FLOW RATE MODELLING: A METHOD OF COMPARING PERFORMANCE IN DEPARTMENTS OF GERIATRIC MEDICINE

A thesis presented for the degree of
Doctor of Philosophy in Medicine
in the University of London

by

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in

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ABSTRACT

The question of comparing performance in departments of geriatric medicine is considered to have immense complexity with methodological problems that are difficult to overcome. Difficulties arise because short stay and long stay patients occupy beds for different dimensions of time. Also the allocated beds are often on more than one site, and there are different styles of practice. Consequently, comparison is difficult. The argument that flows through the thesis is that measuring the time of bed occupancy overcomes the problem.

My previous work on discharge behaviour and space indicated that improved planning would be obtained if decision making was based on two compartmental flow rate models, rather than on linear models. This thesis builds on that work. Considerable effort is now being made to collect vast quantities of historic data concerning the treatment of individuals. Most is analyzed after the admission event is over: all concerns the use made of the occupied beds, none concerns the pattern of bed occupancy. Yet, in geriatric medicine, because of the presence of short stay and long stay patients, what is happening within the beds is an important variable. Also, the only thing that inpatients have in common is that they occupy beds for measurable time.

The reason why geriatric medical beds contain short and long stay patients is discussed. Previous work which supports a hypothesis that patients flow in streams of movement is presented. The problem of measurement is then considered heuristically and practically and analogies with pharmacokinetics, biological models and manpower planning models are drawn. Argument concerns the need to measure flow. Next the research that confirmed the validity of a mixed exponential fit in the departments of geriatric medicine in thirteen health districts is presented and a theoretical mathematical model, developed in association with a Professor of Mathematics, is discussed. That work indicated marked differences in performance and the concluding part of the thesis uses the new methodology to seek the reason for those differences.

The research was based on a point-in-time study in fourteen of the fifteen departments of geriatric medicine. Data was collected by a ward based census, interviews with consultants and nurses, and a ward visit. Then the input, process and output variables were correlated with the calculated flow rates. Statistical analysis indicates that a major explanatory variable which explains differences in performance is ease of discharge to nursing homes. The implication of the results is discussed and a practical, explanatory, flow rate, planning model is developed.
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APPENDIX II: To rehabilitate or to vegetate?
First published in the Nursing Mirror, March 16, 1978 Vol 146:14-16

APPENDIX III: Throughput in a department of geriatric medicine: a problem of time, space, and behaviour.

APPENDIX IV: A case for the development of departments of gerocomy in all district general hospitals: discussion paper.
First published in the Journal of the Royal Society of Medicine, Vol 84, December 1991: 731-733
APPENDIX XIV: Balancing Acute and Long-term Care: The Mathematics of Throughput in Departments of Geriatric Medicine.
First published in Methods of Information in Medicine, Vol. 30, September 1991: 221-8

APPENDIX VI: Occupancy plotting: a new method of measuring the balance of acute / rehabilitative and long stay beds in departments of Geriatric Medicine. A study of the occupancy of the thirteen Departments of Geriatric Medicine in the South West Thames Regional Health Authority. Report published by the Division of Geriatric Medicine, St. George's Hospital Medical School, April 1998.


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DECLARATION

Published articles are included in the Appendix. Papers read at National and International meetings are cited in the references. The research involved assistants. A published paper includes Dr. Amy Roberts who visited the departments with me; a paper (under review) includes two computer programmers, Robert Scott-Stewart and Arif Abidi from my department and Prof G. Harrison from the College of Charleston, S. Carolina.

PERMISSION TO PUBLISH

Some figures come from the preceding thesis. Permission to include the articles in the Appendices was granted by the publishers of the Nursing Mirror, Nursing Times, Methods of Information in Medicine, The Journal of the Royal Society of Medicine and Health Trends.

STATEMENT

Eleven years passed between my registration as a postgraduate student at St. George's Hospital Medical School and the submission of this thesis. The original aim was to undertake a statistical and psychological study of the question of death on movement and Prof. N. Dilly, and Prof G. Paykel were to be my supervisors. I had observed in a data base concerning ten years admission that men were more likely to die in the second week after admission and this masculine tendency to die when stressed (Young, Benjamin, & Wallis, 1963; Rees & Lutkins, 1967; Parkes, Benjamin, & Fitzgerald, 1969) is a possible explanation for differential male/female survival. The approach was to be both mathematical and psychological. However, during data analysis a programming error lead to a discovery that there was a shape to the pattern of bed occupancy.

That observation led to an MD thesis that developed new methods of measuring activity in departments of geriatric medicine and developed a theory for planning (Millard, 1989). This thesis follows on from that work. Dr. J. Kellett, who supervised my MD, kindly agreed to be my supervisor for this thesis and in 1990 the School agreed that I could change registration from the MPhil to the PhD degree. The research reported herein was undertaken between 1988 and 1992.
ACKNOWLEDGEMENTS

Without the willing co-operation of my consultant colleagues and their medical and nursing staff in the Region the study would have been impossible.

Especial thanks go to Dr. John Kellett for his patient supervision over many years; to Dr. Derek Perkins who advised me to divide the work into two parts; to Prof Othoniel in Montpelier who taught me so much; to Prof. Brian Livesley who guided me to Catastrophe Theory; and to my brother Tony for encouraging me to look in new physics.

The census technique was developed by Charles Huthwaite and Tony Moody under the direction of Dr. Val Dickinson in the computing department at St. George's. Shantha Ravindram used Graph Pad INPLOT to determine the best fit. Dr. Paul Higgs, the Eleanor Peel Lecturer, and Dr. Paula Rochon, a visiting Canadian Legion Scholar, co-ordinated the first Regional study and Dr. Kit Byatt assisted with data analysis. Sheila Howells and Wendy Clarke from Regional Planning cooperated.

Prof Alan Johnson, Dean of the Medical University of South Carolina, put me in touch with Dr. Clint Miller of the Department of Biometry. He introduced me to Prof. Gary Harrison of the Department of mathematics in the College of Charleston, U.S. who solved the model in my MD thesis. Also Prof. Sally McClean of the Department of Mathematics in the University of Ulster at Coleraine has given invaluable advice. Local statistical advice came from Dr. Martin Bland and Dr. Sian McGuigan.

Dr. Amy Roberts, a young American doctor, who funded her own stay, helped with protocol and questionnaire design and accompanied me during the Regional visits. Arif Abidi and Robert Scott-Stewart, research assistants in the department, wrote the software programs to perform computer assisted modelling and analysed the results. Dr. Charlotte Platt, when Lecturer in geriatric medicine, co-ordinated the second census.

The thesis was prepared in its final form by Miss Tracy Coleman and Mrs Elizabeth Mosby. Illustrations were made in the Multi-disciplinary Lab at St. George's.

A grant from the Youde foundation was used to fund the development of the software that converts bed occupancy data into bed occupancy statistics. Prof. Gary Harrison wrote the algorithm, and Robert Scott-Stewart and Arif Abidi completed the work.
DEDICATION

To Gill, without her constant support and encouragement this work would never have been completed.

QUOTATIONS

The waves of the sea, the little ripples on the shore, the sweeping curve of the sandy bay between the headlands, the outline of the hills, the shape of the clouds, all these are so many riddles of form so many problems of morphology. D'Arcy Thompson, 1917.

When catastrophes are frequent and close together, each of them taken individually, will not have a serious effect, and frequently each is so small that even their totality is unobservable. When this situation persists in time, the observer is justified in neglecting these very small catastrophes and averaging out only those factors accessible to observation. Prof Rene Thom, 1975.
INTRODUCTION

The world population is ageing, and governments have to decide how best to organise, and pay (Klein, 1988), for the medical care of their ageing population. Shorter hospital stays for older people are not necessarily harmful (Rich & Freedland, 1988), but older people often live alone and usually have multiple medical problems, consequently they occupy beds for longer than their younger counterparts (Mills et al., 1976; Anderson et al., 1988; Munoz et al., 1988; Munoz et al., 1989; Pawlson, 1988). So countries that plan to fund care using Diagnosis Related Groups for single diseases may unintentionally penalise their older patients (Munoz et al., 1988). Presently, the United Kingdom, government is separating the 'purchasers' from the 'providers': the intention is to improve care, but questions are being asked about the impact of contracts on the quality of care (Hopkins & Maxwell, 1990). The aim is to increase throughput, but faster throughput may not imply better care.

The Audit Commission has recently commented that the way forward is to integrate the acute aspects of geriatric and general medical care (The Audit Commission, 1992); but the evidence for the benefit of this approach, based on a comparative study of length of stay at discharge from an integrated medical service and two age related services, is weak. For the integrated service had separate rehabilitation and long stay beds whilst the age related service had combined acute, rehabilitation and long stay wards (Grimley-Evans, 1983). Consequently, like was not compared with like.

People take pride in their performance, and consultants in geriatric medicine are no exception to this rule; the titles of papers reporting the development of styles reflect pride in achievement [see (Hodkinson & Jeffreys, 1972; Bagnall et al., 1973; Das Gupta, 1980; Grimley-Evans, 1983; Millard, 1978; O'Brien, Joshi, & Warren, 1973)]. So performance comparison is fraught with difficulty. What all are seeking is a method of comparison that cuts through the complexity in order to describe the behaviour of the staff. Yet, the more data that is collected the more difficult the problem becomes. Difficulties arise in comparing performance in geriatric medicine because the allocated beds contain a mixture of short and long stay patients. Also several hospitals are often involved and there are different admission and operational policies [see (Brocklehurst & Andrews, 1985)]. So it is difficult to compare like with like. Indeed the whole question of comparing performance is recognised to have immense complexity with methodological problems that are difficult to overcome (DHSS, 1981).

Professor Rene Thom (Thom, 1975) argues that the social sciences have not yet
developed models, not because of complexity, because all of nature is complicated, but because quantitative measures give such a mass of data. The model developed in the thesis is based on the idea that patients flow through the allocated beds in streams of movement (Feldstein, 1964)

The question then becomes: "How does one measure the flow?"

Three observations made while examining the rise and fall of admissions to the St. George's department of geriatric medicine gave clues to the answer. The question being tackled was "Why did admission numbers rise then fall before rising again?" Examination of the average length of stay at discharge and the turnover per allocated bed indicated that performance was continually changing. However, the percentiles showed that introducing a new style of rehabilitative patient management (Millard, 1973) first changed the 50th and 75th percentiles of length of stay, then, suddenly, four years after change began, the 25th percentile of length of stay 'flipped' to a new constant (Millard, 1978; Millard, 1992) (Appendix I and II). Thereafter, the annual admission numbers changed but the percentiles remained constant. Subsequently, the changing admission numbers must have reflected a constant discharge practice (Feldstein, 1964) operating in changing numbers of short and long stay beds. Four monthly censuses of the occupied beds confirmed that long stay bed numbers were changing (Millard, 1992) (see Appendix III) thus over a decade changing annual admission numbers reflected a constant discharge behaviour and changing numbers of short stay beds.

Wisdom suggests that better use of resources is achieved by integrating with general medicine (Royal College of Physicians, 1977; DHSS, 1981; The Audit Commission, 1992), but speed is a scalar, not a vector, and speed alone does not show direction (Epstein, 1989). The specialty of geriatric medicine was developed in order to improve throughput in the chronic sick wards (Warren, 1943; DHSS, 1981); development of the specialty increased throughput in geriatric medical beds from one patient a bed per year in 1948 to 4.5 patients a bed per year in 1978 (DHSS, 1981). The population is ageing, and the 1981 plan was to increase throughput to six patients per bed per year by encouraging integration with general medicine. However, during the last decade there has been a massive expansion in rest and nursing homes and the field research reported herein suggests that the local availability of nursing homes has become a major explanatory variable that determines the speed of discharge.

The study involved the active participation of the consultants in fourteen of the fifteen departments of geriatric medicine in the South West Thames Region. Collecting the data
needed a ward based census, visits to sixty three admission wards, interviews with the twenty eight consultants and discussion with thirty four senior nurses in charge of the wards at the time of the visit. The method is new (Harrison & Millard, 1991) and, perhaps even controversial, for it uses curve-fitting to assess performance, but confirmation of the results in other regions would imply that plans for the treatment of the ageing population need to be rethought.

The ideas developed in the thesis represent discussion with many people throughout the world, and the work could not have been done without their assistance. I present it as my own in full recognition of the debt I owe to them. Many of the references are to books, for the work interweaves ideas from topology, physics and mathematics and the references combine the bibliography and journal articles. However, to aid understanding a summary of the key points from major sources is included after the references.

Capra (1975) argues that concepts of force and pressure are so deeply ingrained in Western though that we have difficulty in thinking in other ways. Also administrators prefer averages because it is easier to think in single numbers (Bartholomew, Forbes, & McClean, 1991). Yet, overlooking bed occupancy is causing planning mistakes (Vere, 1983). Also the idea that increasing the ‘pressure’ will force people to change performance (MacStravic, 1984) is causing strain; if The Behavioural Theory is correct (Feldstein, 1964) staff under pressure will simply adjust admissions rather than change performance. So increasing pressure may solely meet with increasing resistance. There has to be a better way and this research attempts to develop it.

The thesis develops a new science of measurement.

Introduction of the method of flow rate modelling should enable managers to base their plans for an ageing population on scientific principles rather than on feelings (Feldstein, 1963). Waves in the sea are a riddle of form (Thompson, 1917). Like waves in the sea, patients are only present for periods of time, but at any moment of time they have been present for measurable periods of time. Thus the solution to the riddle lies in analyzing (Thom, 1975) the pattern of bed occupancy. For when catastrophes are frequent and close together one is justified in simply measuring that which is present (Thom, 1975).

Yates's (1982) review of the problems of data collection in hospitals ‘Hospital beds: a problem for diagnosis and management’ is an essential starting point for anyone who wishes to understand the problem of data collection and analysis in hospitals. This work could not have been done without it.
DEFINITIONS

The following terms are used:

A: CLINICAL

Geriatrics: the specialty, recommended by Warren (1943) to improve care of the chronic sick. Geriatrics differs from geriatric medicine because the specialists were to have responsibility for the rehabilitation and after care of all older people admitted to homes. The original word, coined by Dr. Ignatius Nascher (Nascher, 1914), described the need for a specialist medical service for older people.

Geriatric medicine: the specialty that emerged from the long stay wards consequent upon the 1948 decision to transfer responsibility for the bed-bound, sick and infirm, to the hospital service (DHSS, 1981). See Horrocks (1986) for a description of resource needs in geriatric medicine.

Style of practice: the strategic approach taken by consultants in the developing specialty of geriatric medicine to make the best use of the local allocation of resources. The main styles are:

1. Specialty specific: patients referred to the specialists according to need (Hodkinson & Jeffreys, 1972).
2. Age related: admission to the department is dependent upon age, i.e., 75 and over (Bagnall et al., 1973; O'Brien, Joshi, & Warren, 1973).
3. Integrated: all older people requiring acute admission are admitted to general medical wards, and those needing rehabilitation or long stay care are transferred to the department of geriatric medicine (Grimley-Evans, 1983).

Rehabilitation: an approach to disability that aims to enable a dependent person to overcome their handicap. Rehabilitation implies an active co-operative approach between patient and staff in a changed environment. Multi-disciplinary team-work is essential. Environmental requirements are: adjustable height beds, chairs of different heights, ease of access to lavatories, central dining tables, space for activities, storage facilities for personal clothing and a trained staff.

Discharge behaviour: the prevailing practice relating to the discharge of patients from admission, rehabilitation and long stay wards. The term embraces the outcomes of death,
transfer and discharge: the hypothesis being that the local style of practice sets up its own
constant rate of flow (Feldstein, 1964; Millard, 1989; Millard, 1992)

**Progressive patient care**: an operational policy developed by Exton-Smith (Exton-Smith,
1962) in which patients move between acute, rehabilitation and long stay wards according
to need.

**Gerocomy**: a word first used in the Corpus of Justinian, A.D. 370, for units for the care of
the aged: lit. old tending. Used here to describe a scientific approach to the care of the
aged (Smith, 1752; Millard, 1991).

**B: TOPOLOGY**

**Topology**: lit: place and study. Mathematically, the study of geometrical properties and
spatial relations unaffected by continuous change of shape or size of figures (Oxford
English Dictionary).

**Topological terms**: the terms used in the theoretical model - vector field, temporal map,
logical succession, catastrophe hypersurface and attractor - were derived from Thom
(1975).

**Vector field**: the direction of flow through the occupied beds. Vectors can be considered
as arrows that connect the place from which a thing is carried to the place it is carried to.
Discharge is a vector because discharge is directional. The interaction of the staff, the
facilities and the resources in the community establish the local directions of flow. Discharge
home after an acute admission lasting two weeks differs from discharge due to
death after seven years in a long stay ward. Consequently, more than one number must
be used.

**Temporal map**: the map that shows the time sequence of observed events. A
photograph gives shape to the waves in the sea; plotting the time sequence of admission
events gives shape to the pattern of bed occupancy. At any point in time the beds have
been occupied by patients for measurable time and the temporal map gives shape to the
form of bed occupancy (see curve fitting and time). In geriatric medicine the map of the
pattern of bed occupancy separates the inpatients into short and long stay components. Plotting the temporal map of bed occupancy identifies the height of the hidden threshold that separates the acute / rehabilitation beds from the long stay beds.
Logical succession: in a topological model the logical succession is the inverse of the temporal map. The time sequence of admission events represents past decision making; but in stable state what has happened reflects what may happen. However, there can be no certainty.

Attractors: attractors influence outcome. Hospital beds attract people from the community (Feldstein, 1964), and facilities in the community attract people from the hospital (Bhowmick & Arnold, 1984). Consequently, outcome is influenced by factors within and without the hospital.

Catastrophe hypersurface: crossing a catastrophe hypersurface implies a change of state. The decision not to discharge implies that the patient crosses a hidden threshold between the rehabilitation stream of flow and the long stay stream of flow.

C: MODELLING


Static models: Models that concern the interaction of events and things without regard to evolution with time. Static models describe resources without regard to process.

Black-box models: models that attempt to predict the process within based on information collected from without. Plans for hospitals are based on data collected from without, i.e., waiting lists, length of stay at discharge, turnover per allocated bed and emptiness; consequently they are 'black-box'.

Stochastic models: stochastic means random. Manpower planners use stochastic models based on mathematical analysis of the interacting probabilities that influence the decision to stay or leave employment to forecast future staff needs. Such a model separates employees into 'movers' and 'stayers'. Similar methods of analyzing length of stay after discharge could be used in hospitals. It is important to recognise that there can be no certainty.

Deterministic models: models in which the output is determined by the inputs. Linear models are deterministic; but the underlying notion, that increasing pressure (MacStravic, 1984) shortens length of stay, is contrary to the space hypothesis (Millard, 1989).
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**Dynamic models**: dynamics concerns the interplay of events. Departments of geriatric medicine contain two streams of movement. One concerns the rate of flow through the assessment/rehabilitation beds the other the rate of flow through the long stay beds. Change in factors within a model is the basis of 'what-if' modelling.

**Kinematic models**: models that consider motion abstractedly without reference to force or mass. Pharmacokinetics involves the characterization of the time components of drug absorption, distribution, metabolism and excretion, and their effects on the intensity and time course of therapeutic and adverse effects of drugs (Gibaldi, 1991). In like manner, the development of a science of noso-kinetics (disease, flow), with strict rules for the interpretation of results and for the design of studies, might improve hospital planning.

'What-if' modelling: what-if modelling forms the basis of decision making. The necessary components are a model and data; decisions are pre-tested by altering parameters within the model.

**D: IDEAS FROM PHYSICS**

**Time**: time is the fourth dimension of space, but time itself brings three dimensions to space (Ouspensky, 1931). The fourth dimension is everlasting now. The fifth dimension expresses the time of the decision that brought something to the present. The sixth dimension is any other decision that could have been made (before) at (or after) that time. The temporal map of bed occupancy measures the remnants of decision making in time past, i.e. it gives a historical sequence to time.

**Space**: in geometry the three dimensions of space are height, breadth and width. In geriatric medicine the three dimensions are:

1. The number of beds, their location and the facilities supporting them.
2. The number of staff, their disciplines and their training.
3. The equipment within the ward and the design of the environment.

All have a dimension of time.

**Behaviour**: patients flow through the beds in streams of movement. Words used to describe facilities, such as acute, assessment, slow stream, continuing care and long stay, imply dimensions of time as well as facilities. Consequently plans have to be based on an understanding of the interaction of time, space and behaviour (Millard, 1992).
Flow: the prevailing discharge practice reflects the interaction of the staff, the patients and the facilities. Thus one can think of flow in terms of waves of patients. Waves of light and electromagnetism are made up of waves and particles, but if you measure the wave you cannot measure the particles and vice versa. The same is true in hospitals. Therefore, to plan, information concerning patients has to be considered in terms of flow.

Orbits: electrons move in orbits, and the same is true of patients. Electrons may or may not be found spinning in a slow or fast (in infinitesimal terms) orbits: there is no certainty. Similarly, whether a patient with a certain disease will be in the same ward tomorrow is unknown; but, as with orbiting electrons, each ward has its own intrinsic rate of flow: accident and emergency (minutes), intensive care (hours), acute medicine (days), rehabilitation (weeks) and long stay (months or even years).

E: THEORIES DISCUSSED

Linear Theory: the linear theory is based on a hypothesis that length of stay shortens linearly with time (Avery-Jones, 1964). Consequently, if the pressure increases the length of stay shortens. This direct interaction between force and movement represents classic Newtonian thought (Capra, 1975).

Behavioural Theory: the behavioural theory considers that discharge is a locally determined constant (Feldstein, 1964), which changes from constant to constant (Millard, 1989; Millard, 1992). Also patients are considered to flow through the allocated beds in streams of movement. The theory is similar to the ideas that underpin concepts of movement in modern physics (Capra, 1975).

Catastrophe Theory: a topological theory developed by Thom (Thom, 1975) in order to explain sudden change from one state to another (see Woodcock and Davis 1980 for a simpler version). This theory explains why discharge behaviour suddenly ‘flips’ from one state to another. The theory underpins the model developed in the first thesis.

F: METHODOLOGY

Curve-fitting: computer assisted curve-fitting separates the components of the pattern of bed occupancy into two compartments. The method is similar to methods used in pharmacokinetics to study the excretion of drugs [see Gibaldi (1991) for a comprehensive discussion]. However, the method analyses the sequence of decision making in time past, whereas pharmacokinetics analyses the sequence of events in time future.
Bed occupancy analysis: The following steps are used:
1. A census is undertaken and the date of admission is determined.
2. The number of days each inpatient has occupied a bed since admission is calculated.
3. The time sequence of admission events is ranked in ascending order.
4. The best fit to the shape of the pattern of bed occupancy is then determined using a curve-fitting algorithm.
5. If the mixed exponential equation \( y = Ae^{Bx} + Ce^{Dx} \) fits the pattern of bed occupancy, the parameters of the equation are used to calculate bed occupancy statistics.

Rider
a) The calculated statistics are based on three assumptions:
   i) That the beds are fully occupied.
   ii) That discharge is independent of length of stay. And
   iii) That the department is in stable state.
b) These assumptions may not be valid but they simplify the mathematics and allow comparison to be made.
c) The model simplifies the immense complexity of a department of geriatric medicine, but if there were no complexity there would be no need for a model (Harrison & Millard, 1991) and Appendix III.

The thesis explains the development of the method and presents the results obtained in a study in fourteen departments of geriatric medicine.
CHAPTER ONE

A HISTORICAL PERSPECTIVE

Although there were units for the elderly called gerokomia in the Roman Empire\(^1\), there is no evidence concerning the development of a specialty of geriatric medicine until the latter half of the 20th Century. However, that does not indicate that there was no need. Two centuries earlier Dr. John Smith, a Fellow of the Royal College of Physicians of London, desired doctors to study the gerocomical part of physic (Smith, 1752). In Paris in 1803, the development of a specialty of gerocomy was suggested by physicians working with the chronic sick: their demands ceased in 1830 when ageing was included in theses (Stearns, 1977). In 1909, Dr. Ignatius Nascher, a physician working with the chronic sick in New York suggested the development of geriatrics (Nascher, 1914). Then in 1943 Dr. Marjory Warren, who was working in the chronic sick wards of the West Middlesex Hospital, recommended the creation of a specialty of geriatrics (Warren, 1943).

Finally, in 1948 the United Kingdom government transferred responsibility for the chronic sick to the Regional Hospital Boards and from that unlikely beginning the specialty emerged (DHSS, 1981). This chapter considers the history of the development of the specialty of geriatric medicine, from 1948 to 1992, in order to draw attention to the problems of planning.

1.1 The impact of War

A major influence on the development of the specialty was the discharge of 140,000 chronic sick patients from the acute hospitals in the United Kingdom in the first two days of the Second World War (Means & Smith, 1983). During the First World War hundreds of thousands of wounded men returned to United Kingdom hospitals so beds were emptied in expectation of casualties; but the Second War was fought differently and problems with the post-discharge care of the chronic sick aroused public concern about the poverty of medical management and lack of rehabilitation in local authority run, general practitioner supervised, chronic sick wards (Warren, 1943). Consequently, at the start of the National Health Service, government took responsibility for the chronic sick wards from local government and gave it to the Regional Hospital Boards (Pater, 1981). Thus, the specialty is based in the rehabilitation of the chronic sick and not in the ageing of the population.

\[^1\] Personal communication by the Librarian of the Wellcome Institute for the History of Medicine.
The post-war operational plan introduced rehabilitation into the chronic sick wards in order to free beds for others to use (Warren, 1943; Warren, 1946). Ever since, the problem of measurement concerns the interrelationship between rehabilitation and long stay care. Yet, nearly all of the research evidence focuses on the acute aspects of care.

1.2 Place of Dr. Marjory Warren

Dr. Marjory Warren pioneered the basic principles of rehabilitation in the chronic sick wards of the West Middlesex Hospital and the early development of the specialty of geriatric medicine involved introducing, and refining, the ideas she had developed [see Howell (1974) and Williamson (1979)]. However, when discussing geriatric medicine, it is important to recognise that the present form of the specialty (though based on her work) bears little relation to her original hypothesis. For, she recommended:

1. The chronic sick should be diagnosed and treated in special blocks in the general hospital set up and equipped for the purpose.
2. The aged should be admitted to homes through hospital units only. All homes for the aged should be attached to hospital units to ensure close follow up.

Although Warren's viewpoint was supported by a British Medical Association Working Party (1947), government decided that the responsibility for residential homes should remain with local councils. The probable reason being, that elderly people - displaced by bombing to the seaside - had managed in residential homes (Means & Smith, 1983). Lord Amulree, later to become the first president of the British Geriatrics Society, speaking in the House of Lords during the debate on the health service, forecast that artificially separating the sick and infirm from the frail would eventually cause problems (Anonymous, 1946). But government decided to leave the frail aged with local government. This explains why,

a) The sick and infirm aged are the responsibility of the hospital service.
b) The frail aged are the responsibility of local government.

Dr. Marjory Warren's contribution to the health care of the Nation was that she changed the management of the chronic sick. Throughout the country, older people are now encouraged to get out of bed, to walk within the ward to tables and to the lavatory, to dress in outdoor clothes and to interact with other patients in day rooms and at communal dining tables [see (Exton-Smith, 1962; Exton-Smith, Norton, & McLaren, 1975)] 2. To achieve

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2 The introduction of the basic principles into the St. George's department is described in Millard 1973, 1978 (see Appendix I and II p145-149).
this, nursing and medical practice had to be changed. Beds had to be lowered, cot-sides had to be removed, chairs with different heights had to be provided, and teamwork had to be introduced etc., [see (Horrocks, 1986)]. Accordingly, the basic principle of geriatric medicine is a changed approach to the in-patient management of potential long stay patients, and the problem is how to measure this.

**Waiting lists and Norms**

When responsibility was transferred the wards were full of bed-bound patients and 54,000 people were awaiting admission (Graham, 1982). Faced with a waiting list there are two, fundamentally different, approaches. Either one can work outside assessing those who need to come inside, or work inside getting those who are inside outside, so those outside can come inside. The first strategy involves home visiting to assess need (Exton-Smith, 1952). The second strategy involves a more active rehabilitative approach. Accordingly, many departments choose to operate without waiting lists (Hodkinson & Jeffreys, 1972). So the presence of a waiting list may (N.A.H.A, 1983), or may not, represent need.

In 1957, the national average provision of geriatric beds was 9.8 beds per 1000 people aged sixty five and over (Boucher, 1957). Fourteen years later the average was taken as the norm [10 beds per thousand of the population aged sixty five and over, with five beds per thousand in acute hospitals (DHSS, 1971)]. Thus the norm reflected:

a) The historical position (Yates, 1982), and

b) A wide scatter, for the range was 1 to 54 beds per 1000.

Achieving the norm in many districts involved closing beds, but some had to provide them. Ten years later the mean provision was 8.1 beds and the range was 1 to 14 beds per thousand aged 65 and over: and the norm was adjusted to 8 beds per 1000 over 65 (DHSS, 1981). Now norms have been abandoned.

**1.4 The search for acute facilities**

At the start of the National Health Service no new beds were provided, only medical responsibility for the long stay wards was transferred.

As the specialty developed different admission policies evolved in different parts of the country. These strategies depended on the historical provision, local negotiations with colleagues, and the availability of alternative hospital beds. Usually new beds were not provided. Often infectious diseases or chest beds were converted into geriatric medical beds. Alternatively, small hospitals changed their use. By 1978 most districts had
provided acute facilities, but forty-one departments of geriatric medicine (twenty percent of all districts) had no beds in their local district general hospital, and others still had too few beds (DHSS, 1981).

In Newcastle, where no geriatric medical beds were allocated in the main hospital, the consultants in geriatric medicine chose to integrate the acute aspects of care with general medicine (Grimley-Evans, 1983). In Hull and Oldham, where most of the beds were in the district general hospital, age related services were developed (Bagnall et al., 1973; O'Brien, Joshi, & Warren, 1973). In Harrow and Merton, where some geriatric medical beds were in the district general hospital, active policies were introduced into the geriatric wards (Hodkinson & Jeffreys, 1972). Thus the location of the local resources influenced the style.

1.5 The debate begins

The early development of the specialty of geriatric medicine took place in the chronic wards. Consequently, it did not impinge on general medicine. At the outset, the responsibilities of the two disciplines were different, for one was based in acute illness and the other in chronic disease. But as cash limits were introduced, and the specialty sought acute resources, debate began concerning the future place of the specialty [see for example (Wilson, 1972; Cross, 1977)]. Then, in 1977, a working party of the Royal College of Physicians recommended that the acute component of geriatric medicine should integrate with general medicine: though reservations were expressed about the ability of some physicians in geriatric medicine to do acute take, no reservations were expressed about the ability of physicians in general medicine to deal with chronic illness. Subsequently, conflict began.

In 1981 the Department of Health also supported the integrated approach. They had no doubt that the specialty of geriatric medicine, in its present form, could cope with the forecast increase in the number of aged people. But problems of consultant recruitment, coupled with economic considerations, favoured integration of geriatric and general medicine. The document states:

"with regard to experimental areas such as Oxford and Newcastle. It is, however, too soon to know whether these will be more successful than specialist departments. In the absence of objective data or scientific evaluation of either geriatric services or integrated medical services the argument cannot be resolved and experience so far has shown this to be a question of immense complexity,"
posing methodological problems that are difficult to overcome (DHSS, 1981)."

However, despite those reservations, the plan fostered integration in order to increase the nationwide turnover per allocated geriatric medical bed from 4.5 to 6 patients per bed per year (DHSS, 1981).

### 1.6 A new problem emerges

Simultaneously the Department of Health introduced experimental National Health Service Nursing Homes (Graham, 1983). The object being to test a hypothesis that changing from consultant responsibility for long term care to nurse responsibility would improve the care (Evers, 1981). The secondary objective being to determine whether long stay patients could be nursed in single rooms in a home-like environment. The work was experimental, but before the results of the research were announced (Bond & Bond, 1990; Donaldson & Bond, 1991) health authorities throughout the country took advantage of a loophole in government policy (Griffiths, 1988) and negotiated with the private and voluntary sector for nursing home care for their long stay patients [see Age Concern (1991) for a discussion of this].

Within the decade, government expenditure on Board and Lodging allowance in rest and nursing homes increased from eight million pounds to 1.8 billion pounds and expenditure is still rising. Thus government, while urging the acute hospital service to make better use of scarce resources, unwittingly underpinned a massive, uncontrolled, expansion in the private sector (Snape, 1984; Bartlett & Challis, 1985; Capewell, Primrose, & MacIntyre, 1986). The Secretary of State asked Sir Roy Griffiths (1988) to advise on ways of controlling the expenditure; he recommended that responsibility for the purchase of care in private rest and nursing homes should be given to local authority social service departments.

Implementation of the recommendation was postponed, but in April 1993 responsibility for the purchase of care in the private and voluntary sector is to be placed on local government. To achieve this, the wording of the 1948 Act which placed responsibility for the sick and infirm aged on to the Regional Hospital Boards has been changed. So, in less than fifty years, government (probably without meaning to) has turned the wheel full circle.
1.7 The need for models

Problems arise when decisions are based on inaccurate information. Wartime experience was that decision making is enhanced if decisions are made after consideration of change in statistically derived models (Feldstein, 1963). But there are no models (DHSS, 1981). So decisions are based on the recommendations of working parties, on business advisors, or on political whim. Thus mistakes are made.

Active departments of geriatric medicine choose to operate without waiting lists (Hodkinson & Jeffreys, 1972). Yet, waiting lists are considered to reflect need (N.A.H.A, 1983), so resources are allocated to clear them. Consequently, the choice to allocate resources to clear waiting lists may encourage those without them to create them. Also active departments providing a community service require empty beds (Horrocks, 1986), but there can be too little or too much emptiness (Yates, 1982). In addition shortening length of stay increases midnight emptiness. Thus perverse incentives arise, wherein the inefficient are rewarded and the efficient have their beds closed (Millard, 1991). There has to be a better way.

Fifteen percent of the population aged sixty five and over pass through hospitals each year. How they are handled has major resource implications. There are three main choices:

1. To admit all older people under specialists in geriatric medicine to the same ward and to rehabilitate them there (age related).

2. To admit acutely ill older people with younger people to general medical wards and to get the consultants in geriatric medicine to rehabilitate them elsewhere (integrated approach).

3. To admit only those with special needs to separate admission / rehabilitation wards run by consultants in geriatric medicine (geriatric traditional).

Each approach has its advocates and opponents. Option one may deny rehabilitation to the middle aged. Option two requires progressive patient care which may or may not be detrimental. Option three may have problems with regard to acute care. Each specialist has their opinion. But the problem as far as hospital planners are concerned is: "What is the best way to use our resources so that the specialists and their supporting teams can provide a first class service to the community within the limitations of the resources that we have?" To do that, they require accurate, reliable, information.
1.8 Problems with the data

No, currently available, method of measuring activity in hospitals and social service departments enables planners to accurately measure the short stay and long stay components of bed usage. So decisions are based on averages of skewed data.

The Körner committee suggested that the average length of stay of those who stay under or over twenty eight days should be calculated (DoH Health Service Indicators Group., 1988). But such artificial separation takes no account of specialty differences. Glover (1990) used survivorship curves to analyse the length of stay after admission of 36,225 patients (36,222 discharges) treated in departments of psychiatry: he recommended that the problem of two cohorts could be overcome by analyzing the 50th, 75th, and 90th percentiles of length of stay. Introducing this approach should enable the problems of specialty differences in length of stay to be overcome, but it would not overcome the problem of the hidden blocked-beds (Vere, 1983). Similarly, adjusting length of stay for those who stay over 190 days (Barer et al., 1990), though an advance, would not solve the problem. Consequently, new methods are needed.

These new methods should:

1. Be universally applicable.
2. Cut through specialty differences and embrace long term care.
3. Enable the contribution being made to the whole by short and long stay patients to be understood.
4. Identify the presence of blocked-beds.
5. Be easy to perform.
6. Give data that is easy to understand.
7. Enable models to be created.

1.9 Conclusion

Geriatric medicine became a specialty because responsibility for the care of the chronic sick was placed on the National Health Service. Now, when the population is ageing, plans are based on speeding up the acute aspects of hospital care. However, it is unclear whether integration of geriatric and general medicine is the best approach. Also, a further problem has emerged because exploitation of a loop-hole in government regulations has funded a two billion pound overspend on Board and Lodging Allowance for (mainly) older people in voluntary and private rest homes.
On the 1st of April 1993 new plans for Community Care are to be introduced. Then local council social service departments will be responsible for purchasing care in private and voluntary nursing homes, and questions are now being asked concerning the future of long stay care in the hospital service. The problem is that decisions are being based on inaccurate data and there are no models. Consequently, the creation of a practical model would be of considerable benefit.

The next chapter considers model making from a theoretical and practical perspective.
CHAPTER TWO

PROBLEMS OF DATA ANALYSIS

This chapter, based on the first thesis, commences by exploring the impact of change in a single line. Then change in six line models is discussed and two compartment models are introduced. Next, data is presented that supports a hypothesis that patients flow through hospital beds in streams of movement. Finally, a theoretical flow rate model is developed.

PART A: HEURISTIC REASONING

Between 1948 and 1978 the turnover in geriatric medical beds increased from one patient a bed per year to four patients a bed per year. This section uses models to illustrate the different reasons why that could have occurred. By its very nature, heuristic reasoning is solely provisional and plausible. Its sole purpose is to attempt to solve a problem (Polya, 1990).

2.1 Change in a single line

A line with one event can be made into a line with four events by placing events, regularly, irregularly, at the beginning, at the end, or randomly anywhere in the line (Fig 2.1). Therefore, to understand why turnover increased in geriatric medical beds, from one patient per bed per year to four patients per bed per year, one needs information concerning the distribution of the events.

Here hospital statistics concerning length of stay and turnover per bed introduce a tautology. For turnover equals admissions divided by beds and the calculated length of stay equals the days in the year, multiplied by the beds, divided by the admissions (Yates, 1982). So turnover equals average length of stay per bed, which, as figure 2.2 shows, may or may not be true.
2.2 Change in six lines

Figure 2.2 shows three reasons why turnover in six beds can increase from one event per bed per year to four events per bed per year. Column A shows a constant change in homogenous space. Column B shows random change. Column C shows a constant behaviour in changing space. Each is plausible. However, because the geriatric medical beds contain both short stay and long stay patients, and separate wards are usually used (Brocklehurst & Andrews, 1985), options A and B are more likely to be incorrect.

Figure 2.2 Six line models demonstrating three different reasons why turnover could have increased in departments of geriatric medicine from one event per bed per year to four events per bed per year.

Column A. Constant change in homogenous space
Column B. Random change
Column C. Constant behaviour in changing space
2.3. Changing Space

Short stay and long stay patients occupy beds for different durations of time (Struthers, 1963; Hodkinson & Hodkinson, 1980). Therefore, admissions can increase and decrease solely because long stay numbers change. Figure 2.3 shows why.

Each model represents changes made in the balance of short and long stay beds within one department over a period of time. The white part represents the available beds. The black part represents the unavailable beds, i.e., beds occupied by the same patients throughout the year. The models show how changing long stay numbers and bed allocations influence the space available for admissions.

Accepting that the prevailing behaviour relating to the discharge of recently admitted patients is a locally determined constant (Feldstein, 1964; Millard, 1989; Millard, 1992), then, passing from time A to time B, admissions will:

- stay the same in models 1, 6 and 8,
- decrease in models 2, 4 and 5, and
- increase in models 3, 7 and 9.

When patient rehabilitative care is at its optimal flow rate - a state of perfection that may never be defined - then the best policy to increase service to the community is illustrated by Model 9, and the worst policy is depicted by Model 5, i.e., a planned decrease in the acute beds with a planned increase in long stay numbers.

Relating the models to the discussion of care options, in Chapter One, Model 9 represents a planned attempt to increase the beds for short term support, in order to give more people time to recover, and to finance this by decreasing expenditure on long term care. And Model 5 represents a planned attempt to provide a service by speeding up treatment
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in fewer beds whilst increasing the number in long term care. Model 5 represents the present position with regard to service delivery to older people in the United Kingdom, for policies are cutting down hospital beds while increasing the numbers in institutional care (Higgs & Millard, 1989).

2.4 Time is the fourth dimension

Time is recognised by physicists to be an important fourth dimension (Ouspensky, 1931), but in hospitals time is only taken into account after the event has happened. Yet words like acute, terminal, rehabilitation, slow stream, continuing care and long stay imply dimensions of time as well as facilities. Consequently, to plan facilities one has to understand the interaction of both facilities and time.

A multiplicity of diverse factors, such as the diagnostic and therapeutic abilities of the physician (Feinglass et al., 1991; Pawlson, 1988), the amount of rehabilitation (Rapoport & Judd-Van Eerd, 1989), the frequency of ward rounds (Vere, 1983), the availability of community support (Carpenter & Demopoulos, 1990), the social class of the admitted patients (Epstein et al., 1988), the presenting problems (Maguire, Taylor, & Stout, 1986) and the local alternatives with regard to placement in nursing and rest homes (Rubin & Davies, 1975; Fitzgerald, Moore, & Dittus, 1988), to name but a few, influence performance. The age of the admitted patients in general medical and geriatric wards may be the same. However, that may not imply, as Leonard (1976) assumed, that the patients are the same (Isaacs, 1969), for age alone is an inadequate indicator of need. Accordingly, the only thing that hospitals have in common is that, at any point in time, the allocated beds have been occupied by individual patients for measurable periods of time.

Einstein asked himself when he was a young man:

"What would I see if I were travelling along at the speed of light".

He answered himself:

"I will see the light waves going up and down" (Capra, 1975).

Physicians, nurses, and administrators travel through the hospital wards at the same speed as the patients. Does that explain why we solely measure them going in and out? Yet, they and we are moving through time. Thus, the solution to the problem of measuring activity in hospitals lies in understanding time.

2.5 The importance of time

A letter by Struthers (1963) gave a clue to a possible solution. Struthers reported that the
pattern of length of stay at discharge from a department of geriatric medicine in Southampton was expressed by an equation with two exponents. One exponent representing the short stay patients had a half life of two months; the other exponent, representing the long stay patients, had a half life of two years. He concluded that short stay and long stay patients are, both practically and mathematically, separate entities. Therefore, he considered that attention to the needs of a few potential long stay patients would free many beds for others to use. His work supported the observations of Arnold and Exton-Smith (1962) concerning the development of geriatric medical services to the community by converting long stay beds into acute. An insurance based study in Canada also came to the same conclusion (Roos, Shapiro, & Roos, 1984).

The reason is that the short stay and long stay patients occupy beds for different dimensions of time. If the average stay of short stay patients is one month and the average stay of long stay patients is one year, there is a twenty four fold difference in length of stay. Given that time difference, then decisions made concerning only five long stay patients a year will effect over a hundred short stay admissions (see table 2.1).

| Table 2.1 Effect on admissions of changing the balance of short and long stay beds |  |
|---|---|---|
| Short stay beds | Long stay beds | Admissions per year |
| Average stay: one month | Average stay: two years | |
| 40 x 12 = 480 | 60 x 0.5 = 30 | 510 |
| 50 x 12 = 600 | 50 x 0.5 = 25 | 625 |
| 60 x 12 = 720 | 40 x 0.5 = 20 | 740 |
| 70 x 12 = 840 | 30 x 0.5 = 15 | 855 |

Consequently, the provision of an acute geriatric medical service depends upon the quality of rehabilitation at the point of entry to long term care. This explains why control of long term care numbers is central to the provision of an acute service (Ramsay, Horsfall, & Rudd, 1987).

2.6 Performance Comparison

The problem of comparing performance in geriatric medicine using single numbers is:

a) They mask the contribution being made to the whole by short and long stay care, and
b) Indicate speed but not direction (Epstein, 1989).

The latter is best illustrated by considering the movement of an airplane. Given the fact that a plane is moving at 600 miles per hour, we know it is not breaking the sound barrier, but we do not know the direction that it is travelling. Indeed, it could be dropping out of the sky and just about to crash. So, to comment on its performance we have to know both speed and direction. Similarly, in hospitals, unless we know both the length of stay and the direction of discharge we cannot comment on performance.

As ease of access to nursing homes has improved throughput in a department in Wales (Bhowmick & Arnold, 1984), areas with more nursing home places may have shorter lengths of stay. Thus a possible explanation for interdepartmental differences in length of stay could be the number of patients being discharged to nursing homes (Turner et al., 1990). Consequently, the local number of available beds in nursing homes could have a major influence on performance in hospitals (Shapiro, Tate, & Roos, 1987). Evidence for this comes from a study, in the United States, of the effect of changed funding policies on bed occupancy by patients with fracture of the neck of the femur. The study showed that the new policies shortened hospital length of stay by increasing the number going to nursing homes (Fitzgerald, Moore, & Dittus, 1988). This was at first thought to be detrimental to the patients, but a later study of mortality did not confirm this, rather it showed that the nursing homes were fulfilling a rehabilitative function (Rya, Griffin, & Baugh, 1990).

2.7 Summary of Part A

Average length of stay is now used as a measure of performance, but speed does not indicate direction. So, to compare performance, we need accurate information concerning:

- The speed and direction of discharge, and
- The balance of short and long stay beds.

PART B: DISCHARGE BEHAVIOUR

Discharge is directional; therefore it is a vector and not a scalar (Epstein, 1989). If discharge was a scalar, then length of stay would be normally distributed, discharge would be the same as death, and transfer to a nursing home would be the same as successful rehabilitation to independent existence in the patient's own home. But as these outcomes are different, single numbers should not to be used to represent length of stay.
Hospital doctors and planners, like manpower planners (Bartholomew, Forbes, & McClean, 1991), have a preference for single numbers. Consequently, data analysts have to look for the single (most relevant for their purposes) number in order to summarize the data. The choices are the mean, the median (or half-life), or the proportion who survive for a fixed length of time (Bartholomew, Forbes, & McClean, 1991). The mean is widely used to report the length of stay, but in specialties with long lengths of stay, such as geriatric medicine and psychiatry, its use is clearly inappropriate.

A preference for the median has been expressed, based on data from survivorship curves (Glover, Farmer, & Preston, 1990). But, the median is also an average from which the mean can be calculated [see Bartholomew, Forbes and McClean, 1991, for a discussion of this]. In 1981, the nationwide median length of stay in geriatric medical beds was twenty one days (Irvine, 1984), and the average length of stay was eighty one days (DHSS, 1971). Consequently, the mean stay gives little or no indication of the processes that are occurring within the allocated beds.

2.8 Rising and falling admissions

Further clues to a possible new approach were found when asking the question:

"Why did admissions to the Merton part of the St. George's department of geriatric medicine first increase, then decrease, before rising again?"

The data analysed concerned the years 1969 to 1984 and the results challenged traditional thinking. In 1969 changes began within the allocated beds to develop a more active approach to rehabilitation. Clearly, those changes explained the early increase in admissions, but it was unclear why admissions then fell before rising again. This section briefly summarises the results. The changes introduced are in Appendices I and II (Millard, 1973; Millard, 1978) and a paper (Millard, 1992) based on the thesis is in Appendix III.

Table 2.2 shows the annual discharges, the mean length of stay and the percentiles of length of stay until discharge of all patients admitted between 1969 and 1984, and a similar table in Appendix III gives the percentiles to discharge and death combined. Superficially, the changing discharge numbers and mean length of stay after admission from 1973 onwards indicate changing performance. However, analysis of the percentiles of length of stay did not support that conclusion.

Notice that the 50th and 75th percentiles began to change in 1970, then in 1973, suddenly, four years after change began, the 25th percentile ‘flips’ to a new constant style.
Thereafter, the 25th, 50th and 75th percentiles are constants. So, from 1973 onwards the changing annual number of discharges reflected a constant form of discharge behaviour operating in changing numbers of available short stay beds. Therefore, changing numbers of admissions do not necessarily reflect changed performance.

Table 2.2: Length of stay till discharge (not transfer or death) of the patients admitted to the department of geriatric medicine which served the London Borough of Merton between 1969 to 1984

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Discharges</th>
<th>Mean Length of stay after admission in days*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>1969</td>
<td>256</td>
<td>59</td>
</tr>
<tr>
<td>1970</td>
<td>293</td>
<td>61</td>
</tr>
<tr>
<td>1971</td>
<td>378</td>
<td>51</td>
</tr>
<tr>
<td>1972</td>
<td>464</td>
<td>40</td>
</tr>
<tr>
<td>1973</td>
<td>551</td>
<td>36</td>
</tr>
<tr>
<td>1974</td>
<td>503</td>
<td>35</td>
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<tr>
<td>1975</td>
<td>533</td>
<td>39</td>
</tr>
<tr>
<td>1976</td>
<td>677</td>
<td>31</td>
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<tr>
<td>1977</td>
<td>657</td>
<td>37</td>
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<tr>
<td>1978</td>
<td>548</td>
<td>37</td>
</tr>
<tr>
<td>1979</td>
<td>496</td>
<td>36</td>
</tr>
<tr>
<td>1980</td>
<td>577</td>
<td>31</td>
</tr>
<tr>
<td>1981</td>
<td>533</td>
<td>37</td>
</tr>
<tr>
<td>1982</td>
<td>587</td>
<td>33</td>
</tr>
<tr>
<td>1983</td>
<td>630</td>
<td>30</td>
</tr>
<tr>
<td>1984</td>
<td>650</td>
<td>31</td>
</tr>
</tbody>
</table>

- in all years except 1970 and 1971 the minimum stay was one day: in 1970 it was 3 days and in 1971 2 days.

Statistical analysis of the differences between the percentiles of length of stay before and after 1973 showed a highly significant difference. From 1969 to 1972 the 25th percentile was $15.5 \pm 0.58$ days and from then on it was $11.83 \pm 0.83$ (p=<.0001). This supports a hypothesis that the old style of discharge behaviour 'flipped' to a new style. Therefore,
topological concepts can be used to create models, [see (Thompson, 1917; Thom, 1975; Woodcock & Davis, 1980)].

Four monthly censuses of the pattern of bed occupancy in the department confirmed that long stay patient numbers had changed (se fig 2.4))

Feldstein (1964) developed the Behavioural Theory after he had observed staff in acute medical wards adjust admissions rather than change discharge practice. He hypothesised that staff, patients and facilities interact to form the local style. What seems to happen is that the multiple probabilities relating to patient management interact to make streams of locally determined, time related, discharge behaviour that flows through the available beds.

So we can take an analogy from physics (Capra, 1975) and imagine movement through hospitals to be made up of waves of patients.

2.9 Summary of Part B

Four years after a changed style of inpatient management was introduced to the St. George's department of geriatric medicine the 25th percentile of length of stay after
admission 'flipped' to a new constant. Thereafter, changing admissions reflected a constant discharge practice and changing space. These findings support a behavioural theory of flow through hospital beds. Consequently, flow rate models can be created.

**PART C: ORDER WITHIN DISORDER**

In the presence of immense complexity one is justified in measuring solely that which is present (Thom, 1975).

The analogy being developed is of waves of patients flowing through the occupied beds. Like waves of light and electromagnetism hospitals are made up of waves of patients. However, as with waves of light if one attempts to measure the wave one cannot measure the particles, and if one measures the particles one cannot determine the wave (Penrose, 1988). Similar problems arise in hospitals. Now hospital staff make considerable effort to collect masses of data related to intermixed probabilities concerning individuals, but (as presently analysed) this mass of data gives no information concerning the wave. So, alternative methods need to be developed that yield information concerning the locally determined rate of flow.

One of these methods could be to calculate the percentiles of length of stay after admission (Glover, Farmer, & Preston, 1990). Another could be to use adjusted length of stay (Barer et al., 1990). However, we have to continually bear in mind that the flow of patients through hospitals reflects the case-mix and the interaction of staff, patients and resources both within and without the hospital. Nevertheless one advantage that hospital planners have over physicists is that on any day they know how long each patient has been present. So given quantitative and qualitative data, stochastic and deterministic models could be developed.

**2.10 Dimensions of time**

Time is the fourth dimension, but time itself has three dimensions. The three dimensions of time can be considered as the fourth, fifth and sixth dimensions of space (Ouspensky, 1931). Everything we see lies on the historical time of the fourth dimension, i.e., everlasting now. Consider a photograph. The photograph represents the things that were present when the photograph was taken. We know, all too well, that the decision to take a photograph changes the performance of the individuals being photographed. Similarly, in data collection the decision to collect influences the record.
An infinite number of past decisions interact in a photograph. Consider the photographer: he had to leave his house, remember his camera, have a film, and travel to the scene etc. Consider the objects in the photograph; the camera and the film: they had to be manufactured, purchased, brought, positioned, etc. The possibilities are infinite, but all of the things present have one thing in common, they have been present for measurable time. Consequently, given the time sequence of events in a photograph we can construct its history.

The historical sequence of the fourth dimension of time is the fifth dimension of space. And, the sixth dimension is the infinite number of other decisions that could have been made in past time. Difficult, if not impossible, to understand: but it is important because all services are infinitely different, for they represent a locally determined, uniquely different, host of interacting probabilities.

Whatever we see in the present represents an infinite number of alternatives, past possible decisions, that interacted to make the present. Therefore, to understand what is happening in hospital departments of geriatric medicine we have to determine (or assume) the order of decision making in time past. Also to create a model we need information concerning the pattern of events within the system under study (Thom, 1975).

2.11 Organised Chaos

Departments of geriatric medicine have immense complexity, (DHSS, 1981) but within there is a simplicity for each of the inpatients has occupied a bed for measurable time. That time is important, for it is the time that clinicians use to differentiate between acute, rehabilitation and long stay care. Also it is that time which classifies some-one (through no fault of their own) as a bed-blocker. This is the time taken into account on ward rounds, and it is the time that planners attempt to influence and data analysts attempt to measure. But they fail to find it because they measure time only after it has past. The waves of the sea, like the waves of patients, are a riddle of form (Thompson, 1917). And like the waves in the sea patients are only present for periods of time. But if we photograph the sea, we can see the shape of the waves and we can use that shape to describe the form. Therefore, to create a model of a hospital department of geriatric medicine we need to gain information concerning the waves of patients. So, we need to develop techniques that measure what is happening within the occupied beds.
2.12 Order within disorder

One thing that all inpatients have in common is that they occupy beds for measurable time. Figure 2.5 shows how ordering and reordering a chaotic pattern of events in a six-line model produces three shapes. Rearranging the sequence of past events gives a backward pattern; reordering future events gives a forward pattern; and shifting the events in time gives an overall pattern. Thus, by arranging the time sequence of admission events, a shape of the pattern of bed occupancy can be created. So, rather like photographing a wave, one can create a shape to the pattern of bed occupancy. The backward pattern is easily observed, for it is the pattern seen on ward rounds. However, the forward pattern can only be seen if one stands still in time and watches the patients leave. And, the overall distribution of the events in time can only be obtained after all the events have finished. Yet, given a data set of admissions over time and a properly programmed computer, all three can be created [see (Millard, 1989)].

2.13 A temporal map of bed occupancy

Figure 2.6 (overleaf) shows the components of the pattern of bed occupancy of 175 inpatients in the Merton Department of geriatric medicine on the 1st. of Jan. 1981 and the fit to the bed occupancy data obtained using the equation \( y = Ae^{Bx} + Ce^{Dx} \). Where:

- \( y \) = the number of occupied beds,
- \( x \) = the time that the beds have been occupied;
- \( e \) = the exponential constant, and
- A, B, C and D are the best fit parameters.
Whatever method of data analysis is used the fit between curve and data should be checked visually as well as statistically (Motulsky & Ransnas, 1987); the closeness of the fit between the calculated curve and the Merton data indicated that curve fitting, using the least squares method, could be useful. So curve-fitting can be used to separate the two components of bed usage and, given a good fit, then one component represents the recently admitted patients, the other component represents the long standing patients. Then \( \log \frac{e^{\frac{1}{2}}}{B} \) gives the half-life and \( \frac{1}{B} \) gives the average length of stay for acute patients and, similarly \( \log \frac{e^{\frac{1}{2}}}{D} \) and \( \frac{1}{D} \) for long stay patients (D).

Figure 2.6 Line of best fit with two-exponent model for inpatient bed occupancy in days since admission. Bed census date 31/12/1977, London Borough of Merton (Geriatrics Department)

Bed occupancy analysis using the least squares method showed:
1. 180.74 occupied beds, rather than 175.
2. 77.36 beds (42.8\%) occupied by short stay patients with a half-life of 18.1 days (\( \log e^{\frac{1}{2}}/B \)) which is similar to the median length of stay after admission of 20 days for all admissions in 1980 shown in table 2.1.
3. 103.37 beds (57.2\%) occupied by long stay patients with a half-life of 462.1 days (\( \log e^{\frac{1}{2}}/D \)).
4. A 26 fold time difference between short and long stay bed occupancy.

2.14 Summary of Part C

Examined from without hospitals have immense complexity, but within there is simplicity for patients have been present for measurable time. Therefore, by ordering and reordering the time sequence of admission events a map can be created which gives form
to the pattern of bed occupancy. That shape:
   a) Fulfils the criteria of a temporal map, so models can be created.
   b) Is expressed by an equation with two exponents.

**PART D: A THEORETICAL MODEL**

Models require information concerning the process that is taking place within the system.

**2.15 The components of a model**

Despite their immense complexity, departments of geriatric medicine have two things in common. First, they have a recognisable form, which we never fail to recognise (Thom, 1975), for the department consists of ‘THE BEDS ALLOCATED TO THE DEPARTMENT OF GERIATRIC MEDICINE’. Second, at any point in time, inpatients have occupied beds for measurable periods of time. Therefore, if the dates of admission are known, the time sequence of events can be used to create temporal maps, which reflect the pattern of bed usage. The practical components of the model are:

1. The occupied beds.
2. The prevailing behaviour related to the discharge of recently admitted and long standing patients.
3. The threshold between short and long stay patients.

And, the theoretical components are:

- Organised chaos
- The temporal map
- The logical succession
- The vector field
- The catastrophe hypersurface
- The attractor.

These theoretical components are interwoven in Figure 2.7 (overleaf). All, except organised chaos, need some further explanation.

**2.16 The temporal map**

The temporal map represents the time sequence of events (Thom, 1975), i.e, the shape to the pattern of bed occupancy. No present decision can effect a past sequence of events. So the map just records that which is present. However, the map can be used to:

1. Forecast the logical succession.
2. Identify the size of the short and long stay components of bed usage.
3. Determine the height of the catastrophe hypersurface that separates the short and long stay beds.
4. Estimate the rate of flow in the vector field.

2.17 The logical succession
The logical succession is the inverse of the temporal map (Thom, 1975). Consequently, in stable state, if patients are flowing through in streams of movement, then what has happened should reflect what will happen. However, the logical succession can be influenced by decision makers and there is no certainty.

Figure 2.7 Theoretical model of a department of geriatric medicine in stable state. The total bed allocation is constant. There is organized chaos in the acute sector with a constant force of behaviour in the vector field. The temporal map plots the time that has passed since the first consecutive admission, i.e. the individual district spells of the acute and longstay patients. The catastrophe hypersurface derived by backward projection of the longstay, seperates the two states. The mirror image of the temporal map shows the logical succession.
2.18 The vector field
Each patient has their own, unique, discharge trajectory. Although during the course of their admission each patient's discharge trajectory may change - death may intervene, rehabilitation may fail, or even be unexpectedly successful (Piper & Hodkinson, 1979) - but these individual, unique, vectors interact to make a vector field [see (Penrose, 1988)] that flows through the beds. Therefore, discharge can be considered to operate in a vector field. So to compare performance one needs information concerning the direction of output as well.

2.19 The catastrophe hypersurface
The catastrophe hypersurface is the hidden threshold between two states. In this case it is the threshold between short stay and long stay care. In model making, crossing a catastrophe hypersurface implies both a change in direction and a change in movement. The term, catastrophe hypersurface, for the threshold between two states is unfortunate, for discharge could be a clinical catastrophe, but it is not clinical care that is being discussed it is movement. And the decision not to discharge implies a change of movement from the stream of action to the stream of inaction.

The hidden threshold within the occupied beds can be observed by:
   a) Plotting a temporal map of bed occupancy, or
   b) Calculating the best fit exponents.
However, only by using mathematical analysis of the pattern of bed occupancy can one determine the rate of change in the two components.

The object of inpatient management is to tend the sick, to facilitate recovery, to encourage independence, and to enable the patient to return home. All of this requires time. The aim is to achieve discharge in the shortest possible time, but little is gained (and much is lost) if patients are immediately readmitted. Running a rehabilitative environment requires that the nurses in the admission wards encourage independence in activities of daily living. In contrast, in the long stay wards nurses often encourage dependence (Evers, 1981). Consequently, the decision that a patient cannot be discharged implies a change in management as well as a change in movement. For thereafter, their bed availability represents the random nature of death, i.e., it is a slow exponential decline with time (Hodkinson & Hodkinson, 1980).

2.20 The Attractor
An important component of a flow rate model is the idea that attractors influence movement (Thom, 1975). Manpower planners call gaining a new qualification, a 'push',
and being promoted to a vacancy, a 'pull' (Bartholomew, Forbes, & McClean, 1991). Using that terminology, discharge home following rehabilitation is a 'push', whereas the transfer of a patient to a long-stay bed because a vacancy arises is a 'pull'. Thus, vacancies in nursing homes 'pull' patients through the beds, and gaining skills 'pushes' them out. Which is surprising, for one would have thought it was the other way round.

However, the important point is that movement is influenced by attractors. Consequently, the speed of movement through hospital beds is, consciously, or subconsciously, influenced by resource provision (Feldstein, 1964). Therefore, turnover and length of stay cannot be considered in isolation from resource allocation in the community.

### 2.21 A network approach

Tausig’s (1987) network approach to the planning of mental health services, takes into account the links between the agencies and identifies the typology of the cracks. Similar models would be helpful for the planning of departments of geriatric medicine. A stochastic method of forecasting bed needs for long stay patients using transition probabilities (Markov chains) based on previous performance (Lane et al., 1987) has been developed in Canada. Also, researchers in America are using multiple regression analysis to predict bed usage by rehabilitation patients (Stineman & Williams, 1990). These predict future bed requirements based on local data sets, but regional variations in bed usage may simply be a question of supply and demand (Wennberg, Freeman, & Culp, 1987; Rosenheck & Astrachan, 1990).

For example, two American towns, Boston and New Haven, are demographically similar, but, Boston has fifty five percent more acute beds (Wennberg, Freeman, & Culp, 1987). In addition introducing new policies, such as check-ups in the community or new technology can decrease (Tatara et al., 1991; Ramaiah, 1990) or increase (Carpenter & Demopoulos, 1990; Niessen & Douglass, 1985) demand. Consequently, planners must take a host of interacting variables into account. However, because all of these variables interact to make the individual patients flow through the beds the creation of a flow rate model should facilitate planning.

### 2.22 Conclusion

Models require information concerning the process that occurs within a system. Data was presented that supports a hypothesis that patients flow through in waves. If the shape of the pattern of bed occupancy can be expressed by a mixed exponential equation then the
shape can be used to create a two compartment flow rate model. The next chapter reviews the literature concerning two compartment models, and the following chapter reports the research that confirmed the exponential fit and encouraged a mathematician to solve the model.
CHAPTER THREE
MODELS AND MODEL MAKING

A literature search revealed no, theoretical, two compartment flow rate models concerning throughput in departments of geriatric medicine, except those published in association with this (Harrison & Millard, 1991) [Appendix V] and the former thesis (Millard, 1992) [Appendix III]. Prof. Rene Thom considers that social scientists rarely use models, not because of complexity, for all nature is complicated, but because quantitative measures give them such a mass of data (Thom, 1975).

The literature contains descriptions of the service requirements (Horrocks, 1986), needs based models (Niessen & Douglass, 1985) and formulae to predict bed needs based on present bed usage (Morris & Cohen, 1978; Andrews & Brocklehurst, 1985; Farmer & Emami, 1990). Also there are several articles based on personal data sets. Among them are: outcome after cardiac disease (Anderson, 1991); survival with breast cancer (Capocaccia et al., 1990), following marrow transplantation (Goldman, 1991) or with the HIV virus (Taylor et al., 1991); survival prediction based on laboratory tests (Sheiner et al., 1991); and forecasting models based on: readmission after discharge (Holloway, Medendorp, & Bromberg, 1990), perinatal mortality (Brand, 1990), trends in dementia (Hafner & Loffler, 1991) and death (Olshansky, 1987; al Haider & Wan, 1991). Mainly these use survivorship curves based on historic data.

3.1 Why model?

As in biology, it is the vast quantities of data that necessitates the creation of models (Finkelstein & Carson, 1979). Also models facilitate understanding. They explain why arrows hit targets and aeroplanes fly, and enable decision makers to pre-test the impact of their decision making (Feldstein, 1963). Models of necessity over simplify, but without complexity (DHSS, 1981) there is no need for a model (Thom, 1975). Yet, simple models enabled astronauts to land on the moon. Consequently, developing a valid flow rate model might enable hospital planners to hit their targets.

Anatomists, physiologists and biochemists would not claim that models of organs, like the heart, lungs, kidneys, liver or brain, represent reality. However, they could claim that the models advanced understanding. Hospital staff make considerable effort to collect masses of data: most concerns the mass of work that is well done and all is collected after the event is over (Yates, 1982). Such data may be useful for epidemiological purposes, and
Flow Rate Modelling: Millard PhD 1993

certainly provides material for statistical analysis, but it gives little information about the process that is occurring within the occupied beds. Continuing our biological analogy, the present state is like trying to fathom the working of the gastro-intestinal tract by studying what is eaten and excreted. Therefore, models are needed of the process that takes place in hospitals in order to make sense out of the vast quantity of data that is collected.

3.2 Types of model

Models that predict with certainty are deterministic, otherwise they are stochastic (Bartholomew, 1973), but both are similar in an ‘average’ sense (Bartholomew, Forbes, & McClean, 1991). For example, a deterministic model may be based on a group having a ten percent chance of leaving. Whereas, a stochastic model would approach the same problem by giving each individual in the group a ten percent chance of leaving.

Black-box models are based on data collected from without, i.e., input and output data (Bartholomew, 1973). Whereas, topological models are based on information collected from within (Thom, 1975), i.e., they are based on structure and form. Kinematic models are concerned with pure motion, whereas dynamic models consider change with time (Thom, 1975).

The shorter Oxford English Dictionary defines dynamics as the branch of physics that treats of the action of force, which is opposite to statics: the science of weight, its mechanical effects and equilibrium. Our present hospital data sets give us masses of statistics that could be used to calculate probability matrices, therefore, stochastic models could be constructed. But dynamic models would require information concerning the flow of patients through the beds.

3.3 Model building

Models are built in four stages. Model building is the role of the scientist; model solving involves mathematicians; model testing requires applied research; and model implementation involves decision makers (Bartholomew, 1973). Tilquin's (1976) review of formal conceptual models concluded that researchers should formulate an overall model, and then systematically tackle it, justifying each hypothesis at each stage. He favoured the introduction of patient behavioural models, which transform streams of demands (defined epidemiologically) into physician behaviour. He considered that such models should be developed in three stages:
1. Stage one: develops the dynamics of the system.
2. Stage two: introduces epidemiological data.
3. Stage three: considers any necessary change in behaviour.

3.4 The metabolism of albumin

The metabolism of albumin (Sterling, 1951) is similar to the two compartment flow through geriatric medical beds. After intravenous injection of 1 to 10mg. of $^{131}$I-tagged albumin into human volunteers there is a relatively rapid initial fall in the radioactivity of the circulating plasma. Then, approximately two days after the injection, the plasma radioactivity diminishes more gradually. That slow exponential rate of decline represents the rate of replacement of tagged by untagged protein, or the turnover of serum albumin. This rapid first phase metabolism followed by a slow exponential second phase is similar to the flow of acute and long stay patients through departments of geriatric medicine (see Hodkinson and Hodkinson 1981).

Other, more recently published two compartment models concern enzyme function (Runyan & Gunn, 1989; Sharp, Fine, & Honig, 1987), ion-channel kinetics (Liebovitch & Toth, 1991), radio-pharmaceutical transport (Bondareva & Narkevich, 1991), ligand disassociation at binding sites (Goldstein & Barrett, 1987), diseased or disease free states (Dean, Voss, & al-Hassan, 1989), pesticide fate (Dean, Voss, & al-Hassan, 1989) and blood flow in tumours (Mäntylä, Kuikka, & Rekonen, 1976).

3.5 Pharmacological models

The distribution of patients in hospitals is analogous to the administration, absorption, distribution, metabolism, binding and excretion of drugs. Drug clearance is a function of the intrinsic ability of organs, such as the kidneys and liver, to excrete or metabolize it and the rate of blood flow through those organs (Gibaldi, 1991). Some drugs, such as tolbutamide or warfarin, are often preferentially bound to plasma proteins; while, other drugs, like amphetamine and propanalol, are more extensively bound to extravascular sites. Similarly, patients with dementia are bound to long stay psychiatric beds, while patients with stroke illness are in long stay geriatric beds. So the problem of creating a two compartment model of flow through a department of geriatric medicine is similar to the two compartment flow rate models used in pharmacokinetics (see Gibaldi 1991).

Obviously, the distribution of patients reflects admission policies, bed allocation, clinical
practice and discharge policies. Also, the disease, in addition to staff behaviour and resource allocation, influences the location, distribution and outcome of admitted patients. Therefore, a model of a hospital has to take a host of interacting probabilities into account and the problem is how to unravel them. Pharmacologists do this in two ways:

1. By using descriptive studies of effect and strictly controlled data analysis (biopharmaceutics).
2. By measuring the blood levels of a drug before, during and after administration in order to understand the way in which it is handled (pharmacokinetics).

3.6 Lessons from biopharmaceutics

Biopharmaceutics concerns the relationship between physical and chemical properties of a drug in dosage form and the pharmacological, toxicological or clinical response observed after its administration (Gibaldi, 1991). Biopharmaceutics is descriptive: so is the literature concerning the development of geriatric medical services [see Bloom and Soper (1980) for a discussion of this]. Differences between drugs are tested in double blind trials according to strict protocols, for this approach overcomes the problem of observer bias. But, this approach is difficult, if not impossible to do in social planning, consequently statistical significance is sometimes used to test the difference between planned and unplanned changes, so the statistics of chance are misused.

Probability theory is the mathematics of chance. Important principles are:

1. Like must be compared with like.
2. That planned changes do not occur by chance.

These principles must always be borne in mind, because there is a tendency to regard correlation as causation. An example of this is the N.H.S. nursing home research which failed to recognise that planned changes do not occur by chance. The study was established to compare traditional long stay care and experimental nursing homes. However, special training was given to the nursing home staff and no training was given to staff in the control group. Then patients were randomly allocated to the two groups, as if it was a drug trial, and the researchers then used the statistics of chance to test differences between planned and unplanned changes. However, a better environment could not have occurred by chance (Bond & Bond, 1990; Donaldson & Bond, 1991).

However, two of the three districts in the experiment discharged significantly more patients from the group which remained under consultant supervision (Bond & Bond, 1990). Consequently, the results support Warren's original hypothesis concerning responsibility for long term care and rehabilitation, because they showed (in two of the three districts)
that introduction of the nursing homes adversely effected rehabilitation. Combining the results from the two districts 22 out of 160 patients were discharged from the control group that stayed in traditional care compared with two out of 162 in the study group. This difference is unlikely to have occurred by chance ($\chi^2$ using Yates’ correction = 16.510, $p<.0001$). But the significance of that result on resource allocation and usage was overlooked and the possibility arises that the results of the study will be used to justify changed medical responsibility for long term care, rather than the provision of quality care for long stay patients. This is of concern because the original hypothesis that underpinned geriatric medicine was that transferring responsibility for the long stay patients to the hospital service would improve rehabilitation (Warren, 1943).

3.7 Lessons from pharmacokinetics

The development of pharmacokinetics enhanced the safe and effective therapeutic management of patients (Gibaldi, 1991). Pharmacokinetics involves the characterization of the time components of drug absorption, distribution, metabolism and excretion, and their effects on the intensity and time course of therapeutic and adverse effects of drugs. In like manner, the development of a science of noso-kinetics (disease, flow), with strict rules for the interpretation of results and for the design of studies, would enhance hospital planning.

Drugs are distributed through the body in one or more compartments. Penicillin is an example of a one compartment drug: so the first order kinetics can be conveniently plotted on semi-logarithmic paper and the half-life of elimination can be calculated. However, when there are two or more compartments, the semi-logarithmic plot of drug elimination is curved. Then, the mixed exponential equation, $y = Ae^{Bx} + Ce^{Dx}$, reflects the curve (Gibaldi, 1991), where:

- $y$ = the observed blood level of the drug,
- $x$ = the time since administration,
- $e$ = the exponential constant, and
- A, B, C and D are the calculated parameters that are used to determine the half-life of elimination from the two compartments.

The methodology is similar to the method used in this thesis to measure the accumulation of patients with time. Therefore confirmation of the face-validity of the exponential fit to the pattern of bed occupancy would mean that experience gained in pharmacokinetics could be used to plan hospitals ³.

³ Because pharmacokinetics based on compartmental models can lead to
3.8 Lessons from manpower planning

Techniques used in man-power planning could well be applied to the analysis of length of stay data in hospitals [see, Bartholomew, Forbes and McClean (1991)]. One method that separates staff into 'movers' and 'stayers' has analogies to the short stay and long stay divide in geriatric medicine. The technique is based on studies of censused populations, i.e., those leaving employment during specified time periods, usually a year. Therefore, the techniques could be used to analyse length of stay after discharge. If hazard rates could be calculated, stochastic output models could be created and it would be possible to determine how resource availability in a catchment area influences flow.

However, one reservation has to be expressed, for the models are based on historic data, so they only give indirect information concerning the process that is occurring within the allocated beds. Yet the techniques developed in man-power planning will probably become an essential complementary part of dynamic modelling, because models based on cohort studies of bed occupancy overestimate the contribution being made to the whole by long stay patients [see Selvin (1977) for a discussion of this problem].

3.9 Conclusion

The planning of hospital services requires accurate data. The models discussed in this chapter are not yet in use. Models simplify complexity. Consequently, the development of a science of measuring activity in hospitals would enhance planning. Flow rate models used in this science could possibly be based on experience gained in biology, pharmacology and manpower planning. Even if this was untrue, introduction of techniques developed in manpower planning should facilitate the creation of stochastic models. However, confirmation of the validity of the exponential fit to the pattern of bed occupancy in departments of geriatric medicine could open the way for dynamic models to be created. Then experience gained with pharmacokinetics could be useful in facilitating understanding between all involved in the provision of health care services of the dynamic processes that make up patient care. The next chapter reports the research that supported the validity of the exponential fit and lead to a mathematical solution.

unreconcilable difficulties, clinicians and investigators are starting to use non-compartmental approaches that can be applied to all drugs. These have the benefit that they do not depend on curve-fitting, computers, or tedious equations (Gibaldi, 1991). The same reservations cannot be expressed for the work in this thesis.
CHAPTER FOUR

MODEL SOLVING

A joint effort with the Planning Department of the South West Thames Region confirmed the validity of the empirical observation concerning the exponential fit. Then, Prof. Gary Harrison, Professor of Mathematics at the College of Charleston, South Carolina, U.S., whom I met on sabbatical leave, solved the Mathematics of the Flow Rate Model. Model solving is the domain of mathematicians (Bartholomew, 1973): without his assistance the two compartmental model would not have been solved. Appendix VI contains the report of the Regional Study; Appendix V contains our paper 'Balancing Acute and Long-term Care: The Mathematics of Throughput in Departments of Geriatric Medicine (Harrison & Millard, 1991).

PART A: THE REGIONAL STUDY

4.1 Confirming the validity of the exponential fit

The hypothesis tested was: the time pattern of bed occupancy in departments of geriatric medicine is expressed by the mixed exponential equation \( y = Ae^{Bx} + Ce^{Dx} \).

Where,

- \( y \) = the number of occupied beds;
- \( x \) = the time in days that the beds have been occupied;
- \( e \) = the exponential constant 2.71828...; and
- \( A, B, C \) and \( D \) are the calculated parameters which best describe the curve.

The underlying theory being that patients flow through departments of geriatric medicine in two streams of time related movement (Millard, 1989).

4.2 Collecting the Midnight Bed States

The research, undertaken between September 1988 and June 1989, involved the collection of Midnight Bed States from the thirteen health districts in the South West Thames Region. These used to be completed by hand, but lately, a computer generated, printed, record, listing the present inpatients and the admissions and discharges during the preceding 24 hours is checked. The following morning any new information concerning admissions, transfers and discharges is entered into the Patient Administration System. Heraclitus of Ephesus, who lived 2,500 years before the computer era, stated "you cannot
step into the river in the same place twice”. That is certainly true for Midnight Bed States, for the printed list is the only record.

Patient Administration Officers (PAO’s) in the thirteen health districts in the South West Thames Region provided a duplicate, validated, printed, copy of a Midnight Bed State Return covering all the geriatric medical inpatients, in all hospitals in their district, on the night of the 5th of December 1988. A geriatric patient was defined as any inpatient coded as being under the care of a consultant in geriatric medicine. The PAO’s updated the return to include information covering the admissions and discharges in the preceding and following twenty four hours and visited the wards to confirm the accuracy of their return.

4.3 Confirming the exponential fit

The returns were sent to the Regional Planning Department where the data was entered manually into a SMART Database (1985) on a IBM compatible personal computer. The event query function in the data base was used to calculate the number of days that had elapsed since admission, by subtracting the date of admission to the department, not to the ward or hospital, from the census date and adding one. Eleven districts completed returns for the 5th December 1988, and two for the 6th of February 1989. Nevertheless, the returns were analysed as if they had all been collected on the same day.

The bed occupancy data was transferred in ASCII code to the Geriatric Teaching and Research Unit at St. George’s Hospital Medical School and read into another IBM compatible computer. Then SPSS/PC (1989) was used to determine the number of occupied beds at specified durations of time. Finally, GraphPAD InPLOT (1990), a curve-fitting package, which uses a modification of the method of Marquardt (1963), was used to confirm that the pattern of bed occupancy in departments of geriatric medicine fits a declining double exponential equation.4

4 The three methods for fitting models are: maximum likelihood, weighted least squares, and semi-parametric. Weighted least squares has the advantage that it is easiest to implement [see Agresti 1981].
4.4 The pattern in the Region

A total of 2335 inpatients were recorded as occupying geriatric medical beds in the thirteen Health Districts. The relationship between the mathematical expression, \( y = Ae^{Bx} + Ce^{Dx} \), and the overall pattern of bed occupancy is shown in Figure 4.1.

N.B.

1. The data points represent the observed values.
2. The vertical axis (y) is the number of occupied beds.
3. The horizontal axis (x) is the time of bed occupancy.
4. The curve that matches the data was drawn using the parameters of the mixed exponential equation \( y = Ae^{Bx} + Ce^{Dx} \).
5. \( R^2 = 0.999 \): in a perfect fit \( R^2 = 1.00 \); in a very poor fit, \( R^2 = .000 \) (Motulsky & Ransnas, 1987).

**Rider**

\( R^2 \) is the fraction of the variance of the y values (from their overall mean) that is reduced (or explained) by the curve. Curve-fitting equations force the curve to fit the data. Therefore, a statistically significant correlation may be observed when there are clearly visible problems (Motulsky & Ransnas, 1987). Consequently, the relationship between the curve and the data must be checked visually. Figure 4.1 also shows that a linear
regression, a single exponential and a polynomial equation do not express the data. Other equations available in GraphPAD InPLOT (1990) were also tested but they did not compute. A lognormal and mixed exponential mixture was not tested. 5

4.5 The pattern in the Thirteen Districts

Bed occupancy data analysis using data obtained from the Midnight Bed States in all of the districts gave an R$^2$ value that was never less than 0.992. Figure 4.2 shows the relationship between the curve and the data in three of the districts. In one district (hospital 12) the number of long stay patients decreases by ten approximately 200 days before the census. Nevertheless, the R$^2$ value for the fit between the curve and the data in that district was 0.994. This shows the importance of visually examining the curve and the data (Motulsky & Ransnas, 1987). Whether the change in long stay patient numbers represents coding errors or a policy change is not known.

4.6 Bed usage in the Region

Table 4.1 gives the actual bed occupancy and the derived statistics. Inter-district differences were found in the number of allocated beds, in the proportion of the beds being used for short stay care, and in the rates of change in the pattern of bed occupancy.

---

5 A mixed log normal and exponential equation fits the pattern of length of stay at discharge in the 1969 - 1984 data set. The reason for this is probably that discharge numbers contain an excess of short stay patients.
Table 4.1 Actual and calculated bed usage statistics for the departments of geriatric medicine in the thirteen health districts

<table>
<thead>
<tr>
<th>Occupied beds</th>
<th>Recently admitted</th>
<th>Long-standing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>Calculated difference</td>
<td>Number and percent</td>
</tr>
<tr>
<td>118</td>
<td>+6</td>
<td>97 78%</td>
</tr>
<tr>
<td>118</td>
<td>+1</td>
<td>57 48%</td>
</tr>
<tr>
<td>134</td>
<td>+5</td>
<td>63 46%</td>
</tr>
<tr>
<td>139</td>
<td>+2</td>
<td>99 70%</td>
</tr>
<tr>
<td>141</td>
<td>+2</td>
<td>54 39%</td>
</tr>
<tr>
<td>146</td>
<td>-9</td>
<td>96 70%</td>
</tr>
<tr>
<td>162</td>
<td>-2</td>
<td>78 49%</td>
</tr>
<tr>
<td>168</td>
<td>-6</td>
<td>98 60%</td>
</tr>
<tr>
<td>178</td>
<td>-6</td>
<td>89 52%</td>
</tr>
<tr>
<td>184</td>
<td>+6</td>
<td>88 46%</td>
</tr>
<tr>
<td>242</td>
<td>-3</td>
<td>141 59%</td>
</tr>
<tr>
<td>259</td>
<td>+4</td>
<td>130 49%</td>
</tr>
<tr>
<td>346</td>
<td>+8</td>
<td>230 65%</td>
</tr>
</tbody>
</table>

Overall Regional Bed Usage Statistics

<table>
<thead>
<tr>
<th></th>
<th>Number and percent</th>
<th>Half-life (days)</th>
<th>Number and percent</th>
<th>Half-life (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2335</td>
<td>+3</td>
<td>1297 55%</td>
<td>17</td>
<td>1042 45%</td>
</tr>
</tbody>
</table>

The table needs some explanation. The calculated difference represents the difference between the calculated value for the bed occupancy [i.e., A + C] and the observed actual bed occupancy. Overall the difference was plus three, however, in the Districts the difference ranged from minus nine to plus eight. Also, the percentages given for the short stay and long stay bed occupancy relate to the calculated values [i.e., A / (A + C) and C / (A + C)] not to the observed values.

Three observations can be made.

1. The number of allocated beds in each district varies.
2. The percentage of beds used for short stay and long stay care varies.
3. The half-lives of short stay and long stay care are different.
4.7 Different half-lives.

The half-life (or median) (Bartholomew, Forbes, & McClean, 1991) represents how many days have passed since 50% of the patients were admitted. Multiplying the short stay half-life of 17 days by five indicates that the majority of short stay patients were admitted in the preceding 85 days. This result supports an observation made in East London that discharge is a rare event after 90 days (Silver & Zuberi, 1965). In stark contrast, the half-life of the long stay inpatients was 447 days, and 447 x 5 = 2235 days (six years and four months). This 26 fold time difference in bed occupancy between short stay and long stay bed usage underlines the importance of understanding the interaction between short stay and long stay care.

4.8 The Region in 1988 and Merton in 1977

Surprisingly, the overall regional short stay component (parameter B) in 1988 - 0.0377 - is similar to the Merton short stay component in 1977 - 0.0383. Also, the overall regional long stay component (parameter D) in 1988 and the Merton long stay component in 1977 were the same: .0015. The proximity of these parameters collected a decade apart indicates that rates of flow through rehabilitation and long stay beds may be rate limited. However, the marked differences between the short stay and long stay half-lives in table 4.1 do not support that hypothesis. But speed is a scalar and not a vector and speed does not indicate direction (Epstein, 1989) so it is possible that health care could be rate limited.

4.9 Bed allocation relative to the catchment population

In 1971, the norm for bed allocation to the specialty of geriatric medicine was 10 beds per thousand of the population aged 65 and over with half the beds acute (DHSS, 1971). In 1988, six of the districts had fewer than ten beds per thousand people aged 75 and over. Yet, despite this (apparent) bed shortage, only one district had less than 45% of the beds occupied by short stay patients. However, although more beds had not been provided, one part of the prophecy had been fulfilled. This would seem to confirm that factors other than the age of the population in the catchment area influence performance (Millard, 1989).

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6 A half-life of 17 days implies that 50% of the surviving group were admitted during the preceding 17 days; 75% in 34 days; 87.5% in 51 days; 93.75% in 68 days; 96.875% in 85 days; 98.4375% in 102 days etc.,
4.10 Significant inter-district differences in performance

The mean and standard deviation (sd) for parameter B was $0.0389 \pm 0.0135$. Nine districts had an acute bed turnover with one sd (i.e. between 0.0254 and 0.0524); two were turning over more slowly (0.018 and 0.020) and two were faster (0.054 and 0.062) which indicates regional differences in the management of short stay patients. Similarly, the mean and sd for parameter D was $0.00148 \pm 0.00028$. Nine were within one sd (i.e. between 0.00120 and 0.00176): one department was slower (0.0011) and three were faster (0.0018, 0.0018 and 0.0019). These rates of change, though small, represent a difference in the half lives ($\text{loge}^{1/2}/D$) for long stay bed usage of between 630 days and 365 days.

Similarly, the acute turnover difference in half-lives ($\text{loge}^{1/2}/B$) reflects a difference of 38 days and 11 days. Such differences are unlikely to occur by chance. So factors within, or without the departments, must influence performance. The full results of this study are in Appendix VI and the relevant table is table 4 page 172.

4.11 Conclusion of part A.

Bed occupancy analysis in thirteen districts:

1. Confirmed that the pattern of bed occupancy in departments of geriatric medicine can be expressed by a mixed exponential equation.
2. Showed marked inter departmental differences in the use being made of short stay and long stay beds.

Consequently, the results support the idea that patients flow through hospital departments of geriatric medicine in two locally determined streams of movement.

PART B: THE MATHEMATICAL SOLUTION

The Regional Report was completed in June 1989. During August and September of that year the School Council granted me two months leave of absence to visit the Medical University of South Carolina. During that visit, the Dean of the Medical Faculty, Prof. Alan Johnson, arranged for me to discuss my research findings with Dr. Clint Miller, the head of the department of Biometry. He gave me the names of five people to visit. One of them - Prof. Gary Harrison, from the Mathematics Department of the College of Charleston - solved the model [(Harrison & Millard, 1991) Appendix V].
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4.12 Assumptions which underpin the model

Three assumptions concerning admission policy, bed occupancy, and discharge policy underpin the mathematical solution:

1. That all patients are initially admitted as short stay.
2. That the beds are always fully occupied.
3. That discharge rates and conversion rates are independent of the length of stay.

These assumptions are not necessarily true, but they do enable a simple model to be constructed, which explains the empirical observation concerning the mixed exponential fit found in the pattern of bed occupancy, and gives important insights into the flow of patients through departments of geriatric medicine (Harrison & Millard, 1991).

The model of patient flow is similar to the two compartment flow models used in pharmacokinetics (Anderson, 1983) and has similarities with models for age structured populations used in population ecology (Leslie, 1945) and demography (Goodman, 1968).

Of necessity it oversimplifies, but if there were no complexity there would be no need for a model (Thom, 1975).

4.13 The stable state solution

Fig 4.3 (overleaf) illustrates the flow of patients through a two compartment model. The stable state solution for the model is given by the equation $A_c = L_v$, where $A_c$ = the conversion rate from acute to long stay and $L_v$ = the discharge rate from long stay, i.e., the model will be in a stable state if the number of patients being converted into long stay
equals the death and discharge from long stay. Conversely, if $A_c > L_v$ then long stay patient numbers are increasing, and if $A_c < L_v$ then long stay patient numbers are decreasing. From that simple beginning the complex solution began (see Appendix V)

### 4.14 Statistics that can be computed from the model

The bed usage statistics that can be computed from the model are listed in table 4.2. The statistics give important insights into the pattern of movement in departments of geriatric medicine. As Midnight Bed States are generated electronically it would be a relatively simple programming task to introduce bed occupancy analysis into all departments of geriatric medicine. Confirmation of the validity of the model would, therefore, open the way for performance comparisons to be based on readily obtainable, easy to confirm, observable, data.

<table>
<thead>
<tr>
<th>Table 4.2. Bed Usages Statistics generated from the pattern of bed occupancy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overall bed usage</strong></td>
</tr>
<tr>
<td>Actual number of occupied beds.</td>
</tr>
<tr>
<td>Calculated number of occupied beds.</td>
</tr>
<tr>
<td>The admission rate: patients per day.</td>
</tr>
<tr>
<td>The proportion of short stay patients.</td>
</tr>
<tr>
<td>The number admitted each day who will be Group II.</td>
</tr>
<tr>
<td>The calculated expected stay in days.</td>
</tr>
<tr>
<td>The turnover per year per occupied bed.</td>
</tr>
<tr>
<td><strong>Group I (short stay) bed usage</strong></td>
</tr>
<tr>
<td>Fraction of beds occupied by short stay patients.</td>
</tr>
<tr>
<td>The number of short stay patients.</td>
</tr>
<tr>
<td>The average expected stay in days.</td>
</tr>
<tr>
<td>The half-life in days.</td>
</tr>
<tr>
<td>The turnover per year per short stay bed.</td>
</tr>
<tr>
<td><strong>Group II (long stay) bed usage</strong></td>
</tr>
<tr>
<td>Fraction of beds occupied by long stay patients.</td>
</tr>
<tr>
<td>The number of long stay patients.</td>
</tr>
<tr>
<td>The average expected duration of long stay in days.</td>
</tr>
<tr>
<td>The half-life of long stay patients in days.</td>
</tr>
<tr>
<td>The turnover per year per long stay bed.</td>
</tr>
</tbody>
</table>

**The Rehabilitation Benefit**

The eventual increase in admissions per year if one more potential, long-stay patient is rehabilitated each year.
4.15 Conclusion of Part B

If patients are flowing through a two compartment model in streams of movement, the beds are full, and discharge is independent of length of stay, then, the same result is obtained whether one takes a snapshot, or follows a cohort. Therefore, bed occupancy data can be used to:

A. Generate bed usage statistics.
B. Create 'what-if' models.

PART C: FITTING THE MODEL TO THE REGIONAL DATA

4.16 Fitting the model to the Regional data.

Table 4.3 gives the calculated average short stay, long stay and overall stay in the geriatric medical beds in the thirteen districts in the South West Thames Region. See Appendix V pages 157-161 for the method used (Harrison and Millard 1991).

<table>
<thead>
<tr>
<th>District</th>
<th>Acute, short stay, patients</th>
<th>Long stay patients</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Expected stay (days)</td>
<td>Half-Life (days)</td>
</tr>
<tr>
<td>1</td>
<td>99</td>
<td>56.1</td>
<td>38.5</td>
</tr>
<tr>
<td>2</td>
<td>59</td>
<td>28.2</td>
<td>19.3</td>
</tr>
<tr>
<td>3</td>
<td>65</td>
<td>22.2</td>
<td>15.1</td>
</tr>
<tr>
<td>4</td>
<td>101</td>
<td>35.0</td>
<td>23.9</td>
</tr>
<tr>
<td>5</td>
<td>57</td>
<td>26.8</td>
<td>18.2</td>
</tr>
<tr>
<td>6</td>
<td>97</td>
<td>25.5</td>
<td>17.3</td>
</tr>
<tr>
<td>7</td>
<td>81</td>
<td>19.7</td>
<td>13.3</td>
</tr>
<tr>
<td>8</td>
<td>101</td>
<td>33.8</td>
<td>23.1</td>
</tr>
<tr>
<td>9</td>
<td>94</td>
<td>33.8</td>
<td>23.1</td>
</tr>
<tr>
<td>10</td>
<td>91</td>
<td>19.0</td>
<td>12.8</td>
</tr>
<tr>
<td>11</td>
<td>146</td>
<td>50.5</td>
<td>34.7</td>
</tr>
<tr>
<td>12</td>
<td>134</td>
<td>16.6</td>
<td>11.2</td>
</tr>
<tr>
<td>13</td>
<td>234</td>
<td>20.1</td>
<td>13.6</td>
</tr>
</tbody>
</table>
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Note that the calculated average rate of flow of the long stay patients was two to three years. Whereas, the short stay patients flow through in between 20 to 50 days. In four districts, the average short stay flow rate was 20 days or less. In four districts, it was between twenty one to thirty days, and in five districts it was thirty one days or more. Such differences indicate differences in performance, but they do not explain why the differences occur.

4.17 Similar turnover, but different causes

Three departments had a turnover per allocated bed of between five and six patients per bed per year. But that overall similarity does not reflect similar discharge behaviour. In hospital 1, the turnover was 5.2 patients per bed per year, and the short stay average speed was 56.1 days. Likewise, in hospital 5, the turnover was 5.6 patients per bed per year, but the short stay average rate of flow was 26.8 days. Similarly, in hospital 9, the turnover was 5.9 patients per bed per year, but the short stay average was 33.8 days. Therefore, districts use their allocated beds in different ways. So improving performance necessitates different plans.

4.18 Flow rate modelling: one example

The paper (Harrison & Millard, 1991) Appendix V illustrated change in a department where long stay patients occupied 59% of the total geriatric beds and bed occupancy analysis forecast that 735 patients would be admitted that year. If the total number of beds are increased by 10% (i.e., 14 new admission beds are provided), then the annual admissions initially increase by about 23% (i.e., 169 more patients a year), because all the new beds are used for acute care patients. However, 4 to 5 years later, if the conversion rate from acute to long term care remains the same, 59% of the new beds will fill up with long stay patients, so the annual admissions drop to 10% (i.e., 74 more patients a year).

Alternatively, the rate at which acute care patients are released can be increased by 10%, i.e., the average length of stay in the admission wards can be decreased by 2.7 days. If that occurs then 70 more patients a bed per year can be admitted each year. i.e., a 9.5% increase in admissions. However, if the same conversion rate to long term care is maintained, the benefit gained drops off to a 4% increase (i.e., 29 more patients a year) as long stay numbers increase.

Alternative approaches could be to increase the rate at which long stay patients are released, or decrease the conversion rate from acute to long term care by 10% (i.e., 4
patients a year). The latter option eventually leads to an increase in admissions of 5.5% (i.e., about 40 more patients a year). Alternatively, one can keep the treatment rate the same, but reduce the fraction who become long stay by 10% (about 4 or 5 fewer patients a year) and eventually free enough beds in 4 or 5 years to increase admissions by 6%. Thus, decision makers can test the impact of their decision making prior to implementing a policy change.

4.19 Forecasting admissions

The accuracy of the assumptions made in the model concerning throughput were tested by comparing the forecast annual admissions in the thirteen Health Districts (using the December 1988 data) with the actual number of annual admissions during 1989. Least squares linear regression with the x and y intercepts set to zero gave an $r^2$ value of 0.36, $p = 0.03$ (two tailed): see figure 4.4.

However, the result should be interpreted with caution, because, if you place a finger over the data point in the top corner the result becomes insignificant. Also the forecast annual admissions and the actual admissions were often wildly inaccurate. A possible reason is that the hazard of discharge and death from departments of geriatric medicine is not independent of time.\(^7\)

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\(^7\) These results were reported to the SYSTED conference in Barcelona in June 1991.
4.20 Conclusion of Part C

The advantages of flow rate modelling are that the method:

1. Uses readily available data.
2. Estimates the overall expected stay.
3. Separates bed occupancy into its two components.
4. Measures the short and long stay flow rates.
5. Calculates the rehabilitation benefit.
6. Enables 'what-if' models to be constructed.

Its limitations are:

1. The predictions may not be accurate.
2. The method is new and untested.
3. It requires computer assisted data analysis.

4.21 Conclusion of Chapter Four

Confirmation of the validity of the exponential fit to bed occupancy data in thirteen districts, led to the creation of a mathematical model that gives useful insights into the pattern of activity in geriatric medical wards. Analysis of the data from the Region confirmed inter-district differences in overall stay and in the speed of treatment of short and long stay patients. However, speed is a scalar and not a vector, so the reasons for the differences are unclear.

The following three chapters report the operational research that was undertaken to find out why the departments were treating patients at different speeds.

The Abstracts of the papers, and others presented at the same time, are included in Appendix VII.
CHAPTER FIVE

THE SEARCH FOR LOCAL DIFFERENCES

The object of the research was to determine why the departments of geriatric medicine in the South West Thames Region treat patients at different speeds. Consultants in fourteen of the fifteen departments of geriatric medicine in the South West Thames Region cooperated with the study. Data was collected in February 1991, and the departments were visited during the next three months. Each department visit lasted one day. Dr. Amy Roberts, a visiting doctor, accompanied me on the visits and helped in data collection and analysis. Prof. Gary Harrison wrote the algorithm at the core of the software program used for data analysis. Robert Scott-Stewart developed the software and Arif Abidi wrote the program used for data entry. This chapter describes the method.

5.1 Method

The research methodology began with a hypothesis then changed it as data were collected (a negative case analysis). Dane (1990) describes such a study as: "searching for data that disconfirm a tentative hypothesis, revising the hypothesis to include the disconfirming data, searching for more data, and so on". The commencing hypothesis was that differences in admission policies explain differences in speed of treatment (DHSS, 1981). And the concluding hypothesis was that ease of discharge of potential long stay patients explains differences in performance. The protocol is in Appendix VIII.

5.2 Data collection

The following methods of data collection were used.

1. A ward based census involving all of the geriatric medical inpatients in fourteen departments.
2. Structured interviews with the twenty three consultants in geriatric medicine who were responsible for the medical care in those beds.
3. Structured interviews with thirty four sisters or senior nursing staff who were in charge at the time of the visit in up to three wards in each department.
4. Observation of ward based facilities and clinical practice in all of the admission and rehabilitation wards in the fourteen departments.

The inpatient census was undertaken on the 7th of February 1991 (a Thursday to represent mid-week bed occupancy) and the departments were visited during the following
two months. Each visit lasted a day.

5.3 The ward based census

The ward based census recorded:

1. The hospital and ward.
2. The names, dates of birth, and sex of all inpatients and their date of admission to the ward and to the department.
3. The consultants name.
4. The clinical diagnosis on admission.
5. The Norton pressure sore score (to indicate disability) (Exton-Smith, Norton, & McLaren, 1975).
6. The reason for admission and the patient's living situation prior to admission.
7. The admission diagnosis.
8. And if discharge was expected in the next month, the probable place of discharge, i.e., home, rest home, nursing home, etc.

The Lecturer in the Department of geriatric medicine co-ordinated the census and the consultants in the individual departments arranged it. The forms were usually completed by junior medical staff, but sometimes they were completed by clinical assistants, nursing staff or the consultants. Appendix IX gives the coding instructions.

5.4 The consultant interview

The consultants in geriatric medicine were interviewed individually by me. The interview commenced by asking them to rate twelve factors concerning the work of their department on a scale of one to ten, one being the worst and ten being the best. The factors considered were:

1. The overall quality of the geriatric service they provided.
2. The number and quality of their junior medical staff.
3. The number of nurses and the standard of nursing.
4. The number of therapists and the overall standard of rehabilitation.
5. The number of social workers and the overall standard of social work.
6. The quality of the community support services.
7. The availability of places for older people to be discharged to, i.e., long stay beds, nursing homes, etc.
8. The quality of the general medical care in the health district.
9. The relation between their service and orthopaedics.
10. The relation between their service and psychiatry.

Subsequently, they were asked to specify the changes needed in order to make the score a ten.

The remainder of the interview consisted of semi-structured questioning that sought for differences between departments. Questions asked concerned:

A. Waiting lists for admission and discharge.
B. The local style of practice.
C. The bed allocation and location.
D. Junior medical staffing.
E. Admission policy.
F. The inpatient routine.
G. Visiting policy.
H. Outpatients and day patients.

All the consultants (23) cooperated, and each interview lasted between forty five minutes and an hour. Thirteen of the fourteen departments had two or more consultants; where there were two or more consultants mean departmental scores were calculated. The questionnaire is in Appendix XI.

5.5 The nursing questionnaire

The senior nurse on duty in one to three of the short stay wards was interviewed either by me or by Dr. Amy Roberts. The interview commenced by asking them to rate five factors concerning their ward on a score of one to ten: one being the worst and ten being the best. The factors were:

1. The overall standard of the ward environment.
2. The number of nurses and the overall standard of nursing.
3. The overall standard of ward based rehabilitation.
4. The quality of the community support services.
5. The availability of places for the elderly to be discharged to.

Subsequently, they were asked to state what would have to happen to make each score a ten.

The remainder of the interview concerned the general running of the ward. Questions
Flow Rate Modelling: Millard PhD 1993

asked concerned:
1. Beds and staffing.
2. Ward policies.
3. Ward routine.
4. Mobility on the wards.
5. Teamwork.
6. Ancillary services.
7. Patient choice.
8. Visitors.
9. Use of volunteers.

The final questions concerned personal training. A total of thirty four nurses were interviewed for between fifteen to twenty minutes each. In all, bar one, of the departments more than one nurse was interviewed, so combined departmental scores were constructed. The questionnaire is given in Appendix X.

5.6 The ward based practice.

The ward facilities and practice was observed in all acute admission and rehabilitation wards in the fourteen departments. Overall sixty three wards in thirty three hospitals were visited by Dr. Amy Roberts and me and a joint overview impression of the ward based nursing practice was recorded. The ward environmental assessment took between ten to fifteen minutes to complete. Three methods were used:

1. Patient location and activity was observed, and visible use of restraint was noted.
2. Positive and negative adjectives, similar to those in a paper by Millard and Smith (1981) that assessed the impact of personal belongings on student's attitudes to patient care, were used to describe and give an overall impression of the ward.
3. Environmental check lists were constructed based on Horrock's article, "The Components of a Comprehensive District Health Service for Elderly People" (Horrocks, 1986) and a King's Fund Project Paper concerning "Achievable Standards of Care of the Elderly" (1987).

The environmental check-list is given in Appendix XII.
5.7 Data analysis

Data analysis was undertaken in the Geriatric Teaching and Research Unit using a PARADOX database (1991) and locally developed software. Following manual entry of the data into the database, discrepancies with regard to date order, e.g., admissions after census date etc., were identified and corrected. Then the query by example function in the database was used to create subsets of the data.

Next the expected length of short stay and long stay patients was calculated using the method of Harrison and Millard (1991) (Appendix V). The algorithm uses the least squares method to calculate the parameters that best fit the curve of the pattern of bed occupancy in the equation:

\[ y = Ae^{-Bx} + Ce^{-Dx}, \]

where

- \( y \) = the number of occupied beds,
- \( x \) = the time (in days) that the inpatients have occupied a bed, and
- \( A, B, C, \) and \( D \) are the calculated best-fit parameters.

The expected stay for Group One (short stay) patients is calculated using parameters \( A \) and \( B \), and parameters \( C \) and \( D \) are used to calculate the expected stay for Group Two (long stay) patients. The relationship between the fit and the data is checked statistically using the \( R^2 \) value, and visually (Motulsky & Ransnas, 1987; Bartholomew, Forbes, & McClean, 1991).

Analysis was undertaken using a locally developed software package (written in turbo C) running on an IBM compatible PC. The central core of the package uses a method (algorithm) written by Prof. Harrison, based on that of Marquhardt (1963); the algorithm adjusts the constants \( A, B, C, \) and \( D \), until they best describe the bed occupancy data. The program first calculates a single exponential equation then uses those derived parameters to calculate the best fit values for the double exponential equation. Accuracy of the software program was checked using GraphPAD INPLOT a commercially available software package (1990).

**Dependent variables**

The dependent variables were the calculated group one, group two, and overall flow rates:

- The Group I (short stay) statistic estimates the average expected length of stay of recently admitted patients.
- The Group II (long stay) statistic estimates the average expected length of stay of
long-standing patients.

- The overall stay statistic estimates the average expected length of stay of long-standing patients.

**Independent variables**

All other calculated, recorded, or observed, variables were treated as independent, variables. Statistical differences were tested between the scalar responses (1-10) to the questions and mean scores using Spearman rank correlation coefficients. This test is suitable for non-parametric data. Statistical significance was only tested if there was a possibility that an observed or recorded difference explained the differences in performance.

Significance was tested using SPSS/PC (1989). In view of the large quantity of data, only statistical correlations at a probability level of p<.001 were included in the final hypothesis.

**5.8 Ethical Permission**

The St. George's Hospital Medical Ethics Committee concluded that ethical approval was not required because the study fell into the realm of medical audit. Consultants in the Health Districts co-operated on the understanding that individual results would not be given without their permission. The general managers of the Districts were informed of the nature and purpose of the study and the nursing staff were asked for consent at the time of the interview.
CHAPTER SIX

CLINICAL PRACTICE: THE RESULTS

The study involved 1937 inpatients in fourteen departments. Their average age was 83.2 years. Twenty eight consultants and thirty four nurses were interviewed. Thirty three hospitals were visited and clinical practice was observed in sixty three acute / rehabilitative wards. The results from the individual departments are given in Appendix XIII

6.1 Difference in Performance

The number of occupied beds and the calculated speeds of inpatient treatment derived from the pattern of bed occupancy in the fourteen departments are shown in table 6.1. (overleaf). Fig 6.1 (facing) shows the fit between the curve and the data in three districts.

The average expected length of stay in the geriatric medical beds was 35.9 days (standard deviation (sd) ± 12.3 days, 95% confidence interval (95% ci) 28.8 to 43.1 days. Within that overall average the long stay patients occupied beds for an average of 786.3 days (sd ± 300.0 days, 95% ci 613.1 - 959.5 days) and the short stay patients occupied beds for an average of 23.5 days (sd ± 6.5 days, 95% ci 19.8 - 27.3 days).

The results are better reported as medians and interquartile ranges. The overall median calculated length of stay was 33.0 days and the interquartile range was 25.6 to 46.2 days.
The short stay median was 21.6 days and the interquartile range was 18.4 to 30.4 days. And the long stay median was 875.2 days, and the interquartile range 626.7 to 985 days.

The overall length of stay in table 6.1 was between 18.8 days to 54.4 days per year, so the turnover in the individual departments per occupied bed varied between 19.4 and 6.7 patients per bed per year. However, within those averages, the length of stay of the short stay patients was between 14.7 days and 32.2 days i.e., between 24.8 and 10.5 patients per bed per year. And, the length of stay of the long stay patients was between 201.5 days and 1208.1 days, i.e., between 1.8 and 0.3 patients per bed per year. Thus there were marked differences in performance.

<table>
<thead>
<tr>
<th>Number of occupied beds</th>
<th>Calculated expected stay in days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
</tr>
<tr>
<td>66</td>
<td>23.0</td>
</tr>
<tr>
<td>88</td>
<td>18.8</td>
</tr>
<tr>
<td>91</td>
<td>22.1</td>
</tr>
<tr>
<td>107</td>
<td>26.9</td>
</tr>
<tr>
<td>110</td>
<td>31.0</td>
</tr>
<tr>
<td>112</td>
<td>55.4</td>
</tr>
<tr>
<td>131</td>
<td>32.4</td>
</tr>
<tr>
<td>131</td>
<td>45.0</td>
</tr>
<tr>
<td>135</td>
<td>41.3</td>
</tr>
<tr>
<td>136</td>
<td>51.5</td>
</tr>
<tr>
<td>137</td>
<td>33.5</td>
</tr>
<tr>
<td>163</td>
<td>54.4</td>
</tr>
<tr>
<td>200</td>
<td>41.4</td>
</tr>
<tr>
<td>330</td>
<td>26.5</td>
</tr>
</tbody>
</table>

The total turnover correlates with the short stay turnover ($r^2=.9033$, $p<.001$) and with the long stay turnover ($r^2=.6791$, $p<.01$) but not with the bed allocation. Consequently, the differences in performance are not caused by local differences in the number of allocated beds.

6.2 Location of facilities
Consultants in two of the departments had no allocated beds in the district general hospital. Of the twelve that did: three had modern wards, six were using upgraded Nightingale wards, four had admission beds in huts built during the Second World War for the Emergency Medical Service, and the two departments in the teaching hospital were sharing beds in a wooden building in the corner of the grounds. Contrary to the recommendation of Warren (Warren, 1943), no purpose designed blocks for the treatment of the aged had been provided at any of the district general hospitals. However, three departments had excellent, imaginatively designed, purpose built, rehabilitation facilities off-site.

The general impression was of unwanted patients in the oldest buildings [see, Old and Forgotten (Millard & Roberts, 1991) in Appendix XIV]. Three departments received negative ratings for fabric maintenance and the chosen adjectives had to be modified to take account of the obvious neglect. In contrast three hospitals were sparkling in their cleanliness. Such marked local differences in standards reflect the priorities, standards of supervision and knowledge of local managers: poor fabric maintenance and ward furnishing is a matter of concern, but the differences in resource allocation were not related to the differences in performance.

One department was integrated with general medicine, three departments were operating an age related admission service (two with a lower admission age of 75 years, the other at 65 years) and the others were operating a traditional specialty specific service. So, operational policies were discounted. One department had one consultant, twelve had two consultants, and one of the two departments in the teaching hospital had three consultants. All had responsibility for beds in two or more hospitals. The average consultant workload was approximately 700 new admissions a year, but workload was not evenly distributed and in the department with 330 beds the two consultants were admitting over 4,500 patients a year. Nevertheless, similar consultant staff numbers cannot explain differences in performance.

The frequency of consultant ward rounds varied. Six consultants visited weekly; fourteen twice weekly; five three times a week; and three daily. Those who visited weekly tended to do a team round at the time of their visit. Whereas those practising an acute admission service tended to visit more frequently, however, this was not always the case.

Half of the departments had neither a senior registrar nor a registrar, whereas, six of the seven departments with a registrar also had a senior registrar. Consequently, departments
Flow Rate Modelling: Millard PhD 1993

without middle grade staff in training grades used clinical assistants instead. The supporting medical staff sessions per consultant varied from 23 to 50, but these considerable differences in staffing and workload were randomly distributed.

One variable which did explain differences in performance was location of the departments. As Fig 6.2 shows, three departments based in London had the slowest turnover; four departments in Sussex (a seaside county) had the fastest turnover; while those in Surrey occupied the middle ground.

6.3 The patients

There were 1937 inpatients: 1406 (72.6%) females and 531 males (27.4%). The overall average age was 83.8 years: 806 (41.6%) had a neurological diagnosis; 402 (20.8%) had musculoskeletal disorders; and 28 were coded as both. Consequently, 1180 patients (60.9%) had problems which effected their neurological or locomotor system.

The percentage seen prior to admission varied from less than five percent in four departments to twenty percent or more (maximum 45%). Eight departments had no patients awaiting admission from home or hospital. Whereas, five had between two and 12 patients (average 9) awaiting admission from acute hospital beds, and four had
patients awaiting admission from their own homes.

All of the patients waiting for admission from their own homes were expected to be admitted within the week, but the patients awaiting admission from hospital could wait for weeks or months. One department in an outer London Borough, practising an age related admission service, had ten patients waiting admission from private rest and nursing homes. However, the number of patients on the waiting list did not correlate with length of stay, but longer durations of stay tended to be associated with a waiting list.

Over 3405 reasons for admission were recorded: an average of 1.8 per patient. Acute illness was the commonest reason (893, 46%), followed by immobility, (637, 33.5%), falls (345, 18%), confusion (297, 15.2%), investigation (231, 12.1%) and incontinence (9.8%).

Table 6.2 shows inpatients in the high turnover departments were more likely to have acute illnesses (a positive correlation), whereas low turnover departments had more inpatients classified as being admitted with confusion, falls or incontinence (a negative correlation).

<table>
<thead>
<tr>
<th>Reason for admission coded in the ward census</th>
<th>Turnover per bed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
</tr>
<tr>
<td>Accident</td>
<td>-.0243</td>
</tr>
<tr>
<td>Acute illness</td>
<td>.6571*</td>
</tr>
<tr>
<td>Confusion</td>
<td>-.6396*</td>
</tr>
<tr>
<td>Falls</td>
<td>-.6132</td>
</tr>
<tr>
<td>Immobility</td>
<td>-.4549</td>
</tr>
<tr>
<td>Incontinence</td>
<td>-.6308*</td>
</tr>
<tr>
<td>Investigation</td>
<td>.1209</td>
</tr>
<tr>
<td>Rehabilitation</td>
<td>.3802</td>
</tr>
<tr>
<td>Not coded</td>
<td>-.0743</td>
</tr>
</tbody>
</table>

1-tailed significance: * - p<.01

6.4 The consultants’ opinion concerning their service

Table 6.3 (overleaf) summarises the consultants’ opinions concerning the strengths and
weaknesses of their service. Marked differences between departments in opinion concerning resource allocation, facilities and staffing are present.

<table>
<thead>
<tr>
<th>Range and (mean)</th>
<th>Major Problems Score 5 or less</th>
<th>Major Strengths Score 8 or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 5.0 - 8.5 (7.3)</td>
<td>Accommodation</td>
<td>Junior medical staff Nursing Rehabilitation Community support Orthopaedics</td>
</tr>
<tr>
<td>2 3.0 - 7.5 (6.2)</td>
<td>Nurse staffing Community Services Psychiatry</td>
<td></td>
</tr>
<tr>
<td>3 4.0 - 7.0 (5.7)</td>
<td>Overall quality Junior medical Community services Psychiatry</td>
<td></td>
</tr>
<tr>
<td>4 5.0 - 8.0 (6.6)</td>
<td>Social work</td>
<td>Overall quality</td>
</tr>
<tr>
<td>5 4.5 - 7.5 (6.5)</td>
<td>Psychiatry</td>
<td></td>
</tr>
<tr>
<td>6 1.8 - 8.3 (5.5)</td>
<td>Accommodation Community services Psychiatry</td>
<td>Discharge places Orthopaedics</td>
</tr>
<tr>
<td>7 5.5 - 8.0 (6.8)</td>
<td></td>
<td>Junior medical staff Accommodation Discharge places</td>
</tr>
<tr>
<td>8 3.0 - 8.0 (6.1)</td>
<td>Accommodation Rehabilitation Social work Orthopaedics</td>
<td></td>
</tr>
<tr>
<td>9 3.5 - 8.0 (5.6)</td>
<td>Junior medical Therapy staff Community services Medicine Psychiatry</td>
<td>Overall quality</td>
</tr>
<tr>
<td>10 3.5 - 8.0 (6.1)</td>
<td>Medicine Psychiatry</td>
<td>Rehabilitation</td>
</tr>
<tr>
<td>11 4.5 - 8.5 (6.5)</td>
<td>Discharge places</td>
<td>Overall quality Junior medical staff</td>
</tr>
</tbody>
</table>

Continued overleaf
Table 6.3 (continued) Geriatric Medicine Satisfaction Index Consultants Viewpoint

<table>
<thead>
<tr>
<th>Range and (mean)</th>
<th>Major Problems Score 5 or less</th>
<th>Major Strengths Score 8 or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 3.3 - 9.3 (6.0)</td>
<td>Social work Community services Discharge places Medicine</td>
<td>Junior medical staff</td>
</tr>
<tr>
<td>13 4.0 - 9.0 (6.5)</td>
<td>Accommodation</td>
<td>Social work Discharge places</td>
</tr>
<tr>
<td>14 4.5 - 8.0 (8.0)</td>
<td>Discharge places Nursing</td>
<td>Junior medical staff Community services Psychiatry</td>
</tr>
</tbody>
</table>

Table 6.4 gives the analysis of the relationship between throughput and the mean departmental scores for the consultants' opinion on a scale of one to ten concerning their service. Positive correlation indicates strength and negative correlation indicates weakness.

Table 6.4 Correlation between the mean score for the consultants opinion concerning the service that they provided and the turnover in their department

<table>
<thead>
<tr>
<th>Factor being described on a scale of one to ten</th>
<th>Turnover per occupied bed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
</tr>
<tr>
<td>Overall quality</td>
<td>-.3804</td>
</tr>
<tr>
<td>Junior medical staff</td>
<td>-.3111</td>
</tr>
<tr>
<td>Nurse staffing</td>
<td>-.1310</td>
</tr>
<tr>
<td>Therapy staffing</td>
<td>-.5156</td>
</tr>
<tr>
<td>Rehabilitation</td>
<td>-.5227</td>
</tr>
<tr>
<td>Social work</td>
<td>.3337</td>
</tr>
<tr>
<td>Community Relations</td>
<td>.0287</td>
</tr>
<tr>
<td>Ward Accommodation</td>
<td>-.2225</td>
</tr>
<tr>
<td>Alternative places</td>
<td>.6780*</td>
</tr>
<tr>
<td>Medical care</td>
<td>.2296</td>
</tr>
<tr>
<td>Orthopaedic Relations</td>
<td>-.1485</td>
</tr>
<tr>
<td>Psychiatry Relations</td>
<td>-.3907</td>
</tr>
</tbody>
</table>
1-tailed significance: * - $p<.01$, ** - $p<.001$

Fig 6.3 shows the correlation between the Group I (short stay) turnover and the consultants mean scores for the question

"On a scale of 1 to 10 how would you rate: the availability of places for the elderly to be discharged to: i.e., long stay beds, nursing homes etc.?"

Turnover increases as one gets closer to the coast (Fig. 6.2) and nursing home places increase as one gets closer to the seaside, so the availability of alternative discharge places in private nursing homes could be a major explanatory variable.

![Figure 6.3](image)

Figure 6.3 The Consultants Opinion of Availability of Discharge Places and Group 1 Turnover (Patients per Bed per Year).

6.5 The nursing care

Four different styles of patient management - acute medical, recovery, rehabilitation and therapeutic - were recognised. In the acute medical style, patients were usually dressed in their night clothes during the day, and if up, they were sitting by their beds in low chairs. In the recovery style, the patients who were out of bed were usually dressed in day attire and sitting in the right height chairs, but they still ate by their beds. In the rehabilitation style, dressed patients were encouraged to eat at communal tables in the ward or in associated day rooms. Finally, in the therapeutic environment, other day time activities apart from meals, such as art, group spelling games, bingo etc., were encouraged. These differences in patient management, which probably reflect differences in aptitude, skill and knowledge, were randomly distributed.
Throughout the Region the predominant nursing and ward management style was a combination of acute and recovery. All, bar one, of the wards had adjustable beds and few wards (with one noticeable exception) were using cot-sides. Most of the nursing sisters were introducing the nursing process, yet this did not imply that there was a uniform standard of care. None of the nursing staff had followed a specialised course of training in rehabilitation of older people. Nurses practising the acute style of care usually considered that therapeutic activity was inappropriate in their ward. However, there was one notable exception to this rule, for one hospital with a heavy acute workload made arrangements at weekends for nurses to co-ordinate therapeutic activity, such as group games and bingo. Most of the nurses considered, within the limitations of the facilities on their ward, that they were managing patients in the correct manner.

In all, bar one, of the departments the style found in one acute admission ward reflected the style in the other wards and hospitals in the same department. However, in one hospital the four different styles of patient management were found in the five admission wards.

Table 6.5 summarises the nurses’ opinion concerning the strengths and weaknesses of their service.

<table>
<thead>
<tr>
<th>Range and mean</th>
<th>Major Problems Score 6 or less</th>
<th>Major Strengths Score 8 or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 5.3 - 7.3 (6.6)</td>
<td>Accommodation</td>
<td></td>
</tr>
<tr>
<td>2 6.7 - 7.5 (7.1)</td>
<td>Accommodation</td>
<td></td>
</tr>
<tr>
<td>3 5.3 - 7.3 (6.5)</td>
<td>Discharge places Community services</td>
<td>Nursing Rehabilitation</td>
</tr>
<tr>
<td>4 5.0 - 8.0 (6.8)</td>
<td>Discharge places</td>
<td>Nursing Rehabilitation</td>
</tr>
<tr>
<td>5 5.0 - 8.0 (6.6)</td>
<td>Discharge places Nursing</td>
<td>Community support</td>
</tr>
<tr>
<td>6 4.0 - 8.3 (6.7)</td>
<td>Accommodation Discharge places</td>
<td>Nursing</td>
</tr>
<tr>
<td>7 5.5 - 7.7 (6.5)</td>
<td>Discharge places Rehabilitation</td>
<td></td>
</tr>
<tr>
<td>8 2.8 - 7.0 (5.7)</td>
<td>Accommodation Rehabilitation</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.5 continued overleaf
The correlation between the nurses opinion on a scale of one to ten (five factors) and the calculated throughput is given in table 6.6.

Nurses in departments with the highest turnover per occupied bed, and per long stay bed, gave statistically significant p<.001 lower scores for the overall standard of ward based rehabilitation (see figure 6.4 facing). Possible explanations are:

A. The acute nature of the inpatients in the high turnover wards implies that rehabilitation is inappropriate,
B. The rehabilitation is being done elsewhere,
C. The correlation occurred by chance.

6.6 Comments concerning service provision

A nurse in a department based in London rated placement availability as 1. She commented:

"Waiting lists for admission to alternative accommodation have to be overcome. Some patients are being pushed to go home because of lack of other places to go to, yet this may not be appropriate."

In the same department a consultant said:

"The problem is a shortage of nursing homes. ---- is selling off well upgraded homes with single rooms. The problem is what to do with those who have insufficient resources for private care: they need nursing homes, but there are none that they can afford and not enough long stay places."

In contrast a nurse in a sea-side town rated discharge availability as 7. She commented:

"Nursing homes, rest homes and Part III places are quite satisfactory, but long stay hospitals - which are much needed - are being closed."

Another nurse in the same department rated discharge as 8. She commented:

"Only the time factor needs to be overcome to make discharge a ten: the problem is that
some relatives/carers have to wait for a preferred placement”.

In the same department a consultant said:

“There are adequate nursing homes, rest homes, and long stay, but plans to close the long stay hospital are detrimental”.

6.7 Place of discharge

Table 6.7 shows statistically significant relationships at the p<.001 level between the percentage of inpatients coded for discharge to private nursing homes and the turnover per allocated bed. Also at the p<.01 level, departments with low turnover were more likely to have coded the place of discharge blank or to be relying on the local authority for a discharge place (see table 6.7).

<table>
<thead>
<tr>
<th>Place of discharge coded on the census form</th>
<th>Turnover per occupied bed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
</tr>
<tr>
<td>Not coded</td>
<td>-.7041*</td>
</tr>
<tr>
<td>Their own home</td>
<td>.4593</td>
</tr>
<tr>
<td>Family residence</td>
<td>.0637</td>
</tr>
<tr>
<td>Other</td>
<td>.3696</td>
</tr>
<tr>
<td>Local Authority Home</td>
<td>-.5308</td>
</tr>
<tr>
<td>Private rest home</td>
<td>.2308</td>
</tr>
<tr>
<td>Private nursing home</td>
<td>.7802**</td>
</tr>
<tr>
<td>Private rest/nursing</td>
<td>.8492**</td>
</tr>
</tbody>
</table>

1-tailed significance: * - p<.01, ** - p<.001

Figure 6.5 (overleaf) shows the correlation between Group 1 turnover and the percentage of inpatients coded for discharge to nursing homes.
6.8 Conclusion of Chapter Six

Three independently collected, but interrelated, variables correlated with rate of turnover. Namely,

1. The consultants’ opinion on a scale of one to ten concerning ease of discharge of potential long stay patients, p<.001.
2. The nurses opinion on a scale of one to ten concerning the quality of the ward based rehabilitation, p<0.001.
3. The percentage of inpatients coded for discharge to nursing homes, p<0.001.

Consequently, the concluding hypothesis was: That the local availability of nursing homes is the major explanatory variable which explains the observed differences in performance in the departments of geriatric medicine in the South West Thames Region.
CHAPTER SEVEN

DISCUSSION

The results confirm that the pattern of bed occupancy in departments of geriatric medicine is expressed by an equation with two exponents. Consequently, non-linear regression analysis of the pattern of bed occupancy in departments of geriatric medicine can be used to compare performance of departments of geriatric medicine. As the pattern of bed occupancy is expressed by an equation with two exponents, then curve-fitting can be used to assess the contribution being made to the whole by short stay and long stay care. However, a word of caution must be introduced, because the results show that performance within is effected by resources without, so the performance of the hospital cannot be considered in isolation from resource allocation in the community.

Curve-fitting is mathematically complex, but given the widespread introduction of computers it is easy to perform. Statisticians may argue that the statistical correlation between the bed occupancy data and the parameters of the mixed exponential equation should be determined using maximum likelihood, but the least-squares method is, mathematically, easier to perform (Agresti, 1989). And, as the curve is visually compared with the data (Motulsky & Ransnas, 1987) the argument is not necessarily valid. Indeed, more problems are likely to be associated with the assumptions that underpin the theoretical model, than with the method of curve-fitting.

The theoretical model that converts the parameters of the equation into flow rates is based on three assumptions which are not necessarily valid. First, discharge is unlikely to be independent of length of stay, especially in the first few days after admission. Second, the beds are not always full. For, the provision of an active geriatric medical service to the community depends upon the availability of empty beds (Horrocks, 1986). Third, the departments are not necessarily in stable state.

Also, the day of the week upon which the census is performed may effect the results. In this study, a Thursday was chosen for data collection because discharge in geriatric medicine usually takes place at the start of the week, but there is no evidence that this was the best day. In addition, conversion to long stay is not necessarily related to bed availability in long stay. Nevertheless, the statistically significant (p<.001) relationship between three independently collected, but interrelated, variables and the flow rates implies that the theoretical model (Harrison & Millard, 1991) can be used to compare performance.
Retrospectively, it is not surprising that the rate of flow through departments of geriatric medicine correlated with ease of discharge to nursing homes. For ease of discharge would imply that more of the allocated beds could be used for acute admissions. However, at the outset of the study it was thought that the probable explanation for the differences in performance would be differences in style of practice: for the perceived wisdom is that one changes the style to get better results (DHSS, 1981).

The research design was a negative case analysis and thousands of variables were observed and recorded. If the hypothesis had been formulated at the start the results would be more trustworthy (Dane, 1990). Also, I am not without bias [see for example (Millard, Higgs, & Rochon, 1989; Millard, 1986)]. Nevertheless, the significance of the correlation between the flow rates and the three variables supports the conclusion (at least for the South West Thames Region of the country) that differences in admission policy are not the major cause of differences in length of stay.

Age Concern England recently expressed doubts about the wisdom of Health Authorities transferring responsibility for long term care to the private sector (Age Concern (England), 1991). The population is ageing, and it is well recognised that older people make more demands on health care. Nevertheless, it is probably a false economy to improve hospital performance by rejection, rather than by increasing skill.

This study was not designed to test the influence of closing long stay beds on health care performance. However, there was a disparity between the number of beds occupied in the Region in this study (1937) and the number occupied three years earlier (2335) and that 17% difference is unlikely to be due to coding errors, or emptiness (because both studies were undertaken in the winter). Hence, the most likely explanation is bed closures. This is a matter of concern.

One of the arguments made to encourage integration of geriatric and general medicine was that it would make better use of resources (DHSS, 1981). Yet, Health Authorities that concentrate on the acute aspects of care Health may be overlooking the benefits to be gained, for their hospital and for their community, by developing quality rehabilitation. For this reason the negative correlation between the nurses’ opinion concerning the quality of rehabilitation and the flow rate is of concern. The most likely explanation is that the wards have acute patients; consequently rehabilitation is not of prime importance. However, if the wards are full of recently admitted acutely ill patients, why then are they coded for discharge to private rest and nursing homes?
If, as in the United States, the nursing home sector is fulfilling a rehabilitative role (Rya, Griffin, & Baugh, 1990) then the approach may not be detrimental. However, in the United Kingdom this seems to be unlikely. Possibly private nursing homes are compensating for the lack of National Health Service convalescent facilities. After all, many old people live alone, and they have to be fit to cope (Patnaik, 1984). So this might be happening, but it seems unlikely.

Noticeably, the slower turnover departments had more inpatients coded as confused, incontinent or falling and more coded for discharge to local authority homes. This does not augur well for the 1st. of April 1993 when the local authority are due to take over responsibility for the purchase, not provision, of care for the sick aged.

During the visits it became clear that the prevailing practice within the beds represented the best use that staff could make, within the limitations of their knowledge and skill, of the resources provided. To say that the facilities provided were, in the main, inadequate, would be an understatement [see Old and Forgotten (Millard & Roberts, 1991)]. Nearly fifty years after Warren (1943) recommended that blocks for the treatment of the aged sick should be established in all general hospitals there were no purpose designed facilities in any of the district general hospitals in the South West Thames Region. Indeed four of the districts were still using wards built for wartime evacuation hospitals for the acute care of geriatric medical patients and two others were using temporary buildings. Also the standard of upgrading and state of decay varied considerably. Clearly, much has to be done if high quality services are to be developed.

But buildings alone will not be enough. For the local standards reflect local priorities and the contrast between dirty, unkempt wards in some districts and clean sparkling wards in others shows differences in local priorities, and local attitudes. Attitudes reflect knowledge. Most of the nurses in charge considered that the care they were giving was adequate, and all they needed was more staff. Yet, none had followed a specific course on the running of rehabilitative environments, and all considered that special training courses would be valuable. As the majority were considered to be running acute/recovery environments then the introduction of a policy of community care based on improved rehabilitation (Griffiths, 1988) necessitates staff training.

All of the consultants had followed a senior registrar training programme, so lack of a defined training could not explain differences in the ward based management. And questions arise as to the suitability of senior registrar training programmes which insist on
the presence of a registrar as well, when over a half of the consultants have no middle grade junior medical staff in training grades. For their training bears little relation to their ultimate responsibility. This may explain why the operational policies adopted by the consultants were different.

One question that needs to be urgently resolved is that of risk taking. In one department apparently well rehabilitated patients were not being discharged, and in other departments staff were concerned that they were placing undue demands on the patients. Those areas with easy access to nursing homes could escape from this responsibility trap by referring to the private sector, but in other areas, where there are few alternative places, the risk taking is considerable. Yet if the risks are not taken the acute hospital geriatric medical service may cease to function. Accordingly, the boundaries and responsibilities for taking risks need to be defined.

The specialty of geriatric medicine was introduced in 1948 in order to introduce rehabilitation into the chronic sick wards. Yet, in some districts the same specialty seems to be achieving faster throughput by discharging (?un-rehabilitated) patients to the private sector. Clearly policies need to be rethought.

The root cause of the present problem is that doctors, nurses, therapists, social workers and families are taking advantage of a loop-hole in government policy concerning the use of public money to fund care for older people in private and voluntary rest and nursing homes. So any new strategy must control this avenue of discharge. That is the intention of the new legislation, but it is unclear who will be responsible for rehabilitation.

Government has given an undertaking to continue to fund the accommodation of all people in care on the 1st. of April 1993. And, if the American experience relating to ‘spend-down’ of Medicare patients is anything to go by they will still be funding 12% of the residents at the turn of the century (Liu & Manto, 1991). The problem is that a choice to introduce one policy is a choice not to introduce another policy (Feldstein, 1963). That is why decision making should be based on statistically derived models.

Operational research, Rehabilitation and the National Health Service were health care legacies of the Second World War (Timm, 1967), and operational research should be used to help solve the problem. This research shows that scientific principles can be applied to the measurement of activity in hospitals. Accordingly, models can be created.

Clearly the problem concerns the management in each district of (perhaps) no more than
200 older people each year, for their management determines the use that is made of long stay beds. Accepting that long stay care lasts for an average of two years, then 200 non-rehabilitated patients a year require 400 long stay beds. Rehabilitate 50, and 100 less long stay beds are required and those freed beds can be used to help underpin the policies of community care. However, nothing is gained if the burden of care is simply transferred to another sector.

If 100 potential long stay patients are rehabilitated a year, 200 less long stay beds are required and some of these beds can be used to improve rehabilitation and provide convalescent care. Change of use of 25 of the freed beds would give the opportunity for each patient being rehabilitated to stay three months. Which is why decision making at the point of entry to long term care and the provision of quality rehabilitation is the key to the running of an acute geriatric medical service (Warren, 1943).

The success of the pioneers of the specialty was that they established a new discipline. Perhaps, our failure is that we took for granted the benefits to be gained from rehabilitation and wrote about the acute aspects of care. Now, acute, rehabilitation and long stay care are discussed as if they are separate entities, which they are not, and scant attention is given to the rehabilitative needs of older people in residential and nursing homes [see Age Concern, England 1991 for a discussion of this]. Consequently, frail aged people are being denied the benefits of multidisciplinary assessment and attempted rehabilitation prior to admission to rest homes, while the aged sick are expected to be rehabilitated ever faster. The time is right for that balance to be redressed.
CHAPTER EIGHT

A PRACTICAL MODEL OF A DEPARTMENT OF GERIATRIC MEDICINE

This concluding chapter first modifies the theoretical model in Figure 2.7 to take account of the results of this study (Figure 8.1) then proposes a way forward.

![Theoretical Model of a Department of Geriatric Medicine](image)

**Figure 8.1 Theoretical Model of a Department of Geriatric Medicine.**

**PART A: THE MODEL**

The model has two compartments with two flowing streams of discharge behaviour. One stream represents the management of the recently admitted patients. The other stream represents the management of the long-standing patients. Both streams are separated by a decision making threshold. Factors that influence flow include:

1. The numbers of medical, nursing, therapy and social work staff, and their knowledge, skills, aptitude and training.
2. The number of allocated beds and ward design, location and equipment.
3. The facilities available for investigation, diagnosis and treatment both at the
bed-side and in the immediate vicinity.

4. The patient's age, sex, diagnosis and social circumstances.

5. The relations with other disciplines especially with medicine, surgery, orthopaedics and psychiatry.

6. The available resources in the community including general practitioner services, home nursing, social services (meals on wheels, home helps etc) and alternative places in hospitals, local authority, voluntary and private rest, residential and nursing homes.

7. The aspirations of the local community and the prevailing attitude towards rehabilitation.

Consequently, a whole host of interacting probabilities interweave to make the local 'Department of Geriatric Medicine'.

Decisions to admit, to transfer, to discharge, to rehabilitate, to keep in, to treat, to operate etc., represent choices which themselves are influenced by a whole host of other variables. The inter-relating probabilities are endless. But the time sequence to the events can be measured, so the time sequence of events can be used to compare performance.

8.1 The map of time

The map of time gives shape to the form of bed occupancy. Ranking the time elapsed since admission into ascending order and plotting the pattern of bed occupancy yields a temporal map that demonstrates the contribution being made to the whole by short and long stay patients. The map in each department separates the two components of short and long stay care and identifies the height of the hidden threshold between the two services. Also, because the shape of the temporal map is expressed by a declining double exponential equation with the form, \( y = Ae^{Bx} + Ce^{Dx} \), where, \( y \) = the number of occupied beds, and \( x \) = the time that the beds have been occupied. Then the parameters A, B, C and D can be used to generate flow rate statistics, and those flow rate statistics can be used to compare performance. However, words of caution must be expressed because:

1. It is essential to visually confirm the fit to the data (Motulsky & Ransnas, 1987).
2. The method is untested.
3. The method does not accurately predict annual admissions.

Therefore, modifications of the method of data interpretation may be needed.

8.2 Discharge behaviour
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Two streams of movement flow through the occupied beds. One stream concerns the prevailing discharge behaviour concerning short stay patients; the other concerns the discharge behaviour concerning long stay patients. Both are directional and must be represented by more than one number. Bed availability in long stay care usually represents a slow exponential decline with time (Hodkinson & Hodkinson, 1980) consequent upon the death of inpatients, and bed availability in admission wards represents acute / rehabilitative care. But the flow rate through both sectors is affected by resource availability in the catchment area, consequently, the flow cannot be considered alone. Also catchment area resources can attract patients from the hospital; consequently, the direction of discharge must be taken into account when comparing performance. Given the widespread introduction of computer assisted analysis techniques it is a relatively simple matter to identify the following major explanatory variables concerning discharge:

- Death.
- Transfer to other hospitals.
- Discharge home,
- Discharge to nursing homes etc.

And identification of these parameters must become an essential part of performance measurement.

One way forward would be to use the stochastic modelling techniques developed by manpower planners [see (Bartholomew, Forbes, & McClean, 1991)]. Another approach would be to use the two compartmental, or non-compartmental methods, developed in pharmacokinetics [see (Gibaldi, 1991)].

8.3 Input, process and output

The input variables from time past can be recorded, the process variables in time present can be observed, and the outcome can be forecast. But there is no certainty. Whether a patient admitted for a simple operation will die is unknown. Skilled staff make it unlikely, but tragedies will continue to occur. Therefore, plans have to be based on probabilities and not on certainties. But within the overall uncertainty one can, by measuring the time sequence of events in time past, measure the prevailing form of behaviour and use that to compare performance.

8.4 Conclusion of Part A

The model is based on the measurement of time. Considerable research effort will be
needed to test the conclusions of this work. Implementation of the method developed in the thesis should facilitate planning. Time alone will tell whether the methodology will be useful.

PART B: A POSSIBLE WAY FORWARD

Researching the preceding thesis I came across the word ‘gerocomy’ in Stearns book ‘Old Age in Europe (1977)’. In 1803 doctors in Paris wanted to develop a specialty of gerocomy: that movement ended in 1830 when ageing was included in theses. In 1943, the specialty of geriatrics was suggested in order to improve the medical care of the chronic sick (Warren, 1943): in 1992 that movement, albeit only partially introduced, seems to be ending because hospital physicians are turning away from long term care. Therefore, history seems to be repeating itself. In a recent paper I argued that recognition that there is a science to the care of the aged (gerocomy) would improve patient care and enhance decision making. That science would recognise the importance of responsibility, accountability, teamwork, leadership, rehabilitation and task definition in the care of the elderly.

8.5 Responsibility

Responsibility for long term care is the key. I became interested in long term care and rehabilitation of the aged sick because I was responsible for the care of the patients in my long stay beds. I am concerned about the problems in other departments in the Region, in residential homes, in rest and nursing homes and I am interested in seeing that the care improves. However, I am not responsible for their medical care, therefore, I can only assist if I am asked. Consequently, defining responsibility is the key to providing quality care.

8.6 Accountability

Responsibility implies accountability. Yet, when visiting the departments in the Region it was clear that no-one seemed to be responsible for the poor standards of ward upkeep in some districts. The consultant was responsible for the medical care; the nurses for the nursing care; the therapists for the therapy services; the community for the community services; the social service departments for their services; the psychiatrists for the psychiatry service etc., and whether or not these groups co-operated together seemed to be simply a matter of chance. Accordingly, plans must be based on responsibility and accountability.
8.7 Teamwork

Leadership (Kayser-Jones, 1981; Wilson, 1972) is essential. Someone has to lead the team. The population is ageing, old people have multiple illnesses, and they often live alone. Consequently, they occupy beds for longer than younger people. However, the majority can be rehabilitated, given accurate diagnosis, time, a changed environment and teamwork.

Not one of the departments of geriatric medicine in the South West Thames Region had purpose built facilities on the district general hospital and all were using upgraded facilities. However, it was clear that the consultants had an important leadership role to play in developing ward based rehabilitation. Thus plans must be based on responsibility, accountability and leadership (Griffiths, 1988).

8.8 Rehabilitation

The aim of the Community Care Act of 1990 is to prevent unnecessary institutionalisation of the aged by making local authorities purchasers, not providers, of care. Rehabilitation is a central platform of the strategy, but it is unclear who is to be responsible for this. The N.H.S. nursing home research seems to show that taking consultants out of the long stay wards is detrimental to rehabilitation (Bond & Bond, 1990). If so consultant responsibility for long term care is an important component of a rehabilitative strategy

The chronic sick wards were transferred to the Regional Hospital Boards, and rehabilitation was introduced at the start of the National Health Service to:

A. Improve care.
B. Control long stay patient numbers, and
C. Free beds for others to use.

Since 1948 the number of hospital geriatric medical beds has decreased but the numbers of beds in residential and nursing homes has increased. Also concern is being expressed about the standards of care in the residential and nursing home sector. Therefore, it would seem wise to implement the 1943 recommendations and introduce policies based on rehabilitation prior to admission to the residential and nursing home sector, by transferring responsibility for admission to the hospital sector. Thus plans must be based on responsibility, accountability, medical leadership, and rehabilitation.
8.9 Defining the task

Government is facing a two billion pound overspend on Board and Lodging Allowance in the private and voluntary residential and nursing home sector. This expenditure, if it was redistributed, is more than enough to pay for the properly co-ordinated medical service for the aged that government decided it could not afford (DHSS, 1981). To achieve this, local authorities and health authorities need to come together to draw up plans for the care of the aged in their community. Those plans should be based on accurate information concerning the number of people at present receiving community support at home, in homes or in hospitals and the time those services have been received.

Each area should then be asked to create a time related model of the interaction between time and service delivery. This model should include the interaction between hospital based specialties, such as psychiatry, general medicine and orthopaedics, and the community based services in residential and nursing homes. Plans should then be drawn based on responsibility, accountability, medical leadership in rehabilitation, task definition and time related models of the locally available resources [see (Millard, 1991)].

9.0 Concluding remarks

Personal difficulties experienced whilst developing geriatric medical services for two London Boroughs motivated this work. Those difficulties took me on a path that embraced a wide reading base. Many of the ideas are based on books that have a primary philosophical content.

Through those books and in discussion with many other people throughout the world I developed the ideas presented in the thesis. The work could not have been done without the expert assistance of countless people. Chief among them are the two mathematicians who have now become close friends. I thank them both and hope that through our efforts we can help others to plan a better world for all of us.
REFERENCES


(1990). GraphPAD INPLOT Version 3.0. #9 San Diego, CA 92121, US: GraphPAD Software, 10855 Sorrento Valley Road.


Flow Rate Modelling: Millard PhD 1993


Feldstein, M.S. (1963). Operational research and efficiency in the Health Service. The
Lancet, i, 491-493.


GUIDE TO THE BOOKS

Inspiration to seek the solution to the problem of measuring activity in hospitals in the field of new physics and the measurement of time came from P.D. Ouspensky's book 'A New Model of the Universe' (1931). The book was first written in 1931, and hidden in its pages is a masterly comparison between old and new physics. Ideas concerning the interaction of Eastern and Western thought concerning flow came from Fritjof Capra's book 'The Tao of Physics' (1975), and the six line models used to illustrate the impact of change are based on the six-line models in the I Ching, The Chinese Book of Changes (1984).

The terms - vector field, temporal map, attractor, catastrophe hypersurface and logical succession - were derived from study of modelling theory in Prof. Rene Thom's book 'Structural Stability and Morphogenesis: An Outline Theory of Models' (1975). Woodcock and Davis's book - 'Catastrophe Theory' - simplifies the theory and relates it to behavioural change.


Prof Bartholomew and his co-authors books on 'Statistical Techniques for Manpower Planning' gave insight into the practice of model making (Bartholomew & Forbes, 1981; Bartholomew, Forbes, & McClean, 1991). Their work convinced me that the to the problem of measuring activity in hospitals solution lies in applying mathematical techniques developed in other fields. Gibaldi's book 'Biopharmaceutics and Clinical Pharmacokinetics' gave useful insight into pharmaco-kinetics (Gibaldi, 1991).
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APPENDIX I
Mixed Sex Nursing in a Scattered Geriatric Unit.

APPENDIX II
To rehabilitate or to vegetate?

APPENDIX III
Throughput in a department of geriatric medicine: a problem of time, space, and behaviour.

APPENDIX IV
A case for the development of departments of gerocomy in all district general hospitals: discussion paper.

APPENDIX V
Balancing Acute and Long-term Care: The Mathematics of Throughput in Departments of Geriatric Medicine.
First published in Methods of Information in Medicine 1991;30: 221-8

APPENDIX VI
A study of the occupancy of the thirteen Departments of Geriatric Medicine in the South West Thames Regional Health Authority.
Report published by the Division of Geriatric Medicine, St. George's Hospital Medical School, April 1988

APPENDIX VII

APPENDIX VIII
Protocol: Regional Study (1991)

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Instructions for the completion of the ward based census.

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Results from the fourteen departments in the February 1991 study.
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Plot of the pattern of bed occupancy and the best fit parameters.

APPENDIX XIV
The Elderly in Hospital - Old and Forgotten?