O | 50 | .1 | .1 | 99.3 |
| 6 | OS | 148 | .3 | .3 | 99.5 |
| 17 | Q | 1 | .0 | .0 | 99.5 |
| 7 | RDNS | 2 | .0 | .0 | 99.5 |
| 9 | S | 84 | .1 | .1 | 99.7 |
| 8 | SC | 175 | .3 | .3 | 100.0 |
| | Total | 56906 | 100.0 | 100.0 | |

## Escort Source

| Frankston and VEMD code | |
|---|---|
| 1 | Emergency Department |
| 2 | ICU/CCU |
| 3 | Ward |
| 4 | Retrieval Service |
| 5 | Nil (no medical or nursing escort) |
| 9 | Other medical or nursing escort |

## Cause of Injury

| Frankston ED Code | VEMD Code | | | VEMD Description |
|---|---|---|---|---|
| | | 40044 | 70.4 | |
| MVD | 1 | 557 | 1.0 | Motor vehicle - driver |
| MVP | 2 | 274 | .5 | Motor vehicle - passenger |
| MCD | 3 | 331 | .6 | Motorcycle - driver |
| MCP | 4 | 55 | .1 | Motorcycle - passenger |
| CYC | 5 | 229 | .4 | Pedal cyclist - rider or passenger |
| PED | 6 | 87 | .2 | Pedestrian |
| HOR | 7 | 100 | .2 | Horse related (fall from, struck or bitten by) |
| TRA | 8 | 22 | .0 | Other transport-related circumstance |

| Frankston ED Code | VEMD Code | | | VEMD Description |
|---|---|---|---|---|
| FAL | 9 | 5182 | 9.1 | Fall - low (same level or less than 1 metre, or no information on height) |
| FAH | 10 | 598 | 1.1 | Fall - high (greater than 1 metre) |
| DSP | 11 | 2 | .0 | Submersion or drowning - swimming pool |
| DOT | 12 | 9 | .0 | Submersion or drowning - other |
| ASP | 13 | 40 | .1 | Other threat to breathing (includes strangulation, asphyxiation) |
| FIR | 14 | 21 | .0 | Fire, flames, smoke |
| SCA | 15 | 45 | .1 | Scalds (hot drink, food, water, other fluid, steam, gas or vapour) |
| CON | 16 | 239 | .4 | Contact burn (hot object or substance) |
| PMD | 17 | 723 | 1.3 | Poisoning - medication |
| POT | 18 | 245 | .4 | Poisoning - other or unspecified substance |
| ARM | 19 | 6 | .0 | Firearm |
| CUT | 20 | 2243 | 3.9 | Cutting, piercing object |
| DOG | 21 | 134 | .2 | Dog related |
| ANI | 22 | 232 | .4 | Other animal related (Excludes dog - use code 21; horse – use code 7) |
| SCP | 23 | 1123 | 2.0 | Struck by or collision with person |
| SCO | 24 | 1497 | 2.6 | Struck by or collision with object |
| MAC | 25 | 89 | .2 | Machinery |
| ELE | 26 | 24 | .0 | Electricity |
| HOT | 27 | 11 | .0 | Hot conditions (natural origin, includes sunlight) |
| COL | 28 | 4 | .0 | Cold conditions (natural origin) |
| OTH | 29 | 1863 | 3.3 | Other specified external cause |
| UNS | 30 | 877 | 1.5 | Unspecified external cause |
| Total | | 56906 | 100.0 | |

## Human intent

| Frankston / VEMD Codes for Human_ | Description |
|---|---|
| 1 | NON-intentional harm |
| 2 | Intentional self-harm |
| 3 | Sexual assault |
| 4 | Child neglect, maltreatment by parent, guardian |
| 5 | Maltreatment, assault by domestic partner |
| 6 | Police, legal intervention or operations of war |
| 7 | Assault not otherwise specified |
| 8 | Adverse effect or complication of medical or surgical care |
| 9 | Intent cannot be determined |
| 10 | Other specified intent |
| 11 | Intent not specified |

## Where injury took place

| Frankston / VEMD Code | Description |
|---|---|
| A | Athletics and sports area Cricket ground, football, hockey field, riding school, basketball court, golf course, stadium, skating rink, tennis, squash court, swimming pool. |
| C | Industrial or construction area. Any building under construction, industrial yard, workshop, dry dock, dock yard, factory building/ premises, gasworks, oil rig & other offshore installation, power station (coal/nuclear/oil), shipyard. |
| F | Farm Farm buildings and land, ranch. |
| H | Home House, home premises, farm house, non-institutional place of residence, apartment, boarding house, caravan park (resident), private: driveway to home, garage, garden/yard or home, path to home, swimming pool in private house, garden. |

| Frankston / VEMD Code | Description |
|---|---|
| I | Residential institution Children's home, orphanage, home for the sick, nursing home, old people's home, hospice, military camp, reform school, prison, pensioners home, dormitory. |
| M | Medical hospital Hospital. |
| O | Other specified place, Forest, beach, pond, abandoned or derelict house, campsite, canal, caravan site NOS, desert, dock NOS, harbour, hill, lake, marsh, military training ground, mountain, parking lot & parking place, prairie, public place NOS, railway line, river, sea, seashore, stream, swamp, water reservoir, zoo. |
| P | Place for recreation, Public park, amusement park. |
| Q | Mine or quarry. Mine or quarry tunnel under construction. |
| R | Road, street or highway Freeway, footpath, motorway, pavement, road. |
| S | School, day care centre, public administration area Building (including adjacent grounds) used by the general public or by a particular group of the public such as: assembly hall, public hall, church, clubhouse, court house, post office, day care centre, preschool, youth centre, gallery, library, museum, cinema, theatre, opera house, concert hall, dance hall, school (public or private), college, university, institution for higher education, movie house, kindergarten, campus. |
| T | Trade or service area Bank, petrol station, supermarket, airport, cafe, casino, garage (commercial), gas station, hotel, market, office building, radio or television station, restaurant, service station, shop (commercial), shopping mall, station (bus/rail), warehouse. |
| U | Unspecified place |

Body region for injuries

Note: VEMD Codes starting with "F" indicate foreign body

| Frankston ED Code | VEMD Code | Description |
|---|---|---|
| ABDO | 5 | Abdomen |
| ALIM | F5 | Digestive tract |
| ANKL | 18 | Ankle |
| EAR | F2 | Ear |
| ELBOW | 10 | Elbow |
| EYE | F1 | Eye |
| FACE | 2 | Face (Excludes eye, use code F1) |
| FARM | 11 | Forearm |
| FOOT | 19 | Foot (includes toes) |
| GENI | F6 | Genitourinary tract |
| HAND | 13 | Hand (includes fingers) |
| HEAD | 1 | Head (Includes ear; excludes face – use code 2) |
| HIP | 14 | Hip |
| KNEE | 16 | Knee |
| LBACK | 6 | Lower back (includes loin) |
| LLEG | 17 | Lower leg |
| MULTI | 21 | Multiple injuries involving more than one body region |
| NA | 22 | Body Region not applicable |
| NECK | 3 | Neck |
| NOSE | F3 | Nose |
| PELV | 7 | Pelvis (includes ano-genital and perineum) |
| RESP | F4 | Respiratory tract (Excludes Nose - use code F3) |
| SHOU | 8 | Shoulder |
| SOFT | F7 | Soft tissue |
| THIG | 15 | Thigh |
| THOR | 4 | Thorax |
| UARM | 9 | Upper arm |

| Frankston ED Code | VEMD Code | Description |
|---|---|---|
| UNSP | 20 | Unspecified body region |
| WRIS | 12 | Wrist |

## Activity when injured

| Frankston ED Code / VEMD Code | Description |
|---|---|
| | |
| C | Other work Unpaid domestic duties, such as: caring for children and relatives, cleaning, gardening, household maintenance, cooking. Other duties for which income is not gained, such as: unpaid work in family business. |
| E | Education Formal education, learning activities, such as: attending school session or lesson, university, undergoing education. |
| L | Leisure Hobby activities; leisure-time activities with an entertainment element such as being at a cinema, a dance or party; participating in activities of a voluntary organisation. |
| N | Being nursed, cared for Care of infant by parent, patient by nurse. |
| O | Other specified activity |
| S | Sports (includes sport as a means of income)Physical exercise with a described functional element such as: golf, riding, jogging, skiing, school athletics, swimming, trekking, water-skiing. |
| U | Unspecified activity |
| V | Vital activity, resting, sleeping, eating. Personal hygiene, other personal activity. |
| W | Working for income. Paid work for salary (manual) (professional), bonus and other types of income; transportation (time) to and from such activities. |
| Total | |

## Financial Classification

| Code | Desc |
|---|---|
| IHOBA- | Public |
| IHOBA-R | Public |
| IHONN- | Public |
| IHOS2- | Public |
| IHOS6- | Public |
| IHOS6-H | Public |
| IHOS8- | Public |
| IHOS9- | Public |
| IHOST- | Public |
| IHOST-E | Public |
| IHOST-EMU | Public |
| IHOST-FD | Public |
| IHOST-FDR | Public |
| IHOST-H | Public |
| IHOST-HE | Public |
| IHOST-HR | Public |
| IHOST-IC | Public |
| IHOST-ME | Public |
| IHOST-MU | Public |
| IHOST-N | Public |
| IHOST-NR | Public |
| IHOST-NT | Public |
| IHOST-NTR | Public |
| IHOST-Q | Public |
| IHOST-QF | Public |
| IHOST-QR | Public |
| IHOST-R | Public |
| IHOST-UN | Public |
| IHOST-UNR | Public |
| IHOWE-SR | Public |
| ILVLV- | Private |

| Code | Desc |
|---|---|
| INHEG-LA | Private |
| INHEG-SA | Private |
| INHEI-C | Private |
| INHEI-CA | Private |
| INHEI-J | Private |
| INHEI-JA | Private |
| INHEI-L | Private |
| INHEI-LA | Private |
| INHEI-M | Private |
| INHEI-MA | Private |
| INHEI-S | Private |
| INHEI-SA | Private |
| INHER-C | Private |
| INHER-CA | Private |
| INHER-LA | Private |
| INHER-MA | Private |
| INHER-S | Private |
| INHER-SA | Private |
| IPRD2-R6 | Private |
| IPRD2-T6 | Private |
| IPRD6-R6 | Private |
| IPRD6-T6 | Private |
| IPRD8-L6 | Private |
| IPRD8-M6 | Private |
| IPRD9-L6 | Private |
| IPRD9-M6 | Private |
| IPRDW- | Private |
| IPRGI-W | Private |
| IPRP2-T6 | Private |
| IPRP6-R6 | Private |
| IPRP6-T6 | Private |

| Code | Desc |
|---|---|
| IPRP6-U6 | Private |
| IPRP8-L3 | Private |
| IPRP8-L8 | Private |
| IPRP8-M3 | Private |
| IPRP8-M8 | Private |
| IPRP9-L3 | Private |
| IPRP9-M3 | Private |
| IPRPR-JR | Private |
| IPRPR-L | Private |
| IPRPR-LR | Private |
| IPRPR-M | Private |
| IPRPR-MR | Private |
| IPRPR-OR | Private |
| IPRRP- | Private |
| IPRRP-EMU | Private |
| IPRRP-GR | Private |
| IPRRP-HE | Private |
| IPRRP-HHU | Private |
| IPRRP-HR | Private |
| IPRRP-J | Private |
| IPRRP-JR | Private |
| IPRRP-LR | Private |
| IPRRP-M | Private |
| IPRRP-ME | Private |
| IPRRP-MR | Private |
| IPRRP-N | Private |
| IPRRP-SD | Private |
| IPRRP-SDE | Private |
| IPRRP-SDER | Private |
| IPRRP-SDR | Private |
| IPRRP-Y | Private |

| Code | Desc |
|---|---|
| IPRSP- | Private |
| IPRSP-A | Private |
| IPRSP-FD | Private |
| IPRSP-GR | Private |
| IPRSP-J | Private |
| IPRSP-JR | Private |
| IPRSP-K | Private |
| IPRSP-L | Private |
| IPRSP-LR | Private |
| IPRSP-M | Private |
| IPRSP-MR | Private |
| IPRSP-O | Private |
| IPRSP-OR | Private |
| IPRSP-Q | Private |
| IPRSP-QB | Private |
| IPRSP-S1 | Private |
| IPRSP-S1R | Private |
| IPRSP-S3 | Private |
| IPRSP-S3R | Private |
| IPRSP-S4 | Private |
| IPRSP-SDR | Private |
| ISCAS- | Private |
| ISCAS-E | Private |
| ISCAS-R | Private |
| ISCAS-SD | Private |

| Code | Desc |
|---|---|
| ISCAS-SDE | Private |
| ISCOC- | Private |
| ISCOC-D | Private |
| ISCOC-E | Private |
| ISCOC-ER | Private |
| ISCOC-R | Private |
| ISCOC-SD | Private |
| ISCOC-SDE | Private |
| ISCOC-SDER | Private |
| ISCRA- | Private |
| ISCRA-EMU | Private |
| ISCRA-H | Private |
| ISCRA-HE | Private |
| ISCRA-LR | Private |
| ISCRA-N | Private |
| ISCRA-NE | Private |
| ISCRA-NER | Private |
| ISCRA-P | Private |
| ISCRA-R | Private |
| ISCRA-SDP | Private |
| ISCRA-SDR | Private |
| ISCRA-SNER | Private |
| ISCSH- | Private |
| ISCSH-SD | Private |
| ISCT2-L5 | Private |

| Code | Desc |
|---|---|
| ISCT6-L5 | Private |
| ISCT6-M5 | Private |
| ISCT8-L5 | Private |
| ISCT9-M5 | Private |
| ISCTAC- | Private |
| ISCW6- | Private |
| ISCWC- | Private |
| ISCWC-EMU | Private |
| ISCWC-H | Private |
| ISCWC-HE | Private |
| ISCWC-N | Private |
| ISCWC-NE | Private |
| ISCWC-R | Private |
| ISCWC-SNER | Private |
| RAP | Private |
| RASN | Private |
| RASNE | Private |
| STNP | Private |
| STP | Private |
| WCP | Private |
| WCSN | Private |
| WCSNE | Private |

# Appendix 4-C

Procedure Codes

Notes: See VEMD Section 8 for Procedure codes. This list derived from Frankston ED data – these are procedures listed in 2002 data – not necessarily complete. There is no VEMD code for “Observation”. Possibly code as VEMD code 91“Other”

| | |
|---|---|
| 01-05 | IV access |
| 11-18 | Medication/Blood products |
| 21-32 | Wound and fracture care |
| 41-60 | Diagnostic procedures |
| 71-85 | Other procedures |

| Frankston ED Code | VEMD Code | Description |
|---|---|---|
| ABG | 46 | ARTERIAL BLOOD GASES |
| ARTL | 04 | ARTERIAL LINE |
| BAC | 60 | BREATH ALCOHOL ESTIMATION |
| BPL | | BLOOD PRESSURE |
| CPAP | 80 | MASK CONTINUOUS POSITIVE AIRWAYS PRESSURE |
| CPR | 82 | CARDIOPULMONARY RESUSCITATION |
| CT | 43 | CT SCAN |
| CVL | 02 | CENTRAL/OTHER LINE |
| DCLS | 81 | CARDIOVERSION DEFIBRILLATION |
| DIG | 25 | DIGITAL OR OTHER NERVE BLOCK |
| DRS | 21 | DRESSING |
| DRUG | 17 | ORAL/SUBLINGUAL/TOPICAL/RECTAL DRUG ADMINISTRATION |
| ECG | 51 | 12 LEAD ECG |
| ECGM | 52 | ECG MONITORING |
| ECHO | | ECHOCARDIOGRAM |
| ENEMA | 77 | ENEMA, MANUAL REMOVAL |
| ETT | 73 | ENDOTRACHEAL INTUBATION AND VENTILATION |
| EYE | 83 | EYE EXAMINATION |
| FWT | 53 | FULL WARD TEST URINE |
| GCH | 75 | GASTRIC CHARCOAL |
| HIO | 84 | HEAD INJURY OBSERVATION |
| IC | 76 | CHEST DRAIN |
| ID | 29 | INCISION, DRAINAGE |
| INF | 11 | INFUSION IV FLUID (excl blood products) |
| IOI | 03 | INTRAOSSEOUS INFUSION |
| IV | 01 | PERIPHERAL IV CATHETER |
| IVI | 16 | IV DRUG INFUSION |
| IVRB | 24 | IV REGIONAL BLOCK |
| IVS | 15 | IV/IM/SC INJECTION |
| LP | 56 | LUMBAR PUNCTURE |
| NAS | 28 | NASAL PACK |
| NEB | 18 | NEBULISED MEDICATION |
| NGT | 72 | NASOGASTRIC TUBE |
| NONE | 99 | NO INVESTIGATION OR PROCEDURE |
| NUC | 44 | NUCLEAR MEDICINE |
| O | | OBSERVATION |
| PA | 48 | PLEURAL ASPIRATION |
| POP | 22 | PLASTER OF PARIS |
| RBG | 55 | RANDOM BLOOD GLUCOSE |
| RED | 26 | REDUCTION (fracture or dislocation-correlates with diagnosis) |
| ROC | 30 | REMOVAL OF CAST, SPLINT, BRACE |
| ROFB | 32 | REMOVAL OF FOREIGN BODY (according to diagnosis) |
| ROS | 31 | REMOVAL OF SUTURES |
| SIG | 58 | PROCTOSIGMOIDOSCOPY |

| Frankston ED Code | VEMD Code | Description |
|---|---|---|
| SPA | 54 | SUPRAPUBIC ASPIRATION/CATHETER SPECIMEN OF URINE |
| SPL | 23 | OTHER SPLINT |
| SPR | 47 | SPIROMETRY |
| SUT | 27 | SUTURE, STERISTRIP, GLUE |
| TET | 14 | TETANUS PROPHYLAXIS |
| THROMB | 13 | THROMBOLYSIS |
| TRANS | 12 | TRANSFUSION OF BLOOD PRODUCTS |
| UC | 71 | URINARY CATHETER |
| ULS | 42 | ULTRASOUND |
| VB | 45 | VENIPUNCTURE |
| VC | 05 | VENOUS CUTDOWN |
| WALK | 85 | WALKING ASSIST DEVICES |
| XRAY | 41 | X-RAY |

# Appendix 5-A

Complete dictionary used for text analysis

BODY
- ABDOMIN
  - BACK
  - ABDO
  - ABDOM
  - ABDOMEN
  - ABDOMINAL
  - BACKBONE
  - BACKBONES
  - BACKED
  - BACKER
  - BACKING
  - BACKINGS
  - BACKREST
  - BACKS
  - BACKUP
  - BACKUPS
  - BACKWARD
  - BACKWARDS
  - BOWEL
  - BREAST
  - BUTTOCK
  - CERVICAL
  - CHEST
  - CHESTS
  - COCCYX
  - EPIGAST
  - EPIGASTRIC
  - FLANK
  - GROIN
  - GROINS
  - KINDEY
  - LIVER
  - LIVERED
  - LIVERS
  - LUMBAR
  - OVAR*
  - PROSTRATE
  - PROSTRATED
  - PROSTRATES
  - PUBIC
  - RENAL
  - RIB
  - RIBBED
  - RIBBING
  - RIBS
  - SACRAL
  - SACRUM
  - SIDE
  - SIDED
  - SIDES
  - STERNAL
  - STERNUM
  - TESTICLE
  - TESTICLES
  - TRUNK
  - TRUNKS
  - URINARY
  - BACKERS
  - BACKBONED
- BLOOD
- HEAD
  - BRAIN
  - BRAINED
  - BRAINING
  - BRAINPOWER
  - BRAINS
  - CHEEK
  - CHEEKS
  - CHIN
  - CHINED
  - CHINING
  - CHINNED
  - CHINNING
  - CHINS
  - EAR
  - EARED
  - EARS
  - EYE
  - FACE
  - FACIAL
  - FACIALS
  - JAW
  - JAWBONE
  - JAWED
  - JAWS
  - MOUTH
  - MOUTHED
  - MOUTHING
  - MOUTHS
  - NASAL
  - NECK
  - NECKED
  - NECKS
  - NOSE
  - NOSED
  - NOSES
  - ORAL
  - ORALS
  - SCALP
  - SCALPED
  - SCALPING
  - SCALPS
  - SKULL
  - SKULLS
  - TEETH
  - TEETHE
  - TEETHED
  - TEETHES
  - TEETHING
  - THROAT
  - THROATED
  - THROATS
  - TONGUE
  - TONGUED
  - TONGUES
  - TONSIL
  - TONSILLAR
- TONSILLECTOMY
  - TONSILLITIS
  - TONSILS
  - JAWBONES
  - JAWBONED
  - TOOTH
- LIMB
  - ANKLE
  - ANKLES
  - ARM
  - ARM?
  - ARMED
  - ARMING
  - ARMS
  - CALF
  - CLAVICLE
  - ELBOW
  - FIB
  - FIBBED
  - FIBBING
  - FIBIA
  - FIBS
  - FING*
  - FING???
  - FINGER
  - FINGERED
  - FINGERING
  - FINGERINGS
  - FINGERNAIL
  - FINGERNAILS
  - FINGERS
  - FINGERTIP
  - FINGERTIPS
  - FOOT
  - FOOTED
  - FOOTING
  - FOOTINGS
  - FOOTS
  - FOREARM
  - HAND
  - HANDED
  - HANDS
  - HIP
  - HIPBONE
  - HIPBONES
  - HIPPER
  - HIPPEST
  - HIPS
  - HUMERUS
  - KNEE
  - LEG
  - LEG?
  - LEGS
  - METACARPAL
  - METACARPEL
  - METATARSAL
  - RADIUS
  - SCAPULA
  - SCAPULAR
  - SCAPULARY
  - SCAPULAS
  - SELF
  - SHOU?????
  - SHOULDER
  - SHOULDERED
  - SHOULDERING
  - SHOULDERS
  - THIGH
  - THIGHBONE
  - THIGHBONES
  - THIGHS
  - THUMB
  - THUMBED
  - THUMBING
  - THUMBNAIL
  - THUMBNAILS

THUMBS
TIB
TIBIA
TIBIAD
TIBIAE
TIBIAL
TIBIAS
TOE
TOED
TOEING
TOES
ULNA
WRIST
WRISTS
TISSUE
BONE
ARTERIAL
ARTERY
BONED
BONER
BONES
JOINT
JOINTED
JOINTER
JOINTS
SKIN
TENDON
TENDONS
SKINS
SKINNED
SKINNING
BONERS
CAUSE
BITE
FOREIGN_BODY
STING
STINGING
STINGS
BURN
BURNED
BURNS
SCALD
SCALDED
SCALDING
SCALDS
FALL
COLLAPS*
FAL??
FALL
FALLEN
FALLING
FALLS
FELL
FELLED
FELLER
FELLING
FELLS
FOREIGN

FOREIGN_OBJECT
HIT
ABUSE
ABUSED
ABUSES
ALLEGED_AS

ALLEGED_ASSAULT

ALLEGE_ASSAULT
ASSAIL
ASSAILED
ASSAILING
ASSAILS
ASSAULT
ASSAULTED
ASSAULTER
ASSAULTING
ASSAULTS
ASSULT
ATTACK
ATTACKED
ATTACKER
ATTACKING
ATTACKS
BEAT
BEATEN
BEATER
BEATING
BEATINGS
BEATNIK
BEATNIKS
BEATS
BLOW_TO
BUMP
CRUSH
CRUSHED
CRUSHES
CRUSHING
FIGHT
FIGHTING
FIGHTS
JAB
JABBED
JABBING
JABS
POKE
POKED
POKES
PRICK
PRICKED
PRICKING
PRICKLE
PRICKLED
PRICKLES
PRICKS
RAPE
RAPED
RAPES
RESISTING_
ARREST
RUN_INTO
SEXUAL_ABUSE
SEXUAL_
ASSAULT
STAB
STABBED
STABBING
STABS
THRUST
THRUSTING
THRUSTS
TWIST
WHIP
WHIPLASH
WHIPLASHES
WHIPPED
WHIPPING
WHIPS
WHIPPINGS
PRICKLING
BEATERS
ATTACKERS
ASSAULTERS
INTAKE
ALLERGIC
CHICKEN
EAT
FISH
FOOD
IMBIBE
IMBIBED
IMBIBES
INGESTED
INJECT*
O.D.
O/D
OD
OVERDOSE
OVERDOSED
OVERDOSES
PANADOL
PILL?
POISON
SUCK_IN
SWALLOW
SWALLOWED
SWALLOWING
SWALLOWS
TAB
TABLET?
TAKE_IN
USE
USED
USES
ODES
ODD
VALIUM
LEVEL
EXACERBATED
ACCUMULATE
ACCUMULATED
ACCUMULATES
ALTER
ALTERED
ALTERING
ALTERS
COMPOUND
ENHANCED
ENLARGE
ENLARGED
ENLARGES
EX
EXAC
EXTEND
EXTENDED
EXTENDING
EXTENDS
INCR*
INCREASED
INTENSIFY
INTENSIFYING
LENGTHEN
LENGTHENED
LENGTHENING
LENGTHENS
RECURRENT
SHARPEN
SHARPENED
SHARPENING
SHARPENS
STRENGTHEN

STRENGTHENED

STRENGTHENING
STRENGTHENS
THICKEN
THICKENED
THICKENING
THICKENS
TIGHTEN
TIGHTENED
TIGHTENING
TIGHTENS
WORSE
WORSEN
WORSENED
WORSENING

WORSENS
GENERAL
GENER*
HIGH
ACUTE
ACUTER
ACUTEST
BAD
BIG
BIGGER
BIGGEST
BIGHEARTED
CRITICAL
DEEP
GREAT
GREATER
GREATEST
GREATS
HEAVY
HI
HIGH_SPEED
LARGE
LARGER
LARGEST
SEVERE
SEVERER
SEVEREST
TREMENDOUS
HIS
HIES
HIED
HID
LOW
DECREASED
EPISODE
LITTLE
LITTLER
LITTLEST
LO
LOW
LOWDOWN
LOWER
LOWEST
LOWLIER
LOWLIEST
LOWLY
LOWS
MODEST
NEW
NEWLY
PARTIAL
SMALL
SMALLER
SMALLEST
SMALLISH
SMALLS
TINY
LOWERED
LOWERING
LOWERS
LOWER
DECREASE*
LOSS
NO
FREE
MISS
NIL
NULL
NULLS
UNABLE
ZERO
ZEROED
ZEROES
ZEROING
ZEROS
FREER
FREEST
FREES
FREED
FREEING
POST
AFTER
AFTERWARD
AFTERWARDS
FOLLOWING
FOLLOWS
FOLLOWINGS
SUDDEN
FAST
FASTED
FASTER
FASTEST
FASTING
FASTS
RAPID
RAPIDLY
RAPIDS
UPPER
UP
WITH
ABOUT

APPROXIMATELY
ASS
ASSOC
ASSOCIATE?
AT
CLOSE_TO
NOW
NOWADAYS
ON
ONES
PRESENT
PRESENTED
PRESENTER
PRESENTING
PRESENTS
PRESENTERS
MODE
ANALYZE
ANALYZED
ANALYZES
APPRAISAL
APPRAISALS
ASK
ASKED
ASKING
ASKS
ASSESSMENT
ASSESSMENTS
CALL_FOR
CHECK
CHECKED
CHECKER
CHECKERED
CHECKERING
CHECKERS
CHECKING
CHECKOUT
CHECKOUTS
CHECKS
ELICIT
ELICITED
ELICITING
ELICITS
EXAMINATION
EXAMINATIONS
EXAMINE
EXAMINED
EXAMINES
FI
FID
INQUIRE
INQUIRED
INQUIRES
INQUIRING
INSPECT
INSPECTED
INSPECTING
INSPECTION
INSPECTIONS
INSPECTS
INVITE
INVITED
INVITES
LETTER
LETTERED
LETTERING
LETTERS
MEET
MEETING
MEETINGS
MEETS
QUERY
R/T
R/V
REASSESSMENT
REASSESSMENTS
RECOMMEND*
RECOMMENDATION
RECOMMENDATIONS
REEXAMINATION
REEXAMINATIONS
REEXAMINE
REEXAMINED
REEXAMINES
REF
REFER
REFERRAL
REFERRALS
REFRESH
REFRESHED
REFRESHES
REFRESHING
REQUEST
REQUESTED
REQUESTING
REQUESTS
REVEIW
REVIEW
REVIEWED
REVIEWING
REVIEWS
SEE
SEED
SEEING
SEEK
SEEKING
SEEKS
SEEN
SEES
SOLICIT
SOLICITED
SOLICITING
SOLICITS
TEST
TESTED
TESTER
TESTES
TESTING
TESTINGS
TESTS
VIEW
VIEWED
VIEWING
VIEWINGS
VIEWS
VISIT

VISITED
VISITING
VISITS
TESTERS
SEEDED
SEEDING
SEEDS
REFERS
REFERRED
REFERRING
REFEREES
REFEREE
REVIEWERS
REVIEWER
REFERENCES
REFERENCED
REFERENCE
REFERRER
REFERRED
LMO
DOCTOR
DR
MEDICAL_OFFICER
MEDICENTRE
MEDI-CENTRE
NURSE
NURSES
NURSED
NURSEMAIDS
NURSEMAID
DOCTORED
DOCTORING
DOCTORS
O/A
ON_ADMIT
ROSEBUD
ORTHO
ORTHOPEDIST
ORTHOPEDICS
ORTHOPEDIC
PAEDIATRIC
PAED*
PAEDIATRICIAN
PAEDS
PROCEDURE
ANGIOGRAM
ADRENALIN_INFUSION
CATHETER
CHEMO
COLONOSCOPY
COMPUTED_TOMOGRAPHY
CT
DIG
ECG
ENCEPHALOGRAM
INFUSION
INTUBATE
INTUBATE?
IV
PLASTIC
PLASTIC_SURGERY
POP
SURGERY
SUT
SUTURE
SUTURES
ULTRASOUND
X-R
XR
XRAY
X-RAY
X-RAYING
XRAY?
SUTURED
SUTURING
PLASTICS
INFUSIONS
CATHETERIZES
CATHETERIZE
CATHETERS
PSYCHIATRIC
PSYCH*
PSYC
PSYCH
PSYCHE
PSYCHED
PSYCHES
POLICE
SELECTOR
BILATERAL
BILAT
BOTH
BOTHER
BOTH
RADIATE
CENTRAL
LEFT
LE
L
LFT
LT
RIGHT
RGT
R
RT
BOTTOM
TOP
SYMPTOM
APPENDICITIS
APPENDICITIS
BLEED
DISCHARGE
EPISTAX*
EPISTAXIS
NOSEBLEED
NOSEBLEEDS
PR
PV
DISCHARGES
DISCHARGED
CARDIA
ACUTE_MYOCARDIAL_INFARCTION
AAA
ABDOMINAL_AORTIC_ANEURISM
ACUTE_PULMINARY_OEDEMA
AF
AMI
ANGINA
APO
BRADY
BRADYCARDI*
CARDI*
CARDIAC_ARREST
CEREBROVASCULAR_ACCIDENT
COMPLETE_HEART_BLOCK
CVA
ICTAL
INFARCTION
STROKE
TACHY
TACHYCARD*
TACHYRHYTHMIA.
TIA
TRANSIENT_ISCHEMIC_ATTACK
STROKES
STROKED
INFARCTIONS
AMID
DEHYDRATED
DEHYD*
DIABETIC
AUTOIMMUNE_DIABETES
DIAB*
GROWTH-ONSET_DIABETES
HYPOGLYCAEMIC
HYPOGLYCEMIC
IDDM
INSULIN-DEPENDENT_DIABETES_MELLITUS
JUVENILE_DIABETES
JUVENILE-ONSET_DIABETES
KETOACIDOSIS
KETOACIDOSIS-PRONE_DIABETES
KETOSIS-PRONE_DIABETES
TYPE_I_DIABETES
DIARRHOEA
DIARR
DIARR*
D'S
GASTRO
GASTROINTESTINAL
HAEMATEM*
MALAENA
MALENA
MELENA
DVT
DEEP_VEIN_THROMBOSIS
FEVER
FEBR*
FEBRILE
FEV*
FEVERISH
FEVEROUS
PYREXIAL
HYPERTENSION
INFLAMMATION
HAEMATOM*
ASCITES
CELLUL
CELLULIT*
COLIC
COLITIS

COLONITIS
HEMATOMA
INFLAM*
MASTITIS

PYELONEPHRITIS
SEPTIC
SWEL*
SWELL
SWOL*
INFECTION
ABSCESS
ABSCESSED
ABSCESSES
ABSCESSING
ABSESS
INFEC*
URTI
UTI
INJURED
CUT
AMP
AMPUTAT*
CUTS
CUTTING
CUTTINGS
DAMAGE
DAMAGED
DAMAGES
DISLOCATE
DISLOCATED
FRAC*
FRACTURED
GASH
GASHED
GASHES
GASHING
IMPACTED
INJ
INJUR*
INJURE
INJURED
INJURES
LAC
LACERATION
LACERATIONS
SEPARATED
SEVERED
SEVERING
SLASHED
TRAUMATISE
TRAUMATIZE
TRAUMATIZED
WOUND
WOUNDED
WOUNDING
WOUNDS
LACES
LACED
LACING
CUTER
CUTEST
CUTOUTS
CUTOUT
CUTOFFS
CUTOFF
CUTBACK
MENTAL
AGGRES*
AGGITAT*
AGITAT*
ALT

ALTERED_CONC_STATE

ALTERED_CONSCIOU

ALTERED_CONSCIOUS_STATE

ALTERED_CONSC_STATE

ALT_CONCS_STATE
ALT_CONS

ALT_CONSC_STATE

ALT_CONS_STATE
AMNESIA
ANX*
ANXIOUS

AUDITORY_HALLUCINATIONS
BIZARE
BIZARRE

BIZARRE_BEHAVIOUR
BIZZARRE
CONFUS*
CONFUSION
DEPRES*
DYSPHASIA
HALLUCINAT*
MENTAL_STATE
PSYCHO*
SCHIZOPH*
SUICID*
THREAT*
UNSTABL*
UPSET
PREGNANT
/40
ABORT
GEST*
PREG*
ABORTING
ABORTED
ABORTS
RESPIRATORY
ASPIR*
APNOEA
APNOEIC
ASTH*
BRONCHI*

CHESTY_COUGH
COAD
COUGH
COUGH*
CROUP

DIFFICULTY_BREATHING

DIFFICULT_BREATH*

DIFFICULT_BREATHING
FLU
HAEMOPTYSIS

HYPERVENTILAT*
INSPIRA*
LLL
PLEUR*
PNEU*
RESP*

RESPIRATORY_DISTRESS

RESP_DISTRESS
S.O.B
SOB
STRIDOR
WHEEZ*
SOBBING
SOBBED
SOBS
FLUES
FLUED
VOMIT
HAEMATEMISIS
HAMETEMISIS
HEMATEMISIS
NAUSE*
V
VOM
VOMI
VOMIT*
V'S
VOMMIT*
UNWELL
WITHDRAWAL
ABPAIN

ALLERGIC_REACTION
ANAPHYLAX*
BLOAT
BLOCKED
BRUIS*
CONSTIPAT*
DIZZINESS
DIZZY
DYSPHAGI??
EARACHE
EAR_ACHE
EAR_ACHEING
EAR_ACHING
HAEMATOMA
HEADAC???
HEADACHE
HEAD_ACHE
HEAD_ACHEING
HEAD_ACHING
LETHARG*
MIGRAINE
PAIN
PAIN?
PAINFUL
PAINS
RASH
MIGRANE
SORE
STIFFNESS
SWEAT
SWEAT????
SWOLLEN
TIGHT
TIGHTNESS
TINGLE
TINGLING
TONSILITIS
TOOTHACHE
UNSETTL*

URINARY_RETENTION
VERTIGO
WIND
VISION
PALPITATION
SEIZURE
PALPITAT*

    TREMOR
    SPASM
  COLLAPSE
    FAINT
    PASS_OUT
    SYNCOPE
    UNCONCIOUS
    UNCONSCIOUS
UTILITY
  CREATURE
    DOG*
    BEE
    CAT
    HORSE
    INSECT
    SPIDER
    SNAKE
    SNAKES
    SNAKEBITES
    SNAKEBITE
    SPIDERS
    INSECTS
    HORSES
    BEES
  VEHICLE
    MBA
    BICYCLE
    BIKE
    BULL_BAR
    CAR
    DRIVER
    MCA
    MOTORCYCLE
    MVA
    MOTOR_BIKE
    PASS
    PEDESTRIAN
    PASSENGER
    PASSENGERS
    PEDESTRIANS
    PASSERSBY
    PASSERBY
    PASSER
    MOTORCYCLES
    MOTORCYCLED
    DRIVERS
    BIKERS
    BIKER
    BIKES
    BIKED
    BICYCLERS
    BICYCLER
    BICYCLES
    BICYCLED
  OBJECT
    STAIR
    ACID
    BED
    BRANCH
    GALLSTONE
    KIDNEY_STONE
    KNIFE
    MONKEY_BAR
    NEEDLE
    PIN
    ROOF
    RUSTY_*
    STAIRS
    STEEL_BAR
    STENT
    STEP
    STEPLADDER
    STEP_LADDER
    STONE
    TREE
    STAIRCASE
    WEIGHT
    WALL
    WALLS
    STAIRCASES
    TREES
    TREETOPS
    TREETOP
    STONES
    STEPLADDERS
    STEPS
    ROOFING
    ROOFER
    ROOFLINE
    ROOFTOP
    ROOFS
    PINPRICKS
    PINPRICK
    NEEDLES
    KNIFES
    KNIFED
    GALLSTONES
    BRANCHES
    BEDS
    ACIDS
    STAIRWAYS
    STAIRWAY
    STAIRWELLS
    STAIRWELL
  DRUG
    ETOH
    ALC
    ALCOHOL
    AMOXIL
    AMPHETAMIN*
    AUGMENTIN
    CANNIBAS
    COKE
    COCAINE
    HEROIN
    TABLET
    TROPONIN
    VENTOLIN
    TEMAZEPAN
    WARFARIN
    ALCOHOLISMS
    ALCOHOLISM
    ALCOHOLICS
    ALCOHOLIC
    ALCOHOLIZE
    ALCOHOLS

# Appendix 6-A

Selected Simul8 simulation model documentation

```
SIMUL8 Documentation for: C:\Documents and Settings\andrzejc\My
Documents\Data\Simulation\Ver11\ver12_Patients_in_ED.S8 at time 11/09/2006 4:48:40
PM Version: 11.0.0.827
-----------------------------------------------------------------------------------
Treatment focussed ED simulation

This simulation is the combination of data mining results and discrete event
simulation.  Patient data was grouped according to similarity of treatment.  The
simulation reflects the likelihood of patients receiving a particular treatment
according to their urgency and ultimate disposal (which is known very early in
treatment).

The model seeks to duplicate ED occupancy.  Patients arrivals and treatment types
(including time for treatment) are inputs to the system. Queues are a partial
input in that patients are sent to optional treatment sites if they queue for too
long.  The number of patients in the ED is the output of the system.  The
conditions necessary for long queue times are studied.

Treatment sites are a combination of real and virtual.  There are 3 resus beds and
27 beds in the actual ED, but staff are adept at 'creating' beds by shuffling
people in queues (e.g. at X-ray) and using treatment chairs and trolleys.  There
can be up to 46 people in the ED 'supply chain' at any given time. This simulation
attempts to capture this coping behaviour.

To run:
1. Open data sheet
2. Reset to reset counters, etc.
3. Select speed, random number streams, etc.
4. Run
5. View results or copy/paste to Excel for easy graphing, etc.

Created by: Business Systems
Last opened by: red

*********************************************************************************
General Simulation Information
------------------------------

  Warm Up Time: 525600   Results Collection Time: 525600 (Minutes)
  Start of day: 0 Length of day: 1440 ,   Days per week: 7
  Current Random Stream Set: 1
  Data display when simulation stopped: Work Item Count
*********************************************************************************
Reset Visual Logic:
  VL SECTION: Reset Logic
    'Obeyed just after all simulation objects are initialized at time zero
    Clear Sheet    iss results[1,1]
    SET iss results[1,1]  =  "ID"
    SET iss results[2,1]  =  "Entry Time"
    SET iss results[3,1]  =  "Changeover time"
    SET iss results[4,1]  =  "Work type"
    SET iss results[5,1]  =  "Age"
    SET iss results[6,1]  =  "Tr_site"
    SET iss results[7,1]  =  "Into_bed"
    SET iss results[8,1]  =  "Exit_ED"
    SET iss results[9,1]  =  "Urgency"
    SET iss results[10,1]  =  "Disposal"
    SET iss results[11,1]  =  "Treatment"
    SET iss results[12,1]  =  "Bed_time"
    SET iss results[13,1]  =  "Wait_time"
    SET iss results[14,1]  =  "Exit_time"
    SET iss results[15,1]  =  "Work time"
End Run Visual Logic:
  VL SECTION: End Run Logic1
    SET is row_counter  =  QU exit.Count Contents
    LOOP 1 >>> is results_loop >>> is row_counter
      IF Lbl Entry_time  >  Warm Up Period
      SET iss results[1,is results_loop]  =  Lbl ID
      SET iss results[2,is results_loop]  =  Lbl Entry_time
      SET iss results[3,is results_loop]  =  Lbl changeover
```

```
      SET iss results[4,is results_loop]  =  Work Type
      SET iss results[5,is results_loop]  =  Lbl Age
      SET iss results[6,is results_loop]  =  Lbl Treatment_site
      SET iss results[7,is results_loop]  =  Lbl Start_treat
      SET iss results[8,is results_loop]  =  Lbl End_treat
      SET iss results[9,is results_loop]  =  Lbl Urgency
      SET iss results[10,is results_loop]  =  Lbl Disposal
      SET iss results[11,is results_loop]  =  Lbl Treatment_path
      SET iss results[12,is results_loop]  =  WORK TIME-Lbl changeover
      SET iss results[13,is results_loop]  =  WAIT TIME
      SET iss results[14,is results_loop]  =  is row_counter
      SET iss results[15,is results_loop]  =  WORK TIME
    Set in EXCEL    iss results[1,1] ,  "Simulation" ,  1 ,  1 ,  15 ,  is
row_counter

********************************************************************************
```